Reconnaissance of Headwater Springs in the Gila River Drainage Basin, Arizona

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1619-H

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By J. H. FETH *and* J. D. HEM

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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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*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington 25, D.C.

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RECONNAISSANCE OF HEADWATER SPRINGS IN THE GILA RIVER DRAINAGE BASIN, ARIZONA

By J. H. Feth and J. D. Hem

ABSTRACT

The springs in the Mogollon Rim region in central Arizona are the source of much of the water in the Gila, Salt, and Verde Rivers. The ground-water resources of the region had not previously been studied systematically.

The Mogollon Rim is an escarpment, formed on northward-dipping rocks mainly of Paleozoic age, that extends about 200 miles northwestward from near Clifton and Morenci in southeastern Arizona; it gradually loses its character northwest of Prescott. Main lines of drainage extend northward on the Colorado Plateau, north of the rim, and southward or southwestward below the rim. For convenience in discussion and because of probable structural differences, the region has been separated into western, central, and eastern divisions.

Rocks of Precambrian to Recent age crop out. Precambrian rocks and those of Paleozoic age constitute the thicker sections. Recent basalt flows cap the plateau, except in the central part of the region, and large areas in valleys below the rim are occupied by lake deposits. The valleys are alined northwestward, suggesting that a structural trough extends almost the full length of the rim southwest of the scarp, and hence that the scarp is of structural origin. In some areas, erosion has caused recession of the escarpment for distances ranging from a few miles to 10 to 15 miles from the inferred locations of the major rim faults.

Granite of Precambrian age and basalt of probable Tertiary or Quaternary age are the igneous rocks most widely exposed in the region. A thickness of 2,000 feet of volcanic rocks of probable Cretaceous and Tertiary age is exposed in one area along the rim, but these rocks as yet have been little studied.

High-angle faults, for the most part normal, are the most prominent structural features identified. Faults parallel to the rim have been mapped in several areas. These faults are thought to account for the presence of two escarpments in the eastern division, and of perhaps as many as three near Payson.

Major orogeny in the region is believed to have occurred in the Precambrian; in Miocene(?) time southwest of the Mogollon escarpment; in Pliocene(?) time, at least in the Flagstaff area; and at or near the beginning of Quaternary time. Laramide structures (Late Cretaceous and early Tertiary), prominent elsewhere on the plateau, are reflected only weakly in the rim region, so far as is known.

Natural lakes, ponds, and swamps lose considerable water, and some dry up each summer. They might be developed as natural water catches from which recharge of ground water could be artifically induced.

Data on precipitation are incomplete. If 16 inches is conservatively assumed as the mean annual precipitation in the region, then about 8½ million acre-feet of water falls annually on the plateau portion of the rim region. Available data indicate that only about 150,000 acre-feet discharges annually from springs in the Gila River headwaters. Thus, more than 98 percent of the precipitation leaves the Mogollon Rim region by evapotranspiration, flood runoff, and sub-surface discharge.

Ground water occurs in rocks of almost every age in the region, and is obtained from springs and from wells. The Naco formation of Pennsylvanian age is the aquifer supplying the group of springs of largest discharge—18,500 gallons per minute at Fossil Creek. Much recharge takes place by direct infiltration of rain and melting snow through jointed basalt, which caps a large part of the eastern and western divisions, and the jointed and channeled Kaibab limestone of Permian age in the central division. The permeable nature of the caprocks, and the relatively high precipitation along the rim, provide conditions favorable for inducing additional recharge.

Faulting is important in controlling the occurrence of springs. Springs occur at places where the discharge is localized by structures and in part at contacts of permeable rocks above and impermeable rocks below. In the Payson region, faulting exposes highly cavernous limestone at two or more levels, which are progressively lower with increasing distance from the rim. Spring discharge from higher levels goes underground at outcrops of the limestone and is believed to reappear downstream as flow from other springs.

Areas in which artesian-conduit springs occur, such as Fossil Creek and Sycamore Canyon, are considered most promising for development. At Clifton Hot Springs in the Gila River drainage, and at the Salt Banks on Salt River, it might be possible to eliminate the salty water from the river flow.

Springs issuing from quartzite of Precambrian age along the Salt River yield water containing as much as 37,000 ppm (parts per million) of dissolved solids, mainly sodium and chloride. Springs issuing from rocks of Paleozoic age in the region yield water that generally contains less than 500 ppm of dissolved solids, mostly calcium, magnesium, and bicarbonate. Springs in basalt near the rim yield the best waters of the region, some of which contain less than 100 ppm of dissolved solids.

INTRODUCTION

Inhabitants of the broad valleys of south-central Arizona have used surface waters of the Gila, Salt, and Verde Rivers since pre-historic time. In the past 50 years the waters of these streams have been increasingly controlled and utilized for agriculture. Until the present investigation, no systematic study had been made of the geology and the hydrologic conditions in the source areas in which much of the water so utilized originates. These source areas are located in the Mogollon Rim region about 100 miles north of the areas of heaviest utilization.

The present investigation, concerned principally with ground water, was under the supervision of S. F. Turner and L. C. Halpenny, successively district engineers of the Ground Water Branch of the U.S. Geological Survey for Arizona, between 1950 and 1953. The study was intended to determine (1) the location of springs contributing to flow in the Gila, Salt, and Verde Rivers; (2) fluctuations in discharge of the principal springs; (3) water-bearing properties of rock formations in spring-discharge areas; (4) the relation of chemical quality of spring waters to the formations from which they emerge; (5) the relation of geologic structures to localization of springs; (6) sources of highly mineralized water detrimental to use for irrigation; and (7) the location of areas in which spring flow might be increased by development.

LOCATION AND EXTENT OF AREA

The principal springs contributing to the Gila, Salt, and Verde Rivers issue along the great southward-facing escarpment of structural origin, formed on northward-dipping rocks mainly of Paleozoic age, known as the Mogollon Rim (fig. 1). The rim is expressed topographically as a scarp, ranging in height from about 100 feet at its northwest end to nearly 2,000 feet in the central part (fig. 1), between Payson and Show Low. At the southeast end, the Mogollon Rim is lost in a complex of volcanic mountains. The Natanes Rim to the south, possibly a structural equivalent of the Mogollon Rim, is 200 to 500 feet high. The Mogollon Rim region is a zone about 200 miles long, trending generally northwestward from near the Arizona-New Mexico State line to an indeterminate point north of Prescott. The zone ranges in width from about 50 miles to more than 75 miles and includes 10,000 to 15,000 square miles. In this report the term "Mogollon Rim" refers to the scarp alone. The "Mogollon Rim region" and the "rim region" are used interchangeably to refer to the zone, 50 to 75 miles wide, extending both north and south of the scarp in which geology and the occurrence of ground water were studied.

