Geology and Ground Water in Verde Valley—the Mogollon Rim Region Arizona

GEOLOGICAL SURVEY BULLETIN 1177

Twenter, Metzger—GEOLOGY AND GROUND WATER, VERDE VALLEY—THE MOGOLLON RIM REGION, ARIZONA—Geological Survey Bulletin 1177

DEC
PUBLICATIONS SECTION

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By F. R. TWENTER *and* D. G. METZGER

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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1963

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

The U.S. Geological Survey Library has cataloged this publication as follows:

Twenter, Floyd R., 1928–

Geology and ground water in Verde Valley—the Mogollon Rim region, Arizona, by F. R. Twenter and D. G. Metzger. Washington, U.S. Govt. Print. Off., 1963.

vi, 131 p. illus., maps (1 fold. col. in pocket) diagrs., tables. 24 cm. (U.S. Geological Survey. Bulletin 1177)
Bibliography: p. 128–129.

1. Geology—Arizona—Verde Valley. 2. Water, Underground—Arizona—Verde Valley. 3. Water supply—Arizona—Verde Valley. I. Metzger, Donald George, 1922– joint author. II. Title: Mogollon Rim region, Arizona. (Series)

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C., 20402

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By F. R. TWENTER and D. G. METZGER

ABSTRACT

Verde Valley is in central Arizona and is a part of the Mogollon Rim region, a mountainous region that forms the transition zone between the Colorado Plateaus and Basin and Range physiographic provinces. Flowing through the valley is the Verde River, which, together with the Salt River, is the chief source of surface water used to support the agricultural economy of central Arizona. The flow in both rivers is perennial and is sustained by ground water from numerous springs.

The average flow in the Verde River near its point of exit from Verde Valley is 470 cubic feet per second. Runoff from precipitation is a major contributor of water to the river, supplying more than half the average flow; but precipitation generally is sporadic, and many weeks may pass without the addition of water from this source. Thus, perennial flow in the river is maintained by ground water that issues either directly to the river or to its tributary streams—West Clear, Beaver, Oak, and Sycamore Creeks. Base flow in the Verde River south of Camp Verde, as measured during the winter, is 225 cubic feet per second.

In Verde Valley, ground water occurs in rocks of Precambrian, Paleozoic, and Cenozoic ages. The Precambrian rocks are chiefly metamorphic and intrusive, the Paleozoic rocks are all sedimentary, and the Cenozoic rocks are chiefly volcanic and sedimentary.

The Paleozoic rocks, in ascending order, are the Tapeats(?) Sandstone of Cambrian age; the Martin Limestone of Devonian age; the Redwall Limestone of Mississippian age; the Supai Formation of Pennsylvanian and Permian age; and the Coconino Sandstone, the Toroweap Formation, and the Kaibab Limestone of Permian age.

The Cenozoic rocks, is ascending order, are the sedimentary rocks of Tertiary age; the volcanic rocks of Tertiary age; the Verde Formation of late(?) Tertiary or early Quaternary age; and the volcanic rocks, gravel, and streamwash of Quaternary age.

The major structural features of the region are the Mormon Mountain anticline and the Verde, Oak Creek, Sedona, and Cathedral Rock faults. Upwarp during Cenozoic time elevated rocks in the Mormon Mountain anticline more than 1,500 feet above stratigraphically equivalent rocks near the central part of Verde Valley. Structural movement during Tertiary and Quaternary time displaced rocks in the Verde fault zone about 3,000 feet and displaced rocks along the other faults 300 to 1,000 feet.

Ground water in the Verde Valley area occurs chiefly in Cenozoic and Paleozoic sedimentary rocks. The major aquifers are the Verde Formation, Supai Formation, Redwall Limestone, and Coconino Sandstone.

More than 100 wells yield ground water from the Verde Formation. Limestones and the coarser clastic rocks are the chief aquifers. Most of the water is under artesian pressure, and, in places, the pressure is sufficient to produce flowing wells. The water is used for irrigation and for public and domestic supplies.

Ground water that issues from springs in the Supai Formation, Redwall Limestone, and Coconino Sandstone supplies most of the perennial flow in the Verde River and its tributary streams. The lower member of the Supai, and possibly the Redwall, yield water to wells in the Sedona area. The Redwall Limestone probably yields water to a spring that supplements the water supply for Clarkdale.

The dissolved-solids content of ground water from rocks in Verde Valley generally ranges from 200 to 90,000 parts per million. Most water in the Verde Formation contains less than 500 parts per million dissolved solids; but near Camp Verde some water is salty—water from one well has a dissolved-solids content of more than 90,000 parts per million. The dissolved-solids content of water from the Paleozoic rocks ranges from about 200 to 500 parts per million.

INTRODUCTION

PURPOSE OF INVESTIGATION

Verde Valley is a part of the Mogollon Rim region of central Arizona (fig. 1). This region, which is drained by the Salt and Verde Rivers, forms the transition zone between the Colorado Plateaus and Basin and Range physiographic provinces. The region takes its name from the Mogollon Rim, a prominent 200-mile-long escarpment which forms much of the northeastern boundary of the region.

The Mogollon Rim region is the source of almost all surface water that supports the agricultural economy of central Arizona. Springs of the region issue from rocks of the plateau, and the water drains downstream where it is utilized in the basins of the Basin and Range province.

The purpose of the investigation of Verde Valley is to supply basic geohydrologic data for use in present and future water-resources development. Specifically, this report should aid ground-water development in the region by showing some of the interrelations of ground water and surface water, by describing the hydrologic conditions in large parts of the region that are not yet developed, and by pointing out the effects of geologic structure and stratigraphy upon the occurrence and movement of ground water.

PREVIOUS INVESTIGATIONS

Many studies have been made of the geology in Verde Valley, particularly in the copper mining area around Jerome; the following articles, listed chronologically, are most pertinent to the present investigation.

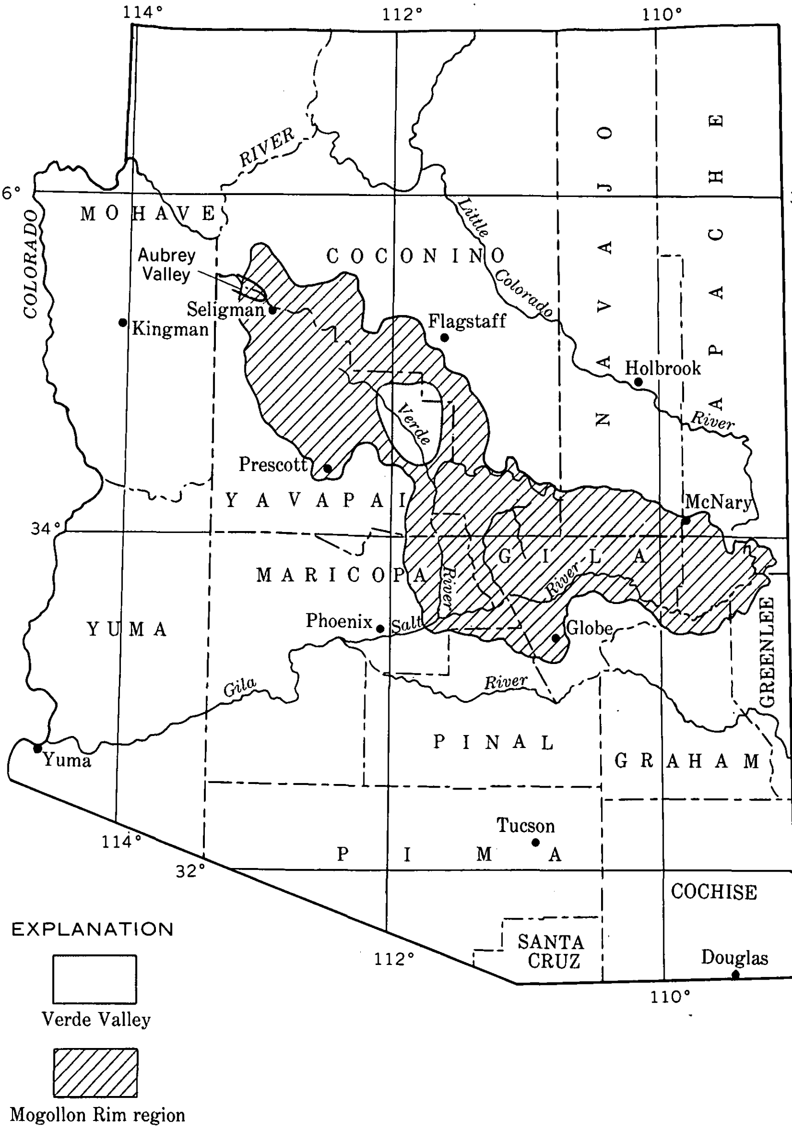

FIGURE 1.—Map of Arizona showing position of Verde Valley in the Mogollon Rim region.

1890. Blake, W. P., Thenardite, mirabilite, glauberite, halite, and associates, of the Verde Valley, Arizona Territory: Am. Jour. Sci., 3d ser., v. 39, no. 229, p. 43–45.

Description of evaporite minerals from the Verde Formation south of Camp Verde.

1922. Reber, L. E., Jr., Geology and ore deposits of Jerome district: Am. Inst. Mining Metall. Engineers Trans., v. 66, p. 3–26.

Good description of the geology and ore deposits in the Jerome area.

1923. Jenkins, O. P., Verde River lake beds near Clarkdale, Arizona: Am. Jour. Sci., 5th ser., v. 5, no. 25, p. 65–81.
First reconnaissance of the Verde Formation.

1926. Lindgren, Waldemar, Ore deposits of the Jerome and Bradshaw Mountains quadrangles, Arizona: U.S. Geol. Survey Bull. 782, 192 p.
Discussion of the mineralogy of the ore deposits in the Jerome mining district.

1949. Mahard, R. H., Late Cenozoic chronology of the Upper Verde Valley, Arizona: Denison Univ. Sci. Lab. Bull., v. 41, p. 97–127.
Geologic history of Verde Valley and description of the Verde Formation and other Cenozoic rocks.

1950. Price, W. E., Jr., Cenozoic gravels on the rim of Sycamore Canyon, Arizona: Geol. Soc. America Bull., v. 61, no. 5, p. 501–508.
Description of, and possible origin for Cenozoic gravels in the Colorado Plateaus along the Mogollon Rim.

1954. Feth, J. H., Preliminary report of investigations of springs in the Mogollon Rim region, Arizona, with sections on base flow of streams by N. D. White and quality of water by J. D. Hem: U.S. Geol. Survey open-file report, 77 p.
One of the first discussions of the hydrologic characteristics of Verde Valley.

1958. Lehner, R. E., Geology of the Clarkdale quadrangle, Arizona: U.S. Geol. Survey Bull. 1021–N, p. 511–592.
Description and geologic history of the rocks north of the Jerome area in Verde Valley.

1958. Anderson, C. A., and Creasey, S. C., Geology and ore deposits of the Jerome area, Yavapai County, Arizona: U.S. Geol. Survey Prof. Paper 308, 185 p.
Comprehensive and detailed report on the geology and ore deposits in the northern part of the Black Hills.

ACKNOWLEDGMENTS

The writers are grateful to the residents in Verde Valley and to all other persons who supplied information concerning wells, springs, and trails to "inaccessible" areas.

Dr. C. W. Hibbard of the University of Michigan kindly identified some of the vertebrate material from the Verde Formation.

Appreciation is expressed to the well drillers for their assistance in the collection of drill cuttings and for supplying logs of wells.

The writers wish to thank Mr. J. A. West of the Salt River Project for information pertaining to irrigation.

FIELDWORK AND PERSONNEL

Fieldwork was started in the summer of 1957. Geologic mapping was finished in 1959, and the hydrologic fieldwork in 1960.

The project began under the direction of D. G. Metzger, who supervised the collection of hydrologic data during the early part of the study and assisted in the early stages of the geologic fieldwork. He was succeeded by F. R. Twenter, who did most of the geologic mapping, measured the stratigraphic sections, compiled most of the data for the report, and interpreted the hydrology. All photographs were made by F. R. Twenter.

Personnel of the U.S. Geological Survey who assisted the authors were R. S. Stulik and W. F. Hardt of the Ground Water Branch and J. E. Bowie and E. J. Jones of the Surface Water Branch. Discussions with M. E. Cooley aided the authors in their interpretations of the Cenozoic geology.

GEOGRAPHY AND HISTORY

Verde Valley, near the center of Arizona (fig. 1), is 20 miles wide and 30 miles long. It is drained by the Verde River and is bounded on the north and east by the Mogollon Rim (fig. 2). The rim rises abruptly above the valley floor as a sheer precipice ranging in height from 1,000 to 2,000 feet (fig. 3). Its altitude is 6,000–7,000 feet along the northern part of the valley and 5,000–6,000 feet along the eastern part.

The Black Hills (fig. 2), a northwest-trending range, bound Verde Valley on the southwest and rise 1,000–3,000 feet above the valley floor. The highest peak, Woodchute Mountain, has an altitude of 7,834 feet. Mingus Mountain, Squaw Peak, and Tule Mesa have altitudes of 7,743, 6,544, and 6,682 feet, respectively.

Two highways, U.S. 79 and U.S. 89A (pl. 1) provide the principal access routes to Verde Valley. Both highways cross and descend the Black Hills, traverse the valley northeastward, and ascend the Mogollon Rim to the Colorado Plateaus. Of the two, probably the most scenic route is U.S. 89A. This highway passes through the ghost town of Jerome (fig. 4) and has a torturous descent from the Black Hills into the valley. From the western part of the valley the geologic features are displayed superbly, as shown by figure 5. In the northeastern part of the valley the highway traverses beautiful "redrock country" and winds its way north along the bottom of Oak Creek Canyon (fig. 6).

Principal centers of population in Verde Valley are Camp Verde, Cornville, Cottonwood, Clarkdale, and Sedona (pl. 1). Each community is on or near the flood plain of a perennial stream, and all are dependent partly on the streams and their flood plains for existence.

Because of the great abundance of easily available good-quality water in a region where water generally is at a premium, Verde Valley has been inhabited for many years, and numerous ruins in the area attest a long and varied history. The following brief summary of the early history of the valley was taken from a brochure, "Monte-

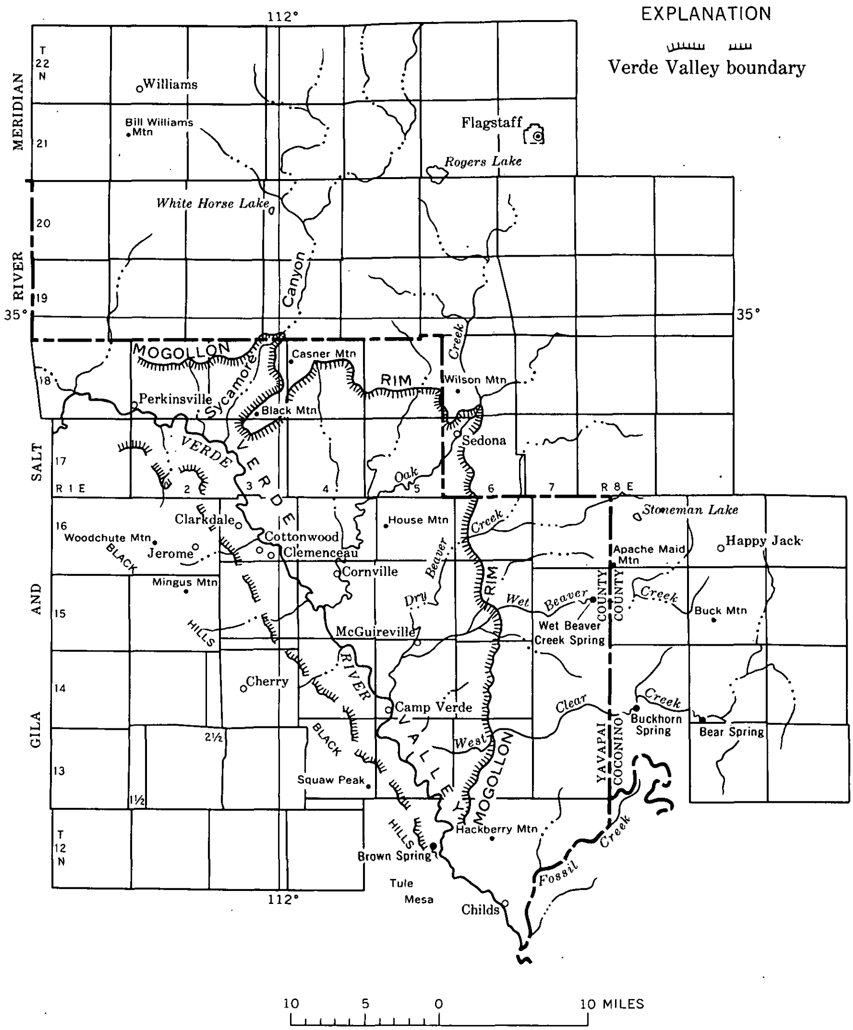

FIGURE 2.—Index map of Verde Valley, Yavapai and Coconino Counties, Ariz.

zuma Castle National Monument, Arizona," distributed by the National Park Service.

Scant archeological evidence so far available indicates human beings were living in Verde Valley over a thousand years ago. These were industrious, sedentary Indians from southern Arizona who settled on the fertile river terraces and began farming. They probably lived in comparative peace in the valley until about the beginning of the 12th century.

After 1100, another group of farm Indians entered the valley from the north. These people constructed communal dwellings, or pueblos, which after A.D. 1250 were converted into large compact defensible structures.

FIGURE 3.—Mogollon Rim in the northern part of Verde Valley. The rim is the boundary between the Colorado Plateaus and Basin and Range physiographic provinces. Supai Formation (PIPs); Coconino Sandstone (Pc); Toroweap Formation (Pt); and Kaibab Limestone (Pk). View east.

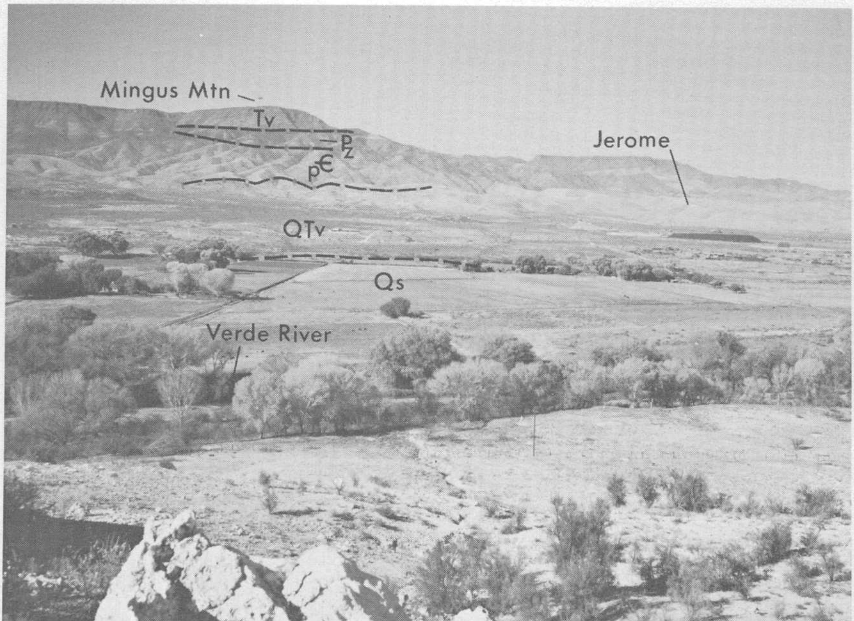

FIGURE 4.—Mingus Mountain area in the northern part of the Black Hills. The Verde fault zone is parallel to the base of the mountain range; one of its principal segments is near Jerome. Precambrian rocks (P€); Paleozoic rocks undifferentiated (Pz); Tertiary volcanic rocks (Tv); sedimentary rocks of the Verde Formation (QTv); and Quaternary streamwash (Qs). View west.

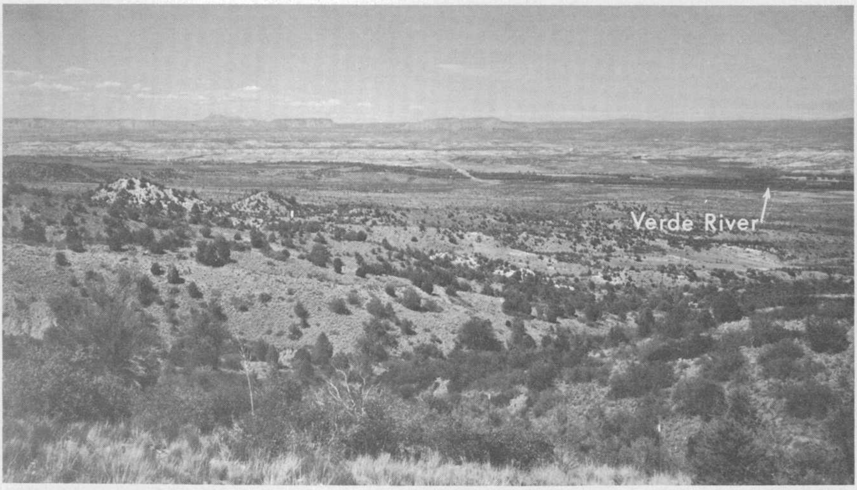

FIGURE 5.—Verde Valley. A part of the Mogollon Rim, the southwestern boundary of the Colorado Plateaus, marks the horizon. Rising above the plateaus is the volcanic San Francisco Mountain. In the Verde Valley area, the surface of the Colorado Plateaus is developed on the Kaibab Limestone of Permian age and on volcanic rocks of Tertiary and Quaternary age. The rocks forming the Mogollon Rim are the Supai Formation of Pennsylvanian and Permian age and the Coconino Sandstone, the Toroweap Formation, and the Kaibab Limestone of Permian age. The white bench-forming deposit below the rim is the Verde Formation of late(?) Tertiary or early Quaternary age. View north from Camp Verde.

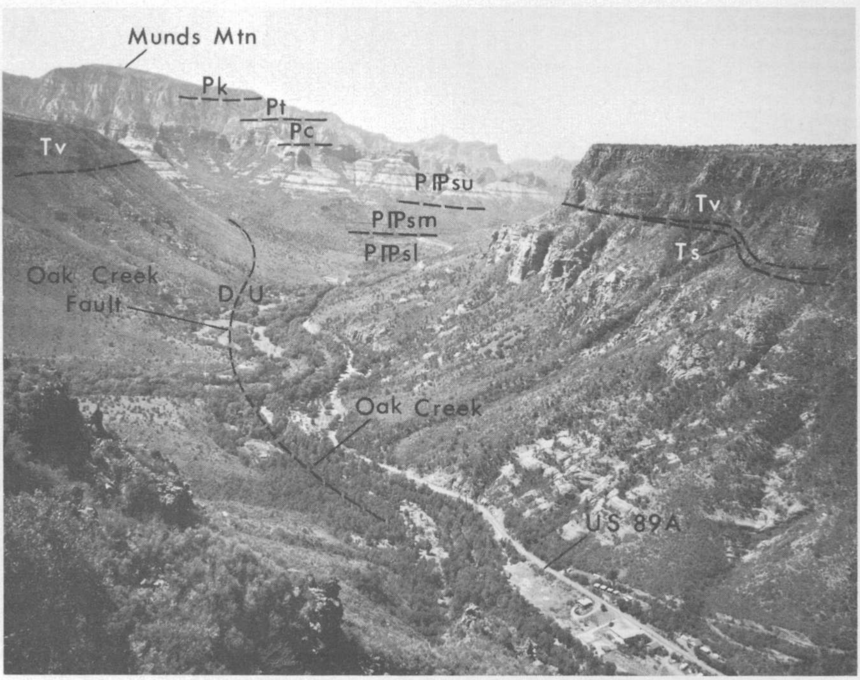

FIGURE 6.—Mouth of Oak Creek Canyon near Sedona. Lower member of the Supai Formation (PIPsl); middle member of the Supai Formation (PIPsm); upper member of the Supai Formation (PIPsu); Coconino Sandstone (Pc); Toroweap Formation (Pt); Kaibab Limestone (Pk); Tertiary sedimentary rocks (Ts); and Tertiary volcanic rocks (Tv). View downstream.

The majority of these Indians concentrated into large settlements for protection. It can be imagined with what enthusiasm a band of the farmers might have first noticed, on the north bank of Beaver Creek, only 4 miles from the Verde River, a great cavern-pitted limestone cliff, well over 100 feet high. This was an ideal spot for a dwelling site, with good farmland nearby on the creek terrace. Here they began building rooms to accommodate their needs. We find that in a quarter-mile strip of cliff there were two distinct apartment houses. Growth during several generations made one of these villages a 5-story structure with 45 rooms. A hundred yards east was a 5-story structure with 20 rooms, which was destined, centuries later, to be inaccurately called Montezuma Castle. As many as 200 persons may well have lived in the several house clusters. Montezuma Castle was probably abandoned during the first part of the 1400's.

Ruins and remains, such as dwelling sites, pottery, jewelry, hunting materials, and stone tools, are abundant throughout the valley and along the Mogollon Rim. The restoration of the dwelling area at Tuzigoot National Monument near Clarkdale has revealed several pueblos which have a total of more than 100 rooms. Numerous small dwellings and at least one 3-story structure are in the West Clear Creek Canyon. The tops of many buttes and mesas, such as Sacred Mountain and those near Cornville, are covered with dwelling ruins and pottery. Several dwellings are in alcoves in Montezuma Well.

The first white man entered the valley in 1583, and in the nearly 300 years that followed, the valley was visited only by explorers, trappers, and prospectors. In 1863, the year that Arizona became a territory, the first settlers arrived and built a settlement on the north bank of West Clear Creek. The settling party "* * * dug a well, dammed West Clear Creek, dug an irrigation ditch (after one unsuccessful start), and by May (1865) had some 200 acres in grain and garden vegetables * * *" (Pierson, 1957, p. 327). However, as stated by Mindeleff (1896, p. 185), "* * * ordinary pursuits were almost impossible * * *" because "* * * the hostile Apache and Walapai roamed over it [Verde Valley] without hinderance or opposition * * *."

Soon after the arrival of the early settlers "* * * there occurred some notorious Apache raids which led to the establishment of Camp Lincoln * * *" (Parker and Humburg, 1960, p. 16). "The original camp was near the river, and in those days much of the land along the river was marshy, supporting heavy growths of willows, reeds, and rushes. Malaria was a problem, according to some chroniclers; there were anopheles and other mosquitoes in the region along with swarms of other insects * * *" (Pierson, 1957, p. 332). To provide for better protection against the Indians and the insects, the camp was relocated and the name changed to Fort Verde; the town of Camp Verde now occupies this site. Today Camp Verde is primarily a farming and ranching community that has a population of about 1,500.

In 1876 "* * * M. A. Raffner discovered an outcropping of ore and located two claims in the present Jerome area * * *" (Parker and Humburg, 1960, p. 26). Mining activity increased rapidly, and by 1929 the population of Jerome was about 15,000. Smelters were built at Clarkdale and Clemenceau. The boom continued for many years, but in January 1953 most of the mining activity ceased. Today the town of Jerome, 2,000 feet above the valley floor on the steep slope of Mingus Mountain, has become a ghost town. The populations of Jerome and Clarkdale are about 250 and 1,000 respectively.

The town of Cottonwood, first settled in the early 1870's is the largest community in Verde Valley. Because of its location in the ranching and farming country along the Verde River and because of its close proximity to the Jerome mining district, Cottonwood has survived the economic changes in the valley and has continued to grow. The population of the town is about 3,000.

In 1902 a post office was established in Sedona. The town is at the mouth of Oak Creek Canyon along the cool waters of Oak Creek amidst spectacular scenery. Thousands of people visit Sedona and the surrounding "red-rock country" each year. The country is a photographers' paradise, where scenes for such pictures as "Apache," "Copper Canyon," and "Broken Arrow" have been filmed. The population of Sedona and the "red-rock country" is about 3,500.

The greatest boon to the economy of the valley in recent years came on October 30, 1959, when the $16 million plant of the Phoenix Cement Co., an Arizona-operated division of the American Cement Co., was located just northwest of Clarkdale. Cement from the plant is being used in the construction of the dam in Glen Canyon of the Colorado River at Page, Ariz.

River flood plains along all perennial streams in the Verde Valley are used for agriculture and are irrigated chiefly by water from diversions, although some water is supplied by wells. In 1960, the irrigated land comprised about 10,000 acres (J. A. West, oral communication, 1961). Irrigation in the valley dates back to the time of the early Indian population, and some stretches of their ancient irrigation ditches are still utilized by ranchers. One of the ditches near Montezuma Well is excellently preserved (fig. 7). The following description of the ditch is taken from a brochure, "Trails at Montezuma Well," distributed by the National Park Service.

> * * * the original prehistoric ditch [was] dug with stone tools to a depth of about 3 feet and a length of over 1 mile. The water from the well [Montezuma Well] contains much lime in solution: experiments have shown that an object left in the ditch water will build up about ¼ inch of lime deposit in a year. When the Indians cleaned their ditches, they evidently took advantage of this natural lining material and didn't scrap the ditch sides too thoroughly. Eventu-

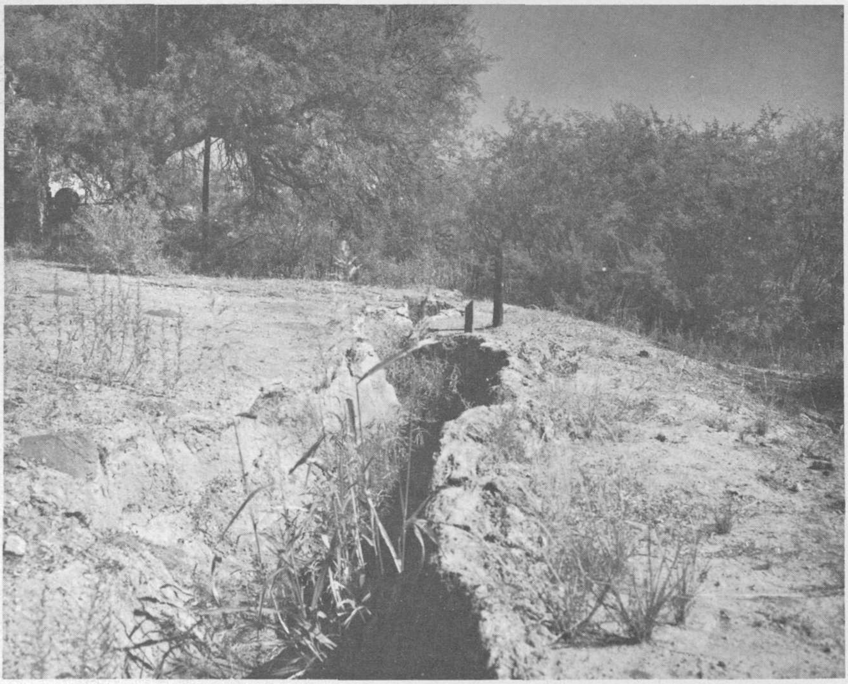

FIGURE 7.—Ancient irrigation ditch near Montezuma Well. The ditch, dug with stone tools, is now lined with limy material deposited from the irrigation water diverted for agriculture by the early Indians.

ally the ditches narrowed, and the lining grew to over a foot in thickness; there was probably very little water loss from either evaporation or seepage in such a deep, narrow ditch.

CLIMATE

Climate and water supplies play a major role in determining the location of areas of habitation and centers of population. Precipitation and temperature, climatological features which are partly determined by altitude, vary considerably in Verde Valley (table 1).

Data from several U.S. Weather Bureau climatological stations at various altitudes in the valley are representative of the climate in the valley. Data from the climatological station at Flagstaff are representative of the climate on the part of the plateau that bounds the valley.

The average annual precipitation ranges from 11.32 inches at Clemenceau to 20.48 inches at Flagstaff. May and June are the driest months at most stations, and during these months the average monthly precipitation at all stations is less than 1 inch. The wettest months are July and August, when the average precipitation at all stations exceeds 1 inch and that at several stations exceeds 2 inches. The highest

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TABLE 1.—*Selected climatic data for stations in and near Verde Valley*

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

Climatological station	Land surface altitude (feet)	Years of record	Highest monthly precipitation, in inches, ever recorded and date of record	Highest daily temperature (°F) ever recorded and date of record	Lowest daily temperature (°F) ever recorded and date of record
Beaver Creek Ranger Station	3,830	1957–59	5.28, Sept. 1958	108°, July 12, 1958	16°, Nov. 18, 1958.
Camp Verde	3,160	1868–90	12.08, Aug, 1876	No record	No record.
Clemenceau	3,460	1920–36	5.25, Sept. 1925	110°, July 13, 1934	9°, Feb. 10, 1933.
Cornville	3,300	1913–20	4.67, Apr. 1917	106°, (1)	8°, (1).
Cottonwood	3,375	1949–59	4.78, July 1952	114°, July 30, 1951	8°, Nov. 17, 1958.
Flagstaff	6,993	1889–1959	12.60, Jan. 1895	99°, July 1897[1]	−30°, Jan. 22, 1937.
Jerome	5,245	1897–1959	8.63, July 1919	105°, Aug. 12, 1933	7°, (1).
Montezuma Castle	3,180	1939–59	4.17, Dec. 1949	114°, July 11, 1958	3°, Jan. 30, 1949.
Sedona Ranger Station	4,223	1944–59	6.34, Jan. 1949	106°, June 29, 1950 and July 11, 1958.	10°, Jan. 4, 1949.

Average precipitation, in inches

	Monthly												Annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Beaver Creek Ranger Station	0.23	1.82	1.19	1.03	0.85	0.47	1.30	1.81	1.81	1.76	1.11	1.31	14.69
Camp Verde	.96	.96	1.10	.62	.26	.21	1.80	2.86	1.08	.73	1.01	1.53	13.12
Clemenceau	.96	1.11	.70	.72	.27	.24	1.38	1.81	1.68	.61	.77	1.07	11.32
Cornville	2.14	1.18	1.02	1.40	.43	.27	1.60	1.04	1.16	.81	.54	.64	12.23
Cottonwood	.95	.82	.75	.51	.40	.80	2.47	2.06	.72	.78	.55	.57	11.38
Flagstaff	2.23	1.95	2.00	1.25	.80	.55	2.80	2.74	1.62	1.40	1.23	1.91	20.48
Jerome	1.82	1.85	1.58	1.08	.51	.40	2.64	3.04	1.39	1.12	1.20	1.67	18.30
Montezuma Castle	.97	.90	.89	.80	.29	.27	1.35	2.05	1.36	.86	.65	1.10	11.49
Sedona Ranger Station	1.91	1.56	1.55	1.15	.65	.59	1.99	2.31	1.02	1.26	1.23	1.47	16.69

Average temperature, in degrees Fahrenheit

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Beaver Creek Ranger Station	45.4	47.5	51.5	59.3	67.1	78.8	82.3	78.7	74.0	62.9	50.3	46.9	
Camp Verde	40.6	46.4	53.3	60.2	66.3	78.3	83.3	80.7	74.1	62.3	48.4	42.2	
Clemenceau	44.3	48.9	54.6	61.3	69.5	77.7	84.0	81.0	75.5	64.8	53.1	45.1	
Cornville	41.8	46.3	51.9	59.5	66.1	76.7	81.9	79.9	73.8	61.2	51.1	41.9	
Cottonwood	43.8	47.4	51.9	60.3	67.4	77.0	82.1	79.4	75.3	64.7	52.1	44.9	
Flagstaff	27.9	30.9	36.1	43.4	50.6	59.4	65.8	64.1	57.7	47.3	37.0	30.0	
Jerome	41.8	44.7	49.6	58.5	65.3	75.4	78.9	76.4	72.3	62.2	51.4	43.6	
Montezuma Castle	42.8	46.1	51.4	59.2	66.8	75.2	81.8	79.8	74.3	62.7	49.9	43.3	
Sedona Ranger Station	42.6	45.7	49.2	57.7	65.5	75.1	79.9	78.2	74.7	64.0	50.7	44.4	

1 From records collected before 1930. Exact dates unknown.

monthly precipitation ever recorded at any station is 12.60 inches at Flagstaff in January 1895; Camp Verde had 12.08 inches of precipitation in August 1876. During much of the year the precipitation is rain; snow is common during the winter at stations above 5,000 feet.

Temperatures generally are highest during June, July, August, and September and lowest during January. The highest temperature recorded was 114°F at Cottonwood on July 30, 1951, and at Montezuma Castle on July 11, 1958. The lowest temperature recorded was at Flagstaff, where the temperature was −30°F on January 22, 1937.

SURFACE WATER

Water has been one of the significant factors influencing the growth and development of Verde Valley, because this valley is one of a few areas in Arizona having perennial streams. The Verde River, the largest stream in the valley, flows southeast from Perkinsville (fig. 2) through the valley for about 65 miles and collects water from several perennial tributary streams. The area of initial perennial flow in the river is about 5 miles northwest of Perkinsville; upstream from there, the Verde River and its tributaries, although draining a large area, are intermittent streams. Downstream from Verde Valley the river flows southward for more than 60 miles and enters the Salt River near Phoenix.

The principal perennial streams tributary to the Verde River in Verde Valley are West Clear, Beaver, Oak, and Sycamore Creeks, all of which are spring fed from the Mogollon Rim. The perennial flow of West Clear Creek beings 40 miles upstream from the mouth, and seeps and springs cause a progressive increase in flow for 25 miles downstream. Beaver Creek has two tributaries, Dry Beaver and Wet Beaver Creeks, but only the latter is perennial. The initial flow in, and the greatest influx of water into, Wet Beaver Creek is 28 miles upstream from the mouth of Beaver Creek; water from Soda Spring and Montezuma Well (pl. 1) flows to the creek in its lower reaches. In Oak Creek much of the water is from many seeps and small springs along a 10-mile stretch in Oak Creek Canyon; the perennial flow begins 50 miles upstream from the confluence of the creek and the Verde River. Seeps and springs in the Page Springs and Spring Creek areas (pl. 1) supply a large volume of water to Oak Creek. Sycamore Creek extends north of the Verde River for 20 miles and is spring fed, but it is perennial only in the lower several miles of its course; the principal influx of water to Sycamore Creek is at Summer's Spring (pl. 1).

Surface-water flow in the Verde Valley area was measured for differing periods of time at 5 stream-gaging stations, and miscellaneous discharge measurements were made at 12 other stations. (See pl. 1 for location of gaging stations.) Summarized streamflow data, including average, minimum, and maximum discharge at the gaging stations, are given in table 2. The complete records have been published in the annual water-supply papers entitled "Surface Water Supply of the United States, Part 9, Colorado River Basin."

The record of most significance in estimating ground-water discharge is that for the Chasm gaging station. This station is at the south end of the valley where the flow is on bedrock and probably represents total outflow from the valley. The period of record is 1934–45. Monthly and average monthly mean discharge at this station are given in table 3, and daily discharge for a representative water year, October 1937–September 1938, is given in table 4.

The average discharge for the Verde River at Chasm gaging station for 11 years was 470 cfs (cubic feet per second) ; the monthly average discharge (fig. 8) ranged from 1,790 cfs in March to 90 cfs in June.

Base flow at Chasm gaging station is maintained chiefly by springs and seeps—that is, by discharge of ground water—and, therefore, probably represents the minimum amount of ground water discharged in Verde Valley. The monthly average base flow for the Verde River at this station (table 5; fig. 8) ranged from 240 cfs in February to 90 cfs in June; the average base flow was 170 cfs. The average base flow for the four months November through February was 225 cfs—this flow probably most nearly represents the ground-water discharge.

Base flow was highest during the winter and lowest during the summer, reflecting changes in the amount of evapotranspiration. As the temperature increases, evaporation increases, reaching a maximum in midsummer. Similarly, transpiration by plants begins with the leafing out in spring, reaches a maximum in midsummer, and declines again with the approach of winter. Discharge above base flow reflects runoff from precipitation and snowmelt upstream and is greatest in February, March, and April.

The average base flow of Oak Creek just above Page Springs during the four winter months mentioned above was 40 cfs (table 5). Adding the flow from Page Springs, 36 cfs, and that from Spring Creek and other springs, about 16 cfs, the actual base flow near the mouth of Oak Creek should be about 90 cfs; this figure is substantiated by a streamflow measurement of 92 cfs made near the mouth of the creek on April 14, 1915. Also, the average base flow of Beaver Creek for October, November, December, and January was 15 cfs, and several measurements of West Clear Creek near Bull Pen Ranch reveal that the average base flow of this stream is 15 cfs or more. Thus, the combined average base flow of Oak, Beaver, and West Clear Creeks is about 120 cfs, and this indicates that more than half of the ground-water discharge is in these tributary streams.

TABLE 2.—*Discharge of streams at gaging stations*

[From records published in U.S. Geol. Survey annual water-supply papers entitled "Surface Water Supply of the United States, Part 9, Colorado River Basin"]

Stream	Location	Drainage area (sq mi)	Period of record	Discharge (cfs)			Date of occurrence of minimum flow	Date of occurrence of maximum flow
				Average (rounded)	Minimum	Maximum		
Verde River	Sec. 28, T. 17 N., R. 3 E., 4 miles downstream from Sycamore Creek and 4 miles north of Clarkdale.	[1] 3,530	June 1915–Oct. 1916, June 1917–July 1921.	270	55	51,000	Aug. 31 and Sept. 1, 1920.	Feb. 21, 1920.
Do	SE¼ sec. 30, T. 14 N., R. 5 E., at highway bridge just upstream from Beaver Creek and 1 mile north of Camp Verde.	[1] 4,220	Jan. 1913–Mar. 1920	440	31	60,000	June 28 and 29, 1914	Feb. 21, 1920.
Do	Sec. 2, T. 12 N., R. 5 E., about 750 feet upstream from mouth of Chasm Creek and about 9 miles southeast of Camp Verde.	[1] 5,000	1934–45	470	41	97,000	July 17, 1940	Mar. 3, 1938.
Oak Creek	SE¼ sec. 23, T. 16 N., R. 4 E., at highway bridge 0.2 mile upstream from Page Springs.	357	July 1940–Sept. 1945, Apr. 1948–Sept. 1959.	80	6	6,000	July 27, 1940	Oct. 19, 1949.
Beaver Creek	SE¼ sec. 30, T. 14 N., R. 5 E., a quarter of a mile upstream from mouth and 1 mile north of Camp Verde.	413	Dec. 1912–Mar. 1920	120	4	17,000	Several days 1915 and 1919.	Feb. 22, 1920.