For convenience of discussion the region has been separated into three generalized divisions on the basis of physiographic and geologic differences. Lines separating the three divisions are shown in figure 1. The position of the lines is arbitrary.

PREVIOUS INVESTIGATIONS

Relatively little geologic work has been done in the Magollon Rim region because ore deposits occur at few localities. Many reports include general reference to the region, and the Mogollon escarpment is

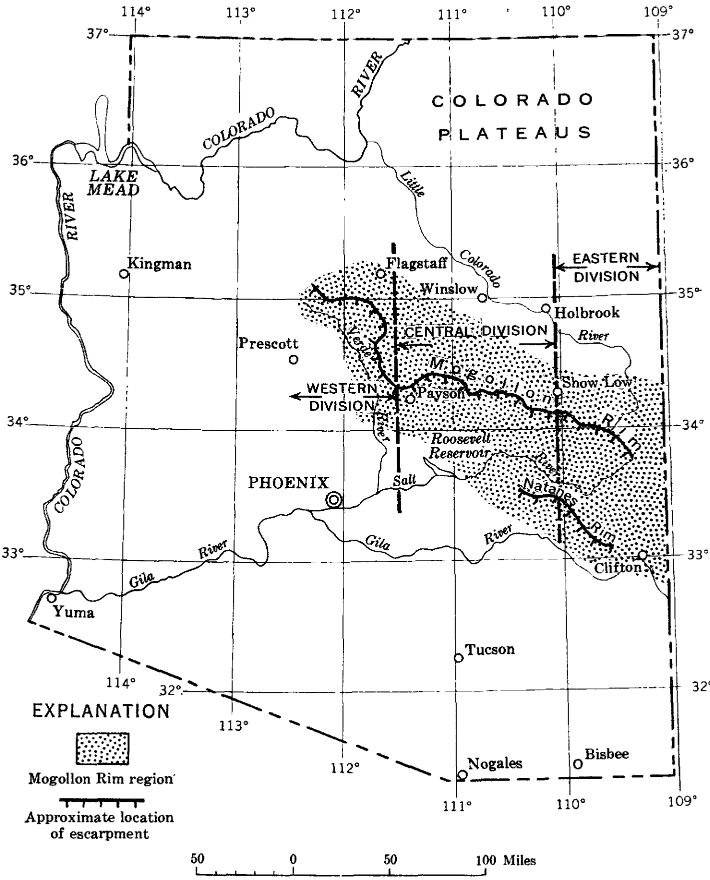

FIGURE 1.—Index map of Arizona showing Mogollon Rim region and approximate location of escarpment.

widely known as the southwestern boundary of the Colorado Plateau. General studies have been made by Darton (1910, 1925), Darton and others (1924), and Wilson (1939). Plate 1 is a generalized geologic map, after Darton and others (1924), showing the location of springs described in this report. Table 1 is a list of the springs shown on the map.

Harrell and Eckel (1939) discussed part of the region with reference to ground water. Details of the geology of the Clifton-Morenci copper deposits were described by Lindgren and Boutwell (1905). Reber (1938) discussed the geology and ore deposits of the Jerome district. Robinson (1913) analyzed the San Franciscan volcanic field, near Flagstaff. Structures in Oak Creek were studies by Mears

(1950). Detailed studies (Anderson and Creasey, 1958) in an area immediately west of the Verde basin (fig. 2) have been made in recent years by the Geological Survey.

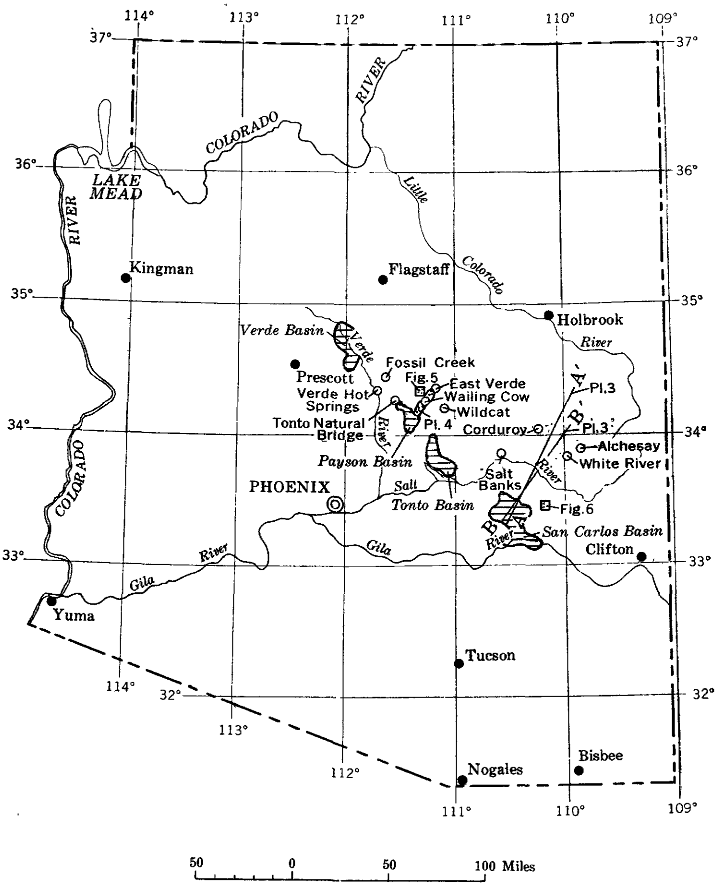

FIGURE 2.—Index map of Arizona showing approximate areas in Mogollon Rim region underlain by Tertiary and Quaternary lake beds and the locations of areas mapped, of geologic sections, and of active and inactive travertine terraces.

The stratigraphy of the Mogollon Rim country is somewhat better known than the structure and the geology of the igneous rocks. Among those contributing to stratigraphic knowledge are Gutschick (1943, 1949), Huddle and Dobrovolny (1945, 1952), Hughes (1949), Jackson (1951), McKee (1934, 1938, 1951), McNair (1951), Reiche (1938), and Stoyanow (1936, 1942).

Other references are listed in "References cited."