[1] Includes 344 square miles in Aubrey Valley (fig. 1), a closed basin.

TABLE 3.—*Monthly and average monthly mean discharge of Verde River at Chasm gaging station*

[From records published in U.S. Geol. Survey annual water-supply papers entitled "Surface Water Supply of the United States, Part 9, Colorado River Basin." Discharge in cubic feet per second]

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Average
1934	------	------	------	------	------	------	200	97.4	82.5	102	316	145	------
1935	138	192	233	648	1,335	1,292	737	110	79.7	106	416	329	462
1936	190	198	212	198	526	725	458	106	71.9	209	299	241	285
1937	175	248	216	248	4,400	2,873	1,186	109	110	153	127	148	808
1938	173	176	211	208	554	4,028	149	89.2	80.3	112	232	135	516
1939	143	169	243	222	221	807	240	85.2	67.4	72.9	201	1,152	301
1940	152	173	199	257	805	280	216	101	90.7	64.7	276	284	239
1941	551	338	1,350	819	2,720	2,987	3,050	337	114	163	155	275	1,059
1942	462	285	277	363	283	833	522	168	88.3	102	122	112	302
1943	158	179	219	247	570	1,468	190	103	82.0	84.2	284	147	310
1944	182	185	256	233	306	1,737	1,463	217	84.7	87.5	114	164	419
1945	172	222	227	230	374	1,545	1,445	149	81.0	121	265	107	413

TABLE 4.—*Daily and monthly discharge of Verde River at Chasm gaging station for water year October 1937–September 1938*

[U.S. Geol. Survey (1939, p. 266). Italic figures represent base flow plus runoff; others represent base flow only. Discharge in cubic feet per second]

Day	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	*509*	159	188	217	192	*8,720*	227	101	77	*153*	118	128
2	*359*	163	200	217	200	*7,760*	209	94	73	*134*	99	131
3	*244*	163	208	217	200	*39,800*	209	88	79	118	90	131
4	*200*	163	208	217	204	*33,000*	200	90	77	118	81	*404*
5	179	156	213	208	208	*7,200*	192	94	88	108	151	*243*
6	175	163	213	213	204	*3,690*	178	114	92	94	*233*	*180*
7	163	179	213	213	204	*2,350*	164	101	79	92	189	*180*
8	159	179	208	208	200	*1,740*	155	104	73	90	*247*	158
9	152	175	200	208	200	*1,320*	155	97	67	90	*294*	144
10	148	163	200	200	196	*1,040*	153	88	67	85	*206*	131
11	148	171	204	200	200	*927*	147	83	69	*169*	169	128
12	144	175	208	204	*426*	*1,330*	139	83	67	99	144	124
13	144	171	222	204	*1,740*	*4,690*	126	85	65	101	*1,590*	124
14	141	175	230	204	*815*	*2,220*	116	88	77	97	*764*	116
15	141	171	217	208	*560*	*1,730*	131	83	81	118	*310*	114
16	141	171	208	213	*411*	*1,220*	142	79	79	104	*240*	108
17	133	167	204	213	*354*	*927*	183	79	69	101	*218*	111
18	144	171	204	213	305	*763*	291	83	67	106	*209*	111
19	144	179	208	208	290	*605*	203	85	69	99	186	108
20	137	179	213	208	276	*490*	150	88	71	111	175	106
21	141	188	208	222	257	*435*	124	90	69	114	161	101
22	137	192	204	226	244	*409*	114	92	69	101	153	99
23	144	188	200	217	239	*357*	106	97	69	116	147	106
24	148	184	213	213	230	*322*	99	97	79	106	136	101
25	148	188	222	213	226	291	101	90	79	*159*	139	108
26	156	188	222	204	230	270	92	85	79	106	134	108
27	156	184	222	192	248	266	90	85	81	131	121	106
28	152	188	222	184	*6,460*	266	90	83	97	111	111	108
29	159	188	217	192	--------	259	93	81	*142*	114	111	114
30	163	188	217	192	--------	243	94	79	*158*	114	136	114
31	163	------	217	188	--------	237	------	79	------	106	128	------

Miscellaneous measurements were made at 14 sites on the Verde River and its tributaries during May 1959 to determine influent and effluent stretches of these streams. For example, measurements at sites on Oak Creek were Sedona, 32 cfs; Red Rock Crossing, 20 cfs; and, near Hidden Valley Ranch, 15 cfs. Thus, 17 cfs of water, including an unknown amount of water diverted to irrigation ditches, was lost between Sedona and Hidden Valley Ranch. From Hidden Valley

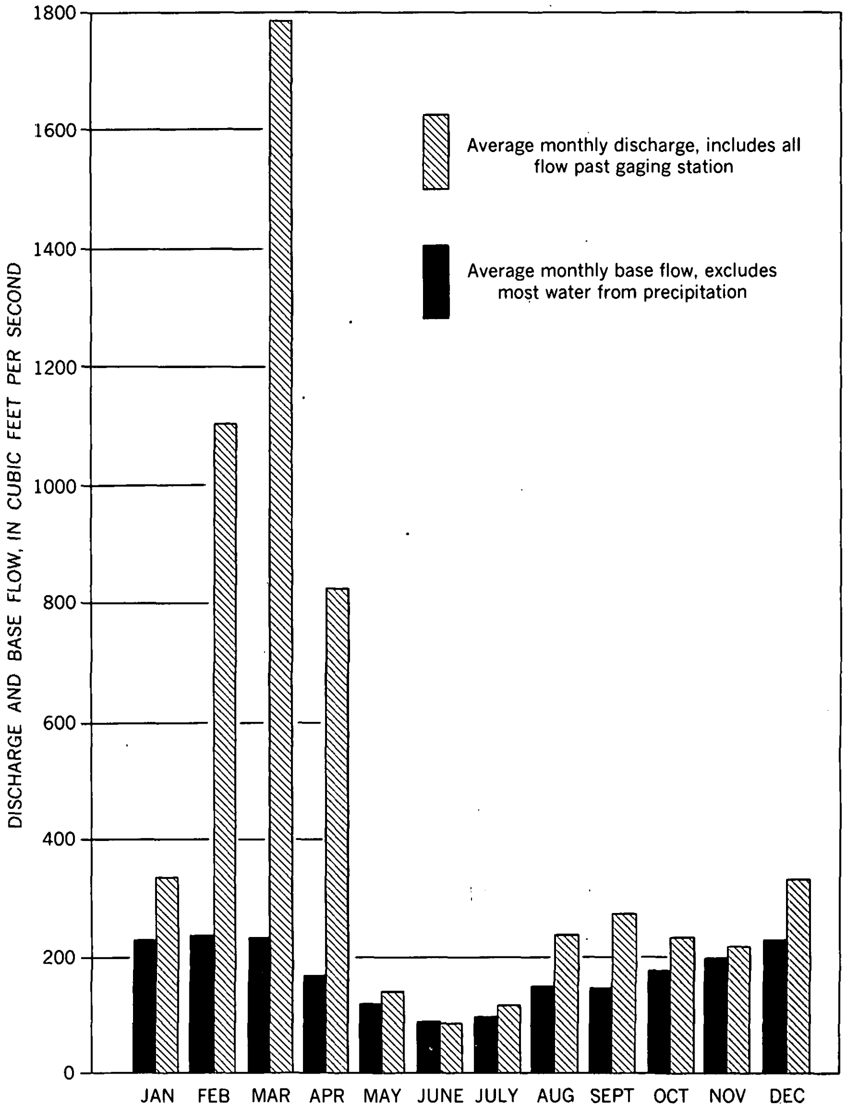

FIGURE 8.—Average monthly discharge and base flow of Verde River at Chasm gaging station (sec. 2, T 12 N., R. 5 E.) for period 1934–45, inclusive.

Ranch to just above Page Springs, the stream gained 7 cfs. The discharge of Page Springs was determined by measuring the flow in Oak Creek just above and just below the springs; the discharge was 36 cfs. The actual discharge of the spring probably is greater, because some water must be lost in the fish hatchery at the spring. If all the water

TABLE 5.—*Monthly average base flow at stream-gaging stations in Verde Valley for period of record shown in table 2*

[From records published in U.S. Geol. Survey annual water-supply papers entitled "Surface Water Supply of the United States, Part 9, Colorado River Basin"]

Stream	Base flow, in cubic feet per second, rounded											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Verde River												
Sec. 28, T. 17 N., R. 3 E.	90	90	80	80	80	80	80	80	80	80	80	80
SE¼ sec. 30, T. 14 N., R. 5 E.	160	150	130	110	80	70	90	90	110	100	130	140
Sec. 2, T. 12 N., R. 5 E. (Chasm gaging station)	230	240	230	160	120	90	100	150	140	170	200	230
Oak Creek												
SE¼ sec. 23, T. 16 N., R. 4 E.	40	40	40	30	30	20	20	20	20	30	40	40
Beaver Creek												
SE¼ sec. 30, T. 14 N., R. 5 E.	20	20	20	10	10	10	10	0	10	10	10	20

lost between Sedona and Hidden Valley Ranch were recharged to the ground-water reservoir feeding Page Springs, it still would not provide the water necessary to account for the large discharge at Page Springs.

WELL-NUMBERING SYSTEM

The well numbers used by the Geological Survey in Arizona are in accordance with the Bureau of Land Management's system of land subdivision. The land survey in Arizona is based on the Gila and Salt River meridian and base line, which divide the State into four quadrants (fig. 9). These quadrants are designated counterclockwise by the capital letters A, B, C, and D. All land north and east of the point of origin is in A quadrant, that north and west in B quadrant, that south and west in C quadrant, and that south and east in D quadrant. The first digit of a well number indicates the township, the second the range, and the third the section in which the well is situated. The lowercase letters a, b, c, and d after the section number indicate the well location within the section. The first letter denotes a particular 160-acre tract (fig. 9), the second the 40-acre tract, and the third the 10-acre tract. These letters also are assigned in a counterclockwise direction, beginning in the northeast quarter. If the location is known within a 10-acre tract, three lowercase letters are shown in the well number. In the example shown in figure 9, well number (A-4-5) 19caa designates the well as being in the NE¼NE¼SW¼ sec. 19, T. 4 N., R. 5 E. Where there is more than one well within a 10-acre tract, consecutive numbers beginning with 1 are added as suffixes.

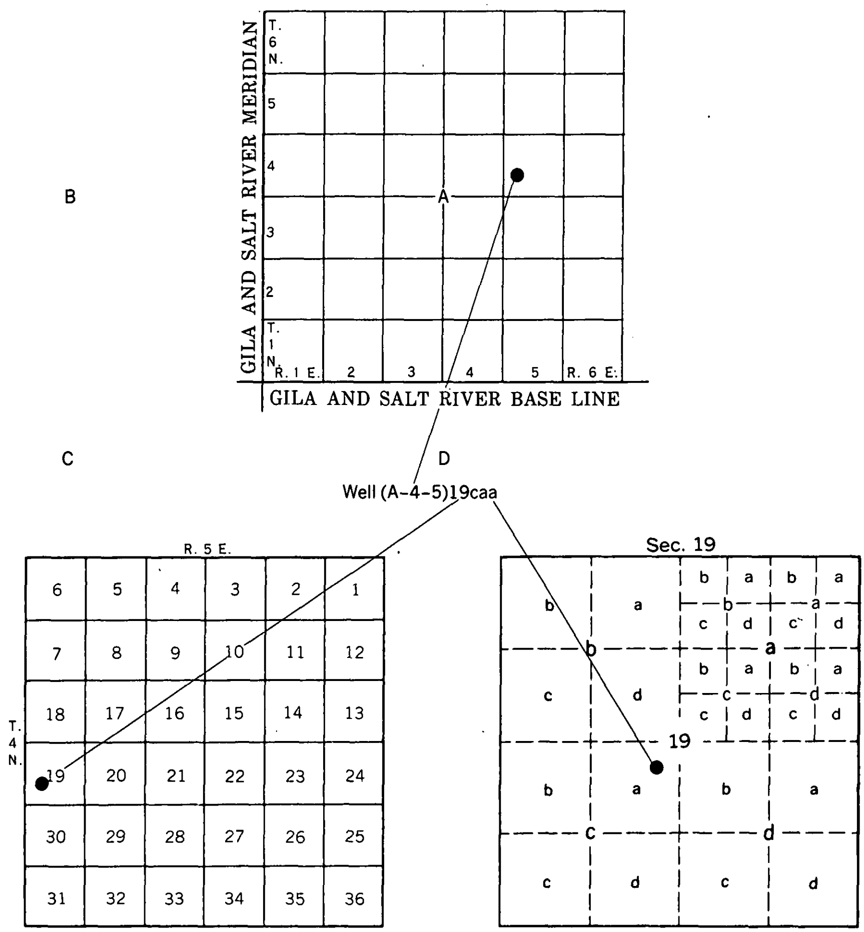

FIGURE 9.—Well-numbering system in Arizona.

GEOLOGY AND WATER-BEARING PROPERTIES OF THE ROCKS

STRATIGRAPHIC SUMMARY

The rocks that crop out in Verde Valley are metamorphic, intrusive, volcanic, and sedimentary. In the area mapped, the metamorphic and intrusive rocks are chiefly of Precambrian age; the unmetamorphosed volcanic rocks are of Tertiary and Quaternary age; and the sedimentary rocks are of Paleozoic, Tertiary, and Quaternary age. The oldest rocks are the metamorphic rocks. A generalized stratigraphic section of the rocks is given in table 6, and the areal extent of exposed rocks is shown on plate 1.

TABLE 6.—*Generalized section of rocks in Verde Valley, Arizona*

Era	System	Series	Group	Formation	Thickness (feet)	Lithologic characteristics	Water-bearing characteristics
Cenozoic	Quaternary	Pleistocene and Recent	Streamwash		0–30+	Terrace deposits and stream deposits	Yields water to a few wells along the Verde River. Generally above the water table.
						Unconformity	
		Pleistocene	Gravel		0–70	Gravel and minor amounts of sand, silt, and clay; fragments derived from adjacent bedrock.	Generally above the water table.
						Unconformity	
			Volcanic rocks		0–300	Rhyolitic lava, rhyodacite, and a few beds of tuffaceous sediments.	Not water bearing.
						Unconformity	
	Tertiary or Quaternary	Pliocene or Pleistocene(?)	Verde Formation		1,800+	Diverse lithology resulting from facies changes of sediments deposited in a closed or partly closed basin. A thick limestone facies is adjacent to the Verde River (thick facies); away from the thick facies the rocks change rapidly to interbedded limestone and clastic material. Several thin basaltic flows are intercalated in the lakebeds.	Principal aquifer in the area. Limestone and sand and gravel facies are water bearing where below the water table.
						Unconformity	
	Tertiary	Miocene(?) and Pliocene(?)	Volcanic rocks		0–1,400+	Basaltic lava, dikes, cinder cones, and volcanic sedimentary rocks. Fragments in the sedimentary rocks are chiefly volcanic; a few beds are composed mostly of fragments of Precambrian and Paleozoic rocks.	Yields water to a few stock wells. Not a major acquifer.
						Unconformity	
		Miocene(?)	Sedimentary rocks		0–1,000+	Conglomerate, gravel, very coarse to very fine grained sandstone, siltstone, bentonitic clay, marl, and some limestone. Precambrian and Paleozoic rock fragments predominate in most exposures.	Not known to be water bearing.

TABLE 6.—*Generalized section of rocks in Verde Valley, Arizona*—Continued

Era	System	Series	Group	Formation	Thickness (feet)	Lithologic characteristics	Water-bearing characteristics
Paleozoic	Permian		Aubrey Group	Kaibab Limestone	300±	Unconformity Limestone or dolomitic limestone containing nodules and thin beds of chert. Some calcareous sandstone, especially in the northwestern part of the area.	Not known to be water bearing.
Paleozoic	Permian		Aubrey Group	Toroweap Formation	150–350	In most of the valley the formation is very fine grained to fine-grained sandstone. In the Sycamore Creek area a basal sandstone is overlain by sandstone and sandy limestone and, in turn, by sandstone, siltstone, and shale.	Not an aquifer.
Paleozoic	Permian		Aubrey Group	Coconino Sandstone	400–650	Sandstone composed of very fine grained to fine-grained rounded to subrounded grains of quartz. Conspicuous large-scale crossbedding.	Yields water to springs in canyons along eastern margin of area.
Paleozoic	Pennsylvanian and Permian		Aubrey Group	Supai Formation	1,500–1,600±	Lower member, about 600 ft thick, is composed of thin beds of sandstone, mudstone, limestone, and dolomite. Middle member, about 275 ft thick, is composed of thin-bedded dolomitic intraformational conglomerate, mudstone, limestone, siltstone, and sandstone. Upper member, more than 650 ft thick, is composed of sandstone and siltstone.	Second ranking aquifer in area. Springs issue from upper member in Oak Creek Canyon. Sandstone lenses in lower member are principal aquifers in Sedona area.
Paleozoic	Mississippian		Redwall Limestone		235–286	Unconformity Coarsely crystalline cherty limestone. Some beds contain crinoids, brachiopods, corals, and other fossils.	Yields water to several springs and possibly to several wells that penetrate the lower part of the Supai Formation.
Paleozoic	Devonian	Middle(?) and Upper Devonian	Martin Limestone		450–500	Unconformity Dolomite and dolomitic limestone. Contains thin beds of mudstone, shale, and sandstone. Some beds are very fossiliferous. Contact with the Tapeats(?) appears gradational.	Not water bearing.
Paleozoic	Cambrian	Lower and Middle Cambrian	Tonto Group	Tapeats(?) Sandstone	0–100±	Upper beds of siltstone and limy or dolomitic mudstone grade downward into beds of conglomerate and coarse-grained sandstone.	Not water bearing.
Precambrian						Unconformity Intrusive rocks, chiefly diorite and quartz porphyry.	Not water bearing.
Precambrian		Yavapai	Ash Creek Group		20,000±	Basaltic, rhyolitic, andesitic, and dacitic flows; rhyolitic and volcanic breccia; basaltic and andesitic agglomerate; and tuffaceous sedimentary rocks. All rocks are metamorphosed.	Not water bearing.

PRECAMBRIAN ROCKS

Metamorphic and igneous rocks of Precambrian age crop out only in the Black Hills (figs. 4, 10). The rocks are exposed at altitudes

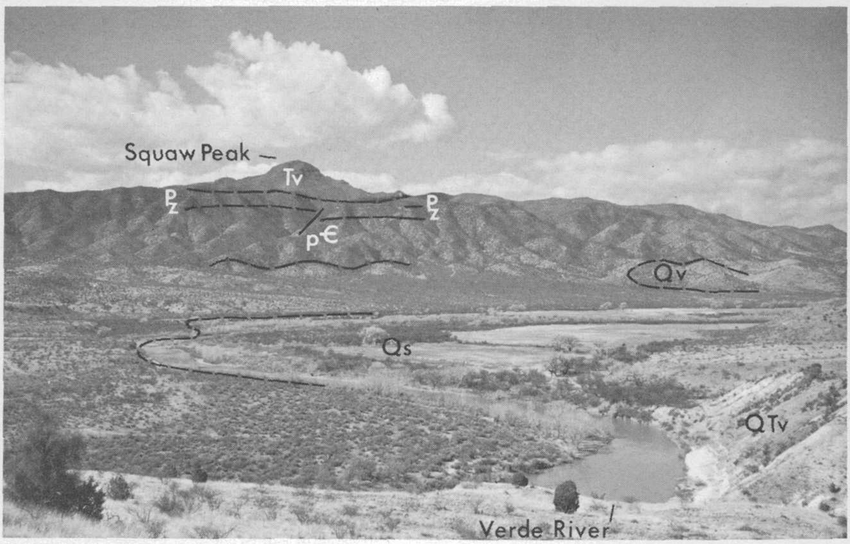

FIGURE 10.—Squaw Peak area in the southern part of the Black Hills. The Verde fault zone is parallel to the base of the mountain range. Precambrian rocks (p€); Paleozoic rocks undifferentiated (Pz); Tertiary volcanic rocks (Tv); sedimentary rocks of the Verde Formation (QTv); Quaternary volcanic rocks (Qv); and Quaternary streamwash (Qs). View east.

from 3,500 feet to more than 6,000 feet and are topographically high compared to correlative rocks in the Colorado Plateaus. They owe their elevated position to the Verde fault which separates structurally the Blacks Hills from Verde Valley and the Colorado Plateaus. (See geologic section, pl. 1.)

The Precambrian rocks of Arizona were subdivided into older and younger Precambrian by Butler and Wilson (1938, p. 11). This subdivision was adopted by Anderson and Creasey (1958, p. 8–45), who made a detailed and comprehensive study of the older Precambrian rocks in the northern part of the Black Hills and assigned the rocks along the western margin of Verde Valley to the Ash Creek Group of the Yavapai Series. They concluded that this group, which they divided into seven formations, is "***perhaps 20,000 feet thick***." The Ash Creek Group, as described by Anderson and Creasey, consists of basaltic flows, rhyolitic flows, andesitic flows, dacitic flows, rhyolitic breccia, volcanic breccia, basaltic agglomerate, andesitic agglomerate, and tuffaceous sedimentary rocks. All the rocks have been metamorphosed, but in some places the metamorphism is so slight that the original rock texture is apparent.

Igneous rocks of Precambrian age intrude the regionally metamorphosed Ash Creek Group. These intrusive rocks are chiefly diorite and quartz porphyry. The intruded rocks show very little effect of contact metamorphism.

Small quantities of water are captured and stored in the joints of the Precambrian rocks. Where the joints that contain water are intercepted by the land surface, a few springs and seeps discharge small amounts of water; however, the rocks are not known to yield water to wells.

PALEOZOIC ROCKS

Sedimentary rocks of Paleozoic age are exposed in the cliffs and mountains that encircle Verde Valley, and they form much of the valley floor in the northern part of the valley. Most Paleozoic rocks were eroded from the central part of the valley prior to Cenozoic sedimentation and volcanism.

The base of the Paleozoic rocks in the Black Hills west of the Verde fault zone generally is above an altitude of 6,000 feet. In the fault zone the rocks are step faulted; the blocks are downdropped to the east, and the lowest outcrop is below an altitude of 3,500 feet. Elsewhere in the valley the base is not exposed, and no wells have penetrated the rocks to their base. Three miles south of the report area along the Verde River the base of the Paleozoic section is at an altitude of about 2,900 feet.

The Paleozoic rocks unconformably overlie the Precambrian rocks and range in age from Cambrian to Permian. The Paleozoic section on the west side of the valley consists of the Tapeats(?) Sandstone, the Martin Limestone, the Redwall Limestone, and the lower part of the Supai Formation. The best exposures of these rocks are on the east side of the Black Hills in the peripheral zone of Mingus Mountain (fig. 4) and Squaw Peak (fig. 10). Paleozoic rocks younger than the Supai Formation have been eroded from the Black Hills, and, chiefly because of this erosion, the preserved thickness varies greatly. However, some variation in thickness is due to the uneven erosional surface upon which the Paleozoic rocks accumulated. The thickest Paleozoic section is near Jerome, probably near the locality where Anderson and Creasey (1958, p. 46) measured about 1,200 feet of Paleozoic rocks.

Throughout the rest of Verde Valley the exposed Paleozoic rocks are chiefly of Pennsylvanian and Permian age. The best exposures form the steep cliffs of the Mogollon Rim (figs. 3, 5). Here the Paleozoic sections consists of the Redwall Limestone, the Supai Formation, the Coconino Sandstone, the Toroweap Formation, and the Kaibab Limestone. The maximum thickness of these rocks is about 2,000 feet. Neither the Tapeats(?) Sandstone nor the Martin Limestone crop out or have been penetrated by wells in this area.

TAPEATS(?) SANDSTONE

The Tapeats(?) Sandstone crops out along the east side of Mingus Mountain and in Squaw Peak at an altitude of 5,000–6,000 feet. Small exposures of Tapeats(?) in downfaulted blocks in the Verde fault zone are at an altitude of 4,000–4,600 feet. Southeast of Squaw Peak, as in Chasm Creek, most outcrops are in the Verde fault zone at an altitude of 3,000–4,500 feet.

The thickness of the Tapeats(?) Sandstone varies greatly, mostly because isolated hills of Precambrian rocks were as much as 100 feet above the surface of low relief upon which the Tapeats(?) was deposited. Locally, these ancestral hills protrude through the Tapeats(?) and into the overlying Martin Limestone. In the Jerome area, Anderson and Creasey (1958, p. 48) found that the thickness of the Tapeats(?) "* * * ranges from a few inches to about 100 feet." In the southern part of the Black Hills, the thickness ranges from 30 to 80 feet; however, a thickness of less than 1 foot was found along the Verde River south of Brown Springs.

Anderson and Creasey (1958, p. 48) described the Tapeats(?) Sandstone in the northern part of the Black Hills as "* * * two lithologic units: a lower unit, which generally comprises two-thirds of the total thickness, consisting chiefly of sandstone, and an upper unit consisting chiefly of limy siltstone and marl." They noted that the color of the lower unit "* * * generally ranges from dusky red to dark reddish brown * * **" and that the beds in the upper unit "* * * grade upward into rocks of light-colored hues, yellowish gray, pale olive and dusky yellow." These two units are exposed in all outcrops of the formation in the Black Hills. Locally in the southern part of the Black Hills, the lower unit is light gray to very pale orange and the upper unit is grayish red to dusky red.

The lower unit of the Tapeats(?) is a coarse-grained to very coarse grained sandstone and conglomerate that forms cliffs. The fragments are chiefly quartz and feldspar and have a maximum diameter of about three-fourths of an inch. The lower unit has a firm siliceous cement and, in places, is so tightly cemented that it is almost a quartzite. The upper unit of the Tapeats(?) is chiefly siltstone and limy or dolomitic mudstone that forms slopes. The rocks in the upper unit are moderately cemented with siliceous and calcareous cement.

No diagnostic fossils were found in the Tapeats(?) Sandstone, and its exact age is unknown. The contact between the Tapeats(?) and the overlying Martin Limestone appears to be gradational. The upper calcareous or dolomitic mudstone of the Tapeats(?) grades imperceptibly into the lowermost dolomitic beds of the Martin.

The siliceous cement that has filled the voids of the Tapeats(?) Sandstone makes the sandstone unsuitable for the storage and transmission of ground water, though a small quantity of water probably is stored in joints. However, none of the inventoried wells or springs obtain water from the Tapeats(?).

MARTIN LIMESTONE

The Martin Limestone is exposed almost continuously in a peripheral zone around Mingus Mountain, and erosional remnants of the formation are exposed south of Mingus Mountain. In the Squaw Peak area the Martin is also well exposed; southeast of Squaw Peak the formation occurs in deep canyons that cut faulted blocks downdropped to the east (fig. 11).

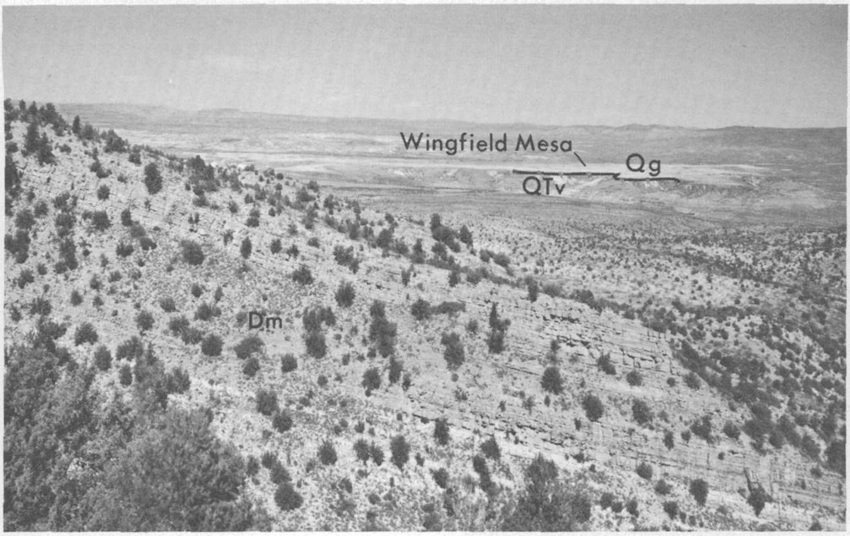

FIGURE 11.—Tilted block of Martin Limestone (Dm) in the Verde fault zone southeast of Squaw Peak. Gypsiferous clay beds of the Verde Formation (Qtv) underlie the Quartenary gravels (Qg) on Wingfield Mesa. View north from Chasm Creek.

The Martin Limestone is generally 450–500 feet thick. In the northern part of the Black Hills, Anderson and Creasey (1958, p. 49) reported 465 feet on the western flank of Mingus Mountain, and Stoyanow (1936, p. 495–497) described a section 505 feet thick near Jerome. The Martin is measured with difficulty in the southern part of the Black Hills chiefly because of erosion of the uppermost beds and extensive faulting.

The Martin Limestone is mostly dolomitic, and many beds are dolomite. Anderson and Creasey (1958, p. 50–51) divided the formation into four units: the lower unit is a coarse-grained dolomitic limestone 34 to 53 feet thick; the second unit is a lithographic limestone and dolomitic limestone 80–90 feet thick; the third unit is a fine- to medium-grained dolomitic limestone 65–78 feet thick; and the upper unit, about 350 feet thick, is chiefly dolomitic limestone, and probably some dolomite, that contains thin interbeds of limy siltstone and shale. Stoyanow (1936, p. 495–497) described the Martin at Jerome, and, although he did not divide it, the four lithologic units can be distinguished in his section.

A partial section of the Martin Limestone was measured by the authors at Squaw Peak, where the uppermost beds are missing or are covered. The section is 326 feet thick and has lithologic characteristics, from top to bottom, as follows:

(6) From 231 feet above the base to the top of the section the beds are mostly light-olive-gray and grayish-purple dolomite and dolomitic limestone and mudstone. The unit forms a steplike ledge-slope topography. The beds are 2 inches to 2 feet thick; some beds have a platy appearance.

(5) From 183 to 231 feet above the base a mottled moderate-red to pale-red argillaceous dolomite and dolomitic mudstone forms a steep slope. The beds are 2 to 6 inches thick. Fossils, chiefly brachiopods, are abundant in the lower 35 feet.

(4) From 156 to 183 feet above the base a very light gray to light-brownish-gray dolomitic limestone forms a slope. The beds are 3 inches to 1 foot thick.

(3) From 143 to 156 feet above the base a white to moderate-reddish-orange medium-grained to very coarse grained sandstone forms a slope. This unit contains plates of arthrodiran fish. The beds are 3 inches to 1 foot thick; the weathered surface reveals a varvelike platy bedding.

(2) From 28 to 143 feet above the base a pinkish-gray to white very fine grained (almost lithographic) dolomitic limestone forms a steep slope. The beds are 2 inches to 1 foot thick. Nodules and lenses of medium-gray chert are scattered through the unit.

(1) The lower 28 feet is a light-brownish-gray dolomite and dolomitic limestone that forms a vertical cliff. The beds are ¼ inch to 2 feet thick; the weathered surface reveals a varvelike platy bedding.

The Martin Limestone at Squaw Peak is similar in lithologic characteristics and thickness to the Martin in the Mingus Mountain area. The following correlation seems justified.

Squaw Peak area		Mingus Mountain area	
Unit	Thickness (feet)	Unit	Thickness (feet)
6	95+	Upper	350±
5 4	48 27	Middle	65–78
3 2	13 115	Lithographic	80–90
1	28	Lower	34–53

About 140 feet above the base of the Martin is a sandstone unit (unit 3 at Squaw Peak) that is distinctive and apparently correlative throughout the Black Hills. In the Mingus Mountain area this sandy unit is near the top of the lithographic unit and is an "excellent key bed" (Anderson and Creasey, 1958, p. 50).

The Martin Limestone yields little or no water to wells or springs in the report area. South of the report area, about 10 miles southeast of Camp Verde on the west bank of the Verde River, the Martin is in the highly fractured Verde fault zone, and here the formation yields water to Brown Spring and to several seeps (pl. 1).

REDWALL LIMESTONE

The only complete sections and extensive outcrops of the Redwall Limestone are in the Black Hills along the edge of Mingus Mountain. Here the altitude at the base of the formation is about 6,600 feet. In the Verde fault zone the altitude at the base is 4,200 feet or less. Several outcrops of the Redwall are in the Squaw Peak area, and a small isolated outcrop is in Oak Creek Canyon at a point where the Oak Creek fault crossed Oak Creek (pl. 1).

The Redwall probably is about 250 feet thick in Verde Valley. In the northwestern part of the valley, as stated by Lehner (1958, p. 529), the Redwall "* * * ranges in thickness from 235 to 285 feet, but probably averages about 250 feet." In Oak Creek Canyon, Mears[1] measured an incomplete section about 200 feet thick.

The contact between the Redwall and the underlying Martin Limestone is disconformable. The lower part of the Redwall in places contains as much as 35 feet of reworked material from the Martin Limestone (Lehner, 1958, p. 529).

The Redwall Limestone is mostly coarse grained and crystalline and is chiefly pure limestone. The color of the weathered surface is medium light gray to light gray, whereas the fresh surface is moderate yellowish brown to pale yellowish brown. Lenses and nodules of yellowish-brown chert that weather very light gray are common. Some chert is concentrated along bedding planes.

The lower third of the Redwall is thin bedded, especially near the base; the upper two-thirds is thick bedded and commonly forms vertical cliffs in canyons and along mountain margins. Part of the Redwall is abundantly fossiliferous; many fossiliferous beds are composed chiefly of crinoids and a few brachiopods and corals.

Some beds of the Redwall Limestone are highly fractured and contain solution channels. Although some channels are along joints and bedding planes, many have no discernible control and appear to occur at random through the formation. Because of the solution channels,

[1] Mears, Brainerd, Jr., 1948, Cenozoic faults, gravels, and volcanics of Oak Creek Canyon, Arizona New York, Columbia Univ. unpublished doctoral thesis, p. 5.

the formation is a potential aquifer. It may discharge a large amount of ground water to the Verde Formation in the northeastern part of the valley. The Redwall yields water to several springs and may contribute water to several wells.

SUPAI FORMATION

The Supai Formation has a greater areal extent than any other Paleozoic formation in Verde Valley. Because of its brilliant red color, great thickness, and steep-walled cliffs and because of the many buttes and spires that have been carved from it, the Supai is one of the most conspicuous rocks in the valley, especially in the northern part. Artists, tourists, and local residents use many rolls of films and tubes of paint in attempting to capture the splendor of the valley's intricately carved erosional features; they never completely succeed.

On the western side of the valley, the Supai crops out only in the northernmost part of the Black Hills; it does not crop out south of Mingus Mountain (pl. 1). The formation is exposed extensively in the northern part of the valley along the Mogollon Rim and on the valley floor (figs. 3; pl. 1). In the eastern part of the valley, most of the formation is covered by Tertiary and Quaternary rocks. However, in Wet Beaver Creek Canyon the Supai is exposed for several miles upstream, and in West Clear Creek Canyon it crops out along the creek channel for a distance of 8–10 miles (pl. 1).

In the Black Hills the base of the Supai Formation is exposed west of the Verde fault zone at an altitude of 6,500 feet. East of the fault zone on the west flank of Black Mountain the altitude at the base is 4,000 feet. In the Sedona area the base of the Supai is exposed only in the channel of Oak Creek 3 miles north of Sedona. Here the base of the formation, which has been elevated by movement along the Oak Creek fault, is at an altitude of 4,500 feet.

The thickness of the Supai Formation ranges from 1,500 to more than 1,600 feet. An exact thickness cannot be given because no single and distinct lithologic break exists between the Supai and the overlying Coconino Sandstone; the contact between the two formations is transitional. In the transition zone, light-colored crossbedded sandstones having lithologic characteristics similar to those of the Coconino Sandstone alternate with dark-colored sandstones having lithologic characteristics similar to those of the upper member of the Supai. The transition zone is 50–150 feet thick. Near Sedona the top of the transition zone is 350 feet above the limestone bed in the upper member of the Supai, and several miles south of Sedona the top of the transition zone is only 200 feet above the limestone. In this report the contact between the Supai Formation and the overlying Coconino Sandstone is placed at the top of the transition zone—that is, at the top of the uppermost bed having lithologic characteristics similar to those of the upper member of the Supai.

A section of Supai measured by the authors in the cliffs just northeast of Sedona is 1,575 feet thick. Lehner (1958, p. 533) measured 1,550 feet of Supai near Sycamore Creek, and Huddle and Dobrovolny (1945) measured about 1,750 feet of Supai in Fossil Creek Canyon just south of the report area (fig. 2).

In the northern part of Verde Valley, the lower member of the Supai rests unconformably on the Redwall Limestone. Along the Mogollon Rim southeast of the valley, the Supai conformably overlies the Naco Formation of Pennsylvanian age.

In Verde Valley and elsewhere in central and parts of northeastern Arizona, the Supai Formation consists of three distinct lithologic units—the lower, middle, and upper members (Huddle and Dobrovolny, 1945).

Sandstone beds in the Supai Formation are permeable and yield water to wells and springs and much of the perennial flow in Oak Creek is from springs in the upper member. Sandstone lenses and shoestringlike sandstone beds in the lower member are the principal aquifers yielding water to wells in the Sedona area.

LOWER MEMBER

The lower member of the Supai Formation is composed of alternate beds of sandstone, shaly mudstone, limestone, and dolomite. The beds commonly are 1–4 feet thick; but several beds are more than 10 feet thick, and two beds near the top of the section in Oak Creek Canyon are more than 25 feet thick. Units of the lower member generally weather to a steep ledge-slope topography except in Oak Creek Canyon, where the top 100–110 feet forms a vertical cliff (fig. 6). In the Sedona area the exposed part of the lower member is about 400 feet thick and consists of shaly mudstone, limestone, and dolomite containing shoestringlike lenses of sandstone. The top 100–110 feet consists mostly of very fine grained sandstone. In the Sycamore Creek area, Lehner (1958, p. 535) reported that the lower member is about 600 feet thick and "* * * consists chiefly of sandstone and siltstone and minor amounts of shaly mudstone; it contains a few limestone beds, and some chert breccia and (or) limestone conglomerate." The color of the lower member is light brown, moderate orange pink, grayish orange pink, grayish red, pale red, and pale to dark reddish brown.

No fossils have been discovered in the lower member of the Supai, and its exact age is not known. The Supai Formation east and southeast of Verde Valley is of Pennsylvanian and Permian age, but in the Grand Canyon area north of the valley, it may be chiefly of Permian age (Fetzner, 1960). In Verde Valley most of the Supai was laid down during Permian time. However, because part of the lower member is lithologically similar to, and occupies the same stratigraphic position as, the fossiliferous Naco Formation of Pennsylvanian age in the Fossil Creek area, the authors believe that at least part of the lower member may be a lateral equivalent of the Naco and, therefore, of Pennsylvanian age.

MIDDLE MEMBER

The middle member of the Supai Formation is composed of alternate beds of pale- to dark-reddish-brown and, locally, grayish-red dolomitic conglomerate, mudstone, limestone, siltstone, and sandstone. It is about 275 feet thick, and individual beds are a few inches to 4 feet thick. Where the middle member is below cliffs it usually forms step-like slopes (fig. 6) ; elsewhere it forms broad nearly level flats, such as Grasshopper Flat (fig. 12), and gently rolling hills. The middle member, because of its dolomitic and calcareous nature, is subject to solution, and in the Sedona area it contains four or more sinkholes as much as 200 feet in diameter and 80 feet deep. A notable lithologic feature of the middle member in the Sedona area is a dolomitic intraformational conglomerate that makes up the upper 125 feet. The matrix and nearly all the fragments in the conglomerate are dolomitic. On fresh surfaces, fragment outlines are difficult to distinguish; on weathered surfaces, however, the fragments, which are slightly more resistant,

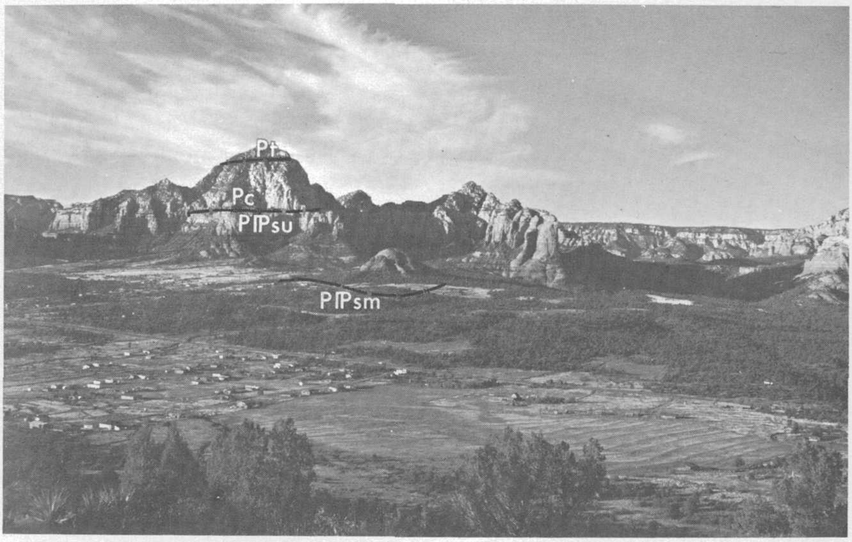

FIGURE 12.—Grasshopper Flat near Sedona. This broad flat is on the middle member of the Supai Formation (PIPsm). The intricately carved cliffs form the Mogollon Rim. Upper member of the Supai Formation (PIPsu); Coconino Sandstone (Pc); and Toroweap Formation (Pt). View north.

impart a conglomeratic appearance to the beds. Lehner (1958, p. 536) reported that "Probably 25 percent of the middle member consists of conglomerate beds * * *" in the Sycamore Creek area.

UPPER MEMBER

The upper member of the Supai Formation is a striking contrast to the lower and middle members. The upper member is mostly barren of vegetation and forms very steep and, in many places, vertical cliffs. The famous "red-rock country" near Sedona with its numerous buttes and spires has been carved from this member (figs. 6, 13). The upper member is composed predominantly of very fine grained to fine-grained sandstone and silty sandstone. The beds are very thick and massive. The color of the upper member is moderate reddish brown to pale reddish brown; several thin (3 in. to 2 ft. thick) beds are moderate orange pink.

Lehner (1958, p. 537) reported that the thickness of the upper member in the Sycamore Creek area ranges from 650 to 750 feet. It thickens to about 900 feet in the Sedona area, and southeastward near Fossil Creek it is more than 1,100 feet thick.

About 550 feet above the base of the upper member in the Sedona area is a grayish-red to grayish-orange-pink sandy limestone (fig. 14). The thickness of the limestone near Sedona is 10–15 feet. It thins and pinches out westward and is only a few inches thick at a point about 6 miles northwest of Sedona. In West Clear Creek Canyon, two beds

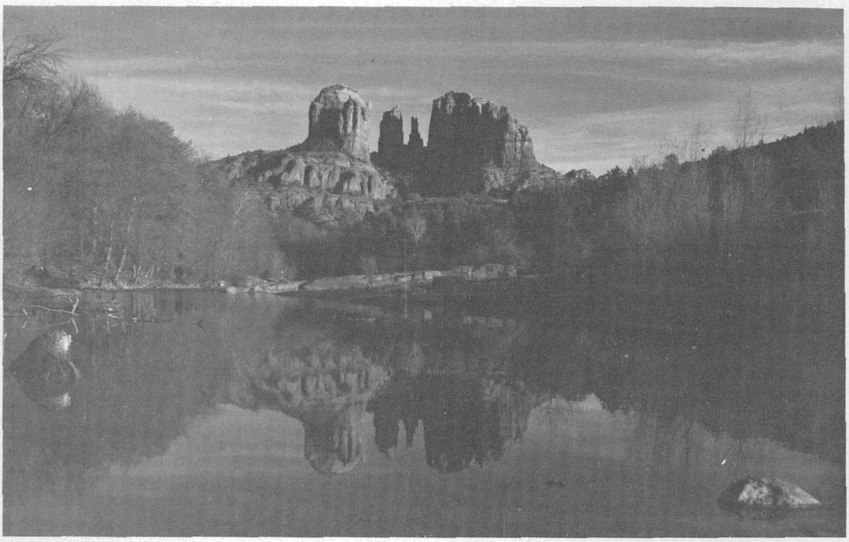

FIGURE 13.—Buttes and spires carved from the upper member of the Supai Formation along Oak Creek at Red Rock Crossing.

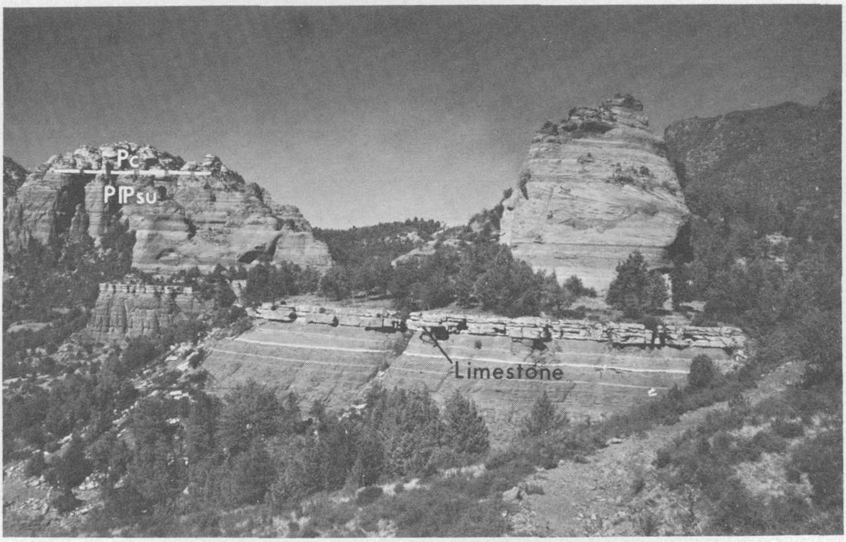

FIGURE 14.—Limestone in the upper member of the Supai Formation (PℙPsu). Coconino Sandstone (Pc). View north from Munds Mountain.

of limestone, similar in occurrence and lithologic characteristics to the limestone near Sedona, are separated by 70 feet of sandstone: the lower limestone is 10 feet thick, and the upper one is 20 feet thick.

The first fossils from the Supai Formation in Verde Valley were collected by the authors from the limestone in the upper member east of Sedona and in West Clear Creek Canyon. The fossils are invertebrates, mostly gastropods and pelecypods, but no further identification has been made.

COCONINO SANDSTONE

The Coconino Sandstone is well exposed and forms a nearly vertical wall along the Mogollon Rim (fig. 3), but the Coconino and younger rocks were removed by erosion in the Black Hills. The base of the formation is at altitudes ranging from 5,000 to 5,500 feet.

The measured thicknesses of the Coconino Sandstone depend on where the contacts of the Coconino Sandstone with the underlying Supai Formation and the overlying Toroweap Formation are placed. These contacts are gradational and intertonguing, and the transitional intervals are less than 50 to more than 100 feet thick.

This thickness of the Coconino in the northern part of the valley ranges from 400 to 650 feet. Brainerd Mears, Jr.,[2] measured 396 feet of the formation near Sedona, but he may have included a part of the Coconino with the Toroweap Formation. Lehner (1958, p. 541) noted

[2] Unpublished doctoral thesis, p. 7. See footnote 1, p. 27.

that the Coconino in the Sycamore Creek area is 500–650 feet thick. The combined thickness of the Coconino and the Toroweap is 800 feet in water wells drilled 6 miles southwest of Flagstaff (Akers, 1962).

In Verde Valley south of U.S. Highway 79, the characteristics that distinguish the Coconino Sandstone from the Toroweap Formation disappear, and rocks equivalent to the two formations appear as a massive sandstone unit containing similar crossbedding types. McKee (1934, p. 82) noted 1,000 feet of Permian crossbedded sandstone about 40 miles southeast of Verde Valley; here the overlying Toroweap Formation is not recognizable.

The Coconino Sandstone is a white to very pale orange sandstone composed chiefly of very fine grained to fine-grained rounded to subrounded grains of frosted quartz. The cement is mostly silica, but some calcium carbonate is present. The degree of cementation ranges from weak to strong. Large-scale (as much as 50 ft long) wedge-type crossbeds are characteristic, but evidence of horizontal lineation is rare.

The Coconino Sandstone is permeable and is an aquifier north and east of Verde Valley. However, in much of the report area the formation has been drained. In some deep canyons on the east side of the valley, such as those of Wet Beaver and West Clear Creeks, the Coconino yields water to springs that maintain perennial streamflow.

TOROWEAP FORMATION

The areal extent of the Toroweap Formation is nearly the same as that of the Coconino Sandstone. The Toroweap forms a vertical cliff along the Mogollon Rim in the northern part of the valley (fig. 3). South of U.S. Highway 79 in the eastern part of the valley the Toroweap cannot be distinguished from the Coconino Sandstone. The altitude at the base of the formation ranges from 5,500 to 6,000 feet.

The Toroweap Formation is 150–350 feet thick. Brainerd Mears, Jr.,[3] measured 330 feet of Toroweap in Oak Creek Canyon. About 20 miles west, in the Sycamore Creek area, the thickness of the formation ranges from 150 to 165 feet (Lehner, 1958, p. 593–595).

In the Sycamore Creek area the lower and upper contacts of the Toroweap can be identified on the basis of lithologic characteristics (Lehner, 1958, p. 543–545). However, in most of Verde Valley the formation is a sandstone similar to the underlying Coconino Sandstone, and the lower contact, which is not easily determined, is set arbitrarily at a distinct vegetation-covered ledge near the base (fig. 3).

In Oak Creek Canyon, Brainerd Mears, Jr.,[4] noted that the Toroweap Formation is a " * * * very pale orange, fine to very fine grained sandstone * * * " and that " * * * from top to bottom * * * there is recognizable no variation in lithology * * *." In the

[3] Unpublished doctoral thesis, p. 8, 9. See footnote 1, p. 27.
[4] Unpublished doctoral thesis, p. 8, 9. See footnote 1, p. 27.

Sycamore Canyon area Lehner (1958, p. 544) noted that " * * * the formation can be subdivided lithologically into three main units, which consist from bottom to top of red and buff sandstone, calcareous sandstone and arenaceous limestone, and alternating red and buff sandstone, siltstone, and some shale * * *." This lithologic change from the Toroweap described by Mears to the Toroweap described by Lehner occurs in a lateral distance of less than 5 miles.

In much of its outcrop area the Toroweap Formation is a sandstone composed largely of quartz grains cemented with silica. Although Toroweap is crossbedded, the crossbeds are not as large as those in the Coconino Sandstone. The smaller crossbeds and horizontal bedding planes in the Toroweap distinguish it from the underlying Coconino.

Because the Toroweap Formation in much of the valley is similar to the Coconino Sandstone, its water-bearing characteristics probably are similar also. Thus, the Toroweap is a potential aquifer, although within the area mapped the formation has been drained.

KAIBAB LIMESTONE

The Kaibab Limestone is best exposed along the Mogollon Rim and in steep-walled canyons such as those of West Clear, Wet Beaver, Oak, and Sycamore Creeks. The Kaibab underlies much of the Colorado Plateau, which bounds Verde Valley to the north and east, although at many places it is covered by Cenozoic rocks (pl. 1). The altitude at the base of the Kaibab is between 6,000 and 6,500 feet.

The Kaibab Limestone is about 300 feet thick, but erosion may have removed the uppermost beds. McKee (1938, p. 186–187) measured about 250 feet of Kaibab in Sycamore Canyon, and, although the section was measured from the top of the Toroweap Formation to the base of the Moenkopi Formation of Triassic age, it probably does not represent the original thickness; some of the Kaibab may have been eroded before Moenkopi time. McKee (1938, p. 183–184) also measured a 381-foot section of Kaibab in the cliffs just east of Sedona.

The Kaibab Limestone is mostly a limestone or dolomitic limestone containing nodules and thin beds of chert. The predominant colors are very pale orange, yellowish gray, very light gray, and white. Many beds are sandy, and some beds, especially those in the northwestern part of the valley, are almost entirely fine-grained calcareous sandstone. The beds range from less than a foot to more than 12 feet in thickness. The formation forms a steep steplike ledge-slope topography and, in many places, erodes into vertical pillars and pinnacles.

Some beds of the Kaibab contain many invertebrate fossils. Most of the fossils are mollusks and brachiopods which occur as interior or exterior molds. A large brachiopod of the genus *Dictyoclostus* is abundant in some beds, and silicified fragments of this brachiopod are common in gravel deposits derived, at least in part, from this formation.

The Kaibab Limestone in most places in Verde Valley probably has been drained. However, because the formation is the surface rock in places along the margin of the Colorado Plateaus, some beds may contain perched water. In the area of this report the Kaibab is not known to yield water to wells.

TIME HIATUS BETWEEN PALEOZOIC AND CENOZOIC ROCKS

Rocks of Mesozoic age are not present in Verde Valley. The Moenkopi Formation of Triassic age crops out just north of the report area in the upper reaches of Sycamore Canyon and near Flagstaff. Rocks of similar age probably were deposited in Verde Valley and subsequently were removed by erosion.

CENOZOIC ROCKS

The rocks of Cenozoic age are chiefly sedimentary and volcanic. The oldest known Cenozoic strata are Tertiary sedimentary rocks composed chiefly of fluviatile materials, but containing local deposits of lacustrine origin. After deposition, most of the Tertiary sedimentary rocks were eroded. Several periods of volcanic activity ensued, and volcanic rocks accumulated over a large part of Verde Valley. The volcanic rocks, most of which are basalt flows and sedimentary rocks derived from volcanic materials, are chiefly of Tertiary age. During the final stages of, and after, Tertiary volcanism, structural movement uplifted the Black Hills and separated them from the Colorado Plateaus. Renewed volcanic activity south of Camp Verde blocked and impounded the water of the Verde River. Lacustrine sediments were deposited in the impounded water, and fluviatile sediments were deposited around the margins and beyond the limits of the lake. The indurated sediments and local intercalated basalt flows constitute the Verde Formation of Tertiary or Quaternary age. The relation of the Paleozoic rocks to the Tertiary sedimentary and volcanic rocks and the Verde Formation is displayed excellently along Oak Creek about a mile southeast of Hidden Valley Ranch (fig. 15).

After deposition of the Verde Formation, erosion produced the pediment surface on which Quaternary volcanic rocks and Quaternary gravels were deposited. The youngest Cenozoic deposit is the streamwash of Quaternary age along the channels of the present streams and washes.

TERTIARY SEDIMENTARY ROCKS

The Tertiary sedimentary rocks described in this report are older than most, if not all, Cenozoic volcanic rocks in Verde Valley. The most extensive deposits extend from Copper Canyon to Cherry Creek

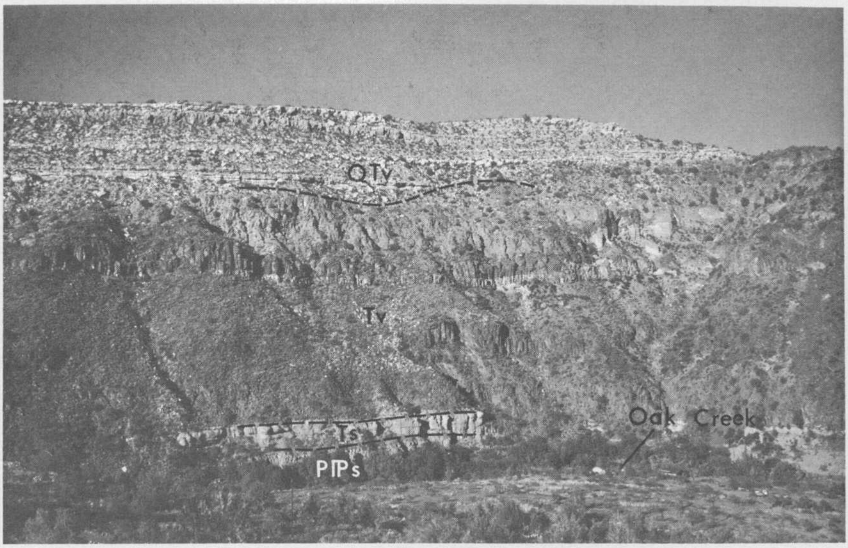

FIGURE 15.—Section of Paleozoic and Cenozoic rocks along Oak Creek near Hidden Valley Ranch. Approximate altitude of Oak Creek is 3,660 feet. About 50 feet of Supai Formation (PPs) is exposed above the creek level. Overlying the Supai is a 27-foot unit of Tertiary sedimentary rocks (Ts), which in turn is overlain by 366 feet of Tertiary volcanic rocks (Tv). About 230 feet of sedimentary rocks of the Verde Formation (QTv) caps the section. View east.

on the west side of the valley and from Red Tank Draw to Dry Beaver Creek on the east side (pl. 1). Smaller deposits are in West Clear Creek Canyon and elsewhere in the valley.

Anderson and Creasey (1958, p. 56–59) applied the name Hickey Formation (Pliocene?) to 1,400 feet of Cenozoic volcanic and sedimentary rocks in the Black Hills, noting that at most localities the rocks are chiefly basalt and that the sedimentary rocks underlying the basalt in the type section are only 50 feet thick. In Verde Valley, the sedimentary rocks underlying the Tertiary volcanic rocks are widespread and at several places are more than 1,000 feet thick. Also, great thicknesses of the sedimentary rocks were eroded before the major period of volcanic activity in Tertiary time. For these reasons, Anderson and Creasey's formational name is not used in this report.

The altitude at the base of the Tertiary sedimentary rocks on the west side of the Verde fault zone near Mingus Mountain is 6,500–6,800 feet; the altitude at the base where exposed on the east side of the fault zone is 4,200–4,500 feet. The altitude at the base of these rocks is 4,000 feet in West Clear Creek Canyon, 3,700 feet in the canyon of Oak Creek near Page Springs, and 3,700–4,700 feet in the canyon along Dry Beaver Creek.

The thickness is variable because the Tertiary sedimentary rocks were deposited on an irregular surface that had a relief of more than

2,000 feet; after deposition the rocks were eroded extensively. The rocks are at least 1,000 feet thick in the Copper Canyon–Cherry Creek area and in the Red Tank Draw–Dry Beaver Creek area and as much as 300 feet thick in West Clear Creek Canyon. Elsewhere throughout the valley the Tertiary sedimentary rocks usually are less than 100 feet thick. The maximum original thickness is not known, but it was probably 2,000–3,000 feet.

The Tertiary sedimentary rocks have a variety of lithologic characteristics. In the Black Hills, in Black Mountain, in West Clear Creek Canyon, and along Oak Creek, they are mostly conglomerate, gravel, and very coarse grained to fine-grained sandstone; bedding is poorly defined and lenticular. In the Red Tank Draw–Dry Beaver Creek area, the Tertiary sedimentary rocks consist of two lithologic units: a lower unit, which contains an abundance of Precambrian fragments and few basalt fragments, and an upper unit, which contains an abundance of basalt fragments but few Precambrain fragments. Several rock types are represented in both units; included are conglomerate, gravel, very coarse grained to very fine grained sandstone, siltstone, bentonitic clay, marl, and some limestone. The beds are generally lenticular and range from thin to very thick. The bedding is poorly defined in the thick sections of coarse-grained material but is distinct where coarse material alternates with fine.

The following is a generalized composite section of Tertiary sedimentary rocks measured at two localities about 5 miles apart. The upper unit is in Rattlesnake Canyon and rests on the Supai Formation at an altitude of 4,400 feet. The lower unit is at Beaver Tail Butte; its base is concealed, but the altitude at the bottom of the section is 3,700 feet.

The Tertiary sedimentary rocks contain many fragments of Precambrian rocks which were derived from local and distant sources. Anderson and Creasey (1958, p. 57) noted that in places in the Black Hills "* * * the lithology of the gravel reflects the lithology of the adjacent bedrock." They found, however, that some rock types were not derived locally and that the source area must have been to the west or southwest.

Mahard (1949, p. 112–113) described some of the Tertiary sedimentary rocks along Dry Beaver Creek and wrote that "The notable features of these gravels is that in spite of their location across the present valley from the Black Hills Range, they contain high percentages of Precambrian rock types * * *." The nearest Precambrian outcrop is in the Black Hills at least 10 miles west of the Tertiary sedimentary rocks along Dry Beaver Creek. However, when the sediments were accumulating, the Black Hills had not been formed; the movement which uplifted the Black Hills and produced most of the

Generalized composite section of Tertiary sedimentary rocks

	Thickness (feet)
Upper unit.	
Basalt	Not measured
Gravel. Fragment types include 25–75 percent volcanic rocks (chiefly basalt) and minor amount of Paleozoic rocks (chiefly sandstone and limestone of the Supai, sandstone of the Coconino and (or) Toroweap, and chert and limestone of the Kaibab). Average diameter of the fragments is ½–3 in., but some fragments have diameter of 2 ft. From 90 to 130 ft. above base, section contains much limy mudstone and bed of clayey limestone	305
Covered. May be either upper or lower unit or both	300±
Lower unit.	
Conglomerate. Fragment types include light- and dark-colored chert, granite of varying composition, various types of gneiss and schist, quartzite, red jasper, sandstone (Coconino and (or) Toroweap), oolitic limestone (probably Redwall), and crinoidal limestone (Redwall). Average diameter of fragments, which are subangular to subrounded, is ½–2 in	55
Limestone, clayey and (or) sandy. Upper 7 ft. mostly conglomeratic and has sandy and calcareous matrix	32
Mudstone, some sandy limestone	52
Limestone, sandy	10
Conglomerate and some clayey and (or) sandy limestone. Fragments mostly chert and smoky quartz	8
Conglomerate, some gravel. Fragment types include sandstone of Supai, sandstone of Coconino and (or) Toroweap, and limestone and chert of Kaibab. Diameter of fragments less than an inch to more than 2 ft. Base is not exposed	235±
Approximate total Tertiary sedimentary rocks	1,000±

displacement along the Verde fault zone did not occur until after accumulation of the Tertiary volcanic rocks (Anderson and Creasey, 1958, p. 80). Thus, the nearest source for the Precambrian fragments along Dry Beaver Creek was west and northwest of the Black Hills.

Price (1950), described two different types of gravel beneath the basalt on the rim of Sycamore Canyon. Price's Type B gravel is composed chiefly of fragments of quartzite and a few fragments of petrified wood; it does not appear to be related, as to source and lithologic characteristics, to the Tertiary sedimentary rocks in Verde Valley. However, his Type A gravel, except for the fact that it is at an altitude of 6,000 feet, is lithologically similar to Tertiary sedimentary rocks in the valley; thus, his Type A gravel and the Tertiary sedimentary rocks may have had a similar source area.

The marl and limestone in the Red Tank Draw–Dry Beaver Creek area contain a few fossil gastropods, pelecypods, ostracodes, and plants. None of the fossils seem to be diagnostic, and no diagnostic fossils have been found elsewhere in the valley in rocks of probable Tertiary age.

The Tertiary sedimentary rocks underlie Tertiary volcanic rocks that can be traced and correlated with other volcanic rocks in the basins and valleys of central Arizona (Twenter, 1961). The volcanic rocks in two of the basins in central Arizona are overlain by lacustrine and fluviatile rocks that are of lower to middle Pliocene age. Because the Tertiary volcanic rocks accumulated before deposition of the lower to middle Pliocene lacustrine and fluviatile rocks, it seems reasonable to assume that the volcanic rocks are Miocene, and possibly lowermost Pliocene, in age and that the underlying Tertiary sedimentary rocks are at least as old as, or older than, Miocene.

The Tertiary sedimentary rocks are not major aquifers. Even the gravel, conglomerate, and sandstone beds are nearly impermeable because they contain an abundance of clay- and silt-sized interstitial material and are moderately to well cemented. The rocks have been eroded from much of the valley, and most of the remnants are above the water table.

TERTIARY VOLCANIC ROCKS

The distribution of Tertiary volcanic rocks in Verde Valley is irregular, and stratigraphic relations are difficult to determine. The rocks are nearly everywhere along the margin of the valley and locally form the valley floor. In places only one or two basalt flows are present, but in other places, as in West Clear Creek Canyon (fig. 16), 5, 10, or more basalt flows are interbedded with volcanic sedimentary rocks. Some flows occupy positions at the tops of high cliffs and mountains; others are in, and partly or completely fill, old stream channels (fig. 17). Tertiary volcanic rocks probably underlie most of the Verde Formation, because they are exposed extensively on both sides of Verde Valley and are penetrated by deep wells.

The Tertiary volcanic rocks rest on older rocks of many different ages, and the base is at different altitudes. In the Black Hills they rest on Precambrian rocks and on sedimentary rocks of Paleozoic and Tertiary age. West of the Verde fault zone, the base is at altitudes from 5,000 to more than 6,500 feet; east of the fault zone the base generally is below 4,000 feet. In the Mogollon Rim area the Tertiary volcanic rocks rest on sedimentary rocks of Paleozoic and Tertiary age, and in the Sycamore Canyon area they rest on the Triassic Moenkopi Formation. The highest altitude at the base of the volcanic rocks along the Mogollon Rim is more than 6,500 feet. Because part of the lava poured over the rim and onto the valley floor, the base is at progressively lower altitudes toward the valley. The lowest altitude at the base of the Tertiary volcanic rocks is near the center of the valley

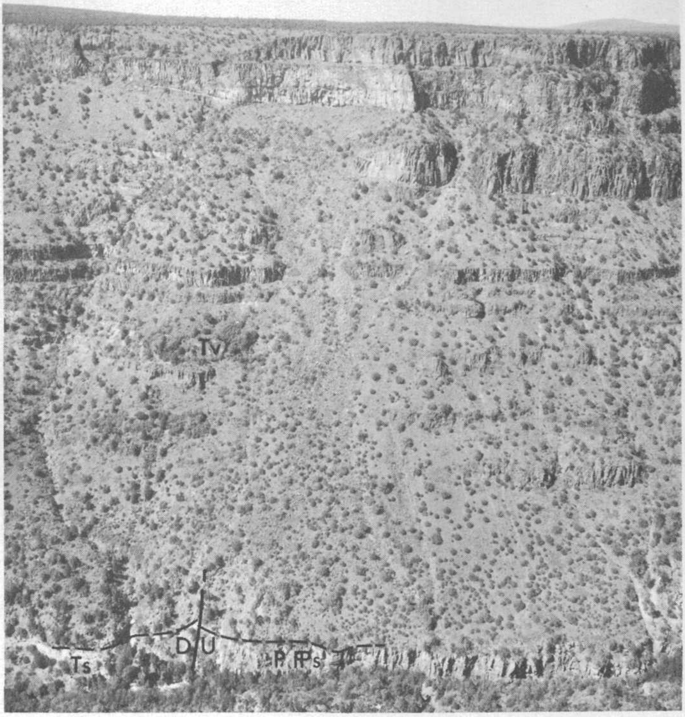

FIGURE 16.—Tertiary volcanic rocks (Tv) in West Clear Creek Canyon; the section at this locality is 1,000 feet thick. Thick-bedded lava flows form the vertical cliffs whereas tuffaceous rocks and thin-bedded flows form the slopes. Supai Formation (PℙPs) and Tertiary sedimentary rocks (Ts). View east.

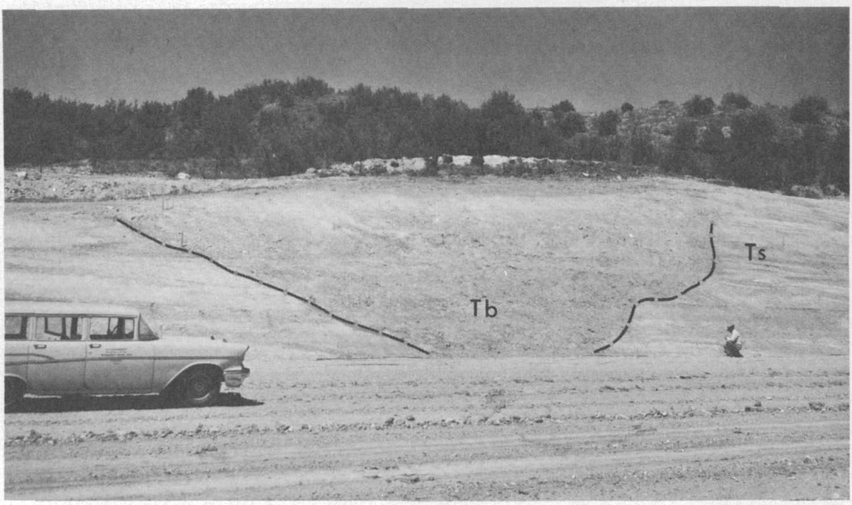

FIGURE 17.—Tertiary basalt flow (Tb) filling shallow channel excavated in Tertiary sedimentary rocks (Ts). View north from U.S. Highway 79 near Red Tank Draw.

and probably is below 2,500 feet. In the southern part of Verde Valley, Tertiary volcanic rocks are in the channel of the Verde River at altitudes of less than 3,000 feet (fig. 18).

The thickness of Tertiary volcanic rocks varies. The composite thickness of basalt flows and interbedded sedimentary rocks is as much as 1,350 feet in the Black Hills (Anderson and Creasey, 1958, p. 56) and at least 1,000 feet in the Mogollon Rim area. In other places in both areas, the thickness is less than 50 feet. The variation in thickness is due to the configuration of the basal contact, the amount of post-lava erosion, and the proximity to the fissures and other vents from which the lava flowed.

The Tertiary volcanic rocks have diverse lithologic characteristics. Locally they consist almost entirely of basalt flows separated only by thin (1 to 3 ft thick) soil or highly weathered cinder zones. Elsewhere, thick deposits of volcanic sedimentary rocks—some more than 100 feet thick—are intercalated with flows. Basalt dikes that cut Paleozoic rocks, Tertiary sedimentary rocks, and some Tertiary volcanic rocks are exposed in several places (fig. 19). Cinder deposits, intercalated with flows, are common (fig. 20).

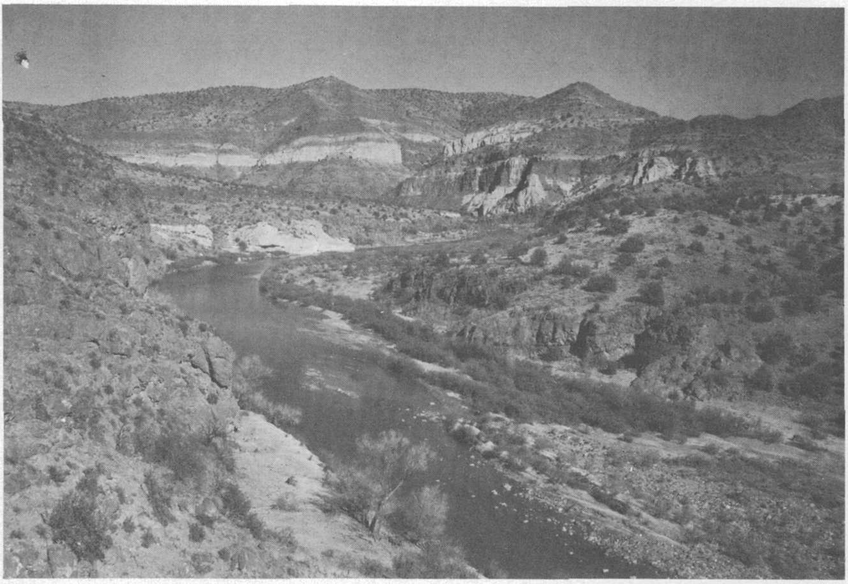

FIGURE 18.—Tertiary volcanic rocks along the Verde River just south of Chasm Creek, showing interbedding of light-colored sedimentary rocks and dark-colored basaltic flows. The volcanic rocks dip about 9° N. View northeast.

FIGURE 19.—Basalt dike cutting Tertiary sedimentary rocks in West Clear Creek Canyon. The sedimentary rocks are coarse grained, well consolidated, and show evidence of bedding.

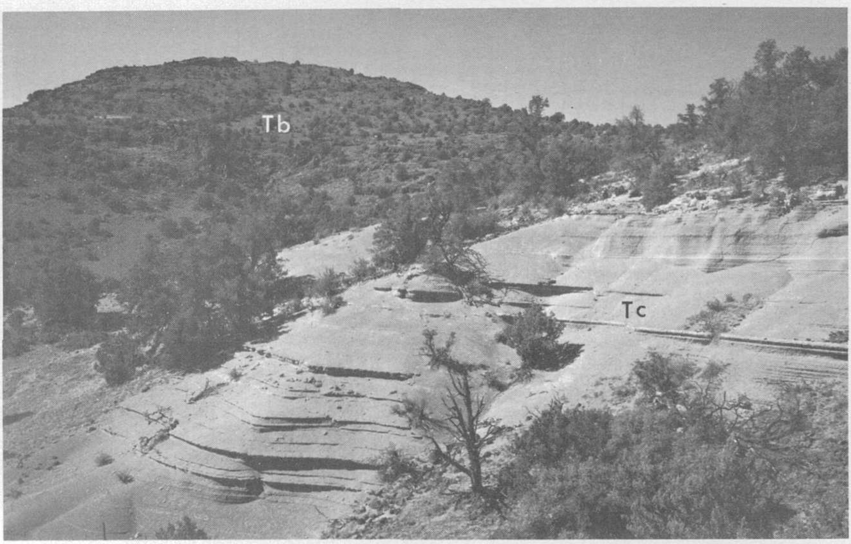

FIGURE 20.—Tertiary volcanic rocks on Walker Mountain. Basalt (Tb) and cinder deposits (Tc). View north.

No petrographic study of the basalt was made for this report. Anderson and Creasey (1958, p. 57) stated that

> The physical character and mineralogic composition of the [Tertiary] basalt [in the Jerome area] appear typical of many plateau basaltic flows. The interior of the flows are massive, except for vesicles, whereas the tops of the flows are blocky from brecciation. * * * the basalt is porphyritic; phenocrysts of olivine and augite are set in a very fine grained or microcrystalline felty (pilotaxitic) groundmass, composed of needles of labradorite in a base of mafic material—presumably augite and olivine.

The fresh surface of the basalt is medium dark gray to light gray, and the weathered surface is brownish black, olive gray, light gray, or medium gray. The weathered surface commonly has a light-brown or grayish-orange stain.

Sedimentary rocks in the Tertiary volcanic rocks are well exposed in Red Tank Draw and Copper Canyon. In Red Tank Draw the section is about 550 feet thick and includes about 200 feet of volcanic sedimentary rocks. Ninety percent of the fragments in most beds are basalt and volcanic debris and 10 percent are locally derived Paleozoic rocks. At the head of Copper Canyon an 80-foot-thick section of light-colored volcanic sedimentary rocks lies between dark-colored Tertiary basalts (fig. 21). The fragments in most beds are basalt and volcanic debris, but several beds are composed chiefly of fragments of Precambrian and Paleozoic rocks.

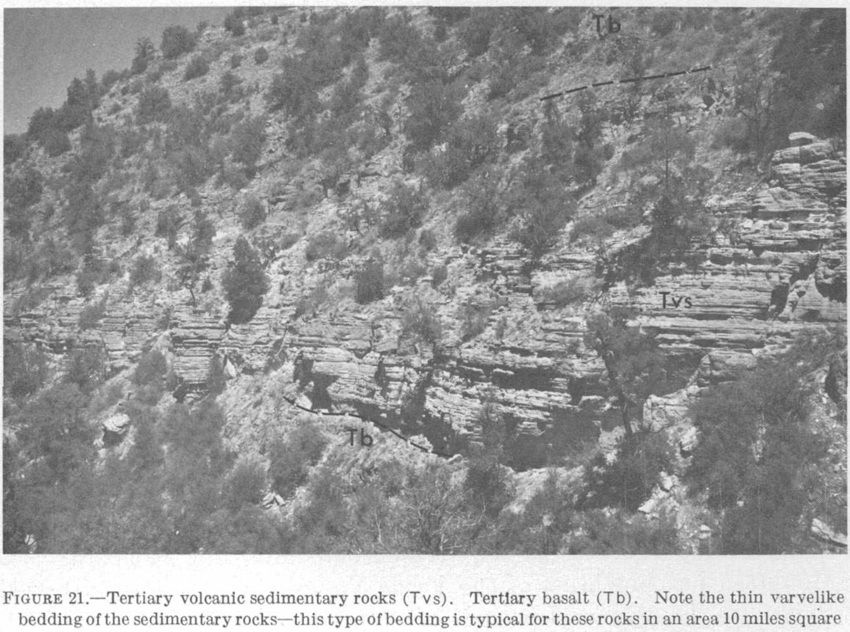

FIGURE 21.—Tertiary volcanic sedimentary rocks (Tvs). Tertiary basalt (Tb). Note the thin varvelike bedding of the sedimentary rocks—this type of bedding is typical for these rocks in an area 10 miles square in the vicinity of Copper Canyon.

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Exposed in the steep wall of the canyon along Oak Creek near Hidden Valley Ranch is a section of Tertiary volcanic rocks underlain by Tertiary sedimentary rocks and overlain by the Verde Formation (fig. 17). The following is a section of the volcanic rocks near Hidden Valley Ranch (NE¼ sec. 14, T. 16 N., R. 4 E.).

Stratigraphic section of Tertiary volcanic rocks

	Thickness (feet)
Pliocene or Pleistocene(?):	
Verde Formation (described in table 12).	
Miocene(?) and Pliocene(?):	
Volcanic rocks:	
Basalt, partly covered, grayish-black and medium-gray; weathers medium dark gray and light gray. Weathers blocky and knobby and forms a steep slope	10
Volcanic conglomerate or agglomerate; scoriaceous fragments as much as 6 in. in diameter, pale red; and weather moderate red; basalt fragments as much as 3 ft in diameter, medium gray, and weather medium light gray. Numerous white calcite veins. Weathers rounded and knobby and forms irregular slope	15
Basalt, lower 30–50 ft is dark gray and medium gray and weathers brownish black to medium light gray; upper 90–110 ft is medium light gray. Some columnar jointing. Lower 30–50 ft forms cliff; upper 90–110 ft forms steep slope. This unit probably continuation of underlying unit, but color change gives sharp separation	140
Basalt, medium-gray, some grayish-black; weathers light gray to light brownish gray. Weathers blocky; spheroidal weathering in upper 3 ft. Some columnar jointing. Forms vertical cliff	18
Volcanic conglomerate; basalt fragments (average diameter about 2 in.), moderate-brown. Matrix is moderate-reddish-brown sandstone; this color is distinctive for unit. Highly calcareous. Unit may be weathered zone	3
Basalt, grayish-black and medium-gray; weathers medium dark gray and light gray; upper 80–100 ft is mostly light gray. Mineral inclusions are moderate olive brown, pale yellowish gray, and moderate reddish brown. Some columnar jointing. Weathers blocky and knobby. Lower 75–100 ft forms vertical cliff; upper 80–105 ft forms steep slope	180
Total Tertiary volcanic rocks	366
Miocene(?):	
Sedimentary rocks.	

The exact age of the Tertiary volcanic rocks is not known. In this report they are referred to simply as of Tertiary age. They underlie the Verde Formation, which is probably Pliocene and early Pleistocene in age. Robinson (1913, p. 38–45) described volcanic rocks on the Colorado Plateaus in the area encompassing the San Francisco Mountain just northeast of the Verde Valley (fig. 22) and separated them into three general periods of eruption. He concluded that vol-

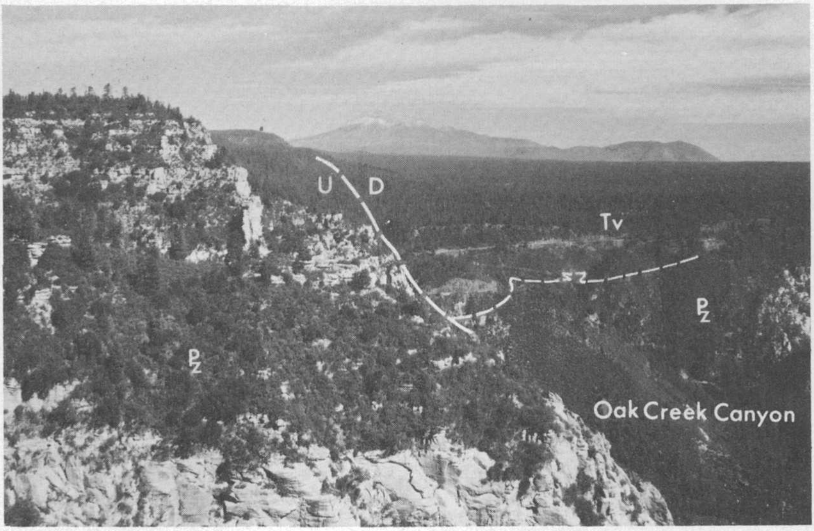

FIGURE 22.—San Francisco Mountain near Flagstaff rising above the general level of the Colorado Plateaus, and the eroded Oak Creek fault scarp. Downdropped block of the Oak Creek fault is on the right (east). Paleozoic rocks undifferentiated (Pz) and Tertiary volcanic rocks (Tv). View north from near the mouth of Oak Creek Canyon.

canic rocks of his oldest period of eruption accumulated during late Pliocene time. In the Black Hills the Cenozoic volcanic rocks were "* * * tentatively assigned to the Pliocene epoch * * *" by Anderson and Creasey (1958, p. 58–59). Cooley (1961), however, suggested that some of the early volcanism is probably of Miocene age. Twenter (1961) cited stratigraphic relations between the volcanic rocks and the lacustrine and fluviatile rocks of lower Pliocene age and concluded that most of the volcanic rocks accumulated in Miocene time.

The authors agree generally with Anderson and Creasey (1958, p. 80–82) that the Black Hills owe most of their present height to several thousands of feet of displacement along the Verde fault zone after the deposition of the Tertiary volcanic rocks and before the deposition of the Verde Formation. Thus, the volcanic rocks probably accumulated in a broad nearly flat valley that encompassed the area now occupied by the Black Hills and that had a total width two or three times that of the present Verde Valley.

Volcanic activity on the surrounding plateaus and within the broad ancestral valley spread lava flows and pyroclastic rocks for great distances. Some lava flowed over the Mogollon Rim from the Colorado Plateaus and coalesced with flows in the valley. During volcanic inactivity, shallow surface depressions were filled with sediments eroded from rocks exposed in the vicinity. Renewed volcanism produced flows that covered the sediments. Many depressions and deep channels (some as much as 1,000 ft deep), such as are exposed today in the walls of West Clear Creek Canyon, were filled and buried. The flows and volcanic sediments tended to "level out" the topography.

The Tertiary volcanic rocks are not major aquifers. However, the basalts are faulted and contain numerous joints, and the volcanic sedimentary rocks contain open and interconnected pore spaces. Both types of rocks absorb water readily. Because the rocks are commonly in high areas surrounding Verde Valley, much of the ground water drains rapidly and leaves little in storage. Where the rocks are beneath the Verde Formation, as in oil-test hole (A-16-3)20bb and possibly in water wells near Page Springs, they yield water to wells.

VERDE FORMATION

Between the Black Hills and the Mogollon Rim, the Verde River flows through lake beds that, when viewed from the surrounding mountains, appear as a great white mass blanketing the floor of Verde Valley. These lake beds and associated fluviatile deposits were named the Verde Formation by Jenkins (1923, p. 69-81).

The Verde Formation covers a generally elliptical area of about 325 square miles (pl. 1). The northwest-trending axis of the outcrop is about 35 miles long and is subparallel to the Verde River.

HISTORY OF DEPOSITION

The distribution and character of the Verde Formation and its relation to older rocks make evident the broader outlines of its depositional history. The formation was deposited in an ancient valley whose boundaries were about the same as those of the present Verde Valley. The valley was formed by faulting, erosion, and volcanic activity. The faulting occurred along the Verde fault zone after deposition of most of the Tertiary volcanic rocks; the Black Hills were uplifted and separated from the Colorado Plateaus and the ancient Verde Valley. The southward-flowing Verde River cut through the Tertiary volcanic rocks in the southern part of the valley while tributary streams stripped rocks from the rest of the valley. Later, intermittent uplift and volcanic activity in the Hackberry Mountain area (fig. 2) dammed the water of the Verde River to form a lake. The lake expanded when volcanic deposits and uplift increased the height of the dam and contracted when erosion cut part way through the dam. Uplift, volcanic activity, impoundment of water, and deposition of sediments were concurrent, especially during the early stages of valley development. Intermittent tributary streams, flowing into the valley from the surrounding highlands, carried a load of very fine to very coarse fragments. The coarse fragments were deposited along the margin of the valley; the fine fragments were carried onto the floor. Limestone was precipitated in the deeper waters of the lake, and evaporite deposits formed in isolated ponds bordering the restricted lake during dry periods.