TABLE 1.—*List of springs shown on plate 1*

[Arrangement follows that of table 5]

No. on map	Name of spring	Township	Range	Sec.
	Western division			
		North	*East*	
37	Oak Creek, sum of many springs not individually reported	16	4	14
37	Frey Ranch Springs	16	4	15
37	Treeroot Spring	16	4	15
37	Bubbling Pond	16	4	15
37	Turtle Pond	16	4	15
36	Springs on Spring Creek	16	4	16
38	Page Fish Hatchery Springs	16	4	23
39	Sheepshead Canyon Springs	16	4	33
39	Hells Canyon Spring	16	4	34
35	Summers Spring	17	3	5
35	(1)	17	3	5
30	Parson Spring	18	3	32
31	(1)	18	6	5
31	(1)	18	6	5
31	Hummingbird Spring	18	6	5
32	(1)	18	6	7
33	Indian Gardens Spring	18	6	27
34	Thompson Pasture Spring	18	6	34
23	Dorsey Spring	19	4	2
24	Lockwood Spring	19	5	9
27	(1)	19	5	13
26	(1)	19	5	22
25	Barney Spring	19	5	30
28	(1)	19	6	15
28	(No. 3 in Oak Creek)	19	6	15
29	(1)	19	6	22
29-A	Grassy Meadow Spring	19	6	34
29-A	Lelani Spring	19	6	34
15	Lower Hulls Spring	20	4	3
16	Poison Spring	20	4	9
16	Greys Spring	20	4	10
17	Babes Hole Spring	20	4	35
17	Kelsey Spring	20	4	35
19	Woody Spring	20	6	3
18	Aspen Spring	20	6	8
20	Landon Spring	20	6	12
7	Little L.O. Spring	21	4	32
9	Navajo Ordnance Spring "0" area	21	5	3
8	N.O.D. Indian Camp Spring	21	5	4
10	Navajo Ordnance Depot Spring No. 2	21	5	10
10	Navajo Ordnance Depot Spring No. 3	21	5	10
11	Navajo Ordnance Depot Spring No. 1	21	5	11
12	(1)	21	6	21
12	(1)	21	6	21
14	Fisher Spring	21	6	28
13	Patterson Spring	21	6	31
	Eastern division			
		South	*East*	
107	Tule Spring	1	24	16
108	Arsenic Cave Spring	1	25	30
110	Clifton Hot Springs group	4	30	30
		North		
102	Ess ("S") Spring	4	27	20
98	White River Salt Spring	4½	20	35
98	do	4½	20	36
98	do	4½	20	36
99	(1)	5	24	18
100	Gillard Hot Spring	5	29	27
94	Alchesay Spring	6	23	4
95	Old Farm Spring	6	23	17
93	Bull Cienega Spring	7	23	3
82	Amos Ranch Big Spring	8	22	11
83	Government Spring (sump)	8	23	24
83	Government Spring	8	23	24
83	Government Spring No. 4	8	23	24
83	Government Spring	8	23	24
84	Gomez Spring	8	23	25
85	Upper Bull Cienega Spring	8	23	27
86	Haystack No. 1	8	24	19

See footnote at end of table.

TABLE 1.—*List of springs shown on plate 1*—Continued

No. on map	Name of spring	Township	Range	Sec.
	Eastern division—Continued			
		North	*East*	
86	Haystack No. 2	8	24	19
86	Earl Spring No. 3	8	24	19
87	(1)	8	24	21
88	Boy Spring	8	24	23
89	Blue Lake	8	24	27
89	(1)	8	24	27
89	Williams Spring	8	24	27
90	Gooseberry Creek Spring	8	25	3
91	Sheep Springs	8	26	26
	Central division			
		South	*East*	
109	Spring Branch Ranch Spring	2	16	14
		North		
105	Maurel Spring	1	15	26
106	Cold Spring at Warm Springs	1	20	12
106	Warm Springs	1	20	12
104	(1)	2	19	10
103	Cassadore Springs	2	19	18
101	Rock Spring	3	16	6
96	Salt Banks (on Salt River)	5	16	13
97	Warm Spring on Salt River	5	19	34
72	Bear Flat Spring	10½	12	24
58	Verde Hot Springs	11	6	3
61	Natural Bridge Springs	11	9	5
61	(1)	11	9	5
62	Springs in lower Webber Canyon	11	10	4
63	The Grotto Spring	11	10	9
63	Big Spring	11	10	9
64	Wildcat Spring	11	11	13
65	Henturkey Spring	11	12	16
66	Indian Gardens	11	12	20
67	R-C Spring	11	12	26
68	Columbine Spring	11	12	34
60	Red Rock Spring	11½	9	23
59	Oak Spring	11½	9	30
60-A	Cold Spring	11½	11	30
44	Fossil Creek springs	12	7	14
43	(1)	12	7	22
45	Strawberry Spring	12	8	23
46	(1)	12	8	26
47	Cottonwood Spring	12	8	35
48	Parsnip Spring	12	9	8
49	Dripping Springs	12	9	30
50	Washington Park Spring	12	10	11
50	McGee Spring	12	10	11
51	East Verde Spring	12	10	14
52	"Burned House Spring"	12	10	34
53	Winters Spring No. 1 (domestic)	12	12	32
53	Winters Spring No. 2	12	12	32
53	Winters Spring No. 3	12	12	32
54	Tonto Spring	12	12	33
40	Foster Spring	16	8	16
	North flowing			
		North	*East*	
81	Pinetop Spring	8	23	4
81	Halleck Spring	8	23	4
91	C. C. Hall Spring	8	26	5
91	C. C. Cabin Spring	8	26	5
73	Big Spring (near Lakeside)	9	22	36
73	Walnut Spring	9	22	36
74	Paige Spring	9	23	18
75	Pat Mullen Spring	9	23	23
76	Whitcomb Spring	9	23	26
76	Chipmunk Spring	9	23	26
77	Thompson Spring	9	23	34
78	Danstone Spring	9	24	21
80	McCormick Spring	9	24	26

See footnote at end of table.

TABLE 1.—*List of springs shown on plate 1*—Continued

No. on map	Name of spring	Township	Range	Sec.
North flowing—Continued				
		North	*East*	
80	Los Burros Spring	9	24	26
79	Telephone Spring	9	24	28
69	Trough Spring	11	18	27
70	Bourdon Ranch Spring	11	23	19
71	Silver Spring	11	23	20
55–A	Old Mill Spring	12	21	25
55	East Shumway Spring	12	22	31
56	[1]	12	22	33
57	Concho Spring	12	26	19
41	Clover Spring	13	9	14
42	Little Pivot Rock Spring	13	9	21
21	Fulton Spring	20	6	13
22	Black Spring	20	7	7
6	Buck Springs	21	3	23
2	Little Leroux Spring	22	6	13
2	Leroux Spring	22	6	14
1	Maxwell Spring	22	6	18
1	[1]	22	6	18
4	[1]	22	7	25
3	Little Elden Spring	22	8	19
5	[1]	22	8	31

[1] Spring visited for which no name is known.