At the south end of the valley and north of Hackberry Mountain, the materials deposited were chiefly tuffaceous sediments and interbedded lava (fig. 23). The tuffaceous sediments were derived partly from active volcanoes and were deposited directly from the air and by northward-flowing streams. The tuffaceous rocks contain a mixture of ash, lava, and fragments of Precambrian and Paleozoic rocks. The lava and tuffaceous rocks of the Verde Formation thin progressively north of the Hackberry Mountain area and intertongue with clastic rocks that contain evaporite minerals.

The evaporite minerals indicate that at times the lake was very shallow and was subjected to almost complete desiccation. Because deposition of these minerals commonly occurred in the area where fine-grained clastic sediments were being deposited, the evaporite minerals and the clastic rocks are intermixed and interbedded. Rocks that contain evaporite minerals extend over an area of about 75 square miles in the southwestern part of the valley (fig. 24).

During the time that rocks rich in evaporite minerals were being deposited and continuing through most of Verde sedimentation, a

FIGURE 23.—Gently dipping basalt and coarse-grained tuffaceous rocks of the Verde Formation in Chasm Creek. The section as shown here correlates, in part, with units 5 and 6 of section 1 (p. 97). View southwest.

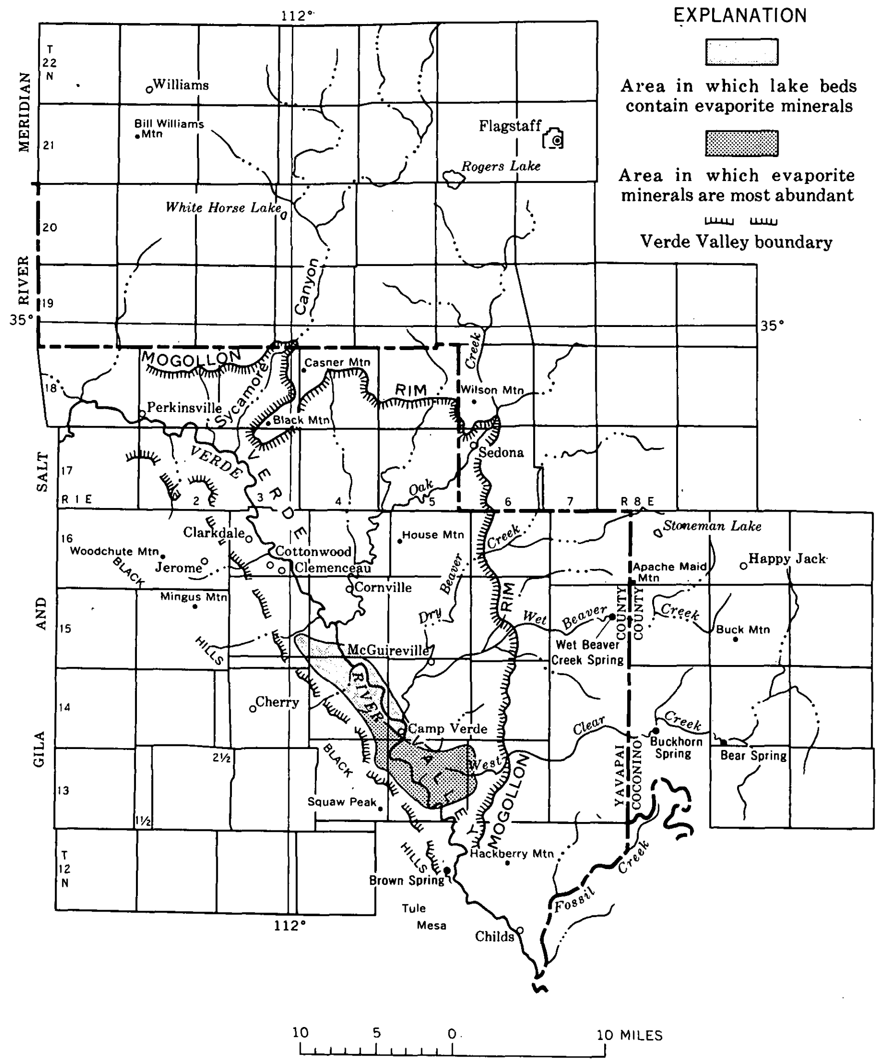

FIGURE 24.—Map showing area in which lake beds of the Verde Formation contain evaporite minerals.

shallow channel occupied the lowest part of the valley floor. Originally the channel was an erosional feature that marked the path of the ancestral Verde River. The channel was maintained throughout the period of deposition of the Verde Formation by more rapid accumulation of sediments along the margins of the valley than in the area of the channel and by periodic scouring of the channel by flood waters. The water in the channel was slow flowing for the most part, and, although not more than 5 or 10 feet deep—as suggested by the environmental requirements of the fossil plant and animal life—it probably was deeper than in the rest of the valley. In this channel, a thick continuous section of limestone—the thick limestone facies (fig. 25)—was deposited.

FACIES CHANGES

The type of material deposited was influenced by fluctuation of the water level in the lake. When the lake water was low or almost nonexistent, gravel, sand, silt, and clay were deposited in much of the valley; it was during these times also that the rocks containing evaporite minerals were deposited. Limestone was deposited only in the waters of the shallow channel that occupied the lowest part of the valley floor. When the water became deeper, deposition of limestone and marl was more extensive; and at times when the water covered the entire valley floor, deposition of limestone and marl was widespread. At least three limestone facies are recognizable—the lower, middle, and upper limestone facies of this report (fig. 25).

GENERAL STRATIGRAPHY

The Verde Formation is a complex assemblage of rocks having a variety of lithologic characteristics. In general, the formation is divided into facies on the basis of lithologic characteristics. (See fig. 25.)

Thick limestone facies.—This facies occupies the central part of Verde Valley. Most of the rocks are limestone and marl. The thick limestone facies comprises limestones that normally would be classified as part of the lower, middle, and upper limestone facies if they could be distinguished from the other limestones.

Mudstone facies.—This facies lies on either side and around the southern edge of the thick limestone facies. It may underlie, be stratigraphically equivalent to, or overlie the lower limestone facies. The rocks in the mudstone facies are predominantly mudstone and claystone, some of which contain evaporite minerals. In some places along the margin of the basin, conglomerate and tuffaceous rock form a major part of the mudstone facies.

Lower limestone facies.—This facies extends laterally from the thick limestone facies until it interfingers with the mudstone facies. The rocks in this facies are principally limestone and marl.

Middle limestone facies.—This facies extends laterally from the thick limestone facies until it overlaps pre-Verde Formation rocks or until it interfingers with clastic rocks of the Verde Formation along the margin of the valley. The middle limestone facies is separated from the lower limestone facies by rocks of the mudstone facies. Most rocks in the middle limestone facies are limestone and marl.

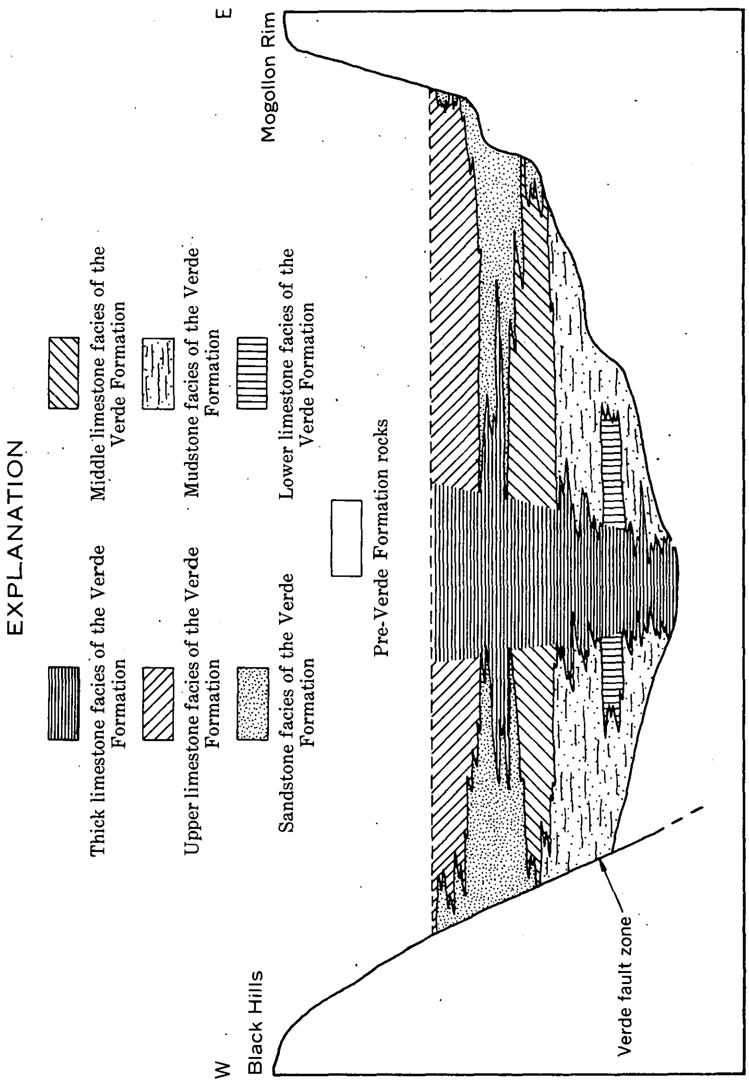

FIGURE 25.—Diagrammatic sketch of Verde Valley showing the probable relationship of facies in the Verde Formation at the end of deposition.

Sandstone facies.—This facies overlies the middle limestone facies. It interfingers with and extends laterally from the thick limestone facies. The sandstone facies is sandstone and siltstone that contain thin interbeds of limestone. In some facies along the margin of the valley the sandstone facies is predominantly conglomerate.

Upper limestone facies.—This facies extends laterally from the thick limestone facies until it overlaps pre-Verde Formation rocks or until it interfingers with clastic rocks of the Verde Formation along the margin of the valley. The upper limestone facies is separated from the middle limestone facies by rocks of the sandstone facies. Most rocks in the upper limestone facies are limestone and marl, although locally this facies contains thin beds of mudstone and sandstone.

THICK LIMESTONE FACIES

The thick limestone facies is chiefly limestone and marl (see stratigraphic sections 6 and 7, p. 104 and 105, respectively). The rocks in the thick limestone facies characteristically are white, although light gray, grayish orange, and pinkish gray are also common. Many beds contain lenses and nodules of white, light-gray, and yellowish-gray chert. Some beds contain silicified plant material. In the outcrop the limestone is hard and resistant, but some of the unweathered rock in fresh roadcuts is soft, marly, and chalklike; weathering seems to have produced much of the hardness and resistance at the surface. The limestone is usually rough, irregular, and gnarly (figs. 26, 27). The beds are about 6 inches to 5 feet thick. This facies commonly forms a steep ledge-slope topography or a vertical cliff.

Beds of limestone and marl in the thick limestone facies thin and intertongue with clastic materials of the mudstone and sandstone facies (fig. 25). Also, the thick limestone facies intertongues with the lower, middle, and upper limestone facies.

LOWER, MIDDLE, AND UPPER LIMESTONE FACIES

The lower, middle, and upper limestone facies are chiefly limestone and marl. These rocks are characteristically white, pinkish gray, and light gray. Some beds contain lenses and nodules of white, pale-blue, greenish-gray, yellowish-gray, and brownish-gray cherts. The beds are gnarly and contain solution channels. Some beds contain abundant plant material, and many beds in the upper facies are very porous because of large quantities of hollow calcified plant stems. Differential weathering commonly forms a rough, pitted surface. The beds are from 1 to 10 feet thick. The three limestone facies usually form vertical cliffs or very steep slopes. Rocks in the lower limestone facies are well exposed near Camp Verde (section 5, p. 102). Rocks in the

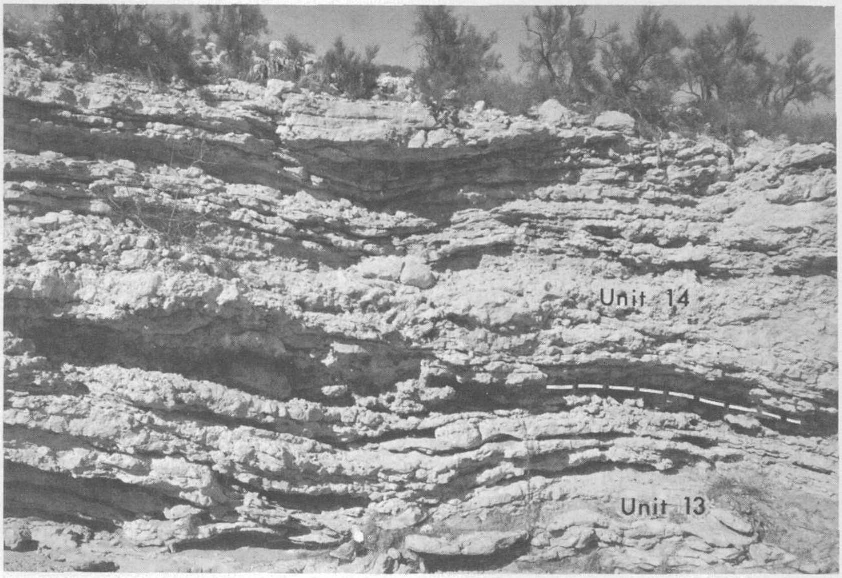

FIGURE 26.—Limestone in the Verde Formation near Clarkdale. The upper part of unit 13 and unit 14 of section 15 (p. 116) are shown. Unit 14 here is very fossiliferous.

FIGURE 27.—Limestone in the Verde Formation near Clarkdale. The upper part of unit 14 and all of units 15, 16, and 17 of section 15 (p. 116) are shown. The compact appearance and blocky weathering of unit 17 are typical for beds that contain abundant "plant hash." Note large nodular mass of limestone interbedded with thin-bedded limestone in upper part of unit 14.

middle limestone facies are well exposed along Minter Wash (section 8, p. 106) and southeast of Camp Verde (section 4, p. 101). Sections 12–16 (p. 111–126) represent the best exposures of the limestone in the upper limestone facies.

MUDSTONE FACIES

In much of Verde Valley the mudstone facies is chiefly mudstone and claystone that contains evaporite minerals. Near House Mountain and probably in the northern part of the valley, the facies is sandy and silty (section 11, p. 109). Locally, especially near the thick limestone facies, the mudstone facies contains thin beds of limestone.

In the areas where mudstone predominates, the rocks characteristically are yellowish green, light gray, pale olive, and yellowish orange. The sandy and silty beds are commonly grayish orange pink and light brown. Evaporite minerals are common in the beds of claystone and mudstone. At the salt mine (pl. 1), 1½ miles southwest of Camp Verde, Blake (1890) reported the occurrence of the minerals thenardite (Na_2SO_4), mirabilite ($Na_2SO_4 \cdot 10H_2O$) halite ($NaCl$), and glauberite ($Na_2SO_4 \cdot CaSO_4$). At the gypsum mine, 4 miles southeast of Camp Verde, the chief mineral is gypsum ($CaSO_4 \cdot 2H_2O$). The beds of the mudstone facies range in thickness from less than an inch to more than 5 feet. The facies generally forms a slope. On the southern edge of Wingfield Mesa the mudstone facies consists of an interbedded series of tuffaceous sedimentary rocks, mudstone, siltstone, clay, volcanic ash, and evaporite minerals (fig. 28). A mile southeast of Wingfield Mesa the tuffaceous rocks weather to unusual tepeelike forms and small pillars (fig. 29).

SANDSTONE FACIES

The best exposures of the sandstone facies are near House and Black Mountains and are represented by sections 12 and 15 (p. 111 and p. 116, respectively). Generally the sandstone facies is sandstone and siltstone interbedded with some mudstone, claystone, and limestone. The sandstone is very fine grained to fine grained, and the grains are mostly quartz. The characteristic colors of the sandstone facies are grayish orange, light brown, and moderate orange pink. The rocks in this facies generally form a steep slope. West of section 15 and about a mile north of Clarkdale, the sandstone facies is primarily sandstone and siltstone. Well (A-15-4)4dd penetrates 250 feet of the sandstone facies; except for a thin limestone bed near the bottom, the material in this well is entirely argillaceous sandstone.

FIGURE 28.—Fine-grained rocks of the Verde Formation on the southern edge of Wingfield Mesa (see unit 13 of section 1, p. 96). Arrow marks a 2-foot-thick ledge-forming bed of volcanic-glass shards about 30 feet below top of unit 13. View northeast.

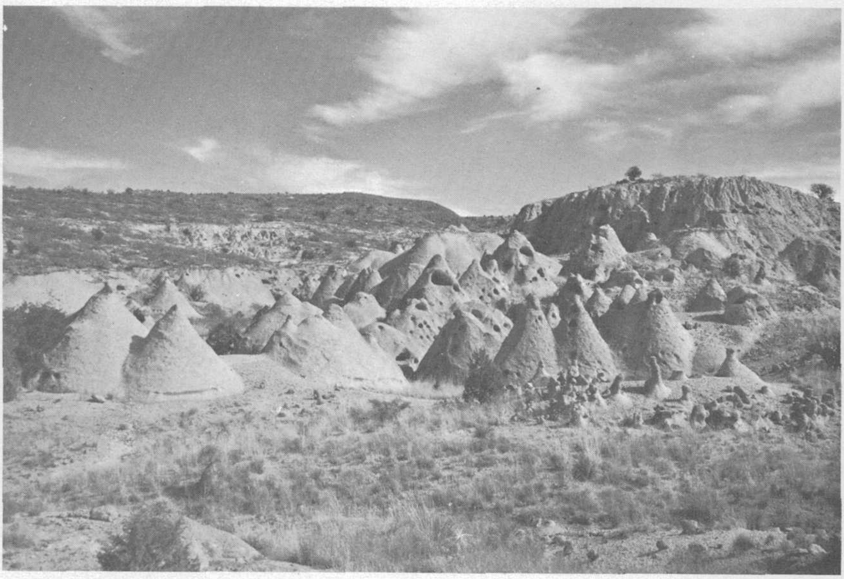

FIGURE 29.—Tepeelike erosion of tuffaceous rocks in the lower part of the Verde Formation southeast of Wingfield Mesa. Note small pillars of tuffaceous rock in the right foreground. View southeast.

VOLCANIC ROCKS

In the northern part of Verde Valley on the flanks of House Mountain, sedimentary rocks of the Verde Formation overlap Tertiary volcanic rocks. The sedimentary rocks thin progressively and pinch out toward the center of the mountain.

South of House Mountain near Adobe House Bend a basaltic lava flow is interbedded with sedimentary rocks of the Verde Formation. Limestone and marl that probably are part of the middle limestone facies overlie the flow; conglomerate of the Verde Formation underlies the flow (section 10, p. 109). The conglomerate thins and pinches out to the northeast. Underlying the conglomerate are Tertiary volcanic rocks, and, where the conglomerate is missing, the basaltic flow in the Verde Formation rest directly on a tilted basalt flow in the Tertiary volcanic rocks.

In the southern part of Verde Valley, volcanic rocks of the Verde Formation rest unconformably on older Tertiary volcanic rocks, and here the contact between the two series of volcanic rocks is not easily recognized. No attempt was made to map the rocks separately, and both are shown on plate 1 as Tertiary volcanic rocks.

THICKNESS

The total thickness of the Verde Formation is unknown because the base of the formation is not exposed and because the records for the two or three oil-test holes which penetrate the formation are poor. However, the available information suggests that the formation is locally at least 1,800 feet thick.

The base of the lowermost measured section is at an altitude of 2,910 feet, and the top of the uppermost measured section is at an altitude of 4,660 feet. The lowermost beds in wells (A–13–5)28bc2 and (A–16–3)33dd are at an altitude of 2,500 feet; if there is no structural displacement between the area of the wells and the area of the uppermost measured section, the Verde Formation may be as much as 2,200 feet thick.

The volcanic sedimentary rocks that constitute the lowermost exposed beds of the Verde Formation in the southernmost part of the valley are 338 feet thick (section 1, p. 96). A great thickness of volcanic sedimentary rock probably is below the base of the exposed section, and erosion here at the lower end of the valley has removed many hundreds of feet of rocks.

The mudstone facies is at least 1,000 feet thick; information from well logs and surface exposures indicates that this facies is at altitudes ranging from 2,500 to 3,500 feet. Because the lowermost beds are not exposed and have not been penetrated by wells, the total thickness of the mudstone facies is greater. The part of the mudstone facies that overlies the lower limestone facies is 200–250 feet thick. Most beds in the mudstone facies contain evaporite minerals. Beds consisting chiefly of evaporite minerals locally are as much as 70–90 feet thick. The thick limestone facies is probably as thick as the total thickness of the Verde Formation, as all evidence indicates that deposition of this facies was concurrent with deposition of all other facies of the formation. The thickest measured section of the thick limestone facies is near Montezuma Castle (section 6, p. 104), where it is about 500 feet thick.

The lower limestone facies is about 90 feet thick (section 5, p. 102). The middle limestone facies is 100–300 feet thick; however, in most localities where sections were measured, the upper beds are eroded. Much of the standstone and upper limestone facies has been eroded, and the original thicknesses of these facies are not known. Exposures of the sandstone facies have thicknesses of 300 feet or more (sections 12 and 15, p. 111 and 116, respectively). The thickest section of the upper limestone facies is on the south flank of Black Mountain (section 5, p. 102), where it is 384 feet thick.

FAUNA AND AGE

Many beds in the Verde Formation, especially in the northern part of the valley, contain fossils, and some beds are abundantly fossiliferous (Twenter, 1962). The fossils, most of which are well preserved, include gastropods, pelecypods, ostracodes, Charophyte oogonia, vertebrate teeth and bones, plant seeds or pods, and plant fragments. Some of the invertebrate fossils are shown in figure 30. Blocks of volcanic ash that contain ripple marks and other markings are shown in figure 31. Dr. C. W. Hibbard (written communication, 1959) reported that samples of small vertebrate teeth collected from the Verde Formation on the south flank of House Mountain (section 12, unit 26, p. 111) contained teeth of the kangaroo rat *Dipodomys* (fig. 32*A*) and the cotton rat *Sigmodon* (fig. 32*B*). Also, he noted that several teeth might be those of *Bensonomys* (fig. 32*C*). Brady and Seff (1959) described tracks found near Montezuma Castle and wrote that the tracks "* * * appear to be those of a small group of elephants * * *." The length of stride is 82 inches, and the diameter of each track is 16–18 inches.

Jenkins (1923, p. 76–77), on the basis of the relation of the Verde Formation to structure and volcanic activity, concluded that "* * * the Verde Formation may be placed as late as Tertiary or very early Pleistocene." Mahard (1949), on the basis of evidence similar to that used by Jenkins, postulated a late Pliocene or Pleistocene age for the lake beds. Anderson and Creasey (1958, p. 60) and Lehner (1958, p. 561–563) reached no definite conclusions as to the exact age of the

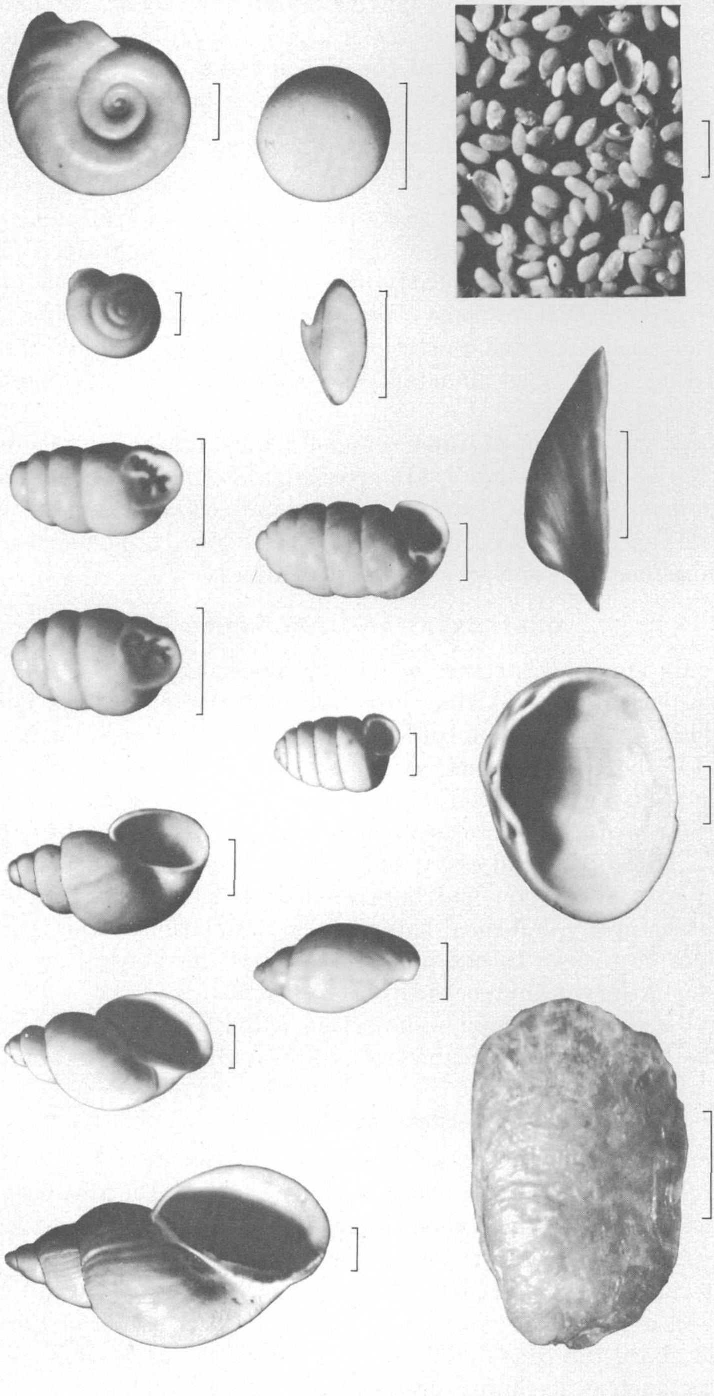

FIGURE 30.—Invertebrate fossils from the Verde Formation. Bar scale under each specimen represents 1 mm.

formation, but as to its relative age they found it to be younger than the Tertiary gravels and volcanic rocks in the Black Hills and mostly younger than the movement of the Verde fault. In this paper the Verde Formation is designated as Pliocene(?) or Pleistocene in age.

WATER-BEARING CHARACTERISTICS

The limestone beds of the Verde Formation contain many joints and solution channels; these rocks readily store and transmit water and are the chief aquifers in the Verde Valley. The fine-grained clastic rocks of the formation are nearly impermeable and retard the movement of ground water. Some clastic rocks, such as the friable sandstone and unconsolidated gravel, store and transmit water; and although they are not as abundant and widespread as the limestone, they are good aquifers.

Only a small amount of water is under water-table conditions in the Verde Formation; most wells are artesian, and some flow. The limestone units in the formation commonly are confined above and below by aquicludes and, when so confined, are hydrologically independent of other limestone units and act as separate aquifers.

QUATERNARY VOLCANIC ROCKS

The only known occurrence of Quaternary volcanic rocks is in the southern part of Verde Valley just northeast of Squaw Peak (pl. 1; figs. 10, 12). These rocks unconformably overlie the Verde Formation except for the volcanic neck which penetrates the formation. The volcanic rocks are at altitudes from 3,300 to 3,700 feet and range in thickness from a few feet to as much as 300 feet. The consist of rhyolitic lava, rhyodacite, and associated tuffaceous sedimentary rocks.

The Verde Formation had been eroded extensively and, in some places, structurally deformed before the accumulation of the Quaternary volcanic rocks. In one place the beds of the Verde Formation that underlie the volcanic rocks dip as much as 63°.

A small areal extent and a high position above the floor of the valley make the Quaternary volacanic rocks unsuitable for the storage of ground water.

QUATERNARY GRAVEL

Quaternary gravel forms an almost continuous strip 4 to 5 miles wide along the Verde River. Most of the gravel is in the area between the Black Hills and the Verde River, where it covers an eastward-sloping pediment cut on the Verde Formation. Several large patches of Quaternary gravel are south of Camp Verde just east of the Verde River. In a few places small hills composed of the Verde Formation rise above the gravel. Where the gravel is cut by washes—in places, as much as 25–50 feet deep—the underlying rocks are exposed.

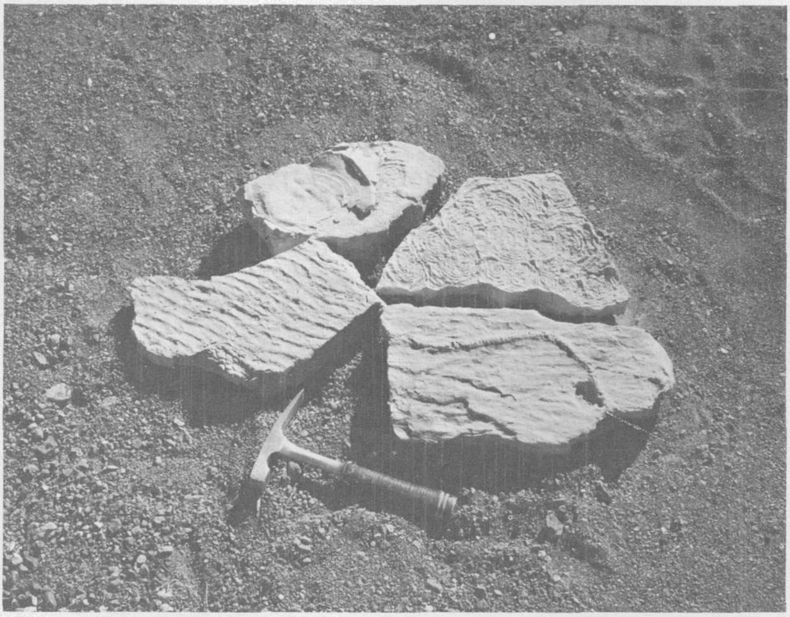

FIGURE 31.—Ripple marks and other unusual markings in volcanic ash from the Verde Formation near Camp Verde.

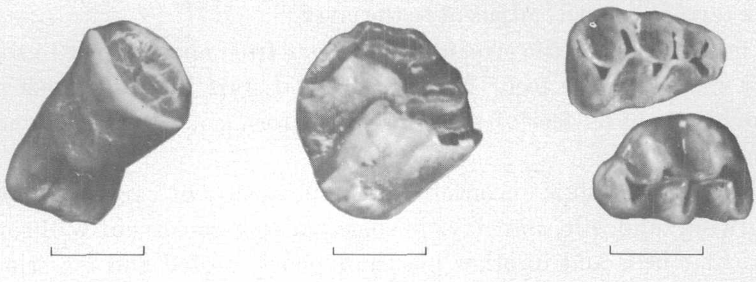

FIGURE 32.—Small vertebrate teeth from the Verde Formation. *A, Dipodomys; B, Sigmodon; C, Bensonomys*(?). Identified by Dr. C. W. Hibbard. Collected from House Mountain (section 12, unit 26 p. 111). Bar scale under specimens represents 1 mm.

The altitude at the base of the Quaternary gravel is 3,000–3,500 feet along the Verde River and 4,000–4,500 feet along the Black Hills. The altitude at the base of the gravel in Wingfield Mesa is 3,400–3,500 feet. Thickness generally ranges from a few feet to 25 feet; in one place, however, the gravel is 70 feet thick.

693-389 O—63——5

The pebbles in the Quaternary gravel were derived from bedrock of the adjacent slopes. Where Precambrian or Paleozoic rocks predominate in the Black Hills, the gravel downhill is composed of these rocks; where Tertiary volcanic rocks are present in the source area, such as in the area east of Wingfield Mesa, the gravel is composed of basalt fragments. In some places the Quaternary gravel contains little cement and forms slopes; in other places it is moderately cemented and forms ledges. The size of the gravel fragments is dependent upon the proximity of the deposit to the source area. Generally the size of the material decreases progressively away from the source toward the Verde River. Near the source area the average diameter of the fragments is 1–2 feet and the maximum diameter is 5 feet; near the Verde River on the other hand, the average diameter commonly is between 2 and 8 inches and the maximum diameter is 2 feet.

Because the Quaternary gravel is mostly above the water table and also because it is a veneer dissected by many washes, no large quantities of water are stored in the rocks and they do not yield water to wells or springs.

STREAMWASH

In this report streamwash is used to designate all sediments that are younger than the Quaternary gravel. It includes all sediments in and near the channels of perennial and intermittent streams and most terrace deposits adjacent to the river.

The thickness of the streamwash ranges from about a foot to somewhat more than 30 feet. Many wells that start in streamwash pass through about 30 feet of this material before penetrating older sedimentary rocks.

The streamwash is unconsolidated and consists of varying amounts of gravel, sand, silt, and clay; in some places it consists of well-sorted lenticular beds and in other places of poorly sorted and indistinctly bedded masses. Fragments constituting the streamwash are from all older rocks; the abundance of fragments of any one particular age is dependent upon the age of the rocks in the immediate source area.

The streamwash deposits are of great economic importance to the inhabitants of Verde Valley, as most of the deposits constitute the flood plain of the Verde River and there support the major agricultural development in the valley (fig. 33). Alfalfa, cotton, fruit, and several varieties of grass are raised by irrigation.

The unconsolidated sand and gravel of the streamwash are usually permeable and form a good water-table aquifer—an abundance of water is stored and transmitted by this material. The water level in wells usually is influenced by the stage of nearby streams.

GEOLOGIC STRUCTURE

Verde Valley owes its location and configuration to upwarp of the Mormon Mountain anticline (fig. 34), to movement along the Verde fault zone (fig. 34), and to extensive erosion. The Mormon Mountain anticline and the Verde fault are the principal features defining the Verde Valley ground-water basin. The Mormon Mountain anticline forms the ground-water divide on the east side of the valley; the crest of the Black Hills, which owes its elevation to movement along the Verde fault zone, forms the ground-water divide on the west side.

The Mormon Mountain anticline which is 15–25 miles east of Verde Valley, is a northwest-trending asymmetrical anticline whose dips do not exceed 4° on either limb. Structural contours on the top of the Kaibab Limestone (fig. 34) reveal that the rocks in the Colorado Plateaus dip westward from the Mormon Mountain anticline toward Verde Valley and that the rocks in the anticline have been elevated more than 1,500 feet above stratigraphically equivalent rocks near the center of the valley.

The Mormon Mountain anticline is the crest of a large anticlinal fold having 1,500 feet of closure (fig. 34). The trough on the west

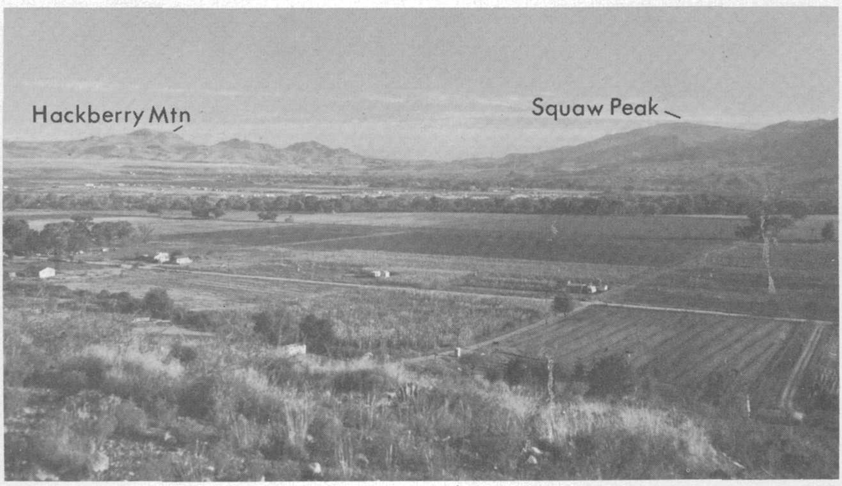

FIGURE 33.—Agricultural development on the streamwash deposits of the Verde River just south of Camp Verde. The Verde River flows out of Verde Valley through the gap between Squaw Peak and Hackberry Mountain. View south.

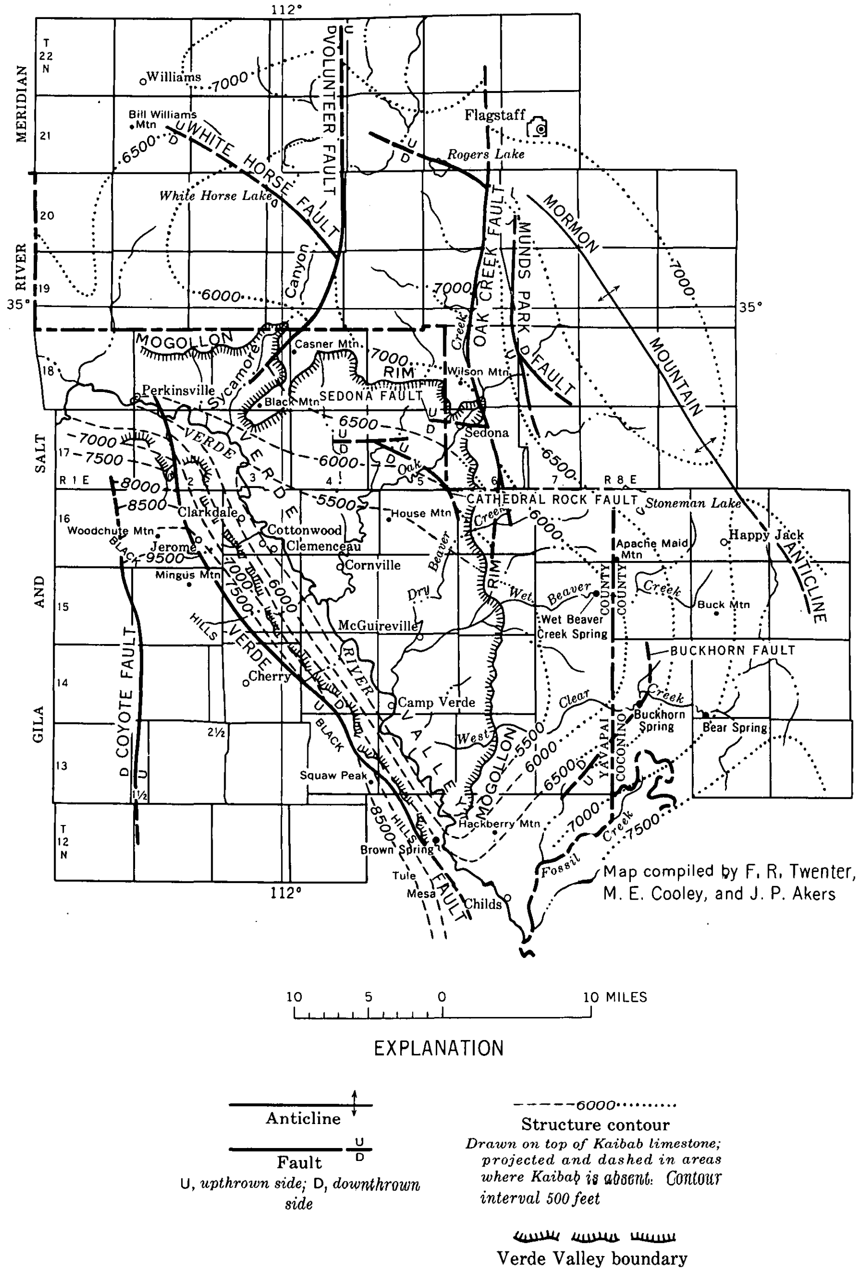

FIGURE 34—Map showing structural features of the Verde Valley area.

side of this structure forms a synclinal fold coincident with Verde Valley. Rocks uplifted by faulting and folding in the Verde fault zone form the western limb of the downwarp. Prior to the last major movement in the fault zone, the synclinal fold encompassed the Black Hills and the adjacent valleys to the west. The anticlinal and synclinal folds are major components of the Verde Valley ground-water basin primarily because the 1,500 feet of downwarp on the western limb of the anticlinal fold gives the aquifiers a slight dip basinward. This dip facilitates the movement of ground water to the collection and storage basin formed by the synclinal fold.

The Verde fault zone, which "* * * comprises a main strand, the Verde fault, and many parallel and subparallel subordinate faults * * *" (Anderson and Creasey, 1958, p. 80), is on the west side of Verde Valley and trends northwestward. Most of the subordinate faults are east of the main fault (pl. 1). The scarp of the Verde fault is conspicuous throughout much of its length and is well displayed at Mingus Mountain (fig. 4) and Squaw Peak (fig. 10). The fault zone was structurally weak as early as Precambrian time, when movement may have displaced Precambrian rocks as much as 1,000 feet (Anderson and Creasey, 1958, p. 147–149). No movement is known to have occurred during deposition of Paleozoic rocks, and if displacement occurred during Mesozoic time the evidence for it was largely destroyed when Mesozoic sediments were eroded.

The most obvious and easily discernible displacement in the Verde fault zone is the result of movement after accumulation of most Tertiary volcanic rocks. This movement, which displaced the Tertiary rocks as much as, and probably more than, 3,000 feet, elevated the Black Hills and separated them from the Colorado Plateaus. Prior to this last major movement, the ancestral Verde Valley was cut into Precambrian and Paleozoic rocks and then filled and blanketed by Tertiary sedimentary and volcanic rocks that now form the Black Hills.

The Verde fault zone is a series of normal faults between which the blocks are progressively downdropped to the east. In the northern part of the Black Hills near the town of Jerome, as many as 13 fault segments occur in a zone about 2 miles wide (Anderson and Creasey, 1958, p. 80). On the northern flank of the Black Hills beyond the area mapped, the fault zone becomes a monoclinal fold. The dip of the beds in the monoclinal fold decreases to the north until only a slight northeastward dip can be seen along the Mogollon Rim west of Sycamore Canyon. In the southern part of the Black Hills near Tule Mesa, as many as 25 fault segments are in a zone about 6 miles wide. Of these, about 17 are in Paleozoic rocks and the rest are in Tertiary and Quaternary rocks.

In the Verde fault zone the Paleozoic rocks are lowered progressively eastward until their altitudes approximate those of correlative Paleozoic rocks in the part of the valley along the Mogollon Rim. The Verde Formation probably conceals a series of faults similar to those exposed.

Three major geologic structural features are dominant in the northeastern part of Verde Valley (pl. 1)—the Oak Creek fault, the Sedona fault, and the Cathedral Rock fault.

The Oak Creek fault, its southernmost limits covered by Tertiary volcanic rock, extends from Dry Beaver Creek northward for about 8 miles, then bends to the northwest and into Oak Creek Canyon, and thence extends northward in Oak Creek Canyon for about 10 miles. A prominent scarp (fig. 7) marks the trend of the fault north of Oak Creek Canyon for about 5 miles to a point where the fault bifurcates; several segments extend north of the point of bifurcation for at least 10 miles (Cooley, 1961). The scarp is less prominent in the Dry Beaver Creek area and in the area north of Oak Creek Canyon, where several minor faults have absorbed part of the displacement.

The Oak Creek fault is a high-angle normal fault that is downthrown to the east and has most of its displacement along a single prominent break. Associated faults and cross faults produce some variation in the amount of displacement along the main fault. Near its southern limits the displacement is 400 feet, but at several places in Oak Creek Canyon the displacement is as much as 700 feet, and along the fault north of Oak Creek Canyon the displacement is 600 feet. The average displacement in the mapped area is probably 600–700 feet.

The Sedona fault trends west-northwest and makes a gentle arcuate curve just north of Sedona. The fault has a displacement of 400 feet, is about 5 miles long, and is downdropped on the southwest side. Where the fault crosses Oak Creek, the cliff-forming sandstone units in the lower member of the Supai Formation on the north side of the fault abut the slope-forming beds of the middle member of the Supai on the south side.

The Cathedral Rock fault is slightly arcuate and extends northwestward for 8 miles from Bell Rock to the Dry Creek area. Because distinctive marker beds are rare in the Supai, the displacement along the fault is difficult to determine. At Bell Rock, where the thin limestone in the upper member of the Supai is exposed on both sides of the fault, the displacement is 250 feet. In the Dry Creek area, where the fault splits into several segments, the limestone in the upper member of the Supai is exposed southwest of the fault at about the same altitude as the contact between the lower and middle members of the

Supai north of the fault, and the indicated displacement is 800 feet. The average displacement along the fault is about 500 feet.

Most rocks in Verde Valley are horizontal or have slight dips. There are no large folds, and beds that dip more than 5° generally are in or near faulted areas. However, solution of limestone and gypsum in the Verde Formation has produced sinkholes and slump blocks in which beds dip as much as 47°; these features are especially conspicuous around McGuireville, Montezuma Castle (fig. 35), and southeast of Camp Verde.

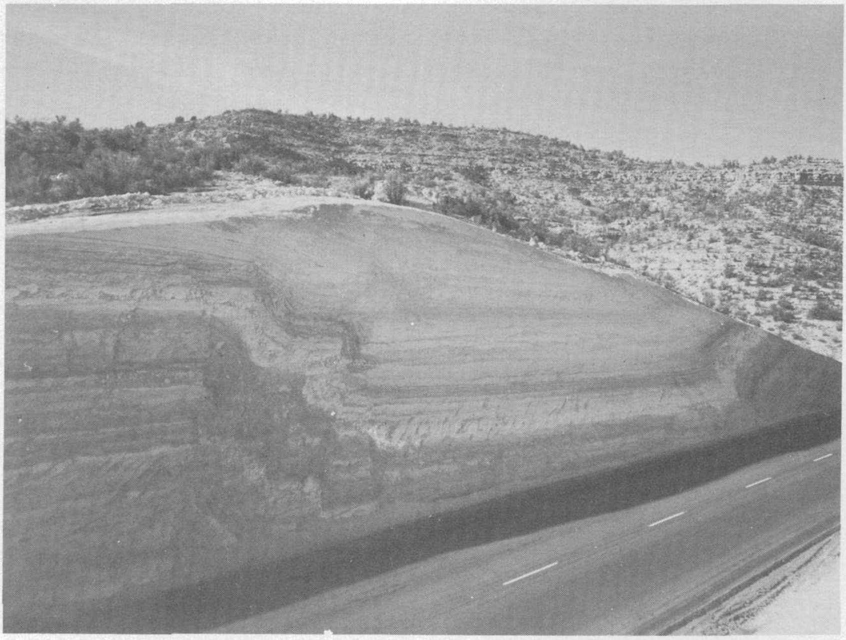

FIGURE 35.—Small slump-block structure in the Verde Formation along U.S. Highway 79 near Montezuma Castle. Ledge-forming limestone in background are in the thick limestone facies. View north.

Structural features in Verde Valley influence the movement of ground water. The basinward dip of the beds in the Mormon Mountain anticline and associated upwarps enables ground water to move freely toward Verde Valley. Where the beds dip away from the basin on the north and east side of the upwarps, the ground water flows to the Little Colorado River. In the Verde fault zone, impermeable igneous and metamorphic rocks on the west abut permeable sedimentary rocks on the east. The impermeable rocks act as a barrier to ground-water movement, and the water flows southeast in the fractures and joints along the fault. Similarly, ground water flows southward along the other large faults in Verde Valley.

GROUND-WATER HYDROLOGY

Verde Valley is hydrologically a part of a much larger area here designated the Verde Valley ground-water basin. Although the present investigation and most of the discussion in this report are confined largely to Verde Valley, some aspects of the Verde Valley ground-water basin that affect the hydrology of Verde Valley are described.

VERDE VALLEY GROUND-WATER BASIN

The Verde Valley ground-water basin (fig. 36), which is delineated by the Black Hills and the Mormon Mountain anticline, includes not only Verde Valley but also that part of the Colorado Plateaus that bounds the valley. Precipitation is heavy in the Colorado Plateaus part of the basin, and most ground water and much surface water is derived from this area.

More than 50 springs and 200 wells are in the Verde Valley area. Only those wells and springs that seem to have hydrologic significance are discussed. Pertinent information for many wells is given in table 7. Data pertaining to some springs and a few wells were collected before the present investigation. All hydrologic interpretations are restricted by a short period of record.

OCCURRENCE OF GROUND WATER

The wells and springs in Verde Valley derive their water from permeable rocks—that is, rocks that have a capacity to absorb, store, and transmit water. A rock unit that contains water and has permeability sufficient to allow water to be transmitted to wells or springs is called an aquifer. In Verde Valley, the aquifers are permeable sedimentary rocks that yield water to most wells and provide the spring water that sustains the perennial flow of the Verde River and its tributaries.

The absorption, storage, and transmission of ground water are determined, for the most part, by the lithologic characteristics of the rocks—mineral composition, grain size, cementation, and porosity.

Mineral composition determines the resistance of a rock to solution. Conglomerate, sandstone, siltstone, and claystone are composed of quartz and clay minerals, which are resistant to solution; whereas limestone and evaporite deposits are composed of calcite, gypsum, and other minerals, which are soluble. Solution develops channels and sinkholes that permit otherwise impermeable rocks to absorb, store, and transmit water.

Uniformity of grain size provides open and connected pores in sandstone and conglomerate and causes such rocks to be very permeable. The degree of permeability may be progressively reduced by cementation with such minerals as calcite and quartz, which bind the grains together and fill the pores.

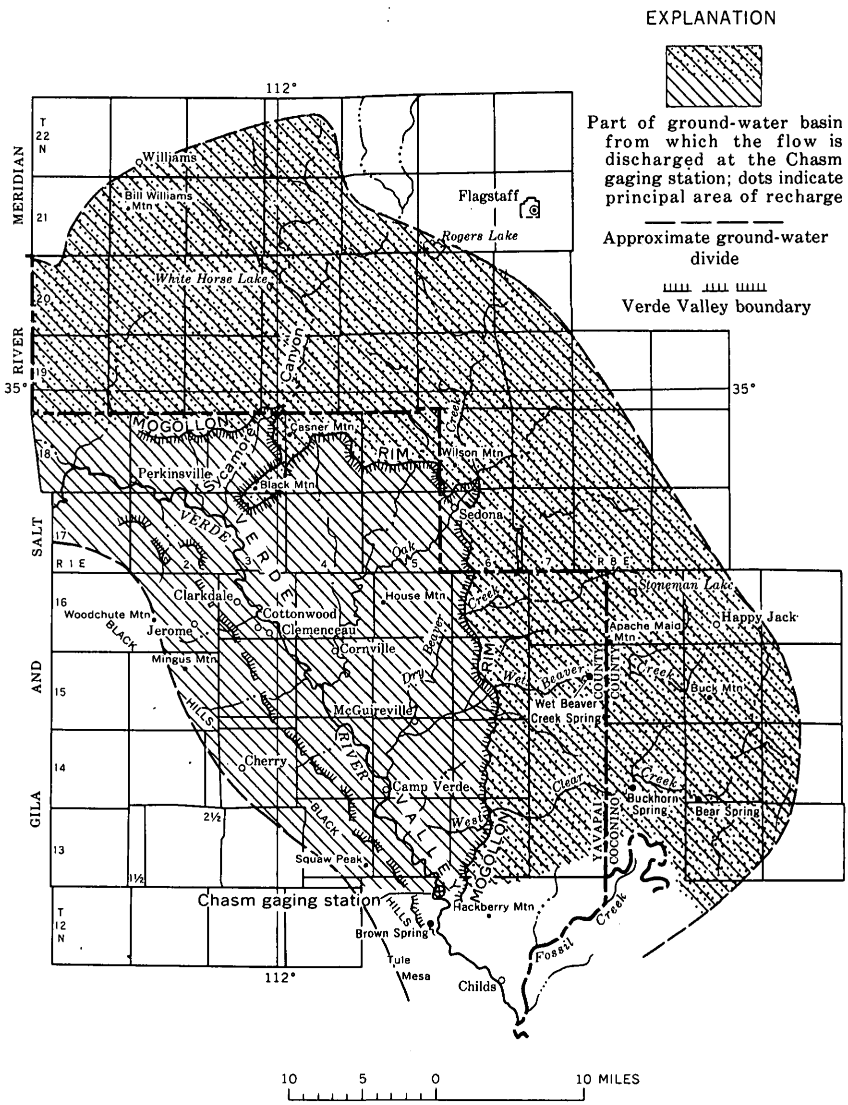

FIGURE 36.—Verde Valley ground-water basin and probable area of recharge.

Grain size alone can limit permeability. In general, this is due to molecular attraction; adhesion of a molecule of water to a molecule of rock is much greater than cohesion of a molecule of water to another molecule of water. In the large pore space between coarse grains, the surface area of rock is small in relation to the quantity of water; only a small part of the water adheres firmly to the rock; and much water can be transmitted. In the small pore space between very fine grains,

TABLE 7.—*Records of wells*

Location: For explanation see section on well-numbering system.
Depth of well: Given in feet below land surface; all depths are reported.
Depth to water: Given in feet below land surface; A, see table 10; F, flowing wells; R, reported depths.
Use of water: Dom, domestic and (or) stock; Irr, irrigation; NU, not used; PS, public supply.
Remarks: C, sample collected for chemical analysis; gpm, gallons per minute; ppm, parts per million.

Location	Owner or operator	Approximate land surface altitude (feet)	Depth of well (feet)	Depth to water (feet)	Geologic source	Use of water	Remarks
(A-13-5)							
4ba	Arizona Verde Oil Co	3,175	1,225	135, R	(?)	NU	Originally an oil-test hole.
5ac3	J. White	3,100	70	44	Verde Formation	Dom	Measurement made 4-29-59.
5adc	G. Turner	3,100	100		do	Dom	
5bd	M. Solt	3,100	65		do	Dom	
5ca	Prescott National Forest	3,100	120	A	do	PS	Observation well. Reported yield, 35 gpm; reported drawdown, insignificant.
6bad	Stevenson	3,060	150		do	NU	
7ba	J. Edge	3,060	170	24, R	do	Irr	Reported yield, 2,000 gpm; reported drawdown, 100 feet.
8aaa	H. Wingfield	3,090	550		do	Irr	Reported yield, 1,000 gpm.
8cb	M. Jones	3,030	200	F	do	NU	Salty; reported 7,500 ppm.
8cdd	A. Foster	3,030		46	do	Dom	Measurement made 4-29-59.
10bca	Arizona Verde Oil Co	3,150	1,625		(?)	NU	Originally an oil-test hole.
11dab	G. French	3,225	150	90, R	Verde Formation	Dom	Used at gypsum mine. Reported salty.
15aa	J. Phillips	3,125	132	44	do	NU	C. Measurement made 4-8-59. Salty.
17ac	J. Reeves	3,050	100	70, R	Verde(?) Formation	Dom	
17dbc	A.M.S. Development Co	3,050	125	70, R	do	Dom	
28bc2	C. Jackson	3,100	700	95, R	Verde Formation	NU	Salty.
(A-14-4)							
2bc	A. Mackey	3,175	126	60, R	do	Dom	C.
2ca	J. Norris	3,150	115	35, R	do	Dom	
4ddc	W. Robertson	3,175	600	42, R	do	Irr	Cloverleaf Ranch. Reported yield 1,600 gpm; reported drawdown, 9 ft.
10cd	N. Fain	3,275	85		do	Dom	
11bbb	W. Robertson	3,150	800	35, R	do	Irr	Cloverleaf Ranch. Reported yield, 1,080 gpm; reported drawdown, 91 ft.
14ad	R. Harris	3,150	180		do	Dom	Reported yield, 15 gpm.
14db	B. Wilson	3,175	200	40, R	do	Dom	C.
24aa	D. Bird	3,175	145	95	do	NU	Measurement made 3-4-60.
(A-14-5)							
1bc2	L. King	3,460	400	F	do	Irr	Reported flow, 440 gpm.
3bb1	R. Hall	3,290	155	27, R	do	Dom	
3dc1	B. Brockett	3,450	520	155, R	do	Irr	Reported yield, 300 gpm.
4aaa	D. Wingfield	3,450	503	223, R	do	PS	Exchange Drive-In Restaurant; reported yield, 35 gpm.
9aa	P. Dyck	3,290	400	20, R	do	NU	
9ad	do	3,290	175	A	do	Dom	Observation well; reported yield, 75 gpm.
17aaa2	National Park Service	3,190	160	A	do	PS	C. Observation well. See figure 38.
31ca	G. Monroe	3,200	300	200, R	do	Dom	
31da2	J. Bullard	3,130	147	69, R	do	PS	Supplemental supply for Camp Verde. Pumping level at 73 ft below land surface on 4-30-59.

(A-14-6)							
9dac1	I. Walker	3,975	410		Tertiary volcanic rocks (?)	Dom	C.
(A-15-3)							
2ca	G. Wright	3,350	131	80, R	Verde Formation	Dom	
2cb2	R. Findlay	3,350	225		do	PS	C. View Motel.
2db	M. See	3,275	102		do	Dom	Supply for trailer court.
5bd	Ogden Ranch	3,725	535	F	Redwall (?) Limestone	Dom	Mineral-exploration core hole. Flows about 5 gpm.
12aba	C. Osborne	3,275	200	130, R	Verde Formation	Irr	Reported yield, 90 gpm.
12abc	E. Stone	3,275	150	20, R	do	Dom	
12adb1	J. Meridic	3,275	400		do	NU	Recorder well. Originally flowed about 5 gpm. Reported yield, 400 gpm; reported drawdown, 100 ft.
21aa	T. Kellis	3,800	550	300, R	Verde(?) Formation	Dom	C.
23ac	Montezuma School	3,525	450	350, R	Verde Formation	Dom	
(A-15-4)							
2ccc1	S. Mongini	3,425	130	70, R	do	Dom	One of six wells in the area.
2ccc4	G. Calkins	3,425	100	65, R	do	Dom	C. One of six wells in the area.
3ad	Semon	3,400	126	59, R	do	Dom	
3bd	F. Buss	3,325	220	39	do	Dom	Measurement made 3-2-60.
3ca	H. Boker	3,325	217	35, R	do	Dom	Water from limestone 210 and 214 ft below land surface. Reported yield, 48 gpm; reported drawdown, 35 ft.
3ddd	T. Witter	3,425	110	80, R	do	Dom	
4aaa1	W. Aspaas	3,300	105	F	do	Dom	Intermittent flow.
4dd	C. Sobley	3,375	250	A	do	Dom	Observation well.
7cbd	K. Quinn	3,250	268	27, R	do	Dom	C.
10cd	F. Savage	3,300	215		do	Dom	C.
18da	W. Skidmore	3,240	250	42, R	do	Irr	Reported yield, 75 gpm; reported drawdown, 123 ft.
20bb	N. Clark	3,275	125	99	do	Irr	Measurement made 3-2-60.
33dcb	C. Simpson	3,200	510	70, R	do	Irr	C.
(A-15-5)							
20ab	D. Wingfield	3,550	500	200, R	do	Dom	
25b	Arizona State Highway Department.	3,700	398	135, R	(?)	PS	
27db	K. Wingfield	3,400		F	Verde Formation	Dom	C.
34cb1	J. Bradford	3,350	175	150, R	do	Dom	
35a	L. King	3,550	150	65	do	NU	Measurement made 4-29-59.
36caa	J. McSparron	3,500	120	2, R	do	Dom	C. Flows part of year.
36cca	Winneman	3,500	170	25, R	do	Dom	C.
36ccc	do	3,475	160	F	do	Dom	C. Flows most of year.
36dbb	F. Bolen	3,500	135		do	Dom	C. Flows part of year.
(A-15-6)							
31bc	National Park Service	3,575	105	79, R	do	Dom	
(A-16-3)							
8cc	The Arizona Power Co	3,400			do	Dom	C. Flowing well until 1960.
15ccb	Phelps-Dodge Corp	3,375	50	25, R	Verde(?) Formation	Dom	
17db	do	3,375	265		Verde Formation	PS	Supplemental supply for Clarkdale. Reported yield, 250 gpm.
22bc	National Park Service	3,400	313	120, R	do	PS	C. Tuzigoot National Monument well.
27ab	H. Young	3,375	1,400	A	do	Dom	Observation well. Mineral-exploration hole. Originally flowed.
27ba	M. Edwards	3,350	420+	F	do	Dom	C. Flow estimated as about 8 gpm.
27cd	B. Siler	3,310		F	Verde(?) Formation	Dom	C.
27da	C. Ireys	3,340	360	F	Verde Formation	Dom	C. Flow estimated as less than 5 gpm.

TABLE 7.—*Records of wells*—Continued

Location	Owner or operator	Approximate land surface altitude (feet)	Depth of well (feet)	Depth to water (feet)	Geologic source	Use of water	Remarks
28ac	H. Quale	3,400	241		Verde Formation	Dom	C.
30ab	Halliburton Estate	3,750	925	360, R	(?)	PS	C. Supplemental supply for Clarkdale. Reported yield, 240 gpm.
33aaa	Starkey	3,390	550		Verde Formation	Dom	Supplies several homes.
33ac1	B. Siler	3,425		70, R	do	PS	C. Supply for Clemenceau.
33dd	Cottonwood Hospital	3,460	940	152, R	do	PS	Reported yield, 850 gpm; reported drawdown, 252 feet.
34acc	W. Helton	3,350	400		do	Dom	
34cdc1	E. Garrison	3,410	1,250		do	PS	Reported yield, 300 gpm.
35aab1	C. McCarty	3,300	161	F	do	Dom	Flow estimated as less than 1 gpm.
35add2	J. Burnett	3,300		F	do	NU	C. Flows 8 to 10 gpm.
35ccc	J. DeWitt	3,340	390	25, R	do	Dom	C.
35dab	M. Rogers	3,300	167	F	do	Dom	
35dba	H. Fish	3,300	97	25, R	do	Dom	
(A-16-4)							
11cbc	T. Allen	3,675	50	9, R	Streamwash	Dom	
14ca	Dr. Slipher	3,590	200	F	Supai(?) Formation	Dom	C.
15dd	R. Grabe	3,600	180	18, R	do	Dom	C. Reported yield, 75 gpm.
20bb	Cottonwood Oil Co.	3,760	1,260		(?)	NU	Oil-test hole. Water reported at several depths.
23bbd	J. Reeves	3,550	160	F	Supai(?) Formation	Dom	C.
23ca	J. Page	3,550	275	F	do	Irr	C. Flows about 50 gpm.
26cd	H. Wilky	3,450	290	F	Supai Formation	Irr	Do.
26da	Christian Indian School	3,425	50	10, R	(?)	Dom	C.
35cbb	Oak Creek School	3,450	837	86, R	(?)	PS	
(A-16-5)							
13ccb	K. Fox	4,075	480	360, R	Supai Formation	Dom	
14aac	F. Crenshaw	4,150	345	300, R	do	Dom	
14dba	W. Coburn	4,100	511		do	Dom	C.
(A-16-6)							
8ccb	E. Phillips	4,250	620	400, R	do	Dom	C.
8dbc	Petty	4,300	640		do	NU	
17caa	H. Meloney	4,225	570	400, R	do	Dom	
17cbb	A. Pyle	4,100	475	382	do	Dom	Measurement made 12-14-60.
18cbd	V. Gulick	4,025		355	do	Dom	Do.
18dda	E. Phillips	4,125	530	400, R	do	Dom	
19bbd	C. Dickinson	4,000	380	300, R	do	Dom	
19cba	R. Beckendorf	4,000	350	290, R	do	Dom	
(A-17-4)							
15cdc	Coconino Cattle Co.	4,090	500	480, R	Supai (?) Formation	Dom	

(A-17-5)							
3ddc	Redcliff Association	4,550	845	400, R	Supai Formation	Dom	C. Supplies several homes.
10bd	Colorcove Association	4,500	700	550, R	do	Dom	Do.
10dca	H. Janetzky	4,450	710	575	do	Dom	C. Measurement made 12-15-60.
11ddd	V. Gulick	4,390	528		do	Dom	C.
14aba	C. Williams	4,350	600		do	Dom	C. Supplies about 30 homes.
25a	Sky Mtn. Estates	4,250	752	590, R	Supai (?) Formation	Dom	
25bbbl	Chavez Ranch	4,050	490	100, R	do	Dom	C.
29ab	L. Owenby	4,050	470	396	Supai Formation	Dom	Measurement made 12-15-60.
32ddc	Billard Ranch	3,790	480	100, R	do	Dom	
33abc	Cross Creek Ranch	3,850	350	262, R	do	Dom	C. Reported yield, 10 gpm.
33cca	H. Frye	3,800	365	298, R	do	Dom	C.
34aba	Lindahl Ranch	3,900	325	168	do	Dom	C. Measurement made 12-16-60.
36ccc	T. Dudley	4,050	600	414	do	NU	Measurement made 5-23-57.
(A-17-6)							
30bc	Carter	4,250		438	do	Dom	C. Measurement made 12-14-60.
(A-18-4)							
25bc	Red Canyon Ranch	4,775	1,120	800, R	Redwall Limestone	Dom	C.
(A-18-5)							
27abb	J. Jackling	4,675	980	680, R	Supai Formation	Dom	C.

the surface area of rock is great in relation to the quantity of water; most or all the water adheres firmly to the rock; and little or no water can be transmitted.

The porosity of a rock is the ratio of the volume of its pore space to its total volume. Thus, porosity determines the quantity of water that a rock can contain but does not determine its permeability. Porosity is related to permeability only when pores are interconnected so that water can pass through the pores and be transmitted to wells and springs.

In summary, then, clastic rocks such as gravel or sand that are composed of coarse uniform uncemented grains and nonclastic rocks such as limestone that contain solution channels are highly permeable and are potentially good aquifers. Fine-grained rocks such as siltstone are less permeable and can store and transmit only small quantities of water and, thus, are poor aquifers. Some clastic rocks such as claystone and shale that are composed of very fine grains may contain water but cannot transmit it to wells or springs; these rocks are called aquicludes.

Structural features such a fractures, faults, and folds help to determine the occurrence of ground water. Fractures increase the rocks' capacity to absorb, store, and transmit water. In rocks that otherwise are impermeable, such as the Precambrian rocks in Verde Valley, fractures are the major, and sometimes the only, source of water.

Where permeable rocks abut impermeable rocks along a fault or fold, the impermeable rocks act as a barrier to water movement, causing ground water to be stored and transmitted along the structural feature.

Many aquifers in Verde Valley are underlain and overlain by aquicludes; water so confined in an aquifer can move laterally much more readily than it can move vertically. Water in a confined aquifer is under pressure and will rise above the level at which it is first found in a well. Such an aquifer is called confined or artesian, and a well tapping it is called an artesian well. If the water rises to the land surface, the well is a flowing well.

In aquifers not underlain and overlain by aquicludes, the water is unconfined and may move up or down freely; the upper surface of this free body of water is referred to as the water table.

The aquifers in the Verde Valley ground-water basin are in the Verde Formation, the Supai Formation, the Redwall Limestone, the Coconino Sandstone, and the streamwash. Ground water is under water-table conditions in the streamwash and, for the most part, is under artesian conditions in the other rocks.

MOVEMENT OF GROUND WATER

The regional movement of ground water in the Verde Valley ground-water basin is basinward from the Mormon Mountain anticline and the crest of the Black Hills (fig. 37). Thus, all ground water flows to the Verde River and its tributary streams. Then, as surface water in the Verde River, it leaves the valley.

The paths—through fractures, solution channels, bedding planes, and permeable beds—by which the ground water finds its way from the recharge area of high precipitation (fig. 36) to its temporary base level, the Verde River, are many and are complexly interrelated, but the general pattern can be presented simply. Some of the water precipitated as rain or snow on the Colorado Plateaus enters the surface rock—in most areas, Kaibab Limestone or Tertiary volcanic rocks—and becomes ground water. It percolates downward through the underlying Toroweap Formation and into the Coconino Sandstone. In parts of the Colorado Plateaus where the Coconino is saturated, the water moves laterally, Where deep canyons intersect the water table, the water will issue as springs or seeps. In parts of the Colorado Plateaus where the Coconino Sandstone is not saturated, the water percolates downward into the underlying Supai Formation. In the Sedona area, part of the lower member of the Supai Formation is saturated, and the water moves laterally to the southwest. If, as in the Sycamore Creek area, the Supai Formation is not saturated, the water percolates into the underlying Redwall Limestone.

Tertiary volcanic rocks on the south flank of House Mountain and along Spring Creek form a barrier to ground-water movement in the Supai Formation, and ground water collects behind this barrier. Where the water intersects land surface, it issues as springs and seeps. (See point labeled Spring Creek on geologic section, pl. 1.)

The direction of movement of the ground water and the configuration of the water-level surface are shown by generalized ground-water contours on plate 1. For example, the effect of the ground-water dam mentioned in the preceding paragraph is shown by the wide spacing between the 3,600- and 3,700-foot contours which indicates a broad flat water-level surface behind the dam.

Ground water probably moves from the Supai Formation and the Redwall Limestone directly into the Verde Formation. In the Verde Formation, ground water moves generally southwestward toward the Verde River. The bending of the contours upstream shows that the Verde River and its principal tributaries are effluent and receive ground-water discharge in parts of their courses.

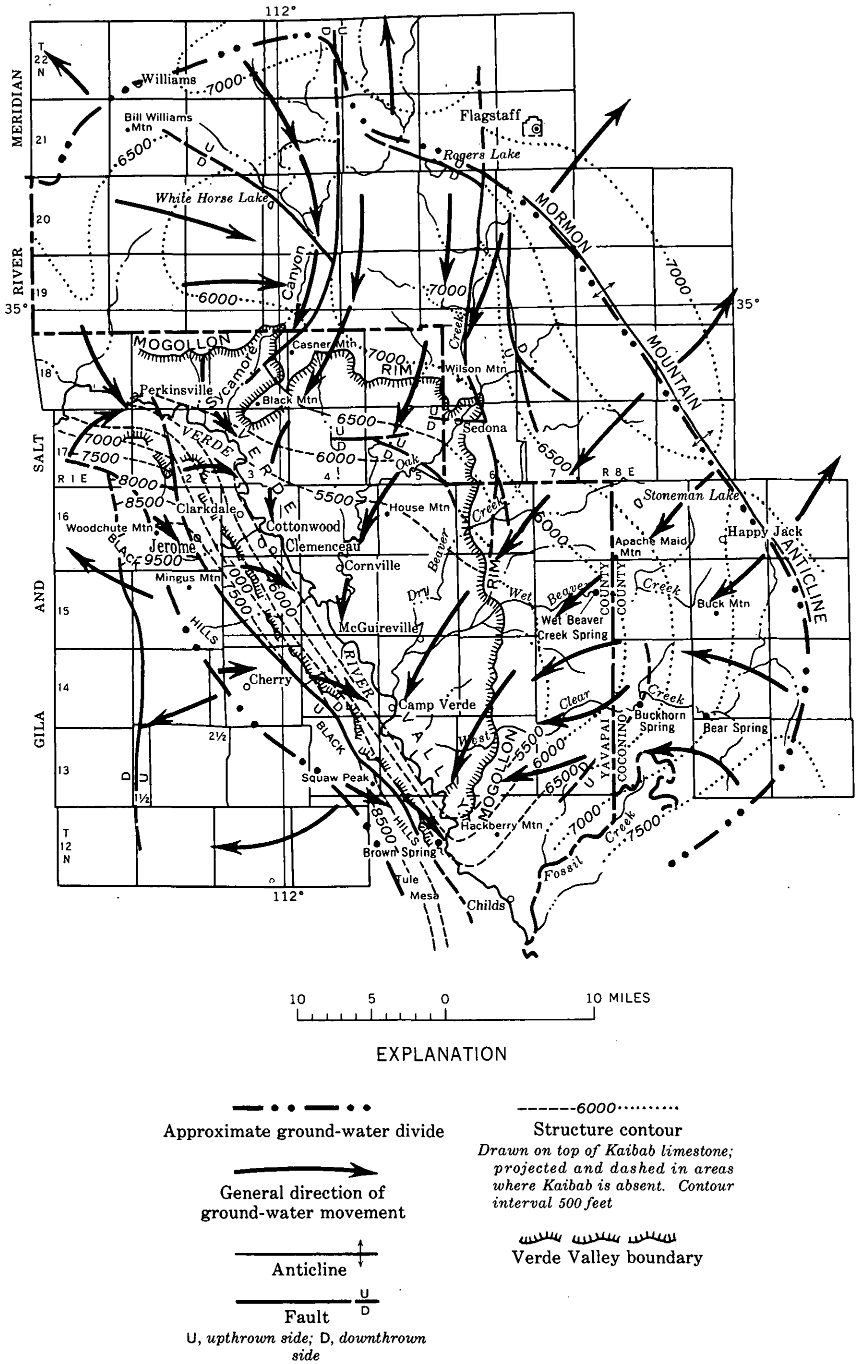

FIGURE 37.—Map showing relation of ground-water movement to structure in the Verde Valley area.

RECHARGE OF GROUND WATER

The chief means of recharge to the Verde Valley ground-water reservoir is by direct penetration of water from precipitation on the Colorado Plateaus (fig. 36). Some recharge to the Verde Formation is from pre-Verde rocks such as the Supai Formation and Redwall Limestone.

Only a small part of the total precipitation is a source of water for recharge, because much of it is lost to the atmosphere by evaporation or transpiration and some may be lost by sublimation. A part of the precipitation becomes runoff, and some of this runoff percolates downward through permeable rocks to the ground-water reservoir.

Ground-water reservoirs that have not been materially affected by development are in hydrologic balance—that is, the amount of recharge is about equal to the amount of discharge. The Verde Valley ground-water basin is in hydrologic balance; the amount of water recharged to rocks in the basin is about equal to the amount of water discharged as base flow at the Chasm gaging station (fig. 36). The average base flow at the gaging station during the winter—225 cfs or 150,000 acre-feet per year—is an approximation of the minimum quantity of water recharged to all rocks in the ground-water basin. The area of rock yielding ground water to surface flow is about 1,400,000 acres; therefore, each acre yields ground water at the rate of 37,000 gallons per year.

The recharge area, about 900,000 acres, receives 20 inches of precipitation per year, and the rest of the ground-water basin receives 12 inches per year; thus, the average annual precipitation in the Verde Valley ground-water basin is 17 inches. Each acre of land receives water from precipitation at the rate of 460,000 gallons per year. On this basis and on the basis that the rocks in the basin yield 37,000 gallons per acre per year, the recharge is 8 percent.

DISCHARGE OF GROUND WATER

All ground water discharged in the Verde Valley ground-water basin, except that lost through evapotranspiration, flows out of the basin at the Chasm gaging station as surface water in the Verde River. The base flow of the river, where it exits from the valley, is 225 cfs. This flow represents the minimum quantity of ground water discharged from rocks in Verde Valley. The quantity of ground water discharged by springs is shown in table 11.

WATER IN THE VERDE FORMATION

Most ground water in the Verde Formation is in limestone, although sandstone, conglomerate, and siltstone yield some water. The water is discharged by springs, artesian wells, and flowing wells.

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Many beds in the Verde Formation are water bearing, yet the amount of water visibly discharged is small. Significant quantities of water probably flow underground through the formation into the streamwash and thence into the perennial streams.

Most wells that penetrate the formation are in the populated part of the valley near perennial streams. Information pertaining to the apparently significant wells is included in tables 7 and 8. The depths of wells range from less than 100 feet to more than 1,000 feet. Water levels range from flowing at the surface to a depth of about 300 feet; the depth to water in most wells is less than 200 feet.

The hydrologic relations between units in the Verde Formation are complex because of rapid facies changes. In general, domestic and industrial supplies of water having less than 500 ppm dissolved solids can be obtained from the limestone and sandstone facies, whereas only small quantities of very salty water can be obtained from the mudstone facies. For example, in the vicinity of Camp Verde the lower limestone facies yields sufficient quantities of ground water for domestic use; the water has less than 500 ppm dissolved solids. However, several miles south of Camp Verde the water from wells in the mudstone facies is small in quantity and is very salty.

The thick limestone facies of the Verde Formation contains joints and solution channels that store and transmit water readily. This facies probably will yield water to wells wherever it is below the regional water table. In general, the thick limestone facies will yield moderate to large quantities of water having less than 500 ppm dissolved solids.

TABLE 8.—*Materials penetrated by selected wells*

Material	Thickness (feet)	Depth (feet)
(A-13-5)10bca [Approximate land-surface alt. 3,150 ft. Driller not known]		
Verde Formation:		
Clay and white rocks	250	250
Alternate beds of clay (25–30 ft thick) and gypsum (10–15 ft thick)	550	800
Verde Formation and Tertiary volcanic rocks:		
Clay and lava	600	1, 400
Tertiary volcanic rocks:		
Igneous rock	225	1, 625
Total depth	--------	1, 625

TABLE 8.—*Materials penetrated by selected wells*—Continued

Material	Thickness (feet)	Depth (feet)
(A-13-5)28bc2		
[Approximate land-surface alt. 3,100 ft. Drilled by Loft Hollamon. Lithologic description of material below 160 ft. by F. R. Twenter]		
Streamwash:		
Gravel, decomposed granite, some red clay	45	45
Gravel, granite, and basalt boulders	25	70
Verde Formation:		
Clay, brown	20	90
Clay, "blue," and salt	70	160
Clay and evaporite minerals; the clay is yellowish gray	20	180
Clay and evaporite minerals in about equal proportions; the clay is very light gray	20	200
Clay, very light gray, some light-greenish-gray; about 15 percent of sample is evaporite minerals	30	230
Evaporite minerals, some well-preserved crystals; contains small amount of very light gray clay	30	260
Evaporite minerals and very light gray clay; some evaporite minerals almost transparent, readily soluble, and have salty taste; white crystalline and fibrous crust forms on dry sample	50	310
Similar to overlying unit except for clay, which is pinkish gray	10	320
Clay, very light gray, and evaporite minerals	10	330
Clay, very light gray; about 25 percent of sample is evaporite minerals; white crystalline crust forms on dry sample	20	350
Clay and evaporite minerals in about equal proportions; clay is very light gray, some pale yellowish brown; white crystalline and fibrous crust forms on dry sample	10	360
Evaporite minerals, some very light gray clay	10	370
Clay and evaporite minerals in about equal proportions; clay is light brownish gray, some very light gray	80	450
Evaporite minerals; about 35 percent of sample is very light gray clay	30	480
Clay, light-brownish-gray, some very light gray; about 25 percent of sample is evaporite minerals	20	500
Clay, very light gray; about 20 percent of sample is evaporite minerals	30	530
Clay, pinkish-gray and very light gray, and evaporite minerals	10	540
Clay, pinkish-gray and very light gray, and evaporite minerals; first evidence of large gypsum crystals	20	560
Clay, grayish-orange-pink and light-brownish-gray, some very light gray, and evaporite minerals; some large fragments of gypsum	40	600
Clay, light-brownish-gray; about 15 percent of sample is evaporite minerals	20	620
Clay, light-brownish-gray and very light gray; about 25 percent of sample is very hard, white, siliceous material that contains minerals indicative of igneous source area	80	700
Total depth	--------	700

TABLE 8.—*Materials penetrated by selected wells*—Continued

Material	Thickness (feet)	Depth (feet)
(A-14-5)4aaa		
[Approximate land-surface alt 3,450 ft. Drilled by Loft Hollamon]		
Verde Formation:		
Limestone	22	22
Limestone and clay, in alternate beds; limestone is 1–2 ft thick; clay is 1 ft thick or less	233	255
Limestone, white, soft	70	325
Limestone and bentonitic clay	77	402
Clay, bentonitic	73	475
Limestone, white, soft and hard beds	14	489
Limestone, brown, vuggy	14	503
Total depth	--------	503
(A-14-5)17aaa2		
[Approximate land-surface alt 3,190 ft. Drilled by Loft Hollamon. Lithologic description by F. R. Twenter]		
Streamwash:		
Gravel, clay, and very fine grained sand, light-brown to moderate-brown; pebbles are basalt, quartz, weathered limestone, and metamorphic rocks	30	30
Gravel, dark-gray; pebbles, mostly basalt, are well rounded and as much as 1 in. in diameter	5	35
Verde Formation:		
Limestone, very pale orange to white; contains manganese dendrites and vugs lined with calcite crystals. General footage characteristics are listed below in descending order:		
From 35 to 40—limestone; about 35 percent clay and silt.		
From 40 to 50—vuggy limestone that contains manganese dendrites; about 5 percent clay and silt.		
From 50 to 75—vuggy limestone that contains manganese dendrites; about 15–30 percent clay and silt.		
From 75 to 85—aphanitic limestone; about 10 percent clay and silt.		
From 85 to 110—vuggy limestone; about 20–40 percent clay and silt.		
From 110 to 135—vuggy, porous limestone; about 15 percent clay and silt.		
From 135 to 140—vuggy, porous limestone; about 30 percent clay and silt.		
From 140 to 160 (bottom of hole)—vuggy, porous limestone; about 10–20 percent clay and silt	125	160
Total depth	--------	160

TABLE 8.—*Materials penetrated by selected wells*—Continued

Material	Thickness (feet)	Depth (feet)
(A-15-3)5bd		
[Approximate land-surface alt 3,725 ft. Drilled by A. B. Peach]		
Quaternary gravel and Verde Formation:		
Gravel, cemented	120	120
Tertiary volcanic rocks:		
Basalt	100	220
Redwall(?) Limestone:		
Limestone	315	535
Total depth	--------	535
(A-15-3)12adb1		
[Approximate land-surface alt 3,275 ft. Drilled by Riley Lee]		
Streamwash:		
Gravel, sand, and clay	33	33
Verde Formation:		
Clay, yellow	37	70
Limestone	330	400
Total depth	--------	400
(A-15-4)3ca		
[Approximate land-surface alt 3,325 ft. Drilled by George Riggins]		
Verde Formation:		
Conglomerate and limestone	45	45
Silt, red	10	55
Clay, "blue"	3	58
Mudstone, red, limy	7	65
Silt, red	11	76
Clay, red	4	80
Sand, red, very loose and friable	52	132
Conglomerate	8	140
Sand, red, very loose and friable	10	150
Conglomerate	10	160
Sand, red, very loose and friable	10	170
Conglomerate	5	175
Clay, "blue"	13	188
Limestone	7	195
Sandstone	13	208
Limestone, flintlike	2	210
Limestone, cavernous	4	214
Clay	3	217
Total depth	--------	217

TABLE 8.—*Materials penetrated by selected wells*—Continued

Material	Thickness (feet)	Depth (feet)
(A-16-3)33dd		
[Approximate land-surface alt 3,460 ft. Drilled by Roscoe Moss Co. Lithologic description by F. R. Twenter]		
Quaternary gravel:		
Gravel and very coarse grained sand. Pebbles mostly basalt (60–75 percent); some fragments from Paleozoic and Precambrian rock; pebbles have maximum diameter of about 1 in.; average diameter ranges from ¼ to ½ in	70	70
Verde Formation:		
Mudstone, grayish-orange-pink; mostly clay, silt, and very fine grained to medium-grained sand; some zones contain small fragments (1/8–1/4 in. in diameter) of basalt. Calcareous	40	110
Sandstone, grayish-orange-pink, very fine grained to fine-grained; mostly quartz. Calcareous	10	120
Mudstone, grayish-orange-pink and light-brown. Chiefly clay, silt, and very fine grained to medium-grained sand; some coarse-grained sand. Very calcareous	40	160
Claystone, grayish-orange-pink and light-brown. Very calcareous	50	210
Marl or argillaceous limestone, white and pinkish-gray; contains some opalized plant material and chert	30	240
Limestone, very dense, almost lithographic; some grayish-pink clay; contains some white chert	10	250
Claystone, calcareous, and argillaceous limestone, grayish-orange-pink and white	50	300
Claystone and siltstone, grayish-orange-pink and light-brown. Very calcareous	20	320
Claystone and limestone, grayish-orange-pink and white; limestone is dense and saccharoidal	10	330
Claystone, grayish-orange-pink; contains tubelike structures of calcite that are probably replaced plant material. Very calcareous	30	360
Claystone and limestone, some fine-grained sandstone, grayish-orange-pink	10	370
Claystone, grayish-orange-pink; some silt and very fine grained sand. Very calcareous	10	380
Limestone, slightly argillaceous, white and grayish-orange-pink; 15 percent of sample is light-colored chert	10	390
Claystone, grayish-orange-pink. Very calcereous	10	400
Marl or argillaceous limestone, white; 20 percent of sample is white chert	20	420
Claystone, grayish-orange-pink; some silt and fine-grained sand. Very calcareous	20	440
Limestone, dense and finely crystalline, white	20	460
Claystone, moderate-reddish-brown and dark-reddish-brown, 15 percent of sample is silt and fine-grained sand	10	470
Claystone and limestone, pinkish-gray and white	20	490
Siltstone, pale-reddish-brown, Calcareous	10	500
Claystone, pinkish-gray and pale-reddish-brown; 10 percent of sample is fine-grained sand. Slightly calcareous	20	520
Limestone, white; 30 percent of sample is pale-reddish-brown clay and fine-grained sand	10	530
Mudstone, yellowish-gray and moderate-orange-pink. Chiefly clay, silt, and very fine grained to medium-grained sandstone. Calcareous to very calcareous	40	570

TABLE 8.—*Materials penetrated by selected wells*—Continued

Material	Thickness (feet)	Depth (feet)
(A-16-3) 33dd—Continued		
Verde Formation—Continued		
Claystone, grayish-orange-pink; 15 percent of sample is yellowish-gray mudstone. Very calcareous	10	580
Limestone, argillaceous, grayish-orange-pink	10	590
Mudstone, pale-reddish-brown and grayish-orange-pink. Chiefly clay, silt, and very fine grained to medium-grained sand. Very calcareous	20	610
Claystone, limy, or very argillaceous limestone, grayish-orange-pink; some very fine grained to medium-grained sandstone. Very calcareous	100	710
Mudstone, pale-reddish-brown. Chiefly clay, silt, and very fine grained to medium-grained quartz sand. Slightly calcareous	10	720
Claystone, arenaceous, grayish-orange-pink. Very calcareous	20	740
Mudstone and claystone, pale-reddish-brown and grayish-orange-pink. Chiefly clay, silt, and very fine grained to medium-grained quartz sand. Calcareous to very calcareous	50	790
Claystone, calcareous, or very argillaceous limestone, grayish-orange-pink and white. Very calcareous	10	800
Mudstone, moderate-orange-pink. Chiefly clay, silt, and very fine grained sand. Very calcareous	20	820
Sandstone, very argillaceous, light-brown; very fine grained to fine-grained; mostly quartz. Slightly calcareous	10	830
Claystone, very arenaceous, grayish-orange-pink and pale-reddish-brown. Very fine grained to fine-grained quartz sand abundant. Calcareous to very calcareous	60	890
Limestone and claystone, white and grayish-orange-pink. Very calcareous	10	900
Claystone and siltstone, light-brown. Very calcareous	40	940
Total depth		940
(A-16-4) 26cd		
[Approximate land-surface altitude 3,450 ft. Drilled by Loft Hollamon]		
Streamwash:		
Gravel, sand, and clay	14	14
Verde Formation:		
Clay, "blue"	41	55
Sand, very friable	12	67
Clay, "blue"	13	80
Basalt	7	87
Tertiary volcanic rocks:		
Conglomerate	16	103
Basalt	17	120
Clay, brown, some red; probably tuffaceous	156	276
Supai Formation:		
Sandstone, red	14	290
Total depth		290

Well (A-14-5)17aaa2 at Montezuma Castle National Monument is 160 feet deep and is typical of wells in the thick limestone facies. Water was first reached at a depth of 87 feet, but it rose in the well to 65 feet below the land surface. The well yields 45 gpm of water having 321 ppm dissolved solids.