GEOGRAPHY

The cliffs of the Mogollon Rim, the rock-walled canyons, and the outlying buttes and mesas are the dominant features of the landscape. Owing to the brilliant reds that characterize many beds at the base of the rim, and the contrast with overlying buff sandstone, light-yellow to white sandy limestone, and caprocks of black basalt, the area has become famous for its scenic attraction. Forested slopes at higher altitudes and tumbling mountain streams add to the scenic beauty.

The high plateau country north of the rim consists of flatlands and hills separated by steep-walled canyons. Southward below the base of the rim are broad valleys, separated by irregular hills and mountains in varying stages of dissection. These valleys in large measure are occupied by lacustrine sediments that erode readily to form a butte-and-canyon topography similar to the margins of the Mogollon Rim, but smaller in scale.

Streams flow northward and southward from a drainage divide near the crest of the Mogollon escarpment. Most streams flowing northward follow the dip-slope surface of the plateau. Locally, joint trends are reflected in rectangular patterns of the smaller streams. The principal stream draining the plateau is the Little Colorado River, which flows northwestward to join the Colorado River in northern Arizona.

Southwest of the drainage divide, the Gila River (pl. 1), which flows nearly due west through central Arizona, is the trunk stream.

The Salt River, principal tributary of the Gila, drains the central division of the Mogollon Rim region. The Salt River flows generally westward from its headwaters to its junction with the Gila River, near Phoenix, and supplies most of the impounded water used for irrigation in the Phoenix area. The White and Black Rivers meet to form the Salt River. Southward-trending Carrizo Creek, Tonto Creek, and the Verde River are major tributaries of the Salt River.

The country along and immediately north of the topographic rim has a cold-temperate climate, and moisture sufficient to support what is reportedly the largest stand of yellow pine in the United States. Farther north, where the altitude is lower, temperatures are more moderate and precipitation drops markedly. Weather Bureau records indicate that mean annual temperature and precipitation vary with location and altitude, although not consistently. In general, north of the rim, mean annual temperatures range from 55.5°F at Winslow (altitude 4,880 feet) to 45°F at Flagstaff (6,993 feet) and corresponding mean annual precipitation from 6.96 to 25.79 inches. On the rim itself, precipitation ranges from an average of 19.55 inches at Alpine (8,000 feet) to 29.60 inches at nearby McNary (7,305 feet), illustrating the importance of local orographic effects in modifying the pattern of precipitation. Precipitation at stations south of the rim, but within the rim region, ranges from 13.81 inches in the Verde Valley (3,180 feet) to 27.74 inches at Payson Ranger Station (4,900 feet). A detailed study of precipitation in the Mogollon Rim region has been made by the U.S. Weather Bureau (1953).

The principal climatological factor related to water supply is movement of moisture-laden air masses from the south and southwest toward the north and northeast. The barrier formed by the rim causes sufficient elevation of the air masses to result in cooling, condensation, and precipitation. Thus, the country along the crest of the rim and immediately to the southwest receives relatively large amounts of moisture annually, both as rain and as snow. The Mogollon Rim serves as a water catch and provides an area favorable for recharge to subsurface reservoirs as well as a source area for runoff. The possibility of inducing additional ground-water recharge is discussed later in this report.

GEOLOGY

STRATIGRAPHY

ROCKS OF PRE-MESOZOIC AGE

Rocks of Precambrian and Paleozoic age form the basement of the region. Wilson (1939, p. 1118) reports an aggregate thickness of older Precambrian sedimentary and volcanic rocks of 12,000 to 15,000 feet in the Payson region. Overlying these, in parts of the area he studied, are more than 1,000 feet of younger Precambrian sedimentary rocks of the Apache group. Precambrian rocks are prominently exposed in the canyon of the Salt River and in the San Carlos Indian Reservation, but in many places in the Rim region they are deeply buried by younger rocks.

Strata of Paleozoic age tend to be persistent in thickness throughout the region studied. (See pl. 2.) Several lines of reasoning indicate that most of these strata originally extended far south of their present limits of exposure. McKee (1951, p. 486–487) summarized the evidence as follows: (1) Except for the Cambrian, strata of Paleozoic age exposed along the rim give no evidence of being marginal facies; (2) Devonian and Mississippian strata thicken toward the southwest; and (3) Permian strata aggregate about 2,000 feet in thickness where exposed along the rim. Evidence regarding former southwestward extensions of strata of post-Paleozoic age includes the following: (1) The presence of 300 feet of the Moenkopi formation of Early and Middle(?) Triassic age at points along the rim indicates a former extension of these deposits; and (2) along the southern margin of the Colorado Plateau, Pliocene(?) gravel contains pebbles and cobbles composed of rocks ranging from Precambrian to Permian. According to McKee, the only likely direction from which these gravels could have come is the south. It is concluded, therefore, that the sedimentary rocks at one time extended far to the south and southwest of their present limits of outcrop; that the region south-southwest of the present topographic rim was formerly much higher than the plateau region; and that, during long-continued erosion of the uplifted area, detritus moved generally north-northeastward and was in part deposited as gravel over a wide area along the southern margin of the Colorado Plateau.

UPPER CRETACEOUS SEDIMENTARY ROCKS

Darton (Darton and others, 1924, p. 150) reported the occurrence of Cretaceous clastic deposits in Apache and Navajo Counties, especially in areas adjacent to the rim. Fossils from these beds were identified by J. B. Reeside, Jr., of the U.S. Geological Survey (written communication, 1925), as being of Late Cretaceous (Carlile) age.

Fossils were collected from two localities during the present study. Dr. Reeside (writen communication, 1952) again made the determinations and concluded that the assemblage would "indicate an age about equivalent to that of the Greenhorn limestone of the High Plains," thus perhaps slightly refining the age determination reported in 1925.

Fossils identified by Reeside from yellowish-tan sandstone exposed in a road cut 3.3 miles south of Show Low along Arizona State Route 173 included the following:

Ostrea soleniscus Meek
Cardium pauperculum Meek
"*Mactra*" *utahensis* Meek
Cassiope sp.
Cliona sp.
Inoceramus labiotus Schlotheim var. *aviculoides* Meek and Hayden
"*Cyrena*" sp.
"*Tellina*" sp.
Gyrodes depressa Meek
Volutoderma gracilis (Stanton)
Lamna sp.