Well (A-15-3)12adb1 is near the eastern margin of the thick limestone facies and is about 400 feet deep. The driller's report indicates that (1) at a well depth of 33 feet the depth to water was 33 feet, (2) at a well depth of 90 feet the depth to water was 20 feet, (3) at a well depth of 130 feet the depth to water was 12 feet, (4) at a well depth of 175 feet the depth to water was 6 feet, and (5) at a well depth of 390 feet the water flowed 5 gpm at the land surface. The flow gradually decreased and eventually ceased. From July 1959 to July 1960 the depth to water ranged from 15 to 19 feet.

The flowing wells in secs. 27 and 35, T. 16 N., R. 3 E., on the east side of the Verde River near Cottonwood (pl. 1), are in the thick limestone facies. The depths of these wells range from 150 to 400 feet. All the wells have small flows; well (A-16-3)35add2 flows about 8 gpm and is probably typical.

Water from the mudstone facies generally is not suitable for domestic use because of high concentrations of dissolved solids. Most wells in this facies are near Camp Verde in an area where the facies is exposed. Well (A-13-5)15aa penetrated 132 feet of the mudstone facies and yielded water having 90,300 ppm dissolved solids.

The lower and middle limestone facies of the Verde Formation are artesian aquifers. The limestone is jointed, contains many solution channels, and is highly permeable. These facies yield moderate to large quantities of water having less than 500 ppm dissolved solids; some irrigation wells pump at least 1,000 gpm. The upper limestone facies also contains many solution channels and is permeable. However, this facies generally is above the water table and is not penetrated by wells.

Well (A-13-5)5ca is typical of several wells in the Camp Verde area that obtain water from the lower limestone facies. The well is 120 feet deep (table 7). The "first" water was found at a depth of 68 feet in a hard crystallized limestone; in July 1959 the depth to water was 55 feet. The well yields moderate to large quantities of water having less than 500 ppm dissolved solids. In this area the lower limestone facies is the main source of fresh water; the bounding mudstone facies contains only salty water. The source of the fresh water is probably the Verde River. About 1 mile north of well (A-13-5)5ca the lower limestone facies is exposed along the Verde River and provides an excellent recharge area for the aquifer. The lower limestone series has a southerly dip and within a short distance is below the level of the river.

Wells in T. 15 N., R. 5 E., in the vicinity of Montezuma Well, obtain some water from the middle limestone facies. These wells are 100–400 feet deep. Several of the wells flow, and in others the depth to water is 2–200 feet. All the wells yield moderate quantities of water having less than 500 ppm dissolved solids.

Some thin limestone beds in the Verde Formation are excellent aquifers; they yield moderate to large quantities of water having less than 500 ppm dissolved solids to springs and wells. Most of the water is under artesian pressure. Near Cottonwood, well (A–16–3)33dd penetrated more than 900 feet of the Verde Formation. The well is just west of the thick limestone facies. The rock penetrated is chiefly claystone and mudstone interbedded with a total of 180 feet of thin-bedded limestone in 5–15-foot-thick layers. Because the claystone and mudstone are nearly impermeable and other clastic rocks, such as sandstone and siltstone, are not abundant, the thin limestone beds probably are the aquifers that transmit large quantities of water.

The significance of thin limestone beds in transmitting water is exemplified further by wells near Cornville. Many wells penetrate from 10 to more than 75 feet of water-bearing friable sandstone and siltstone in the sandstone facies of the Verde Formation, but because this material caves excessively, it is usually cased off, and most water for domestic supply is from the thin limestone beds. Water from wells in the Cornville area is artesian and has less than 500 ppm dissolved solids. Typical wells are (A–15–4)2ccc1, (A–15–4)3ca, and (A–15–4)4aaa1. Of interest on the driller's record for well (A–15–4)3ca (table 8) is the notation that a thin limestone at a depth of 188 feet is a "good water strata," and another thin limestone at a depth of 208 feet contains "* * * a 4-foot cavity that yields a good supply of water."

Thin limestone, friable sandstone, and siltstone in the Verde Formation are the source of water for Sheepshead Canyon Spring, Hells Canyon Spring, and Cottontail Spring. Near Clarkdale, Gravel Plant Spring issues from a thin limestone that is underlain and overlain by fine-grained clastic rocks.

Ground water discharged from springs in the Page Springs and Spring Creek areas may flow through the Verde Formation during the last few feet of underground travel, but the chief source of water probably is the Supai Formation.

The source of the water discharged by the springs and flowing wells in the Montezuma Well area (pl. 1) cannot be ascertained definitely. Exposures show that the Verde Formation is very thin, and much of the water may be derived from older rocks.

WATER IN ROCKS OTHER THAN THE VERDE FORMATION

Exclusive of water in the Verde Formation, the principal occurrences of ground water in the Verde Valley ground-water basin are in the Supai Formation, the Coconino Sandstone, the Redwall Limestone, and the streamwash. Precambrian rocks and Tertiary volcanic and sedimentary rocks collect and store some water, but the yield to wells and springs is usually small. About 6 miles south of Wingfield Mesa, Brown Spring flows from the Martin Limestone in the Verde fault zone.

WATER IN THE SUPAI FORMATION

Sandstone beds in the lower and upper members of the Supai Formation transmit water to wells and springs in the Verde Valley ground-water basin. The 3,600- through 4,000-foot ground-water-altitude contour lines on plate 1, for the Sedona, House Mountain, and Big Park areas, are based primarily on water levels in wells that obtain water from the Supai. As indicated by the contour lines, water in the aquifier flows southwest.

Near Sedona, Red Rock Crossing, and Big Park, large amounts of ground water are withdrawn from wells that penetrate the lower member of the Supai. The water is under artesian pressure and in some wells rises as much as 80 feet. Most wells produce an adequate domestic water supply, and several supply water to housing subdivisions consisting of 20 or more homes. Many of the wells are from 300 to 700 feet deep; several are more than 800 feet deep. Depth to water ranges from less than 100 feet to more than 600 feet.

In Big Park, 11 wells penetrate the lower member of the Supai. The depth to water in these wells is 300–400 feet. Just northwest of Big Park, well (A–17–5)36ccc penetrated about 300 feet of this member; the water level is 414 feet below land surface.

Southwest of Cathedral Rock fault near Red Rock Crossing, the water level in several wells in the lower member of the Supai is between 100 and 400 feet below land surface. Northeast of Cathedral Rock fault in wells that penetrate most of the lower member, the depth to water is 100–600 feet.

In Grasshopper Flat just west of Sedona, the depth to water in wells that obtain water from the lower member of the Supai Formation is between 400 and 600 feet.

The Supai Formation probably supplies water mostly to the springs, seeps, and flowing wells along Oak Creek near Page Springs and along Spring Creek south of U.S. Highway 89A. The ground water probably occurs in sandstones of the Supai where the formation is confined by the overlying less permeable Tertiary volcanic rocks (pl. 1, section *A–A′*). The springs and flowing wells in this area discharge at least

16,000 gpm, and possibly as much as 23,000 gpm, to Oak Creek. Well (A–16–4)26cd penetrates the Supai at a depth of 275 feet and flows about 50 gpm.

Springs and seeps along Oak Creek fault in Oak Creek Canyon are in the upper member of the Supai Formation and the lower part of the Coconino Sandstone. The Oak Creek fault and its associated fractures provide a permeable zone in which water can be stored and transmitted readily. Water, flowing southwestward, enters this permeable zone and flows southward. The water is intercepted by the land surface at progressively lower altitudes in Oak Creek Canyon, and this causes springs and seeps to issue from the Supai and Coconino.

WATER IN THE COCONINO SANDSTONE

The Coconio Sandstone in the Verde Valley ground-water basin is permeable and, where saturated, is a good aquifer. However, in most of the area shown on plate 1 the Coconino is eroded or is drained. In the area mapped, only one spring, Walker Spring, flows from the Coconino, and it does so at a basalt dike along a fault. On the east side of the ground-water basin outside the area shown on plate 1, the Coconino Sandstone yields water to springs and seeps in Wet Beaver, West Clear, and Oak Creeks.

Most of the water in Wet Beaver Creek issues from the Coconino Sandstone. The initial and greatest flow is from Wet Beaver Creek Spring (fig. 2), which is several hundred feet upstream from a fault. Perennial flow in West Clear Creek is sustained by water from the Coconino; a few spring outlets, such as those of Bear Spring and Buckhorn Spring (fig. 2), are along faults. The springs and seeps in Oak Creek Canyon that issue from the Coconino are along the Oak Creek fault.

WATER IN THE REDWALL LIMESTONE

The Redwall Limestone yields water to springs and wells in the Verde Valley ground-water basin by means of many connected solution channels. In this aquifer the ground water flows toward the Verde River in a direction similar to that of most ground water in the ground-water basin (fig. 38).

Near Cottonwood, well (A–15–3)5bd penetrated the Redwall and flows 5 gpm. In the same area, Haskell Spring, which supplies supplementary water for the city of Clarkdale, is near the contact of the Redwall Limestone and the Tertiary volcanic rocks in the Verde fault zone; the source of water is probably the Redwall. Summer's Spring, in the canyon of Sycamore Creek, issues from several openings in the Redwall Limestone; the point of issuance is localized by small faults.

WATER IN THE STREAMWASH

Most of the streamwash along the perennial streams in Verde Valley is water bearing and is a good unconfined aquifer. Much of the recharge is from the perennial streams and from the Verde Formation. The water level in wells in the streamwash commonly is at an altitude that approximates that of the nearest stream. As long as the streams contain water, the streamwash will yield moderate to large quantities of water to wells. Because water in the wells is influenced by the stage of the perennial streams, the wells in the streamwash were not inventoried for this report.

PUMPING TEST AT MONTEZUMA CASTLE NATIONAL MONUMENT

A 24-hour pumping test on November 24, 1958, lowered the water level 33.1 feet in Montezuma Castle National Monument well (A-14-5)17aaa2 (table 7). The well was pumped at 45 gpm. The static water level, before the test, was 65 feet. Thus, the specific capacity—that is, the discharge per foot of drawdown—is 1.3 gpm.

The well bottoms near the middle of the thick limestone facies of the Verde Formation (pl. 1) at a depth of 160 feet.

The pump is 140 feet below the land surface. Earlier pump tests, in which the well was pumped at 100, 80, and 70 gpm, caused the water level to quickly decline below the pump.

The coefficient of transmissibility—gallons of water per day transmitted at existing temperature through a strip of aquifer 1 foot wide extending the full height of the aquifer under a unit hydraulic gradient—was determined by the Jacob modified-nonequilibrium formula. Values of s, drawdown in feet, are plotted as ordinates, and values of t, time, in minutes since pumping began, are plotted as abscissas on semilogarithmic paper (fig. 38). The early data generally will plot as a curve and will be invalid. As t becomes larger, the points fall in a straight line. The simplified expression for the computation is:

$$T=\frac{264Q}{\Delta s}$$

where:

T=coefficient of transmissibility, in gallons per day per foot;
Q=discharge, in gallons per minute;
S=drawdown difference per log cycle, in feet.

The transmissibility coefficient computed for the limestone aquifer was 1,300 gpd per ft (gallons per day per foot) (fig. 38).

The pumping-test data indicate a recharge boundary at a depth of about 95 feet. This boundary produced a straight-line plot of different slope, indicating a permeable zone having a coefficient of transmissibility of 6,600 gpd per ft.

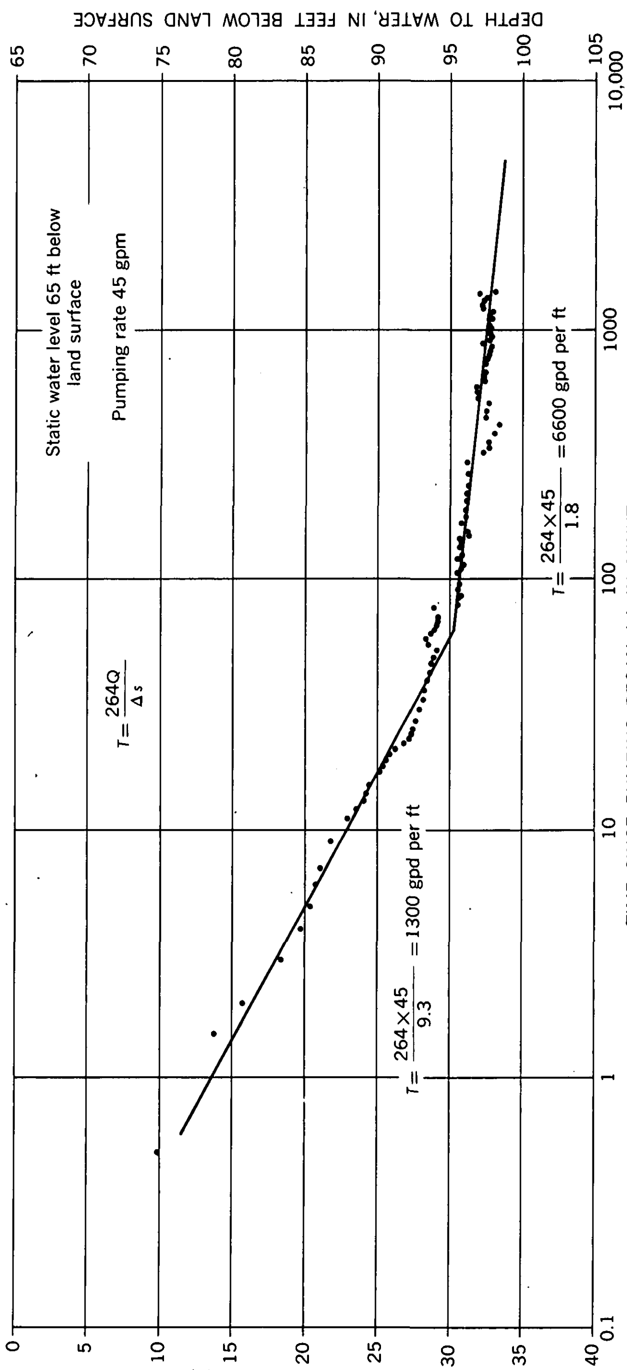

FIGURE 38.—Semilogarithmic plot of water-level drawdown during pumping test of well (A-14-5)17aaa 2 at Montezuma Castle National Monument, Ariz.

Pumping tests indicate that the limestones of the thick limestone facies are not capable of yielding 70 gpm of water at the Montezuma Castle National Monument well. When the well was pumped at this rate, the water level declined to the pump in less than an hour. However, the tests do indicate that the well can be pumped at 50–60 gpm.

The yield of the Montezuma Castle National Monument well is below the average of the reported yields for other wells in the thick limestone facies of the Verde Formation. This is due to the extremely varied and complex hydrologic characteristics of limestones. The yield from wells in limestone depends on the amount and type of fractures and solution channels—these vary greatly in the thick limestone facies.

WATER-LEVEL FLUCTUATIONS

The level of the water surface in a well seldom remains stable. Generally, there is continual change. If for no other reason, a slight change in water level will result from atmospheric-pressure variations. In areas where large quantities of water are discharged with little or no recharge, the water level may continually decline; where recharge exceeds discharge, the water level may rise. In areas where discharge only slightly exceeds recharge, the overall decline in water level over the years may be only slight; the level will decline markedly during periods of greatest discharge, such as the summer growing season, but will recover almost to its previous level when discharge is greatly reduced, such as during the winter. This probably is the nature of ground-water fluctuations in Verde Valley.

In 1959–60 several wells in the Verde Formation were measured periodically, and a recording gage was in operation on one well. Table 9 gives the data collected for five observation wells, and figure 39 is a hydrograph illustrating water-level fluctuations in the recorder well.

The depth to water in the five observation wells was less than 75 feet. During the period of data collection for this report, the change in water level was not significant.

The hydrograph (fig. 41) for well (A–15–3)12adb1 shows that the highest water levels are recorded during January, February, and March and that the level gradually declines to a low in July. During July, when the temperature is highest, evapotranspiration is greatest. Generally, the level in this well reflects the growing season and the climate of the valley floor.

CHEMICAL CHARACTER OF GROUND WATER

The quantity of dissolved solids in water is a general indication of the water's suitability for use by plants and animals and ordinarily is determined from the weight of solid material remaining after evap-

TABLE 9.—*Water-level measurements for selected wells in the Verde Formation*

[Depth to water, in feet below land surface]

Date of measurement	Depth to water (feet)	Date of measurement	Depth to water (feet)
(A-13-5)5ca [Approximate land-surface alt 3,100 ft]			
7-15-59	54.1	12-16-59	54.1
8-20-59	54.0	4-22-60	53.7
9-17-59	53.7	6-02-60	53.6
10-16-59	53.8	7-21-60	54.0
11-13-59	54.1		
(A-14-5)9ad [Approximate land-surface alt 3,290 ft)			
6-10-59	21.4	11-11-59	19.1
7-15-59	22.4	1-21-60	18.8
8-19-59	19.8	3-02-60	20.6
9-16-59	23.3	4-20-60	18.9
10-15-59	17.4		
(A-14-5)17aaa2 [Approximate land-surface alt 3,190 ft]			
11-25-58	63.0	8-19-59	65.2
6-12-59	65.0	1-21-60	64.4
7-15-59	65.2		
(A-15-4)4dd [Approximate land-surface alt 3,375 ft]			
8-18-59	36.8	3-02-60	37.9
9-18-59	37.2	4-21-60	37.6
10-15-59	36.8	6-02-60	37.2
12-18-59	36.9	6-23-60	37.1
1-21-60	37.5	7-21-60	37.3
(A-16-3)27ab [Approximate land-surface alt 3,375 ft]			
4-23-59	22.1	12-17-59	20.4
6-11-59	22.4	1-22-60	20.3
7-13-59	22.4	3-02-60	20.2
8-18-59	21.8	4-21-60	20.7
9-17-59	21.5	6-02-60	21.4
10-15-59	21.4	6-23-60	21.7

oration of a water sample. Generally, water that contains less than 500 ppm dissolved solids can be used for domestic purposes; when the concentration is more than 1,000 ppm, the water is unsuitable for many purposes, especially domestic use.

The concentrations of dissolved chemical constituents determine the suitability of water for various uses. Some constituents, such as calcium and magnesium, are beneficial to the soil and to proper growth

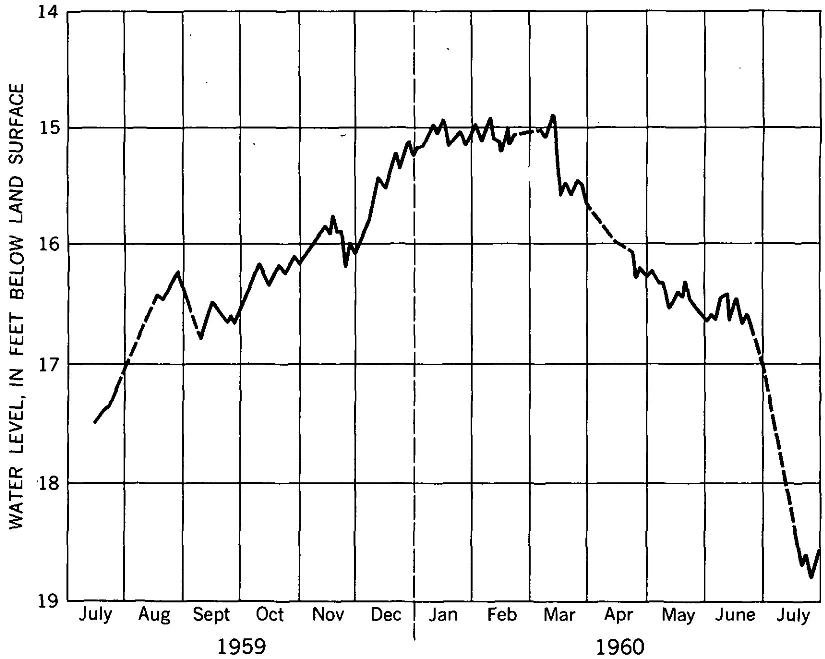

FIGURE 39.—Hydrograph of well (A-15-3)12adb1, showing midnight water levels only. Dashed line indicates period of no record. Approximate altitude at measuring point is 3,275 feet.

and development of plant or animal life; however, these constituents also cause hardness of water. Other constituents, such as sodium, potassium, and chloride, may be detrimental to plant and animal life. Fluoride in concentrations of about 1 ppm is beneficial in preventing tooth decay, but concentrations in excess of 1.7 ppm may cause mottling of the tooth enamel when used by children during the time their permanent teeth are forming (U.S. Federal Register, 1962).

The chemical character of water from wells and springs most pertinent to the present investigation is given in tables 10 and 11, respectively. The analyses of the ground water show only the chemical constituents and do not reflect the sanitary conditions.

All springs and wells in Paleozoic rocks yield water containing less than 500 ppm dissolved solids. Ranges of concentration for some of the dissolved chemical constituents are: Silica, 15–20 ppm; calcium, 40–75 ppm; magnesium, 15–40 ppm; sodium and potassium, 5–30 ppm; and bicarbonate, 200–375 ppm.

Water from the Verde Formation in the northern part of Verde Valley is generally of a chemical quality suitable for domestic use. Water from most wells in the formation in this area contains less than 500 ppm dissolved solids. Ranges of concentration for some of the dissolved chemical constituents are: Calcium, 30–75 ppm; magnesium, 25–50 ppm; sodium and potassium, 15–40 ppm; bicarbonate, 200–400 ppm; sulfate, 5–50 ppm; and chloride, 15–30 ppm.

In the Camp Verde area, wells in the lower limestone facies usually yield water that has less than 500 ppm dissolved solids. However, in this same area, water from wells in the mudstone facies is generally salty. The water from well (A–13–5)15aa contains high concentrations of magnesium, sodium, sulfate, and chloride. These dissolved solids are from evaporite minerals—such as gypsum, glauberite, mirabilite, thenardite, and halite—common in the sourthern part of the valley (fig. 26).

The concentration of magnesium in several samples of water from some beds in the Verde Formation exceeds the concentration of calcium. The calcium-magnesium ratio in these samples of water ranges from 1:8 to 1:2. The usual ratios of calcium to magnesium in ground water range from 5:1 to 1:1. The presence of evaporite minerals in the rocks from which the ground water was obtained probably explains the high concentration of magnesium. Magnesium salts are deposited from saline water and commonly are associated with evaporite minerals, such as those in Verde Valley.

Because of the high dissolved-solids content of water in the southern part of the valley, the dissolved-solids content of the Verde River water increases south of Camp Verde. In December, when base flow in the river is high, two samples of the river water were taken—one upstream from Camp Verde and the other downstream from where the evaporite minerals in the Verde Formation crop out. Analyses indicate that the dissolved-solids content of the water increases from 344 at the upstream point to 394 ppm at the downstream point. This increase in dissolved-solids content is due principally to the following increases: 21 ppm sulfate, 10 ppm bicarbonate, 6 ppm silica, and 5 ppm chloride.

Sulfate increased from 45 to 66 ppm, an increase which, at first glance, appears to be insignificant. However, the increase becomes more significant when calculated for a 24-hour period and a base flow of 278 acre-feet per day at the point of collection upstream in the Verde River and 446 acre-feet per day at the point of collection downstream (table 5). The water at the upstream point contains 45 ppm of sulfate, which represents 0.06 ton per acre-foot of water. The water at the downstream point contains 66 ppm of sulfate, which represents 0.09 ton per acre-foot of water. Therefore, sulfate increases 0.03 ton per acre-foot of water passing between the two points; in 24 hours the increase is about 23 tons. Because most of the water that produced the increase inflow is from tributary streams that con-

TABLE 10.—*Chemical character of ground water from wells in Verde Valley*

[Analyses by U. S. Geol. Survey. Results in parts per million, except as indicated]

Location: For explanation see section on well-numbering system.

Location	Date of collection	Source	Temperature (° F)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (sum)	Hardness as ($CaCO_3$)	Sodium (percent)	Specific conductance (micromhos at 25°C)	pH
(A-13-5)																	
15aa	5-25-59	Verde Formation	------	14	518	4,110	22,500	209	59,800	3,260	------	------	90,300	18,200	73	------	7.7
(A-14-4)																	
2bc	12-9-58	do	------	48	56	68	35	491	22	40	0.5	14	524	418	16	923	7.5
14db	10-21-58	do	67	78	32	48	289	338	490	80	2.4	[illegible]	1,190	278	69	1,700	7.5
(A-14-5)																	
17aaa2	11-25-58	do	64	25	49	35	20	335	9.5	17	.2	.3	321	266	14	552	7.5
(A-14-6)																	
9dac1	10-29-58	Tertiary(?) volcanic rocks	66	23	34	20	76	311	5.4	47	.2	3.9	362	166	50	671	7.3
(A-15-3)																	
2cb2	10-9-58	Verde Formation	------	58	35	34	16	208	43	31	.2	2.2	321	228	13	505	7.4
21aa	10-16-58	Verde(?) Formation	68	56	39	52	39	436	8.6	20	.5	.2	429	312	21	686	7.4
(A-15-4)																	
2ccc4	8-21-59	Verde Formation	66	23	64	15	20	297	4.1	10	.2	3.7	286	222	16	487	7.3
7cbd	10-21-58	do	70	48	35	39	34	278	49	.2	1.0	------	372	248	23	514	7.4
10cd	12-9-58	do	62	29	72	36	42	450	17	22	.2	.5	440	328	22	738	7.2
33dcb	12-9-58	do	68	42	185	401	67	212	1,910	65	.4	2.2	2,780	2,110	6	3,070	7.4
(A-15-5)																	
27db	12-9-58	do	68	32	63	27	32	371	8.4	17	.6	.8	363	268	21	609	7.7
36caa	10-15-58	do	68	30	50	43	23	383	8.6	20	.4	.8	364	302	14	629	7.4
36cca	10-16-58	do	68	22	70	22	38	374	8.0	22	.4	.2	367	265	24	625	7.5
36ccc	10-16-58	do	69	26	68	24	36	372	8.6	21	.5	.8	368	268	22	629	7.4
36dbb	10-29-58	do	67	30	76	39	27	435	12	28	.2	.4	427	350	15	734	7.2
(A-16-3)																	
8cc	10-9-58	do	------	22	58	27	16	308	6.4	22	.2	.5	303	256	12	541	7.5
22bc	8-18-59	do	------	41	42	26	19	263	8.2	19	.5	1.2	286	213	16	464	7.4
27ba	10-15-58	do	70	22	57	25	20	293	6.0	29	.2	.8	304	245	15	539	7.3
27cd	10-15-58	Verde(?) Formation	------	24	60	29	17	314	5.4	29	.2	.8	319	268	12	568	7.4
27da	10-9-58	Verde Formation	------	22	60	28	20	314	5.6	30	.1	.8	320	264	14	558	7.5
28ac	11-10-58	do	------	28	37	32	31	316	11	14	.2	.9	309	224	23	520	7.7
30ab	10-9-58	(?)	72	32	27	50	21	197	112	24	.2	7.3	370	273	14	595	7.6
33ac1	10-9-58	Verde Formation	------	24	64	34	20	333	24	30	.2	1.2	361	300	12	620	7.4
35add2	8-18-59	do	68	22	65	26	17	310	7.6	28	.4	1.0	319	267	12	555	7.4
35ccc	10-7-58	do	------	24	54	29	20	302	5.2	30	.2	.8	312	254	15	543	7.3

(A-16-4)																	
14ca	10-14-58	Supai(?) Formation	68	17	59	23	20	281	5.8	34	.1	1.0	298	242	16	533	7.3
15dd	10-14-58	do	69	14	59	23	21	279	6.0	36	.1	.8	297	242	16	547	7.3
23ca	10-14-58	do	69	18	60	23	24	299	5.2	32	.1	1.0	310	244	18	556	7.4
23bbd	8-17-59	do	66	20	57	15	9.9	250	5.1	9.2	.3	1.1	241	204	10	411	7.3
26cd	2- 4-59	Supai Formation	71	18	44	41	15	317	6.4	30	.2	.9	312	278	10	558	7.8
26da	10-15-58	(?)	63	42	84	49	29	528	5.0	24	.2	1.0	494	411	13	837	7.5
(A-16-5)																	
14dba	5-23-57	Supai Formation	60	18	33	16	16	201	5.4	8.5	.2	.7	197	148	19	310	7.4
(A-16-6)																	
8ccb	5-23-57	do	62	17	47	20	5.5	233	6.2	9.0	.2	1.0	221	200	6	422	7.3
(A-17-5)																	
3ddc	5-21-57	do	62	12	54	24	29	277	10	42	.2	.3	308	233	22	526	7.3
10bd	5-21-57	do	62	15	77	38	.5	368	7.2	28	.2	.7	348	348	0	681	7.5
10dca	5-21-57	do	64	19	71	34	11	373	6.6	20	.2	.7	346	217	7	604	7.3
11ddd	5-21-57	do	61	19	40	17	6.9	211	4.1	4.5	.2	.7	196	170	8	330	7.4
14aba	5-21-57	do	61	18	35	17	7.8	201	4.3	3.0	.4	.6	185	158	10	314	7.6
25bbbl	5-21-57	do	60	19	60	24	8.5	311	4.9	4.0	.2	.8	274	248	7	481	7.3
33abc	5-22-57	do	62	19	59	41	27	382	16	24	.2	12	386	316	16	667	7.4
33cca	5-22-57	do	59	17	51	24	8.0	283	4.9	4.0	.2	.3	248	226	7	437	7.3
34aba	5-22-57	do	62	22	56	36	11	362	4.5	6.0	.2	1.0	315	288	8	540	7.3
(A-17-6)																	
30bc	5-22-57	do	60	17	38	19	10	226	4.1	3.5	.2	.5	203	173	12	343	7.1
(A-18-4)																	
25bc	10-10-58	Redwall(?) Limestone	62	12	78	38	4.8	398	2.5	18	1.6	4.3	355	351	3	665	7.5
(A-18-5)																	
27abb	10-10-58	Supai(?) Formation		12	71	30	58	302	16	114	.2	.5	451	300	29	829	7.5

TABLE 11.—*Records and chemical character of*

[Analyses by U.S. Geol. Survey. Results

Discharge: gpm, gallons per minute; E, estimated; M, measured; R, see remarks

Name	Approximate land surface altitude (feet)	Date of collection	Source	Discharge (gpm)	Temperature (° F)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)
Bear Spring[1]	6,200	5-27-59	Coconino Sandstone	100E	52	21	55	22
Brown Spring[1]	2,990	2- 3-59	Martin Limestone	50E	71	54	58	42
Bubbling Pond	3,560	7-14-59	Supai(?) Formation	3,700-4,500R	68	20	56	22
Buckhorn Spring[1]	5,150	5-28-59	Coconino Sandstone	1,000E	60	20	51	22
Cottontail Spring	3,400	2- 6-59	Martin Limestone	3-5E	51(?)	19	78	34
Gravel Plant Spring	3,350	10-29-58	Verde Formation	60E, R	67	36	212	98
Haskell Spring	3,860	10-24-58	Redwall Limestone	600E	65	32	72	38
Hells Canyon Spring	3,450	2- 6-59	Verde Formation	3-5E	62(?)	23	70	37
Montezuma Well springs.	3,600	7-14-59	Verde(?) Formation	1,000M, R	77	22	117	37
Page Springs	3,500	8- 4-49	Supai(?) Formation	10,000R	68	18	42	19
Sheepshead Canyon Spring.	3,450	2- 4-59	Verde Formation	100M, R	61	21	45	43
Soda Spring	3,625	2- 6-59	Verde(?) Formation	25E	75(?)	19	94	55
Spring Creek Spring	3,575	2- 4-59	Supai(?) Formation	100E, R	70	18	55	32
Summer's Spring	3,700	10-10-51	Redwall Limestone	1,900-2,700R	67	15	72	27
Walker Spring	4,250	7-10-59	Coconino Sandstone	75E	70	24	32	21
Wet Beaver Creek Spring.[1]	5,025	10-19-59	do	1,200-1,500E	60	23	29	10

[1] Outside of mapped area.

tain less than 20 ppm sulfate, the primary source of sulfate must be from the evaporite minerals in the southern part of the Verde Valley.

CONCLUSIONS

Ground water in Verde Valley has a twofold importance: (1) in its contribution to the water supply of the Salt River Valley and (2) in its utilization within Verde Valley itself. Large quantities of water derived from Verde Valley by way of the Verde River help to support the agricultural economy of the Salt River Valley in central Arizona. The perennial flow of the Verde River is sustained by ground water from springs that issue from rocks in the Verde Valley ground-water basin. About 225 cfs of the 465 cfs average flow of the river near its exit from Verde Valley is base flow.

Ground water in Verde Valley is used for irrigation and for industrial, domestic, and other purposes. Spring flow is the most intensively utilized source of ground water. Some springs discharge less than 10 gpm, whereas several springs, such as Page Springs, *ground water from springs in Verde Valley*

in parts per million, except as indicated]

Sodium and Potasium (Na+K)	Bicarbonate ($CaCO_3$)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (sum)	Hardness as ($CaCO_3$)	Sodium (percent)	Specific conductance (micromhos at 25° C)	pH	Remarks
5.1	284	0.6	4.0	0.1	0.3	248	228	5	418	7.8	Outlet in West Clear Creek Canyon at intersection with small fault.
36	414	29	16	.2	1.4	441	316	20	678	8.0	
13	270	4.7	20	.2	.8	270	228	11	463	7.6	Range of several measurements.
5.5	268	1.6	6.0	.0	.5	239	218	5	401	8.0	Outlet in West Clear Creek Canyon at intersection with fault.
20	380	12	38	.2	.3	388	334	12	669	7.9	
39	277	673	52	.2	16	1,260	930	8	1,620	7.3	Estimate includes flow from numerous seeps.
23	294	95	28	.2	8.0	441	336	13	709	7.6	Supplementary supply for city of Clarkdale.
12	359	11	34	.2	.7	365	328	7	626	8.0	
49	598	10	35	.4	.8	565	446	19	970	6.9	Discharge measurement at well outlet.
8.7	227	3.7	8.0	.0	.8	212	183	9	364	------	Average of several measurements.
15	330	6.6	30	.2	.7	324	288	10	577	7.8	Flow in creek about half a mile downstream from spring is about 125 gpm.
116	765	16	48	.2	.7	725	460	35	1,230	6.7	
16	304	7.0	32	.2	.9	310	268	11	549	7.3	Flow in Spring Creek about half a mile downstream from spring is about 2,500–3,000 gpm.
5.8	341	7.6	10	.2	1.5	307	290	4	543	------	Range of several measurements.
11	212	5.4	7.0	.1	1.0	206	166	13	331	8.0	Outlet at point where dike and fault intersect Coconino Sandstone.
4.8	147	.2	2.5	.2	1.1	143	115	8	236	7.4	Initial flow is several hundred feet upstream from fault.

discharge more than 10,000 gpm. Development of ground water from wells is increasing, but this development is concentrated in small areas near Camp Verde, Cornville, Cottonwood, and Sedona.

Water from most wells and springs is generally of a chemical quality suitable for use by plants and animals; the dissolved-solids content of the water is less than 500 ppm. Only in the southern part of the valley, where water from the Verde Formation contains more than 90,000 ppm of dissolved solids, is the water salty and unsuitable for use.

The chief aquifers are in the Verde and Supai Formations. Most ground water in the Verde Formation is under artesian pressure, and the depths to water in wells are 200–300 feet. Several flowing wells discharge 10–450 gpm near Cottonwood and Page Springs. Aquifers in the Supai Formaiton furnish water to wells in the Sedona area. Yields generally are small but are adequate for domestic purposes. Depths to water range from 150 to 800 feet.

No water-level decline has been noted in the short-period records available. Recharge to the aquifers probably balances discharge.

STRATIGRAPHIC SECTIONS, VERDE FORMATION

The generalized descriptions and interpretations of the Verde Formation are based largely on measured sections, some of which are presented in detail here. The sections are numbered generally from south to north in the valley, and the location of each section is shown by corresponding number on plate 1. Units in each section are numbered from bottom to top. Colors and their numerical designation were determined by comparison with chips on the rock-color chart (Goddard, 1948). The color of weathered rock is the same as the color of the fresh surface except as indicated, and base of a unit is gradational unless indicated otherwise. The term "plant hash" is used to designate rocks that are chiefly macerated plant material, whether carbonaceous, calcareous, or siliceous. Also, the term "drapery" beds is used to designate beds that, in two dimensions, appear as large wave-made ripple marks and, in three dimensions, appear as small contiguous basins. Sections were measured by F. R. Twenter.

SECTION 1.—*NW¼ sec. 1, T. 12 N., R. 5 E., to SW¼ sec. 25, T. 13 N., R. 5 E.*

[Section started at Verde River about 7 miles southeast of Camp Verde near mouth of Cottonwood Wash and was measured north along Verde River and Cottonwood Wash to top of Wingfield Mesa. Dip of beds in Wingfield Mesa is about 1°–2° N. 30° W. but increases toward the south and is 7° N. 35° W. at the point where the section was started. Approximate alt at top of section 3,425 ft; approximate altitude at base of section 2,910 ft]

Quaternary gravel, not described.

Verde Formation:

	Thickness (feet)
Mudstone facies:	
13. Mudstone, bentonitic clay, and volcanic ash, some fine-grained sandstone and siltstone; mudstone, sandstone, and siltstone are grayish orange pink (5YR 7/2), pale yellowish brown (10YR 6/2), and pale brown (5YR 5/2); volcanic ash and bentonitic clay are white (N 9). Beds from 15 to 54 ft above base contain selenite crystals. Overall appearance is that of sequence of alternate beds about 1–5 feet thick. Weathers slabby and forms steep slope with several ledges	196
12. Mudstone, siltstone, and limestone; mudstone and siltstone are light gray (N 7), light olive gray (5Y 6/1), and yellowish gray (5Y 7/2); limestone is white (N 9). Beds 1–3 in. thick and varvelike. Weathers slabby and forms slope	28
11. Limestone, arenaceous and argillaceous, white (N 9). Beds 1–3 in. thick and varvelike. Weathers slabby and forms prominent ledge	6
10. Tuffaceous sediments, mostly sandstone and some conglomerate, light-gray (N 7) and light olive gray (5Y 6/1). Sandstone is fine to coarse grained; conglomerate pebbles have maximum diameter of 2 in. Weathers smooth and forms slope	8
9. Limestone, similar to unit 12	5
8. Tuffaceous sediments, similar to unit 10	6

SECTION 1.—*NW¼ sec. 1, T. 12 N., R. 5 E., to SW¼ sec. 25, T. 13 N., R. 5 E*—Con.

	Thickness (feet)
Verde Formation—Continued	
Mudstone facies—Continued	
7. Limestone, similar to unit 12	8
6. Tuffaceous sediments, very light gray (N 8), pinkish gray (5YR 8/1), and light gray (N 7) mostly conglomerate; pebbles in lower 95 ft are 1–6 in. in diameter and have medium- to coarse-grained sandstone matrix; pebbles in upper 125 ft average one-half inch in diameter; some coarse-grained to very coarse grained sandstone. Most pebbles are volcanic rocks; volcanic bombs scattered throughout; less than 1 percent of pebbles are Precambrian rocks. Massive bedding. Weathers knobby and forms vertical cliff or steep slope	220
5. Basalt, medium-dark-gray (N 4) and medium-gray (N 5); weathers medium gray (N 5) and olive gray (5Y 4/1). Two flows; lower flow is 8–10 ft thick, and upper flow is 25–50 ft thick; flows separated by 1–3-ft-thick zone of nodular basalt having yellowish-gray (5Y 7/2) calcareous cement. Some of basalt is dense and has flow lines that give bedded appearance. Weathers blocky and forms vertical cliff or very steep slope	40
4. Tuffaceous sediments, very coarse grained sandstone and conglomerate, grayish-orange-pink (5YR 7/2), grayish-pink (5R 8/2), light-brown (5YR 6/4), dark-reddish-brown (10R 3/4), medium-gray (N 5), and very light gray (N 8). Coarse sand grains and pebbles averaging one-half inch in diameter are volcanic rocks. "Floating" boulders (as much as 8 in. in diameter) scattered throughout; calcium carbonate cement; ⅛–¾-in.-thick lenses of arenaceous dolomite. Beds 1 in. to 1 ft thick. Weathers smooth and forms vertical cliff	23
3. Tuffaceous sediments, grayish-orange-pink (5YR 7/2), grayish-pink (5R 8/2), light-brown (5YR 6/4), dark-reddish-brown (10R 3/4), medium-gray (N 5), and very light gray (N 8); mostly conglomerate; very coarse grained sandstone matrix. Pebbles are 6 in. to 3 ft in diameter and are mostly volcanic rocks. Massive bedding. Weathers knobby and forms vertical cliff	21
2. Basalt, light-olive-gray (5Y 6/1) to yellowish-gray (5Y 8/1). Highly jointed and fractured; lower 1 ft very gnarly. Weathers blocky and forms vertical cliff or very steep slope	23
1. Tuffaceous conglomerate, pinkish-gray (5YR 8/1) and white (N 9); very coarse grained sandstone matrix; weathers pinkish gray (5YR 8/1). Pebbles have maximum diameter of 8 in. and are mostly volcanic rocks; upper 6 in. contains several pebbles of chert and Precambrian rock. Gnarly bedding. Weathers rounded and forms slope or small recess. Base concealed	3
Total measured mudstone facies	587

SECTION 2.—*SW¼ sec. 3, T. 12 N., R. 5 E.*

[Section measured about 8 miles southeast of Camp Verde. Beds dip about 8° N. 35° E. Approximate alt at top of section 3,500 ft]

	Thickness (feet)
Quaternary gravel, not described.	
Verde Formation:	
Middle limestone facies:	
13. Limestone, very pale orange (10YR 8/2), grayish-orange-pink (5YR 7/2), and white (N 9); weathers very pale orange (10YR 8/2), white (N 9), and very light gray (N 8); some grayish-orange (10YR 7/4) surface stain. Some 3–5-in.-thick nodules and lenses of yellowish-gray (5Y 6/2) and white (N 9) chert; some beds contain tubelike structures that are 1/10 to ¼ in. in diameter. Several 1–3-ft-thick beds of conglomerate containing pebbles ¼–2 in. in diameter are mostly scoriaceous basalt. Some "drapery" beds. Gnarly, slabby bedding. Weathers gnarly and forms very steep ledge-slope topography	55
12. Limestone and mudstone, some sandstone and siltstone, alternate beds, very light gray (N 8), pinkish-gray (5YR 8/1), and grayish-orange-pink (5YR 7/2). Sandstone is fine to medium grained; several beds contain pebbles of scoriaceous basalt. Beds generally are 6 in. to 1 ft thick. Weathers very gnarly and forms slope having several ledges	110
11. Marl, white (N 9) to pinkish-gray (5YR 8/1). Contains replaced plant stems with excellent structure preservation. Beds are 6 in. to 1 ft thick. Weathers rounded and smooth and forms ledge	6
Total measured middle limestone facies	171
Mudstone facies:	
10. Sandstone, highly calcareous, and pinkish-gray (5YR 8/1) arenaceous limestone. Sandstone is fine to medium grained and mostly quartz. Beds 1–6 inches thick. Weathers smooth and forms slope	15
9. Conglomerate, grayish-orange-pink (5YR 7/2); fine- to medium-grained sandstone matrix. Pebbles are ¼–3 in. in diameter and are chiefly scoriaceous basalt; calcium carbonate cement; massive bedding. Weathers smooth and knobby and forms vertical cliff	7
8. Limestone, white (N 9) and very light gray (N 8), arenaceous; some light-olive-gray (5Y 6/1) chert. Gnarly bedding; beds 3–8 in. thick. Weathers gnarly and forms small ledge	5
7. Limestone, white (N 9) and very light gray (N 8), arenaceous; some pinkish-gray (5YR 8/1) surface stain; some lenses of very light gray (N 8) chert. Some siliceous plant stems with excellent structure preservation. A 1-ft-thick light-brownish-gray (5YR 6/1) sandstone layer at top. Massive bedding. Weathers smooth and forms prominent ledge	4
6. Sandstone, pinkish-gray (5YR 8/1) and grayish-orange-pink (10R 8/2), very fine grained; mostly quartz. Most beds contain some volcanic ash; some beds contain ¼–½-in.-thick lenses of very light gray (N 8) volcanic-glass shards; calcium carbonate cement. Weathers rough and forms very steep slope	23

SECTION 2.—*SW¼ sec. 3, T. 12 N., R. 5 E*—Continued

Verde Formation—Continued	
Mudstone facies—Continued	*Thickness (feet)*
5. Limestone, white (N 9), argillaceous; weathers white (N 9) and very light gray (N 8). Contains 1/16–1/8-in.-thick clay galls; also contains many lenses and 1–3-in.-thick beds of light-olive-gray (5Y 6/1) chert. Gnarly bedding. Weathers gnarly and forms small ledge	4
4. Standstone, grayish-orange-pink (5YR 7/2); some pale yellowish brown (10YR 6/2); very fine grained. About 75 percent volcanic-glass shards; some biotite and scoriaceous basalt fragments. Weathers smooth and forms slope	5
3. Sandstone, grayish-orange-pink (5YR 7/2); very fine grained; mostly quartz. Several 1–3-in.-thick lenses contain pebbles of scoriaceous basalt. Calcium carbonate cement. At top is 1-ft.-thick white (N 9) to very light gray (N 8) arenaceous limestone layer that contains some tubelike structures. Varvelike to massive bedding. Weathers smooth and rounded and forms steep slope	16
2. Limestone, white (N 9) to very light gray (N 8), very arenaceous; weathers very light gray (N 8); contains some clay galls that are one-sixteenth inch in diameter. Weathers blocky and gnarly and forms small ledge	2
1. Sandstone, grayish-orange-pink (5YR 7/2), very fine grained; about 65 percent volcanic-glass shards. Beds ¼–1 in. thick. Weathers smooth and rounded and forms slope. Base concealed	3
Total measured mudstone facies	84
Total measured section	255

SECTION 3.—*NW¼ sec. 13, T. 13 N., R. 4 E.*

Section measured about 3 miles southwest of Camp Verde. Beds dip about 8° N. 65° E; thickness adjusted for dip. Approximate alt at top of section 3,740 ft]

Quaternary gravel, not described.	
Verde Formation:	
Middle limestone facies:	*Thickness (feet)*
21. Mostly covered. Few poor exposures indicate white (N 9) slabby arenaceous limestone	30
20. Limestone, white (N 9); weathers white (N 9) and very light gray (N 8). Most of unit is highly weathered and porous. Gnarly bedding; beds 3 in. to 1 ft. thick. Weathers knobby and pitted and forms small ledge	4
19. Sandstone, very light gray (N 8) and pinkish-gray (5YR 8/1), fine-grained; mostly quartz. Gnarly and slabby bedding; beds 3–6 in. thick. Weathers blocky and slabby and forms small ledge	7
18. Sandstone, yellowish-gray (5Y 7/2); some very light gray (N 8); fine grained; mostly quartz; calcium carbonate cement. No distinct bedding. Weathers smooth and forms slope	5

SECTION 3.—*NW¼ sec. 13, T. 13 N., R. 4 E*—Continued

	Thickness (feet)
Verde Formation—Continued	
Middle limestone facies—Continued	
17. Volcanic ash, yellowish-gray (5Y 8/1) and white (N 9); weathers yellowish-gray (5Y 8/1). Moderate-yellowish-green (5GY 7/4) copper carbonate stain along fault zone. Slabby bedding; beds 1–3 in. thick. Weathers slabby and blocky and forms small ledge	2
16. Mudstone, pinkish-gray (5YR 8/1) and grayish-orange-pink (5YR 7/2); some very pale orange (10YR 8/2); calcium carbonate cement. Varvelike bedding; beds ¼–1 in. thick. Weathers smooth and rounded and forms vertical cliff. Base is concealed	12
15. Mostly covered. Lower 25 ft similar to underlying unit; upper 15 ft similar to overlying unit	40
14. Limestone, some mudstone, white (N 9) and very light gray (N 8); some light olive gray (5Y 7/1). Limestone is argillaceous and arenaceous. Some beds and lenses of chert. Varvelike bedding; beds 1 in. to 3 ft thick. Weathers slabby and blocky and forms vertical cliff	90
Total measured middle limestone facies	190
Mudstone facies:	
13. Mudstone, some gypsum, light-olive-gray (5Y 7/1). Weathers smooth and forms slope	4
12. Limestone, white (N 9); some pale yellowish orange (10YR 8/6). Contains lenses and 1–2-in.-thick beds of very light gray (N 8) chert. Gnarly bedding; beds 1–3 in. thick. Weathers blocky and knobby and forms prominent ledge	4
11. Mudstone, claystone, and glauberite(?) crystals, some argillaceous limestone, very light gray (N 8), pale-yellowish-orange (10YR 8/6), yellowish-gray (5Y 8/1), and white (N 9). Glauberite(?) crystals $\frac{1}{10}$–½ in. long make up 85–95 percent of some beds. At 44 ft above base a 1-ft-thick bed is about 25 percent white (N 9) chert. Beds are ¼–1 in. thick. Weathers knobby and forms steep ledge-slope topography	70
10. Limestone, may be dolomitic, white (N 9). Weathers blocky and forms ledge	2
9. Mudstone, volcanic ash, and sandstone; mudstone and sandstone are yellowish gray (5Y 7/2) and pale yellowish brown (10YR 7/2), some pale yellowish orange (10YR 8/6) and greenish gray (10GY 6/1); volcanic ash is white (N 9). Sandstone is very fine grained to fine grained. Weathers smooth and forms slope	46
8. Sandstone, light-brownish-gray (5YR 7/1), very fine grained to fine-grained; mostly quartz. Varvelike bedding. Weathers smooth and forms slope	6
7. Sandstone, yellowish-gray (5Y 7/2), some pinkish-gray (5YR 8/1); very fine grained; mostly quartz; some volcanic glass shards and gypsum. Weathers smooth and forms slope	6

SECTION 3.—*NW¼ sec. 13, T. 13 N., R. 4 E*—Continued

	Thickness (feet)
Verde Formation—Continued	
Mudstone facies—Continued	
6. Limestone, arenaceous; white (N 9), probably dolomitic; weathers white (N 9) but has very pale orange (10YR 8/2) surface stain. Small irregular cavities make unit porous. Slabby bedding. Weathers smooth and forms small ledge	2
5. Sandstone, very pale orange (10YR 8/2) and yellowish-gray (5Y 8/1), very fine grained to fine-grained; mostly quartz. Massive bedding. Weathers smooth and rounded and forms slope	12
4. Limestone, white (N 9), arenaceous; may be dolomitic; weathers white (N 9) and pinkish gray (5YR 8/1). Beds 1–2 in. thick. Weathers slabby and forms small ledge	2
3. Limestone, light-olive-gray (5Y 6/1) and yellowish-gray (5Y 8/1), highly arenaceous. Massive bedding. Weathers rounded and smooth and forms slope	3
2. Limestone, similar to unit 4	2
1. Limestone, very pale orange (10YR 8/2) and pinkish-gray (5YR 8/1), arenaceous; may be dolomitic; some 1–3-in. thick lenses of light-olive-gray (5Y 6/1) fine-grained sandstone. Weathers smooth and rounded and forms slope. Base is concealed	2
Total measured mudstone facies	161
Total measured section	351

SECTION 4.—*SE¼ sec. 1, T. 13 N., R. 5 E., to NW¼ sec. 1, T. 13 N., R. 5 E.*

[Section measured about 4 miles southeast of Camp Verde. Beds are nearly horizontal. Approximate alt at top of section 3,840 ft]

	Thickness (feet)
Erosion surface.	
Verde Formation:	
Middle limestone facies:	
6. Limestone, some mudstone, white (N 9), very light gray (N 8), grayish-orange-pink (10R 8/2), and grayish-orange-pink (5YR 7/2). From 19 to 21 ft above base is an oolitic limestone. Weathers blocky and forms steep ledge-slope topography	78
5. Mudstone and marl, alternate beds; mudstone is pale yellowish brown (10YR 6/2), pale red (10R 6/2), light brown (5YR 6/4), and light olive gray (5Y 6/1); marl is white (N 9), yellowish gray (5Y 8/1), and grayish orange pink (10R 8/2). Several 3–6-in.-thick beds of volcanic ash. Forms steep ledge-slope topography	225
Total measured middle limestone facies	303

SECTION 4.—*SE¼ sec. 1, T. 13 N., R. 5 E., to NW¼ sec. 1, T. 13 N., R. 5 E*—Con.

	Thickness (feet)
Verde Formation—Continued	
Mudstone facies:	
4. Gypsum, mudstone, and volcanic ash, pinkish-gray (5YR 8/1), pale-yellowish-brown (10YR 6/2), pale-greenish-yellow (10Y 8/2); some dark yellowish brown (10YR 4/2) and grayish olive (10Y 4/2); partly covered. Some beds 90–95 percent gypsum; upper 30 ft consists of alternate beds of gypsum and volcanic glass. Forms slope. (About three-fourths of a mile southwest of this point, near the gypsum mine, this unit is about 100 ft thick and is nearly all gypsum)	90
3. Limestone and marl, white (N 9) and yellowish-gray (5Y 8/1); some chert. Gnarly bedding; beds 1–8 in. thick. Lower 10 ft forms vertical cliff; upper 13 ft forms ledge-slope topography	23
2. Mudstone and marl, some fine- to coarse-grained sandstone, alternate beds; mudstone is yellowish gray (5Y 8/1) and light brownish gray (5YR 6/1); marl is white (N 9) and yellowish gray (5Y 8/1). Forms slope	21
1. Mudstone and marl, alternate beds; mudstone is pale red (10R 6/2) and grayish red (10R 4/2); marl is white (N 9). Selenite makes up 10–20 percent of unit. Forms slope. Base concealed	30
Total measured mudstone facies	164
Total measured section	467

SECTION 5.—*NE¼ sec. 32, T. 14 N., R. 5 E., to NE¼ sec. 28, T. 14 N., R. 5 E.*

[Section started about half a mile northeast of Camp Verde; base of section near Verde River. Beds are nearly horizontal. Approximate alt at top of section 3,700 ft]

	Thickness (feet)
Erosion surface.	
Verde Formation:	
Middle limestone facies:	
7. Limestone and marl. Lower 40 ft is white (N 9); upper 132 ft is white (N 9), very light gray (N 8), grayish orange (10YR 7/4), and grayish orange pink (10R 8/2). Much of the limestone in the upper 132 ft has a breccialike appearance; contains ¼–1-in.-diameter angular fragments of aphanitic limestone in matrix of crystalline limestone. Lower 40 ft of unit contains beds, lenses, and nodules of glossy very light gray (N 9) and dark-yellowish-brown (10YR 4/2) chert. At 15 ft above base is a 3–6-in.-thick bed of very light gray (N 8) volcanic-glass shards. From 10 to 20 ft above base the beds contain pale-yellowish-brown (10YR 6/2) and grayish-brown (5YR 3/2) silicified plant stems. Weathers rough and cavernous; lower 75–80 ft forms a vertical cliff; upper 92–97 ft forms ledge-slope topography	172
Total measured middle limestone facies	172

SECTION 5.—*NE¼ sec. 32, T. 14 N., R. 5 E., to NE¼ sec. 28, T. 14 N., R. 5 E*—Con.

	Thickness (feet)
Verde Formation—Continued	
Mudstone facies:	
6. Mudstone, some marl; mudstone is dark yellowish green (10YR 4/2), dark yellowish orange (10YR 6/6), and pale yellowish brown (10YR 6/2) and weathers pale olive (10Y 6/2); marl is white (N 9) and commonly contains white (N 9) chert nodules. Most beds in lower 60 ft contain selenite. From 175 to 210 ft above base most beds contain glauberite. Massive to varvelike bedding. Weathers smooth and rounded and forms steep slope with several small ledges	232
5. Marl, sandstone, and mudstone, alternate beds; marl is white (N 9); sandstone and mudstone are light greenish gray (5GY 8/1). Sand is very fine grained; 10–15 percent of material in many beds is biotite. Beds 2–8 in. thick. Weathers rounded and smooth and forms steep slope	31
Total mudstone facies	263
Lower limestone facies:	
4. Marl or chalklike limestone, white (N 9). Several beds contain volcanic ash. Beds 1–5 inches thick. Weathers blocky to rounded and forms steep slope	18
3. Limestone, white (N 9); weathers white (N 9) to light gray (N 8); "drapery" beds 2–4 ft long constitute most of unit. Gnarly and massive bedding. Weathers blocky and knobby and forms small ledge	6
2. Marl and argillaceous limestone, white (N 9); weathers white (N 9) to very pale orange (10YR 8/2); some 1–4-in.-thick beds of very light gray (N 8) mudstone. Contains lenses and 1–3-in.-thick beds of white (N 9), greenish-gray (5GY 6/1), pale-blue (5B 6/2), and brownish-gray (5YR 4/1) chert. Beds from 33 to 43 ft above base contain mudcracks. Gnarly bedding; beds 3 in. to 2 ft thick. Weathers blocky and forms vertical cliff	68
1. Marl and highly calcareous mudstone; marl is white (N 9) to yellowish gray (5Y 7/2); mudstone is light greenish gray (5GY 8/1), dusky yellow green (5GY 5/2), and grayish yellow green (5GY 7/2); 10–20 percent of the material in some beds is biotite; most beds contain 1/16–1/4-in.-long crystal cavities, and some beds in lower 6 ft contain gypsum. Beds 1–3 in. thick. Weathers rough and gnarly and forms steep ledge-slope topography or vertical cliff. Base concealed	25
Total measured lower limestone facies	117
Total measured section	552

SECTION 6.—*SE ¼ sec. 17, T. 14 N., R. 5 E.*

[Section started at Wet Beaver Creek about a mile south of Montezuma Castle. Beds are nearly horizontal. Approximate alt at top of section 3,650 ft]

	Thickness (feet)
Erosion surface.	
Verde Formation:	
Middle limestone facies:	
11. Limestone, white (N 9), yellowish-gray (5Y 8/1), and grayish-orange (10YR 7/4), finely crystalline to aphanitic: weathers yellowish gray (5Y 8/1), very light gray (N 8), and white (N 9); several beds of light-brown (5YR 6/4) argillaceous limestone. Many stringers and vugs of crystalline calcite; some chert; some beds cavernous. Beds 1–3 ft thick. Weathers blocky and knobby and forms ledge-slope topography; lower 10 ft commonly forms vertical cliff	110
10. Limestone, white (N 9), yellowish-gray (5Y 8/1), and very light gray (N 8), highly siliceous. Nodules, lenses, irregular masses, and beds of white (N 9), light-olive-gray (5Y 6/1), and yellowish-gray (5Y 8/1) chert throughout. Gnarly bedding; beds 6 in. to 2 ft thick. Weathers blocky and, for most part, forms slope; beds in lower 5 ft and from 24 to 30 ft above base form ledges	43
9. Marl, white (N 9); contains a few nodules of light-olive-gray (5Y 6/1) and black (N 1) chert. Beds varvelike	3
8. Limestone, white (N 9); argillaceous and chalklike; some light-brown (5YR 5/6) surface stain. Upper 4 ft contains "drapery" beds. Beds 6 in. to 1 ft thick. Weathers blocky and forms ledge	6
7. Marl and argillaceous limestone, white (N 9) and yellowish-gray (5Y 8/1). Massive bedding. Weathers rounded and smooth and forms slope	8
Total measured middle limestone facies	170
Mudstone facies:	
6. Shale, pale-yellowish-green (10GY 7/2) and pale-greenish-yellow (10Y 8/2); calcium carbonate cement. Beds varvelike and ½–2 in. thick. Weathers smooth and forms gentle slope	25
5. Limestone, argillaceous limestone, and highly calcareous mudstone; limestone is white (N 9); mudstone and argillaceous limestone are grayish orange pink (5YR 7/2), very pale orange (10YR 8/2), and grayish orange (10YR 7/4). Nodules, lenses, and beds of white (N 9) and very light gray (N 8) chert make up 30–40 percent of upper 28 ft. Beds 6 in. to 2 ft thick. Weathers blocky; lower 27 ft forms slope, and upper 28 ft forms ledge-slope topography	55
4. Limestone, yellowish-gray (5Y 8/1) and white (N 9), finely crystalline to aphanitic. Contains 1–6-in.-thick beds and lenses of white (N 9) chert; lower 5 ft is 70–80 percent chert. Gnarly bedding; beds 2–5 ft thick. Weathers very rough and forms very steep ledge-slope topography or vertical cliff	40
3. Marl and chalklike limestone, white (N 9) and very light gray (N 8). Massive bedding. Forms slope	18

SECTION 6.—*SE¼ sec. 17, T. 14 N., R. 5 E*—Continued

	Thickness (feet)
Verde Formation—Continued	
Mudstone facies—Continued	
2. Limestone, argillaceous limestone, and marl, white (N 9), very light gray (N 8), and pinkish-gray (5YR 8/1). Limestone is crystalline to aphanitic; several beds are almost lithographic. Contains nodules, lenses, and irregular masses of white (N 9) chert. Gnarly bedding; beds 1–3 ft thick. Weathers rough and forms steep ledge-slope topography	90
Total mudstone facies	228
Lower limestone faces:	
1. Limestone, white (N 9), pinkish-gray (5YR 8/1), and very light gray (N 8), slightly argillaceous and arenaceous; weathers grayish orange (10YR 7/4) and very pale orange (10YR 8/2); some light-brown (5YR 5/6) surface stain; cavernous and contains vugs filled with calcite crystals. "Drapery" beds from 50 to 52 ft above base. Gnarly and massive bedding; beds 3–10 ft thick. Weathers blocky and knobby and forms vertical cliff. Base concealed	90
Total measured lower limestone facies	90
Total measured section	488

SECTION 7.—*SW¼ sec. 9, T. 14 N., R. 5 E., to NE¼ sec. 9, T. 14 N., R. 5 E.*

[Section started at Wet Beaver Creek about a mile northeast of Montezuma Castle; base of section at Wet Beaver Creek. Beds are nearly horizontal. Approximate alt at top of section 3,600 ft.]

	Thickness (feet)
Erosion surface.	
Verde Formation:	
Middle limestone facies;	
7. Limestone and mudstone, alternate beds, pinkish-gray (5YR 8/1), white (N 9), and grayish-orange-pink (5YR 7/2). Beds 1–3 ft thick. Forms ledge-slope topography	27
6. Limestone, white (N 9), aphanitic; some veins of crystalline calcite. Two massive beds each 10 ft thick. Weathers gnarly and forms small cliff	20
5. Limestone, white (N 9) and grayish-orange-pink (10R 8/2); weathers white (N 9), grayish orange (10YR 7/2), and very pale orange (10YR 8/2). Lower 10 ft dense; upper 40 ft argillaceous. Chert abundant in beds from 15 to 16, 29 to 31, and 39 to 42 ft above base. Gnarly bedding; beds 1–10 ft thick; masses of limestone extend downward as much as 3 ft into underlying unit. Weathers blocky and knobby and forms steep ledge-slope topography	50
Total measured middle limestone facies	97

SECTION 7.—*SW¼ sec. 9, T. 14 N., R. 5 E., to NE¼ sec. 9, T. 14 N., R. 5 E*—Con.

	Thickness (feet)
Verde Formation—Continued	
Mudstone facies:	
4. Mudstone and marl, light-brown (5YR 7/4), light-brown (5YR 5/6), and light-brown (5YR 6/4). Weathers smooth and forms slope	58
3. Limestone, white (N 9), aphanitic to crystalline; some grayish pink (5R 8/2); weathers white (N 9), very light gray (N 8), and grayish orange (10YR 7/4). Massive bedding; beds 1–2 ft thick. Weathers very rough and blocky and forms vertical cliff	50
2. Limestone and mudstone, alternate beds; limestone is white (N 9), pinkish gray (5YR 8/1), and very light gray (N 8) and weathers grayish orange (10YR 7/4) and very pale orange (10YR 8/2); mudstone is grayish orange pink (10R 8/2). Gnarly bedding; beds 1–5 ft thick. Forms steep ledge-slope topography. Locally this unit and underlying and overlying units form vertical cliff	93
Total mudstone facies	201
Lower limestone facies:	
1. Limestone, white (N 9), pinkish-gray (5YR 8/1), and very light gray (N 8), slightly argillaceous and arenaceous; weathers grayish orange (10YR 7/4) and very pale orange (10YR 8/2); some light-brown (5YR 5/6) surface stain; most beds cavernous. Beds 3 in. to 5 ft thick; some beds varvelike. Weathers rough and gnarly and forms vertical cliff. Base concealed	78
Total measured lower limestone facies	78
Total measured section	376

SECTION 8.—*SW¼ sec. 2, T. 14 N., R. 4 E., to SE¼ sec. 35, T. 15 N., R. 4 E.*

Section measured in Minter Wash; base of section near Verde River. Beds are nearly horizontal. Approximate alt at top of section 3,680 ft]

	Thickness (feet)
Erosion surface.	
Verde Formation:	
Middle limestone facies:	
7. Limestone, white (N 9) and pinkish-gray (5YR 8/1); weathers white (N 9) and very pale orange (10YR 8/2). Contains lenses and nodules of very light gray (N 8) chert which weather grayish orange (10YR 7/4) and very pale orange (10YR 8/2). Beds 2–4 ft thick. Forms steplike ledge-slope topography; forms vertical cliff in some places	75

SECTION 8.—*SW¼ sec. 2, T. 14 N., R. 4 E., to SE¼ sec. 35, T. 15 N., R. 4 E*—Con.

	Thickness (feet)
Verde Formation—Continued	
Middle limestone facies—Continued	
6. Limestone, white (N 9), arenaceous and argillaceous; some pinkish gray (5YR 8/1); weathers white (N 9), grayish orange (10YR 7/4), and pale yellowish orange (10YR 8/6). Several beds contain siliceous plant stems. Lower 25 ft contains beds, lenses, and nodules of glossy very light gray (N 8), dark-yellowish-brown (10YR 4/2), and very pale orange (10YR 8/2) chert. Very rough and gnarly bedding; beds 2–5 ft thick. Forms steep steplike ledge-slope topography	70
5. Limestone, white (N 9), arenaceous and argillaceous; some pinkish gray (5YR 8/1); weathers white (N 9), grayish orange (10YR 7/4), and pale yellowish orange (10YR 8/6); some beds contain siliceous plant stems. From 45 to 135 ft above base, beds contain lenses and nodules of very light gray (N 8) chert which weather grayish orange (10YR 7/4) and very pale orange (10YR 8/2). Very rough bedding; beds 2–3 ft thick. Forms a steplike ledge-slope topography; locally, lower 20 ft forms vertical cliff	135
4. Limestone, white (N 9) and yellowish-gray (5Y 8/1), arenaceous and argillaceous. Upper 5 ft contains many siliceous plant stems. Massive bedding; beds 6 in. to 3 ft thick. Weathers blocky and rounded and forms vertical cliff	25
Total measured middle limestone facies	305
Mudstone facies:	
3. Mudstone, siltstone, and sandstone, some limestone. Mudstone, siltstone, and sandstone are grayish yellow green (5GY 7/2), moderate greenish yellow (10Y 7/4), and light olive gray (5Y 7/1); some dark yellowish orange (10YR 6/6). Limestone is yellowish gray (5Y 8/1), yellowish gray (5Y 7/2), and very light gray (N 8). Sandstone is very fine grained; calcium carbonate cement. Varvelike bedding; beds ½–6 in. thick. Forms slope except for limestones which form small ledges. (About 1,000 ft southeast of measured section, upper 50–75 ft forms vertical cliff.) Base concealed	175
2. Concealed	17
Total mudstone facies	192
Lower limestone facies:	
1. Limestone, white (N 9), arenaceous and argillaceous; weathers white (N 9) and grayish orange (10YR 7/4). Some beds have a cone-in-cone type structure; 1-ft-thick bed of marl 5 ft above base contains white (N 9) silicified plant stems in which plant structure is very well preserved. Gnarly and massive bedding. Weathers knobby and forms prominent ledge. Base concealed	12
Total measured lower limestone facies	12
Total measured section	509

SECTION 9.—*SW¼ sec. 27, T. 15 N., R. 6 E.*

[Section measured on north side of Sacred Mountain. Beds are nearly horizontal. Approximate alt at top of butte 4,130 ft]

	Thickness (feet)
Erosion surface.	
Verde Formation:	
Middle limestone facies(?):	
6. Limestone, white (N 9) and very light gray (N 8); beds are separated by 2–6-in.-thick layers of yellowish-gray (5Y 8/1) and pale-greenish-yellow (10Y 8/2) siltstone; some beds contain abundance of "plant hash." Very gnarly bedding; beds 1–5 ft thick. Weathers rough and blocky and forms vertical cliff or steep ledge-slope topography	40
5. Marl, siltstone, and mudstone, yellowish-gray (5Y 8/1) and pale-greenish-yellow (10Y 8/2); calcium carbonate cement. Lenses of "bone hash" near middle of unit. Massive bedding. Weathers smooth and rounded and forms recess	5
4. Limestone, white (N 9), and several beds of yellow-gray (5Y 7/2) siltstone and mudstone. About 6 ft from top of unit on northeast side of butte is a 6-in.- to 1½-ft-thick gravel and mudstone bed which contains vertebrate material; some beds contain gastropods. Very gnarly bedding; beds 1–3 ft thick. Weathers gnarly and forms steep cliff	12
3. Conglomerate; matrix is pale-greenish-yellow (10Y 8/2) mudstone. Pebbles average about one-half inch in diameter, have a maximum diameter of about 4 in., and are chiefly basalt. Weathers smooth and rounded and forms recess	1
2. Limestone, very light gray (N 8) and white (N 9); weathers white (N 9) to yellowish gray (5Y 8/1); some 1–3-in.-thick lenses of grayish-yellow-green (5GY 7/2) mudstone. Beds 6 in. to 3 ft thick. Weathers gnarly and forms steep ledge-slope topography	18
1. Limestone, very pale orange (10YR 8/2) and yellowish-gray (5Y 8/1); weathers white (N 9) and yellowish gray (5Y 8/1); contains abundance of "plant hash." A 1-ft-thick light-brown (5YR 6/4) and grayish-orange (10YR 7/4) mudstone forms recess at top. Weathers rounded and smooth and forms small ledge. Basal bed is concealed at measured section, but about 150 ft to east it is moderate-reddish-brown (10R 4/6) mudstone which rests unconformably on Supai Formation	4
Total measured middle limestone facies(?)	80

SECTION 10.—*SW¼ sec. 14, T. 15 N., R. 5 E.*

[Section measured about 4 miles northeast of McGuireville on east side of small hill at Adobe House Bend; base of section near Dry Beaver Creek. Beds are nearly horizontal. Approximate alt at top of section 3,740 ft]

	Thickness (feet)
Erosion surface.	
Verde Formation:	
Middle limestone facies:	
3. Limestone and marl, some sandstone, siltstone, and conglomerate; limestone is pinkish gray (5YR 8/1), white (N 9), and very pale orange (10YR 8/2) and weathers white (N 9), very light gray (N 8), and pinkish gray (5YR 8/1); marl, sandstone, siltstone, and conglomerate are grayish orange (10YR 7/4), grayish orange pink (5YR 7/2), and light brown (5YR 6/4). Weathers irregular and forms steplike ledge-slope topography	78
Total measured middle limestone facies	78
Mudstone facies:	
2. Basalt, grayish-black (N 2), olive-black (5Y 2/1), and black (N 1); weathers brownish gray (5YR 4/1), medium dark gray (N 4), and moderate brown (5YR 4/4); joints and amygdules filled with calcite. Upper 43 ft forms slope; lower 12 ft forms ledge	55
1. Conglomerate; matrix grayish orange (10YR 7/4) and very pale orange (10YR 8/2), some moderate greenish yellow (10YR 7/4). Calcium carbonate cement. Nearly all pebbles are basalt and have average diameter of one-half inch. Massive bedding. Forms slope. Unit rests unconformably on Tertiary basalt	35
Total mudstone facies	90
Total measured section	168

SECTION 11.—*SE¼ sec. 10, T. 15 N., R. 4 E., to SW¼ sec. 11, T. 15 N., R. 4 E.*

[Section measured on east side of Oak Creek about a mile southeast of Cornville; base of section at Oak Creek. Beds are nearly horizontal. Approximate alt at top of section 3,500 ft]

	Thickness (feet)
Erosion surface.	
Verde Formation:	
Middle limestone facies:	
16. Sandstone and siltstone, some mudstone, alternate beds, moderate-orange-pink (5YR 8/4), pinkish-gray (5YR 8/1), grayish-orange-pink (5YR 7/2), and light-brown (5YR 5/6); weathers light brown (5YR 6/4) and light brown (5YR 5/6). Sandstone is very fine grained to fine grained; mostly quartz. Some beds are well cemented with calcium carbonate; other beds contain little cement and are friable. Gnarly bedding. Weathers smooth and rounded and forms steep slope	40
15. Limestone, grayish-orange-pink (10R 8/2) and white (N 9), argillaceous and dense. Gnarly bedding. Weathers gnarly and knobby and forms prominent ledge	3

SECTION 11.—*SE¼ sec. 10, T. 15 N., R. 4 E., to SW¼ sec. 11, T. 15 N., R. 4 E*—Continued

	Thickness (feet)
Verde Formation—Continued	
Middle limestone facies—Continued	
14. Sandstone and siltstone, some mudstone, pinkish-gray (5YR 8/1), grayish-orange-pink (5YR 7/2), and light-brown (5YR 5/6); weathers light brown (5YR 6/4) and light brown (5YR 5/6). Sandstone is very fine grained to fine grained; mostly quartz. About 25 percent of unit is composed of beds and lenses of friable sandstone; except for friable sandstone, material is well cemented with calcium carbonate. Gnarly bedding. Weathers blocky and irregular and forms steep slope	15
13. Limestone, grayish-orange-pink (10R 8/2), slightly argillaceous; weathers very light gray (N 8). Gnarly bedding. Weathers blocky and knobby and forms prominent ledge	2
12. Sandstone and siltstone, some mudstone; similar to unit 14	30
11. Sandstone, moderate-orange-pink (5YR 8/4) and light-brown (5YR 5/6), very fine grained to fine-grained, friable; mostly quartz. Weathers smooth and rounded and forms slope	7
10. Sandstone and siltstone, some mudstone, pinkish-gray (5YR 8/1), grayish-orange-pink (5YR 7/2), and light-brown (5YR 5/6); weathers light brown (5YR 6/4) and light brown (5YR 5/6). Sandstone is very fine grained to fine grained; mostly quartz. Conglomerate lens 15 ft above base is composed of pebbles of basalt and chert of Kaibab. Well cemented with calcium carbonate. Gnarly bedding. Weathers gnarly and forms steep slope	35
9. Conglomerate; matrix is grayish-orange-pink (10R 8/2) and light-brown (5YR 6/4) fine- to coarse-grained sandstone. Pebbles have average diameter of about one-half inch and are mostly basalt. Calcium carbonate cement. Weathers pitted and knobby and forms slight recess	1
8. Sandstone and siltstone, similar to unit 10	9
7. Limestone, pinkish-gray (5YR 8/1), slightly arenaceous and argillaceous. Weathers blocky and forms recess	1
6. Sandstone, similar to unit 11	5
5. Limestone, pinkish-gray (5YR 8/1) and white (N 9), argillaceous. Contains many (30–40 percent) tubelike structures that are one-sixteenth inch in diameter and are lined with calcite. Weathers blocky and forms prominent ledge	1
4. Sandstone and siltstone, pinkish-gray (5YR 8/1), grayish-orange-pink (5YR 7/2), and light-brown (5YR 5/6); weathers light brown (5YR 6/4) and light brown (5YR 5/6). Sandstone is very fine grained to fine grained; mostly quartz. Well consolidated and well cemented with calcium carbonate. Gnarly bedding. Weathers gnarly and blocky and forms steep slope	4
Total measured middle limestone facies	153

SECTION 11.—*SE¼ sec. 10, T. 15 N., R. 4 E., to SW¼ sec. 11, T. 15 N., R. 4 E*—Continued

	Thickness (feet)
Verde Formation—Continued	
Mudstone facies:	
3. Conglomerate; matrix is grayish-orange-pink (10R 8/2) and light-brown (5YR 6/4) fine- to coarse-grained sandstone. Pebbles have average diameter of about one-half inch, and most (85–95 percent) are basalt. Calcium carbonate cement. Some lenses of very fine grained to fine-grained sandstone. Gnarly bedding. Weathers pitted and knobby and forms recess	7
2. Sandstone and siltstone, some mudstone, similar to unit 14. Base concealed	45
1. Mostly concealed. A few scattered outcrops indicate that this unit is similar to overlying unit. Base concealed	45
Total measured mudstone facies	97
Total measured section	250

SECTION 12.—*NE¼ sec. 4, T. 15 N., R. 5 E., to NE¼ sec. 29, T. 16 N., R. 5 E.*

[Section measured on south flank of House Mountain about 5 miles east of Cornville. Approximate alt at top of section, 4,660 ft]

	Thickness (feet)
Erosion surface.	
Verde Formation:	
Upper limestone facies:	
32. Limestone, sandstone, and siltstone, some mudstone, alternate beds. Limestone is white (N 9) and very light gray (N 8); some yellowish gray (5Y 7/2). Sandstone, siltstone, and mudstone are light greenish gray (5GY 6/1) and grayish orange (10YR 7/4). Calcium carbonate cement. Sandstone is very fine grained to fine grained. Upper 25 ft contains molds of gastropods and pelecypods; "plant hash" and plant stems are abundant. Beds 1–3 ft thick. Forms very steep slope	85
31. Sandstone, light-brown (5YR 6/4) and moderate-orange-pink (5YR 8/4), very fine grained to fine-grained; mostly quartz; calcium carbonate cement. Several 4–6-in.-thick beds of white (N 9) argillaceous limestone. Weathers smooth and rounded and forms irregular slope	25
30. Limestone, white (N 9); some very fine grained to fine-grained sandstone. Weathers rough and pitted and forms small ledge	15
29. Sandstone, similar to unit 31	40
28. Limestone, grayish-orange-pink (10R 8/2), argillaceous and arenaceous; weathers pinkish gray (5YR 8/1) and very light gray (N 8). Weathers blocky and forms small ledge	5
27. Sandstone, light-brown (5YR 6/4) and light-brown (5YR 5/6); some pale-yellowish-brown (10YR 6/2) siltstone; very fine grained to fine-grained; mostly quartz; calcium carbonate cement. Some 3–6-in.-thick beds of very light gray (N 8) limestone. Beds 1–3 in. thick. Weathers smooth and forms slope	17

Units 27–32 were measured about 1½ miles northwest of units 1–26. Because unit 26 forms broad bench, it can be traced laterally without difficulty.