A collection obtained near Pinedale, Navajo County, in sec. 16, T. 10 N., R. 20 E., contained the following forms:

Serpula intrica White
Pteria gastrodes Meek
Ostrea soleniscus Meek
Lucina juvenis Stanton
Cardium pauperculum Meek
"*Mactra*" *arenaria* Meek
Pugnellus fusiformis Meek
"*Gervillia*" *propleura* Meek
Exogyra columbella Meek
Veniella, n. sp. a globose form
Legumen n. sp.
Corbula kanabensis Stanton

Well-log data and examination of a partial suite of drill cuttings from a well drilled at Pinetop, in sec. 4, T. 8 N., R. 23 E., show the presence of about 600 feet of bluish-gray shaly rocks whose stratigraphic position is not known. Overlying these strata are 250 to 300 feet of tan and reddish sandstone and clay that the writer believes to be equivalent to Upper Cretaceous strata exposed nearby, along the rim. The shaly beds are not known to crop out in the area and may represent a tongue of Cretaceous rocks covered elsewhere by a mantle of volcanic rocks.

TERTIARY AND QUATERNARY SEDIMENTARY ROCKS

Sedimentary rocks of Tertiary and Quaternary age consist of alluvium, lake deposits, spring-deposited travertine, and very locally, sand dunes. Some deposits of sand and gravel now cap erosional remnants of older rocks in the region north of the rim or crop out along the rim itself and along canyons cut northward into the rim. In the latter instances the gravel and sand deposits underlie basalt flows and their extent beneath the volcanic rocks is not known. Lake-deposited sediments and travertine deposits are discussed separately below.

Recent alluvium occurs in the valleys of the principal streams and some of the tributaries. In areas adjacent to some of the larger streams, especially the Little Colorado River, sand dunes cover the land surface locally. Of all the Tertiary and Quaternary sediments, however, only the lake deposits are very thick. In the Verde Valley, and near San Carlos, they are hundreds of feet thick and contain supplies of ground water that are developed by wells.

LAKE DEPOSITS

Figure 2 shows the location and approximate outlines of four areas of lacustrine sediments. It is estimated that lakebed deposits occupy more than 1,000 square miles in the four areas shown. Jenkins (1923, p. 70–71) estimated that, in the Verde Basin, lacustrine strata of the Verde formation cover more than 300 square miles and are more than 2,000 feet thick. One of the largest deposits in the world of the sodium sulfate minerals thenardite, mirabilite, and glauberite occurs in the lacustrine sequence near Camp Verde. The origin of the deposit is uncertain (Mahard, 1949), but it may be genetically related to the occurrence of sulfide mineralization in the mining areas near Jerome or to presently unknown springs of mineralized water, now perhaps dried up.

SAN CARLOS BASIN

An even larger area in the San Carlos Indian Reservation is underlain by Tertiary and Quaternary rocks, mostly lake deposits. Knechtel (1938, p. 197) concluded that these sediments are equivalent to part of the Gila conglomerate. The aggregate thickness of the lacustrine strata is estimated to be between 700 and 800 feet.

Although the full section was not measured, partial sections are shown in figure 3. Section A shows the general composition of what is apparently a nearshore facies. Section B is representative of part of the total sequence, in which tuffaceous material is abundant. Section C is characteristic of a calcareous facies that occurs within a few miles of the reservation headquarters at San Carlos. In other exposures the limy facies is far thicker, possibly 500 feet or more. Toward the top of the thicker exposures, 1 and locally 2 basalt flows are intercalated and very light colored tuffaceous beds are common. Basalt commonly caps the sequence.

About 20 miles northeast of San Carlos, in the canyon of Blue River (pl. 1), beds equivalent to part of the lacustrine series are about 200 feet thick and consist almost exclusively of evaporite limestone. Other evaporites may be present in this sequence.

A Pliocene or Pleistocene age for much of the lacustrine deposits is suggested by small collections of fossils. Basal sandstone shown in section B (fig. 3) contained bones identified by Jean Hough of the U.S. Geological Survey (written communication, 1952) as parts of the radius and ulna of a large camel, perhaps *Camelops*, a Pleistocene form. Mrs. Hough points out, however, that large camels existed in Pliocene time as well, and identification of the bone fragments was tentative. The beds could, therefore, be of either Pliocene or Pleistocene age. According to T. C. Yen of the U.S. Geological Survey (written communication, 1952), snails found at the site of section C

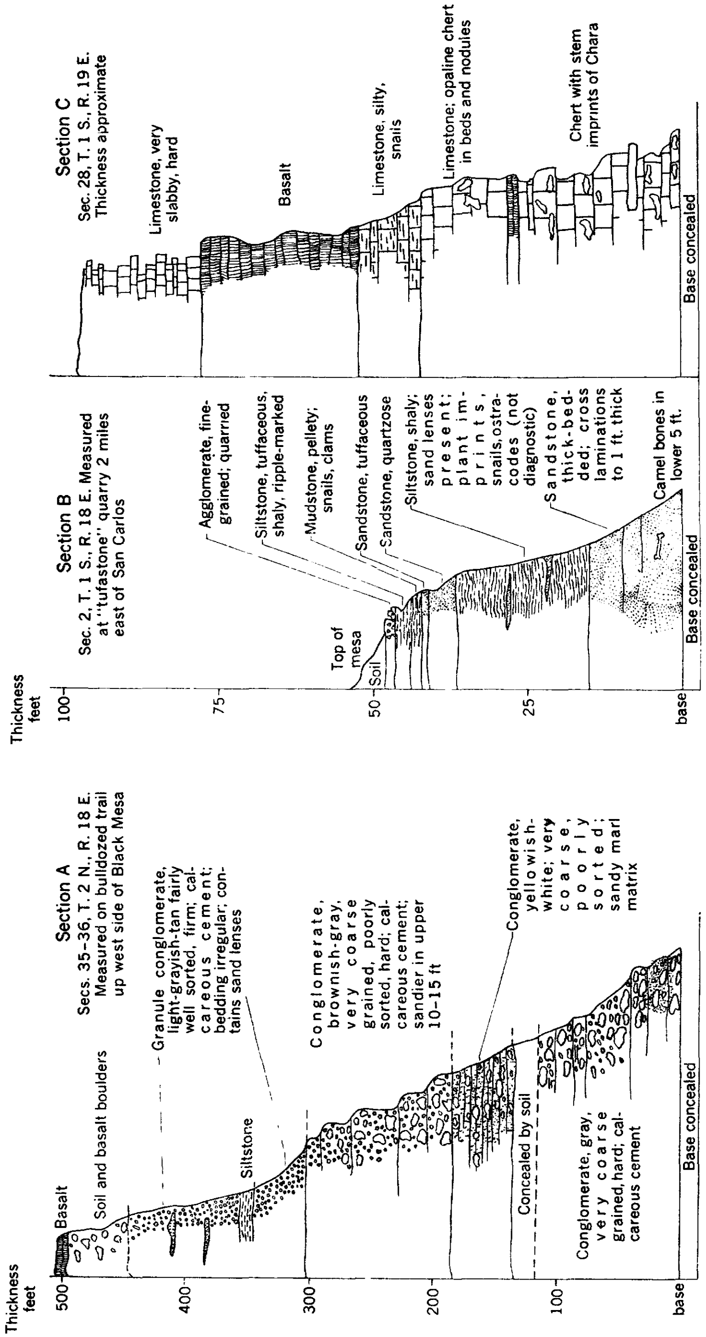

FIGURE 3.—Stratigraphic sections of lake beds probably equivalent to the Gila conglomerate, San Carlos Indian Reservation, Ariz.

(fig. 3) are identifiable as *Physa* sp. and *Physa* cf. *P. anatina* Lea. He considers the forms suggestive of early Pleistocene age.

The occurrence of gypsum and of diatomaceous earth of low economic value in the lacustrine sequence has been discussed by Bromfield and Shride (1956).

OTHER BASINS

So far as is known, the lake deposits of the Tonto and Payson Basins have not been described elsewhere. As these beds were examined but superficially, it can be noted here only that the beds in the Tonto Basin differ markedly from those in the other basins. Their predominantly red and green shades, and the presence of gypsum in beds and as crystals or anhedral masses disseminated profusely in silt and clay, are the obvious points of difference. Many erosional remants in the basin, each 50 to 150 feet in height, appear to consist of more than 50 percent gypsum. In color, texture, and high gypsum content these strata bear a striking resemblance to strata in the Lower and Middle(?) Triassic Moenkopi formation near Snowflake. No genetic relation to the Moenkopi has been established, however.

In the Payson Basin the lacustrine sediments include a fairly high proportion of sand and pebbles. Some of the beds are buff to light rusty red, but the prevailing colors are light creamy yellow to white, more nearly comparable to the color of beds in the Verde and San Carlos basins than to the color of beds in the neighboring Tonto Basin. A few snails were found in the limestone in the Payson Basin, but the forms have not been identified.

ALINEMENT OF LAKE-BED AREAS

A northwestward alinement of the four areas of lake deposits is apparent on the map (fig. 2). The Verde Basin is tentatively interpreted in the present report as a graben. The Payson Basin is almost certainly a graben. On Table Mountain, near the center of the basin, horizontal strata of the Tapeats sandstone of Cambrian age occur about 1,000 feet topographically lower than equivalent beds in the Mazatzal Mountains (Wilson, 1939, pl. 10) to the southwest and on the hills to the northeast of the Payson Basin near Payson (pl. 4). It is possible that the four lake-bed areas mark a generally depressed region southwest of, and parallel to, the Mogollon Rim. Outside the Mogollon Rim region, alinement of ancient lake deposits continues southeastward through the Safford Basin in the Gila River basin, and through San Simon Valley to Lakes Guzmán and Santa María, in Chihauhau, México. Much additional work will be needed, however, to evaluate the significance of this striking lineation.

TRAVERTINE

Travertine deposits of significant size were observed at 10 localities (fig. 2). Active deposition is continuing at four places: Tonto Natural Bridge, Fossil Creek, Salt Banks on the Salt River, and Alchesay on the White River. No recent deposition had occurred on the other six terraces. Several features of the travertine deposits are noteworthy

The observed travertine deposits range widely in size. The smallest is at Verde Hot Springs, where the travertine clings to volcanic rock above the present spring orifices. The deposit is about 20 feet long and from less than a foot to 5 feet in other dimensions. The deposits at Fossil Creek and on the White River are each about half as large as the famous Mammoth Hot Springs in Yellowstone National Park, Wyo. The inactive terrace at Fossil Creek is nearly a mile long and more than half a mile wide (fig. 4) and extends several hundred feet up the slope of the mountain against which it lies. The terrace terminates in a sheer cliff about 100 feet high facing Fossil Creek. Deposi-

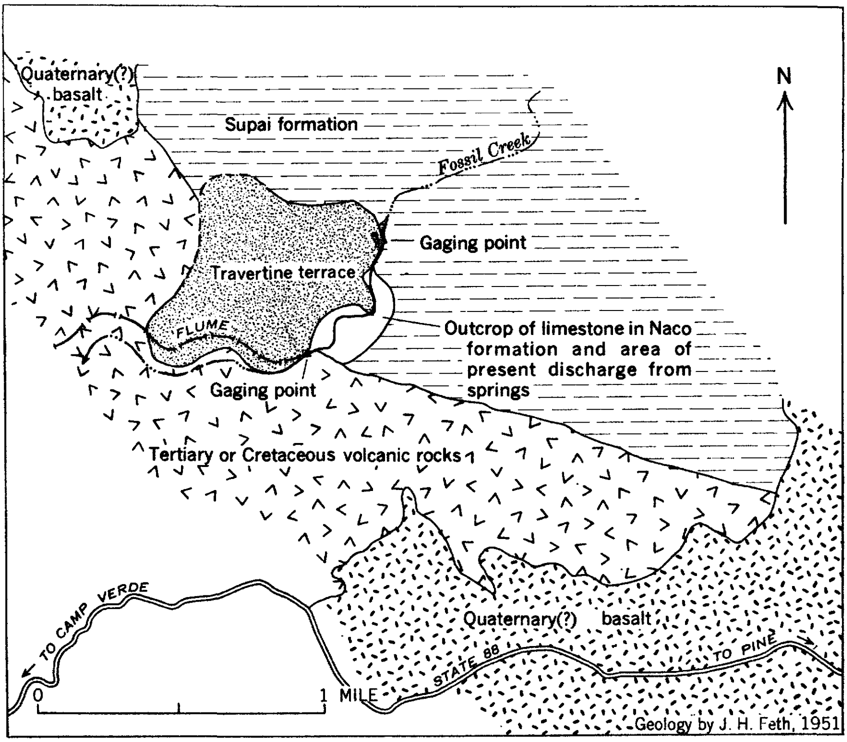

FIGURE 4.—Sketch map of geology of the area near the head of perennial flow in Fossil Creek.

tion of travertine in the Fossil Creek spring area is taking place about the orifices of most of the springs, all of which now discharge within a zone extending from creek level to about 10 feet above creek level. The White River terrace (fig. 2) is more than 1½ miles long and about half a mile wide, and the deposits are 50 feet thick at the river margin of the terrace.