SECTION 12.—*NE¼ sec. 4, T. 15 N., R. 5 E., to NE¼ sec. 29, T. 16 N., R. 5 E*—Continued

	Thickness (feet)
Verde Formation—Continued	
Upper limestone facies—Continued	
26. Limestone, white (N 9), very light gray (N 8), and grayish-orange-pink (10R 8/2); some 1–6-in.-thick beds of mudstone. Lower 3 ft is pale-greenish-yellow (10Y 8/2) shale that contains numerous silicified plant stems; from 3 to 6 ft above base is white (N 9) fossiliferous limestone that contains nodules of yellowish-gray (5Y 8/1) and light-greenish-gray (5GY 8/1) chert. (About 3,000 ft north of this section, lower 15 ft of this unit contains abundant gastropods, pelecypods, ostracodes, bones of vertebrates, and other fossils.) Beds 3 in. to 1½ ft thick. Lower 15–25 ft commonly forms vertical cliff; upper 135–145 ft commonly forms steep steplike ledge-slope topography; top of unit forms broad bench	160
Total measured upper limestone facies	347
Sandstone facies(?):	
25. Sandstone and siltstone, some mudstone, moderate-orange-pink (5YR 8/4) and light-brown (5YR 6/4). Sandstone is very fine grained to medium grained; mostly quartz; calcium carbonate cement. Entire unit contains calcite-filled tubelike structures that are 1/16–1/8 in. in diameter. Weathers rounded and smooth and forms slope with a few small ledges	73
24. Limestone, white (N 9) and very light gray (N 8). Molds of gastropods very abundant in lower 4 ft; some beds almost coquina. Weathers blocky and forms small ledge	8
23. Mostly covered; few exposures indicate a grayish-orange (10YR 7/4) very fine grained sandstone. Forms slope. Base concealed	8
22. Limestone, white (N 9). At 4½ ft above base is gnarly 6-in.-thick zone of white (N 9) chert containing plant material. Gnarly bedding	8
21. Sandstone, grayish-orange (10YR 7/4) and very pale orange (10YR 8/2), very fine grained; mostly quartz; weathers grayish orange (10YR 7/4); calcium carbonate cement. Weathers rounded and blocky and forms irregular slope	13
20. Limestone, white (N 9) and yellowish-gray (5Y 8/1), argillaceous. Very gnarly bedding; beds 6 in. to 1 ft thick. Weathers rough and forms steplike ledge-slope topography	40
19. Mudstone, very pale orange (10YR 8/2); some 2–5-in.-thick beds of argillaceous limestone. Calcium carbonate cement. Gnarly bedding. Weathers rounded and knobby and forms irregular slope	6
18. Limestone, white (N 8), argillaceous. Beds are 1 in. to 3 ft thick. Weathers smooth and rounded and forms small ledge	5
17. Mudstone, very pale orange (10YR 8/2); calcium carbonate cement. Contains boxwork structure of calcite veins enclosing particles of clay. Gnarly bedding. Weathers knobby and forms irregular slope	7

SECTION 12.—*NE¼ sec. 4, T. 15 N., R. 5 E., to NE¼ sec. 29, T. 16 N., R. 5 E*—Continued

	Thickness (feet)
Verde Formation—Continued	
Sandstone facies(?)—Continued	
16. Limestone, white (N 9), finely crystalline. Some tubelike structures that are one-sixteenth inch in diameter. Massive bedding. Weathers pitted and forms prominent ledge	4
15. Sandstone and siltstone, light-brown (5YR 7/4). Sandstone is mostly fine-grained quartz; calcium carbonate cement. Some beds crossbedded. Weathers smooth and forms slope	14
14. Limestone, grayish-pink (5R 8/2), arenaceous; weathers white (N 9) and grayish pink (5R 8/2). Forms irregular slope with several small ledges	9
13. Siltstone, limy, and arenaceous light-brown (5YR 6/4) limestone; weathers light brown (5YR 6/4) and moderate orange pink (5YR 8/4). Gnarly bedding. Weathers smooth and rounded and forms slope	25
12. Limestone, white (N 9), aphanitic, almost lithographic. Some veins of crystalline calcite. Weathers rough and pitted and forms small ledge	5
11. Siltstone, limy, and arenaceous limestone; similar to unit 13	16
10. Limestone, pinkish-gray (5YR 8/1), argillaceous. Gnarly bedding. Weathers pitted and rough and forms slope	12
9. Limestone, white (N 9) and pinkish-gray (5YR 8/1), finely crystalline, almost lithographic; weathers white (N 9); has many ¼–½-in.-diameter solution channels. Weathers blocky with pitted surface and forms small ledge	2
8. Siltstone, light-brown (5YR 6/4); some argillaceous beds; all beds have calcium carbonate cement. Weathers rounded and forms slope	8
7. Limestone, white (N 9) and grayish-orange-pink (10R 8/2), arenaceous; weathers white (N 9) and very light gray (N 8). Weathers knobby and forms very small ledge	3
6. Mostly covered; a few exposures indicate that unit is composed of light-brown (5YR 6/4) mudstone and argillaceous siltstone. Forms slope. (Unit pinches out several hundred feet to north.) Base concealed	5
5. Limestone, similar to unit 7	2
4. Sandstone, light-brown (5YR 5/6) and moderate-reddish-brown (10R 5/6), very fine grained to fine-grained, very friable; mostly quartz; calcium carbonate cement. Very gnarly bedding. Weathers rounded and forms slope	38
3. Limestone, mottled white (N 9) and light-brown (5YR 6/4), arenaceous; weathers light brown (5YR 6/4). Unit lenticular and ranges in thickness from less than 1 in. to 1½ ft	1
2. Sandstone, moderate-orange-pink (5YR 8/4) and light-brown (5YR 5/6), fine- to medium-grained, friable, highly calcareous; mostly quartz; some very pale orange (10YR 8/2) stain. Contains lenses and irregular masses of calcareous sandstone which form protruding knobs and slight ledges. Forms slope	5

SECTION 12.—*NE¼ sec. 4, T. 15 N., R. 5 E., to NE¼ sec. 29, T. 16 N., R. 5 E*—Continued

	Thickness (feet)
Verde Formation—Continued	
Sandstone facies(?)—Continued	
1. Sandstone, moderate-orange-pink (5RY 8/4); some 2–4-in.-thick beds of moderate-brown (5YR 3/4) and light-brown (5YR 5/6) mudstone. Sandstone is fine to medium grained, mostly quartz; calcium carbonate cement. Very gnarly and lenticular bedding; beds 1–8 in. thick. Weathers gnarly and pitted and forms irregular slope. Base concealed. (About 300–400 ft north of this section, basalt is exposed at this altitude)	5
Total measured sandstone facies(?)	322
Total measured section	669

SECTION 13.—*NW¼ sec. 13, T. 16 N., R. 4E.*

[Section measured about a mile southeast of Hidden Valley Ranch. Beds are nearly horizontal. Approximate alt at top of section 4, 370 ft. The relationship of this section to the underlying Tertiary volcanic rocks is shown in figure 15]

	Thickness (feet)
Erosion surface.	
Verde Formation:	
Upper limestone facies:	
7. Limestone, grayish-orange (10YR 7/4), finely crystalline; some white (N 9). Lower 10 ft contains many hollow tubelike structures that are ¼–¾ in. in diameter and gastropods. Beds in lower 15 ft are about 5 ft thick; beds in upper 25 ft are 6 in. to 1 ft thick. Weathers pitted and blocky; lower 15 ft forms vertical cliff; upper 25 ft forms slope	40
6. Siltstone and sandstone, very pale orange (10YR 8/2). Sandstone is very fine grained; mostly quartz. Many molds of gastropods and ostracodes. Weathers rounded and smooth and forms recess or slope	5
5. Limestone, grayish-orange (10YR 7/4) and light-brownish-gray (5YR 6/1); weathers grayish orange (10YR 7/4) and dark yellowish orange (10YR 6/6). Contains stalactites and stalagmites. "Plant hash" abundant; some hollow plant stems are 1 ft in diameter and 8 ft long. Weathers rough, blocky, and knobby and forms vertical cliff	35
4. Limestone, very pale orange (10YR 8/2) and grayish-orange (10YR 7/4). At 14 ft above base is a 4-ft-thick yellowish-gray (5Y 7/2) sandstone bed. Partly covered between 25 and 50 ft above base; scattered exposures indicate alternate beds of limestone and sandstone. Plant stems abundant in some beds. Beds 1–3 ft thick. Weathers blocky and forms steep slope except for lower 5 ft which forms vertical cliff	63
Total measured upper limestone facies	143

SECTION 13.—*NW¼ sec. 13, T. 16 N., R. 4 E*—Continued

	Thickness (feet)
Verde Formation—Continued	
Sandstone facies(?):	
3. Sandstone, limy, and arenaceous limestone, limestone, and conglomerate; limy sandstone and arenaceous limestone are pinkish gray (5YR 8/1) and weather pale pink (5RP 8/2); limestone is pale yellowish brown (10YR 6/2). Lower 30 ft of unit partly covered; upper 15 ft massive conglomerate; pebbles 1/16–1 in. in diameter and mostly basalt and limestone. Some beds contain ostracodes. Forms steep slope	45
2. Limestone, very pale orange (10YR 8/2) and grayish-orange (10YR 7/4). Beds 1–3 ft thick. Weathers rough and blocky and forms vertical cliff	19
1. Conglomerate; matrix is light-brown (5YR 6/4) and moderate-orange-pink (5YR 8/4) fine-grained sandstone; weathers pinkish gray (5YR 8/1) and light brown (5YR 6/4). Massive bedding. Weathers rounded and knobby and forms steep slope. Unit rests unconformably on Tertiary volcanic rocks	25
Total sandstone facies(?)	89
Total measured section	232

SECTION 14.—NW¼ sec. 17, T. 16 N., R. 5 E.

[Section measured on north side of House Mountain. Beds are nearly horizontal. Approximate alt at top of section 4,450 ft]

	Thickness (feet)
Erosion surface.	
Verde Formation:	
Upper limestone facies:	
6. Limestone, white (N 9), finely crystalline; weathers white (N 9) and very light gray (N 8). Many gastropod molds in lower 2 ft. Beds 1–2 ft thick. Forms vertical or very steep cliff	26
5. Limestone, white (N 9) and very pale orange (10YR 8/2); weathers white (N 9) and very light gray (N 8). Very rough bedding; beds about 1 ft thick. Weathers very rough and knobby and forms steep slope	17
4. Shale and claystone, light-brown (5YR 5/6) and dark-yellowish-orange (10YR 6/6), silty; some greenish-gray (5GY 6/1). Forms recess	1
3. Limestone, white (N 9) and grayish-orange-pink (10R 8/2). Some 1/10-in. diameter tubelike structures, especially between 3 and 5 ft above base. Beds 6 in. to 1½ ft thick, forms steep cliff	10
2. Siltstone, argillaceous, or mudstone; lower 14 ft dark yellowish orange (10YR 6/6) and light brown (5 YR 5/6); upper 2 ft pale reddish brown (10R5/4). Calcium carbonate cement. Beds 1–6 in. thick. Forms slope	16

SECTION 14.—*NW¼ sec. 17, T. 16 N., R. 5 E*—Continued

	Thickness (feet)
Verde Formation—Continued	
Upper limestone facies—Continued	
1. Conglomerate; matrix dark yellowish orange (10YR 6/6. Some very fine grained sandstone; mostly quartz and basalt. Pebbles have average diameter of about 2 in. and are chiefly basalt and sandstone of Supai. Forms slope. Unit rests unconformably on Supai Formation	2
Total measured upper limestone facies	72

SECTION 15.—*NE¼ sec. 9, T. 16 N., R. 3 E., to NW¼ sec. 36, T. 17 N., R. 3 E.*

[Section started about 2 miles northeast of Clarkdale; base of section is near Verde River. Beds are nearly horizontal. Approximate alt at top of section 4,220 ft. Section is described in terms of general units only because complete and detailed section would require definition and description of beds 1-6 inches thick. Nearly all beds above unit 11 contain fossils; many beds are very fossiliferous. Fossils occur as original shell structure, internal and external molds, casts, vertebrate material, carbonaceous plant debris, and "plant hash" and plant stems. Fossils include plant seeds(?), Charophyta oogonia, ostracodes gastropods, pelecypods, vertebrate teeth and bones, and various types of plants. All "plant hash" and hollow plant stems in limestones are replaced with calcium carbonate. Many uranium prospect pits occur in this area, and fossils were found in most pits]

	Thickness (feet)
Erosion surface.	
Verde Formation:	
Upper limestone facies:	
59. Limestone, marl, sandstone, siltstone, and shale, alternate beds. Limestone is yellowish gray (5Y 7/2), light olive gray (5Y 6/1), pale yellowish brown (10YR 6/2), very light gray (N 8), and white (N 9); weathers white (N–9), very light gray (N 8), very pale orange (10YR 8/2), grayish orange (10YR 7/4), and pale yellowish brown (10 YR6/2). Marl, fine grained sandstone, siltstone, and shale are very pale orange (10YR 8/2), pale greenish yellow (10Y 8/2), white (N 9), very light gray (N 8), and moderate greenish yellow (10Y 7/4); weather very pale orange (10YR 8/2), pale greenish yellow (10Y 8/2), and white (N 9). All beds very fossiliferous, containing "plant hash" and shells or molds of gastropods, pelecypods, and ostracodes; many limestone beds composed almost entirely of "plant hash"; in some beds, plant stems replaced with calcium carbonate form hollow tubes 1/16–1/4 inch in diameter and occur is such great abundance that beds have spongelike appearance. Very rough bedding; beds 3 in. to 2 ft thick. Limestone weathers blocky and forms small ledges; marl, sandstone, siltstone, and shale form rubble-covered slopes or small recesses. Base concealed	55+
58. Marl and argillaceous limestone, moderate-orange-pink (10R 7/4) and grayish-orange-pink (10R 8/2); weathers grayish orange pink (10R 8/2). Many calcite tubes that are 1/16–1/10 in. in diameter. Weathers blocky and pitted, has spongy appearance, and forms steep slope	14

SECTION 15.—*NE¼ sec. 9, T. 16 N., R. 3 E., to NW¼ sec. 36, T. 17 N., R. 3 E*—Con.

	Thickness (feet)
Verde Formation—Continued	
Upper limestone facies—Continued	
57. Mudstone and marl, some irregular lenses and beds of highly calcareous sandstone; mudstone is light brown (5YR 6/4); marl is pale pink (5RP 8/2); sandstone is moderate orange pink (10R 7/4). Marl contains very fine "floating" quartz grains and manganese dendrites. Weathers knobby and forms slope	13
56. Limestone, very pale orange (10YR 8/2) and pale-yellowish-brown (10YR 6/2); weathers very pale orange (10YR 8/2), grayish-orange (10YR 7/4), white (N 9), and pale-yellowish-brown (10YR 6/2). Contains tubelike structures and "plant hash"; tubes $\frac{1}{10}$–½ in. in diameter. Beds 2 in. to 1 ft thick. Weathers blocky and pitted and forms prominent ledge	17
55. Limestone, white (N 9); contains manganese dendrites and many solution channels. Weathers knobby and forms slope	5
54. Limestone, arenaceous, and limy sandstone; partly covered; mainly grayish orange pink (5YR 7/2) and grayish orange (10YR 7/4), but some light brown (5YR 5/6); weathers grayish orange pink (5YR 7/2) and grayish orange (10YR 7/4). Contains tubelike plant structures that are one-tenth inch in diemeter and are filled with manganese; calcium carbonate cement. Forms a slope. Base concealed	26
53. Limestone, white (N 9), very light gray (N 8), and grayish-orange-pink (10R 8/2), aphanitic. At 3 ft above base is 2-ft-thick bed of argillaceous limestone that contains prismatic structures; prisms are 1–3 in. wide and 6–8 in. long. Beds 6 in. to 1 ft thick. Weathers pitted and knobby and forms small ledge	13
52. Mudstone and marl; mudstone is light brown (5YR 6/4); marl is pale pink (5RP 8/2). Contains lenses of moderate-orange-pink (10R 7/4) arenaceous limestone. Many beds contain manganese dendrites. Forms slope	27
51. Limestone, pinkish-gray (5YR 8/1) and grayish-orange-pink (10R 8/2), aphanitic; some white (N 9); weathers pale pink (5RP 8/2); has many $\frac{1}{16}$-in.-diameter tubelike structures filled with calcite. Gnarly bedding; beds 1 in. to 1 ft thick. Weathers knobby and forms gentle slope	24
50. Limestone, white (N 9) and yellowish-gray (5Y 8/1), aphanitic to sublithographic; weathers white (N 9) and very light gray (N 8). Manganese dendrites in most beds. Beds 1–6 in. thick. Weathers very rough and knobby and forms slope	18
49. Shale, light-olive-gray (5Y 5/2). Forms recess	1

SECTION 15.—*NE¼ sec. 9, T. 16 N., R. 3 E., to NW¼ sec. 36, T. 17 N., R. 3 E*—Con.

	Thickness (feet)
Verde formation—Continued	
Upper limestone facies—Continued	
48. Limestone, very pale orange (10YR 8/2) and pale-yellowish-brown (10YR 6/2), finely crystalline; weathers very pale orange (10YR 8/2), grayish orange (10YR 7/4), and very light gray (N 8). Plant stems and "plant hash" abundant. Beds 1–2 ft thick. Weathers blocky and pitted and forms prominent ledge	12
Total measured upper limestone facies	225+
Sandstone facies:	
47. Sandstone, moderate-orange-pink (5YR 8/4), light-brown (5YR 5/6), and moderate-reddish-brown (10R 4/6); weathers moderate orange pink (5YR 8/4) and light brown (5YR 5/6); lower 15 ft contains 1–5-in.-thick beds of white (N 9) limestone. Sandstone is very fine grained to fine grained and is mostly quartz; calcium carbonate cement. Gnarly bedding. Weathers pitted and knobby and forms slope. Base concealed	27
46. Mostly concealed; made up of 6–8-in.-thick beds of yellowish-gray (5Y 7/2) limestone that weathers yellowish gray (5Y 7/2) and white (N 9). Forms small ledge	5
45. Limestone, marl, sandstone, siltstone, and carbonaceous material; limestone and marl are arenaceous, white (N 9), very light gray (N 8), and very pale orange (10YR 8/2) and weather white (N 9) and very pale orange (10YR 8/2); sandstone and siltstone are calcareous, grayish orange pink (10R 8/2) and grayish orange (10YR 7/4) and weather grayish orange pink (10R 8/2) and very pale orange (10YR 8/2); carbonaceous material is medium light gray (N 6) and black (N 1). Sandstone is very fine grained to fine grained and is mostly quartz. Plant stems and other fossils very abundant in some beds. Beds 1–6 in. thick. Weathers knobby and forms slope	17
44. Limestone, aphanitic to lithographic, and marl; yellowish gray (5Y 7/2) and white (N 9); weathers white (N 9), very light gray (N 8), and grayish orange (10YR 7/4). Contains "plant hash" and gastropods. Beds in lower 10 ft are 6 in. thick and form steep slope; beds in upper 3 ft are massive and form prominent ledge	13
43. Shale and limestone; shale is pale olive (10Y 6/2) and greenish gray (5GY 6/1) and weathers pale olive (10Y 6/2) and yellowish gray (5Y 8/1); limestone is white (N 9) and yellowish gray (5Y 8/1). Gastropod and pelecypod shells very abundant. Forms slope	8

SECTION 15.—*NE¼ sec. 9, T. 16 N., R. 3 E., to NW¼ sec. 36, T. 17 N., R. 3 E*—Con.

	Thickness (feet)
Verde Formation—Continued	
Sandstone facies—Continued	
42. Limestone, marl, mudstone, and shale, some sandstone, and several beds of peatlike material; limestone is white (N 9), grayish orange (10YR 7/4), and yellowish gray (5Y 8/1); marl is very light gray (N 8) and weathers white (N 9); mudstone and shale are pale olive (10Y 6/2) and greenish gray (5GY 6/1) and weather pale olive (10Y 6/2); sandstone is dark yellowish orange (10YR 6/6) and weathers grayish orange (10YR 7/4); peatlike material is very pale orange (10YR 8/2). Most beds very fossiliferous. Forms slope	12
Units 42–59 were measured in wash just south of ridge where units 23–41 were measured.	
41. Sandstone, moderate-orange-pink (5YR 8/4) and light-brown (5YR 6/4); weathers moderate orange pink (5YR 8/4). Very fine grained to fine grained; mostly quartz; calcium carbonate cement. Weathers rounded and forms slope	5
40. Limestone, white (N 9), dense. Weathers knobby and forms small ledge	4
39. Sandstone, light-brown (5YR 5/6) and moderate-reddish-brown (10R 4/6), very fine grained to fine-grained, very friable; mostly quartz. Forms slope	3
38. Limestone, pale-yellowish-brown (10YR 6/2) and very pale orange (10YR 8/2); weathers very pale orange (10YR 8/2) and grayish orange (10YR 7/4). Contains "plant hash." Weathers blocky and pitted and forms small ledge	1
37. Sandstone, moderate-orange-pink (5YR 8/4) and light-brown (5YR 6/4), very fine grained to fine-grained; mostly quartz; calcium carbonate cement. Contains tubelike structures that are one-sixteenth inch in diameter and are filled with calcite. Weathers rounded and forms slope	9
36. Limestone, arenaceous, and limy sandstone; very pale orange (10YR 8/2); weathers white (N 9) and very pale orange (10YR 8/2). Sand is fine grained and is mostly quartz. Contains charophyta oogonia	1
35. Sandstone, moderate-orange-pink (5YR 8/4) and light-brown (5YR 6/4), very fine grained to fine-grained; mostly quartz; weathers moderate orange pink (5YR 8/4); calcium carbonate cement. Forms slope	10
34. Limestone, white (N 9); some yellowish-gray (5Y 8/1); weathers white (N 9); some greenish-gray (5GY 6/1) shale. Some beds contain "plant hash." Beds 4–8 in. thick. Weathers blocky; lower 5 ft forms small ledge; upper 4 ft forms prominent ledge	9
33. Sandstone, light-brown (5YR 5/6) and moderate-reddish-brown (10R 4/6), very fine grained to fine-grained, very friable; weathers light brown (5YR 5/6); mostly quartz. Forms slope	1

SECTION 15.—*NE¼ sec. 9, T. 16 N., R. 3 E., to NW¼ sec. 36, T. 17 N., R. 3 E*—Con.

	Thickness (feet)
Verde Formation—Continued	
Sandstone facies—Continued	
32. Limestone and shale; limestone is yellowish gray (5Y 8/1) and white (N 9) and weathers white (N 9); shale is yellowish gray (5Y 8/1) and greenish gray (5GY 6/1) and weathers yellowish gray (5Y 8/1). Weathers blocky	5
31. Sandstone, moderate-orange-pink (5YR 8/4) and light-brown (5YR 6/4), very fine grained to fine-grained; mostly quartz; weathers moderate orange pink (5YR 8/4); calcium carbonate cement. Weathers pitted and forms slope	3
30. Limestone and shale; limestone is yellowish gray (5Y 8/1) and white (N 9) and weathers white (N 9); shale is yellowish gray (5Y 8/1) and greenish gray (5GY 6/1); has hydrogen sulfide odor. Weathers blocky and knobby and forms slope	5
29. Sandstone, moderate-orange-pink (5YR 8/4) and light-brown (5YR 6/4), very fine grained to fine-grained; mostly quartz; calcium carbonate cement. At 13 ft above base is a 1½-ft-thick bed of white (N 9) limestone containing "plant hash." Weathers rounded	30
28. Limestone, very pale orange (10YR 8/2) and pale-yellowish-brown (10YR 6/2); weathers grayish orange (10YR 7/4) and white (N 9); contains "plant hash." Weathers rough and blocky and forms small ledge	2
27. Limestone and shale, partly covered; limestone is very pale orange (10YR 8/2) and pale yellowish orange (10YR 8/6) and weathers white (N 9); shale is greenish gray (5GY 6/1). At 3½ ft above base are many gastropod molds. Beds are 3 in. to 1 ft thick. Weathers irregular to blocky and forms slope	12
26. Limestone, grayish-orange (10YR 7/4); weathers dark yellowish orange (10YR 6/6) and very light gray (N 8); contains "plant hash" and manganese-filled tubelike structures that are one-sixteenth inch in diameter. Weathers rough and blocky and forms ledge	1
25. Limestone, sandstone, and siltstone, partly concealed. Limestone is white (N 9) light gray (N 7), very pale orange (10YR 8/2), and pale yellowish orange (10YR 8/6) and weathers white (N 9) and yellowish gray (5Y 8/1). Sandstone and siltstone are moderate reddish orange (10R 6/6) and moderate reddish brown (10R 4/6), some grayish orange pink (10R 8/2), and weather moderate reddish brown (10R 4/6) and grayish orange pink (10R 8/2). Limestone is 6 in. to 1 ft thick, lenticular, and contains 1/2–3-in-thick layers of pale-olive (10Y 6/2) shale. Sandstone is very fine grained to fine grained. Forms steep slope	43
Total measured sandstone facies	226

SECTION 15.—*NE¼ sec. 9, T. 16 N., R. 3 E., to NW¼ sec. 36, T. 17 N., R. 3 E*—Con.

	Thickness (feet)
Verde Formation—Continued	
Sandstone facies(?):	
24. Limestone, very pale orange (10YR 8/2) and pale-yellowish-brown (10YR 6/2); weathers grayish orange (10YR 7/4) and white (N 9); "plant hash" and plant stems abundant. Weathers blocky and pitted and forms prominent ledge	2
23. Limestone and sandstone, partly covered. Limestone is white (N 9), very pale orange (10YR 8/2), and pale yellowish orange (10YR 8/6); weathers white (N 9), yellowish gray (5Y 8/1), and grayish orange (10YR 7/4); and contains 1–2-in.-thick beds of olive-gray (5Y 4/1) and yellowish-gray (5Y 8/1) shale. Sandstone is moderate reddish orange (10R 6/6) and moderate reddish brown (10R 4/6); weathers moderate reddish brown (10R 4/6) and grayish orange pink (10R 8/2); and is fine-grained. Forms steep slope. Base concealed	27
Because of poor exposures, units 23–41 are a composite of beds measured at several localities on same ridge; this was accomplished by tracing distinctive beds laterally, then measuring up or down.	
22. Limestone, very pale orange (10YR 8/2) and pale-yellowish-brown (10YR 6/2); weathers very pale orange (10YR 8/2), grayish orange (10YR 7/4), and white (N 9). Contains a 2-in.-thick bed of carbonaceous material; "plant hash" and excellently preserved hollow plant stems abundant. Weathers blocky and pitted and forms prominent ledge	10
21. Sandstone, siltstone, mudstone, limestone, marl, shale, and claystone, partly covered; sandstone, siltstone, mudstone, and claystone are calcareous and are light brown (5YR 6/4), moderate orange pink (5YR 8/4), moderate reddish brown (10R 4/6), and moderate reddish orange (10R 6/6); limestone, marl, and shale are white (N 9), yellowish gray (5Y 8/1) very pale orange (10YR 8/2), and pale yellowish brown (10YR 6/2) and weather white (N 9), yellowish gray (5Y 8/1), very pale orange (10YR 8/2), and grayish orange (10YR 7/4). Sandstone is very fine grained to fine grained, and both the sandstone and siltstone are mostly quartz. Fossils very abundant; upper 15 ft contains abundance of "plant hash." Lower 28 ft forms slope; upper 15 ft forms steplike ledge-slope topography	43
Total sandstone facies(?)	82
Middle limestone facies(?):	
20. Limestone, very pale orange (10YR 8/2) and pale-yellowish-brown (10YR 6/2); weathers very pale orange (10YR 8/2), grayish orange (10YR 7/4), very light gray (N 8), and white (N 9); contains abundance of "plant hash" and hollow plant stems that are $\frac{1}{10}$–$\frac{1}{2}$ inch in diameter. Weathers pitted and blocky and forms prominent ledge	5

SECTION 15.—*NE¼ sec. 9, T. 16 N., R. 3 E., to NW¼ sec. 36, T. 17 N., R. 3 E*—Con.

	Thickness (feet)
Verde Formation—Continued	
Middle limestone facies(?)—Continued	
19. Limestone, mudstone, sandstone, shale, and peatlike material, partly covered; limestone and shale are white (N 9), yellowish gray (5Y 8/1), and pale yellowish brown (10YR 6/2) and weather white (N 9), yellowish gray (5Y 8/1), and grayish orange (10YR 7/4); sandstone and mudstone are light brown (5YR 6/4), moderate orange pink (5YR 8/4), moderate reddish brown (10R 4/6), and moderate reddish orange (10R 6/6). Sandstone is fine grained to fine grained and is mostly quartz. Pale-olive (10Y 6/2) and greenish-gray (5GY 6/1) peatlike material has "papery" appearance and contains dark-gray (N 3) and medium-dark-gray (N 4) plant carbon. Most beds very fossiliferous; "plant hash" and plant stems abundant. All beds calcareous. Very rough, gnarly bedding. Forms slope with some small ledges	31
18. Limestone and shale, white (N 9) and very light gray (N 8); weathers white (N 9) and very light gray (N 8); some grayish-orange (10YR 7/4); "plant hash," plant stems, and fossils abundant. Weathers very rough and forms ledge	5
17. Limestone, very pale orange (10YR 8/2) and pale-yellowish-brown (10YR 6/2); weathers very pale orange (10YR 8/2), grayish orange (10YR 7/4), and white (N 9). Contains abundance of "plant hash" and hollow plant stems. Weathers pitted and blocky and forms prominent ledge	7
16. Limestone and shale, white (N 9) and very light gray (N 8). Weathers gnarly and forms slope	2
15. Sandstone; lower 7 ft is moderate orange pink (5YR 8/4) and light brown (5YR 6/4); upper 4 ft is moderate reddish orange (10R 6/6) and moderate reddish brown (10R 4/6). Very fine grained to fine grained; mostly quartz; upper 4 ft very friable. Forms slope	11
14. Limestone, some shale, and peatlike material; limestone is white (N 9), very light gray (N 8), and yellowish gray (5Y 8/1); shale and peatlike material are pale olive (10Y 6/2), greenish gray (5GY 6/1), and yellowish gray (5Y 8/1). Shale and peatlike material appear "papery" or varvelike. Most beds very fossiliferous. Very gnarly bedding; beds 3 in. to 1 ft thick. Forms steep irregular slope	24
13. Sandstone, light-brown (5YR 6/4), moderate-orange-pink (5YR 8/4), moderate-reddish-brown (10R 4/6), and moderate-reddish-orange (10R 6/6), very fine grained to fine-grained; mostly quartz; some limestone. Forms slope	23
12. Limestone, very pale orange (10YR 8/2) and pale-yellowish-brown (10YR 6/2); weathers very pale orange (10YR 8/2), grayish orange (10YR 7/4), white (N 9), very light gray (N 8), and pale yellowish brown (10YR 6/2); 75–90 percent of beds contain "plant hash" and hollow plant tubes 1/10–3/4 in. in diameter; very porous. Weathers blocky and pitted and forms prominent ledge	6

SECTION 15.—*NE¼ sec. 9, T. 16 N., R. 3 E., to NW¼ sec. 36, T. 17 N., R. 3 E*—Con.

Verde Formation—Continued

Middle limestone facies(?)—Continued — *Thickness (feet)*

11. Sandstone, siltstone, limestone, mudstone, and some conglomerate; sandstone and siltstone are light brown (5YR 6/4), moderate orange pink (5YR 8/4), moderate reddish brown (10R 4/6), and moderate reddish orange (10R 6/6); limestone is white (N 9), very light gray (N 8), and pinkish gray (5YR 8/1); mudstone is moderate brown (5YR 4/4) and moderate reddish brown (10R 4/6). Sandstone is very fine grained to fine grained and mostly quartz and weathered basalt; calcium carbonate cement; some sandstone is very friable. Limestone is dense; some is arenaceous and argillaceous. Conglomerate pebbles are 1–4 inches in diameter; mostly basalt. Forms steep slope; calcareous units form small ledges — 54
10. Limestone, white (N 9), very light gray (N 8), and pale pink (5RP 8/2). Very rough bedding; beds 1–3 ft thick. Weathers knobby, gnarly, and pitted and forms small ledge — 7
9. Sandstone and mudstone, sandstone is light brown (5YR 5/6), moderate reddish brown (10R 4/6), and light brown (5YR 6/4); mudstone is light brown (5YR 6/4). Entire unit is highly calcareous and contains scattered thin lenses and nodules of limestone and marl throughout. Sandstone is very fine grained to fine grained; 60 percent of grains are quartz and 40 percent are basalt. Very gnarly bedding; beds 1–6 in. thick. Weathers pitted and knobby and forms steep slope — 26
8. Limestone, white (N 9), dense to chalky; weathers white (N 9) and very light gray (N 8); some "floating" grains of very fine quartz sand. Very gnarly bedding. Weathers pitted and knobby and forms prominent ledge — 10
7. Sandstone and limestone lenses; sandstone is moderate orange pink (5YR 8/4), light brown (5YR 6/4), moderate reddish brown (10R 4/6), and light brown (5YR 5/6); limestone is grayish orange pink (10R 8/2) and weathers white (N 9). Sandstone is very fine grained to fine grained and friable and is mostly quartz; calcium carbonate cement. Forms steep slope. (Upstream about 1,000 ft from measured section this unit is nearly all limestone) — 9
6. Limestone, grayish orange pink (10R 8/2) and white (N 9): weathers white (N 9). Weathers rounded and forms slight ledge — 3
5. Sandstone, light brown (5YR 5/6) and moderate reddish brown (10R 4/6), very fine grained to fine grained, friable; mostly quartz; calcium carbonate cement. About 2 ft above base is 1-ft thick gravel bed. Weathers rough and gnarly and forms slope — 10
4. Limestone, grayish orange pink (10R 8/2), dense; weathers white (N 9). Contains hollow tubelike structures $\frac{1}{10}$–$\frac{1}{4}$ in. in diameter. Gnarly bedding. Weathers pitted and knobby and forms prominent ledge — 4

693-389 O—63——9

SECTION 15.—*NE¼ sec. 9, T. 16 N., R. 3 E., to NW¼ sec. 36, T. 17 N., R. 3½ E*—Con.

	Thickness (feet)
Verde Formation—Continued	
Middle limestone facies(?)—Continued	
3. Sandstone, moderate orange pink (5YR 8/4) and light brown (5YR 6/4), very fine grained to fine grained, mostly quartz; calcium carbonate cement; some lenticular beds of light brown (5YR 5/6) and moderate reddish brown (10R 4/6) friable sandstone. Contains hollow tubelike structures 1/10–¼ in. in diameter. Very rough and gnarly bedding. Weathers very rough and gnarly and forms steep slope	15
2. Limestone, grayish orange pink (10R 8/2) and white (N 9); weathers white (N 9). Gnarly bedding. Weathers blocky and knobby and forms small ledge	5
1. Sandstone, moderate orange pink (5YR 8/4) and light brown (5YR 6/4), very fine grained to fine grained; mostly quartz; calcium carbonate cement. Weathers rounded and pitted and forms small ledge. Base concealed	4
Total measured middle limestone facies(?)	261
Total measured section	794+

SECTION 16.—*SE¼ sec. 11, T. 17 N., R. 3 E.*

[Section measured on south flank of Black Mountain. Beds are nearly horizontal. Approximate alt at top of section 4,435 ft]

	Thickness (feet)
Erosion surface.	
Verde Formation:	
Upper limestone facies:	
21. Limestone; some highly calcareous siltstone and very fine grained sandstone, partly covered. Limestone is very pale orange (10YR 8/2) and yellowish gray (5Y 8/1); some is white (N 9); weathers very pale orange (10YR 8/2), light brown (5YR 6/4), and white (N 9). Siltstone and sandstone are grayish orange pink (10R 8/2) and moderate orange pink (10R 7/4). "Plant hash" abundant; upper 3 ft contains gastropods. Beds 1–5 ft thick. Forms steep ledge-slope topography	145
20. Limestone, very pale orange (10YR 8/2) and yellowish-gray (5Y 8/1); weathers very pale orange (10YR 8/2) and light brown (5YR 6/4). "Plant hash" abundant; some beds contain gastropod molds. Massive bedding; beds 2–10 ft thick. Weathers blocky. Lower 35 ft forms vertical cliff; upper 45 ft forms steep ledge-slope topography	80
19. Mudstone and siltstone, yellowish-gray (5Y 7/2) and yellowish-gray (5Y 8/1). Massive bedding. Weathers smooth and forms recess. Base concealed	3
18. Concealed	5
17. Limestone, very pale orange (10YR 8/2) and white (N 9), dense. "Plant hash" abundant. Massive bedding. Weathers blocky and pitted and forms ledge. Base concealed	8
16. Concealed	10

SECTION 16.—*SE¼ sec. 11, T. 17 N., R. 3 E*—Continued

	Thickness (feet)
Verde Formation—Continued	
Upper limestone facies—Continued	
15. Limestone, very pale orange (10YR 8/2) and light-brownish-gray (5YR 6/1). "Plant hash" abundant; some beds contain a few gastropods; about 2 ft above base is ½-inch-thick zone of yellowish-gray (5Y 8/1) shale that contains numerous pelecypods. Massive bedding. Weathers blocky and pitted and forms prominent ledge	7
14. Sandstone, yellowish-gray (5Y 8/1), very fine grained to fine-grained; mostly quartz; calcium carbonate cement. Pebbles of chert and basalt ⅛–¾ in. in diameter scattered throughout. Massive bedding. Weathers smooth and rounded and forms recess. Base concealed	4
13. Concealed	7
12. Limestone, very pale orange (10YR 8/2) and grayish-orange (10YR 7/4). "Plant hash" abundant. Gnarly bedding. Weathers blocky and pitted and forms small ledge	4
11. Claystone, yellowish-gray (5Y 8/1). Several 1-in.-thick zones contain abundance of gastropods and pelecypods. Massive bedding. Weathers smooth and forms recess	1
10. Limestone, very pale orange (10YR 8/2) and grayish-orange (10YR 7/4). Gnarly bedding. Weathers blocky and pitted and forms small ledge. Base concealed	4
9. Concealed	56
8. Limestone, pale-yellowish-brown (10YR 6/2) and yellowish-gray (5Y 7/2); weathers grayish orange (10YR 7/4) and very pale orange (10YR 8/2). Upper 3 ft contains tubelike structures that are 1/32–1/16 in. in diameter. "Plant hash" abundant in lower 5 ft. Massive bedding. Weathers blocky, pitted, and knobby and forms prominent ledge. Base concealed	8
7. Concealed	5
6. Limestone, white (N 9), partly aphanitic. Contains many tubelike structures that are 1/16–¼ in. in diameter. Massive bedding. Weathers smooth and rounded and forms vertical cliff	10
5. Sandstone, grayish-orange-pink (10R 8/2) and moderate-orange-pink (10R 7/4), very fine grained to fine-grained; mostly quartz; calcium carbonate cement. Gnarly bedding. Weathers pitted and knobby and forms recess	3
4. Limestone, white (N 9) and yellowish-gray (5Y 8/1); some dark-yellowish-orange (10YR 6/6). Contains many tubelike structures that are 1/16–¼ in. in diameter. Gnarly bedding. Weathers blocky and forms irregular cliff with several recesses	9
3. Sandstone, siltstone, and mudstone, light-brown (5YR 6/4) and grayish-orange-pink (10R 8/2). Sandstone is very fine grained and is mostly quartz; calcium carbonate cement. Massive bedding. Weathers smooth and knobby and forms recess	3

SECTION 16.—*SE¼ sec. 11, T. 17 N., R. 3 E*—Continued

	Thickness (feet)
Verde Formation—Continued	
Upper limestone facies—Continued	
2. Limestone, white (N 9). Contains many tubelike structures that are 1/32 in. in diameter; lower 1 ft and upper 3 in. contain pale-yellowish-brown (10YR 6/2) plant stems. Gnarly bedding. Weathers rounded and blocky and forms small ledge	7
1. Sandstone, grayish-orange-pink (10R 8/2) and moderate-orange-pink (10R 7/4), very fine grained to fine-grained; mostly quartz; calcium carbonate cement. Upper 1 ft contains grayish-orange-pink (5YR 7/2) and light-olive-gray (5Y 6/1) clay. Weathers pitted and knobby and forms recess. Base concealed	5
Total measured upper limestone facies	384

SECTION 17.—*NW¼ sec. 17, T. 17 N., R. 4 E.*

[Section measured on east side of Anderson Butte. Beds are nearly horizontal. Approximate alt at top of section 4,325 ft]

	Thickness (feet)
Erosion surface.	
Verde Formation	
Upper limestone facies:	
12. Limestone, white (N 9); weathers white (N 9) and very light gray (N 8). Contains gastropod molds and many tubelike structures. Gnarly bedding; beds 6 in. to 2 ft thick. Weathers blocky and pitted and forms small ledge	20
11. Sandstone, moderate-reddish-orange (10R 6/6), very fine grained; calcium carbonate cement. Beds 6 in. to 2 ft thick. Forms irregular slope	5
10. Limestone, pinkish-gray (5YR 8/1) and grayish-orange-pink (5YR 7/2); weathers white (N 9) and very light gray (N 8). Some "floating" sand grains. Weathers very rough and forms small ledge	1
9. Sandstone, moderate-reddish-orange (10R 6/6), very fine grained; calcium carbonate cement. Beds 6 in. to 2 ft thick. Forms irregular slope	10
8. Limestone, pinkish-gray (5YR 8/1); weathers white (N 9) and very light gray (N 8). Some "floating" sand grains. Contains many tubelike structures that are one-tenth inch in diameter. Weathers very rough and forms small ledge	1
7. Sandstone, moderate-reddish-orange (10R 6/6) and moderate-reddish-brown (10R 4/6), very fine grained; calcium carbonate cement. At 10 ft above base is a white (N 9) nodular limestone. Beds 6 in. to 2 ft thick. Forms irregular slope	49
6. Limestone, pinkish-gray (5YR 8/1) and grayish-orange-pink (5YR 7/2), arenaceous; weathers white (N 9) and very light gray (N 8). Weathers rough and forms small ledge	2
5. Sandstone, moderate-reddish-orange (10R 6/6), very fine grained; calcium carbonate cement. Forms irregular slope	4

SECTION 17.—*NW¼ sec. 17, T. 17 N., R. 4 E*—Continued

	Thickness (feet)
Verde Formation—Continued	
Upper limestone facies—Continued	
4. Limestone, pinkish-gray (5YR 8/1); weathers white (N 9) and very light gray (N 8). Some "floating" sand grains, numerous manganese dendrites, and some tubelike structures that are one-tenth inch in diameter. Weathers rough and forms small ledge	1
3. Sandstone, moderate-reddish-brown (10R 4/6) and moderate-reddish-orange (10R 6/6), very fine grained; calcium carbonate cement. At 4 ft above base is a 6-in.-thick pinkish gray (5YR 8/1) limestone bed. Forms irregular slope	10
2. Limestone, pinkish-gray (5YR 8/1) and grayish-orange-pink (5YR 7/2), arenaceous; weathers white (N 9) and very light gray (N 8). Weathers knobby and blocky and forms small but distinct ledge	1
1. Sandstone, moderate-reddish-orange (10R 6/6) and moderate-reddish-brown (10R 4/6), very fine grained; calcium carbonate cement. Beds 6 in. to 2 ft thick. Forms irregular slope. Unit rests unconformably on Supai Formation	122
Total measured upper limestone facies	226

SECTION 18.—*NW¼ sec. 24, T. 17 N., R. 4 E.*

[Section measured about a mile southwest of Lobo Butte. Beds are nearly horizontal. Approximate alt at top of section 4, 320 ft]

	Thickness (feet)
Erosion surface.	
Verde formation:	
Upper limestone facies:	
6. Limestone, medium-light-gray (N 6), very light gray (N 8), and white (N 9); weathers white (N 9) and very light gray (N 8). Contains many hollow tubelike structures that are $\frac{1}{10}$–$\frac{1}{2}$ in. in diameter; gastropod and ostracode molds in lower foot of unit. Beds 4–8 in. thick. Weathers blocky and forms prominent ledge	3
5. Sandstone, calcareous, and marl, moderate-orange-pink (10R 7/4), moderate-reddish-orange (10R 6/6), and light-brown (5YR 6/4); weathers moderate orange pink (10R 7/9) and moderate reddish orange (10R 6/6). Sand is mostly quartz. Forms smooth steep slope	25
4. Limestone, medium-light-gray (N 6), very light gray (N 8), and white (N 9); weathers white (N 9) and very light gray (N 8). Contains many hollow tubelike structures that are $\frac{1}{10}$–$\frac{1}{4}$ in. in diameter. Beds 4–6 in thick. Weathers blocky and forms prominent ledge	3
3. Sandstone, similar to unit 5	80
2. Limestone, grayish-orange-pink (10R 8/2), arenaceous; weathers moderate orange pink (10R 7/4) and white (N 9). Forms prominent ledge	2
1. Conglomerate; matrix moderate orange pink (10R 7/4); very fine grained sand. Pebbles are basalt and sandstone of Supai. Massive bedding. Forms smooth steep slope. Unit rests unconformably on Supai Formation	20
Total measured upper limestone facies	133

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[Where several references are given, major reference is in italic]