The Tonto Natural Bridge is a tourist attraction of some note. This travertine terrace spans Pine Creek about 180 feet above creek level. Travertine is being deposited from seeps on the lower 10 or 15 feet of the buttresses that support the span. Deposition is taking place also in an artificial ditch that conducts flow from a spring that issues on the surface of the terrace at its upstream end. Travertine has nearly closed over the top of some parts of the ditch, as well as having formed a solid flume of travertine in the ditch.

Two periods of travertine deposition related to late basaltic eruptions along the Mogollon Rim are indicated. The White River terrace rests on basalt that flowed down the canyon of the White River, after the canyon had already been well established. The Corduroy terrace (fig. 2), on the other hand, is overlain by a layer of oxidized red soil less than 1 foot to about 3 feet thick, which in turn is overlain by basalt. Leaf imprints from the travertine of the Corduroy terrace were examined by R. W. Brown of the U.S. Geological Survey (written communication, 1951), who reports *Salix* sp. (willow), and *Prunus* sp. (cherry or plum) and considers the composition of the flora and appearance of the leaves to indicate the latter half of the Cenozoic era. If the basalt capping the Corduroy terrace and the basalt underlying the White River terrace are of comparable age, the deposition of travertine was contemporaneous with the later stages of basaltic activity along the rim. The other travertine terraces examined are not in contact with basalt.

The terraces at Fossil Creek, Tonto Natural Bridge, Wailing Cow, and Corduroy rest upon 2 to 10 feet of boulders, cobbles, and pebbles, which overlie the bedrock and which are cemented by the oldest part of the travertine. These basal conglomerate deposits are integral parts of the terrace deposits and, where terraces are cut by gullies that reach the bedrock, are seen to extend continuously beneath the travertine. The conglomerate deposits thus indicate that travertine deposition progressed upward, and suggest that artesian pressures at one time were adequate to force water to emerge at levels as much as 100 feet above the base of the terrace. At the localities named, the base of the conglomerate is now 5 to at least 150 feet above the stream channel. Artesian pressures of the magnitude suggested do not exist at present in the region.

Qualitative spectrographic analyses of 21 travertine samples were made by Prof. J. W. Anthony, University of Arizona. The samples represented, respectively, 3 zones at Tonto Natural Bridge, 6 at the Salt Banks, and a complete section of the Wailing Cow travertine terrace, sampled at 5-foot intervals. The basal zone at Wailing Cow showed only a very faint strontium line. A sample from the far upstream end of the terrace at Tonto Natural Bridge showed calcium only—no other metallic elements. This part of the terrace had presumably been subject to leaching and weathering for a long period. The remaining 19 samples from the 3 terraces showed definite strontium lines.

Interestingly enough, a single sample from the gypsum series of lake beds in the Tonto Basin, and two random samples of limestone from the lake beds in the Payson Basin, also showed the presence of strontium. Seven samples from zones shown in measured section B (fig. 3) in the tuffaceous facies of the lake beds in the San Carlos Basin were run. Possible faint strontium lines appeared in two instances. The other five samples were barren of strontium. The common occurence of strontium in evaporites of the Mogollon Rim region suggests that the element is widespread in the older rocks from which the salts deposited by evaporation must have been leached. A search for strontium-bearing minerals to be used in age determinations might prove rewarding.

IGNEOUS ACTIVITY

PRECAMBRIAN AND CAMBRIAN(?) INTRUSIVE ROCKS

Precambrian intrusive rocks in the region near Payson were mapped and described by Wilson (1939, p. 1127–1130), in the Clifton-Morenci area by Lindgren and Boutwell (1905, p. 2–3, 9), and in the Jerome area by Reber (1938, p. 46–50). The general pattern of outcrops of Precambrian intrusive rocks is shown on the geologic map of the State of Arizona (Darton and others, 1924). In the present study, rocks of this category were of interest primarily in that locally they constitute a basement of low permeability and help to control the occurrence of springs. They were not otherwise considered.

Diabase, tentatively assigned to the Cambrian by A. G. Shride of the U.S. Geological Survey (oral communication, 1951), occurs in the Salt River canyon as dikes, and more commonly as sills that range in thickness from less than 1 inch to at least 200 feet. In that locality, Shride found the diabase intruding the Troy quartzite (Cambrian) and all older formations, but at no place was diabase found intruding the Martin formation of Devonian age, which unconformably overlies the Troy quartzite. Shride considers the intrusions to have taken place probably, but not certainly, in Late Cambrian time, as no exposures were found that showed the Martin formation in contact with eroded diabase surfaces. Comparable diabase intrusions occur throughout the southeastern part of the Mogollon Rim region, where rocks of the Apache group and the Troy quartzite are exposed.

No other intrusive rocks were observed in the present investigation except for a few basaltic feeder dikes related to extrusive rocks of Tertiary and Quaternary age in the Oak Creek Canyon area.

EXTRUSIVE ROCKS

Precambrian extrusive igneous rocks in the Payson region were described by Wilson (1939, p. 1120). More than 2,000 feet of agglomerate and tuff of probable Cretaceous and Tertiary age are exposed in the valley of Fossil Creek (fig. 4). The State geologic map (Darton and others, 1924) shows a broad belt of volcanic material that trends south-southwestward and separates the lake deposits in the Verde Basin from those in the Payson Basin. Map relationships suggest that the volcanic rocks rest on Permian strata north of the Verde-Payson axis, and for the most part on Precambrian metamorphic rocks south of the axis. So far as is known, no intensive study of these volcanic rocks in central Arizona has been made.

At Fossil Creek about 100 feet of basalt caps the canyon rims on both sides. The basalt is thought to be of Quaternary age. Elsewhere in the Mogollon Rim region, basalt flows of Tertiary or Quaternary age are a prominent feature of the geology. On the San Carlos Indian Reservation basalt flows cap hundreds of square miles of plateau and mesa lands. Other flows are intercalated with lake deposits in the San Carlos and Verde Basins.

Northward, the margin of the Colorado Plateau is capped by volcanic materials, largely basalt flows and cinders. A mountainous region where volcanic rocks are widely exposed extends from the Clifton-Morenci district northward along the State line to and beyond Springerville.

In areas south of the rim basalt occurs less commonly, although in the Verde Basin the Verde formation rests in many places on an erosional surface having steep-walled canyons cut at least 200 feet into basalt. In the same area basalt flows are found locally interstratified with the Verde formation, and other flows cap strata of the Verde. At a few places in Oak Creek Canyon, strata of the Verde overlie basalt that rests on the Supai formation. Northeast of the limits of the Verde formation basalt rests on rocks of the Supai formation.

CANYON BASALTS

The occurrence of basalt flows within the canyons of three southward-draining streams is of interest. The canyon basalts have been observed only along Sycamore Creek northwest of Cottonwood, and along Forestdale Creek and the White River, near Show Low. In each, the flow is several miles long and 200 feet to about 1,000 feet below the canyon rims. The basalt in places has been completely cut through by the stream; elsewhere it rests on sedimentary rocks a few feet to 50 feet or more above the present stream channel.

STRUCTURE

The basic structure of the Mogollon Rim region is a northward-dipping homocline, passing northward into the more nearly horizontal strata of the Colorado Plateau and terminating to the south in a scarp that, as suggested by alined basins, is of structural origin. The major structure is modified by several minor structures.

FOLDING

The largest fold known in the Mogollon Rim region, the Holbrook structure (pl. 1), was described by Darton (1925, p. 202–203), who noted that it passed into a monocline at its west end. Approximately 4 miles north-northeast of Snowflake, near the east end of the Holbrook structure, Silver Creek has cut a gorge through the Coconino sandstone. To the south, an artesian basin occurs in the valley of Silver Creek; the Coconino sandstone is the aquifer. Incomplete investigation suggested that the Silver Creek valley, upstream from Snowflake, occupies a structural trough. This trough is diagramitically illustrated on the geologic section (pl. 3, section *A–A′*).

A phenomenon common in the Oak Creek Canyon area is reverse drag of strata adjacent to faults of the Oak Creek fault system. Mears (1950a, 1950b) discussed the occurrence and presented hypotheses to explain its origin. He concluded that, for the Oak Creek Canyon examples, the most satisfactory explanation involves faulting and normal drag, subsequent reversal of direction of movement along the faults, and preservation of drag direction because of lubrication resulting from gouge in the fault zones.

In the canyon of Wet Beaver Creek in the Verde Valley (pl. 1), the Verde formation has been warped into gentle alternate anticlinal and synclinal folds having crest-to-crest magnitudes of a few tens of feet, and amplitudes ranging from a few feet to a maximum of about 10 feet. Montezuma Well (pl. 1) is a spring located a few miles up the valley of Wet Beaver Creek from Montezuma Castle. The "well" is interpreted as a collapse depression in limestone of the Verde formation that is locally domed to form a hill about 100 feet high. According to E. D. McKee of the U.S. Geological Survey (oral communication, 1949) soundings in the pool of water that occupies the "well," and exploration by a diver, showed the bottom to be about 50 feet and below the water surface to be approximately level, having no marked depressions or "bottomless pits." Water from the pool emerges through an opening a few feet wide and about 2 feet high in one flank of the dome.

FAULTING

FAULTING TRANSVERSE TO THE RIM

As the investigation progressed, it became evident that marker formations of Paleozoic age occur along the Mogollon Rim at altitudes differing by more than 2,000 feet at points visited. A compilation of these observations led the senior author to the tentative conclusion that the Mogollon Rim can be divided into three sections which may represent major structural blocks. This division into western, central, and eastern sections shown on the index map (fig. 1), is tentative and necessarily arbitrary. Detailed mapping would be required to determine whether the divisions of the rim occur along rather narrow zones of large-scale faulting transverse to the trend of the rim, or whether the relative elevation or depression of a formation used as a structural marker results instead from accumulated movement along numerous faults of relatively small throw distributed over a broader area, from folding, or from a combination of movements.

In the western division the lower part of the Supai formation occurs most commonly at altitudes ranging from about 3,500 to 4,500 feet in the area around Cottonwood and Sedona, and, so far as observed, eastward to Fossil Creek. In the central division, the base of the Supai formation is found most commonly between 4,500 and 6,000 feet, between Payson and Tonto Creek. The eastern half of the central division was almost untouched in the present reconnaissance. In the eastern division, on the Fort Apache Indian Reservation, the base of the Supai formation, so far as observed, lies in the range from 4,000 to 5,000 feet. Granting that lateral variations in thickness of the formations underlying the Supai may account for some of the differences in altitude, it is nevertheless the senior author's opinion that in general the western division is structurally lowest; the central division is structurally highest; and the eastern division, north of the Salt River, is intermediate in degree of uplift.

Altitudes at the base of the Martin formation observed in the Payson region are summarized in the following table. Data have been compiled from locations and descriptions of sections given by Huddle and Dobrovolny (1952, p. 103–104) and from observations made by the senior author. The localities are arranged in order from west to east. The rise in altitude of the base of the Martin formation from west to east is tentatively considered to be the result of movement along a series of faults transverse to the rim. The decline in altitude from Diamond Point to Tonto Creek is an expression of dip of the strata on that structural block.

Altitude of the base of the Martin formation (Devonian) at points in the Payson region

Locality	Altitude, base of Martin formation (feet)
1. East Verde River, west of Pine-Payson road	4,000±300
2. East Verde River, half a mile east of Pine-Payson road	4,600
3. Wailing Cow Ranch on East Verde River	4,600
4. Ellison Creek, at Cold Spring	5,250±50
5. Diamond Point, one-foruth mile east of fire lookout tower	5,750±50
6. Tonto Creek, 1 mile north of Kohl Ranch	5,400±50

FAULTING PARALLEL TO THE RIM

The geologic map of Arizona (Darton and others, 1924) shows faults parallel to the rim in only a few places, as follows: (1) Sycamore Canyon northwest of Cottonwood; (2) the Jerome mining district immediately southwest of Cottonwood; (3) the area between the north end of the Mazatzal Mountains and the rim near Pine; and (4) the Sierra Ancha north of Roosevelt Reservoir. It is only in the areas named above that sufficient work, even of reconnaissance nature, had been done by 1924 to identify such structures.

Two traverses are presented as diagrammatic sections (pl. 3). The sections drawn to illustrate structures between Payson and Ellison Creek (pl. 4) are based on a complete traverse. The vertical and horizontal scales are the same. The two diagrammatic sections in figure 6 extending from San Carlos northeastward across the Natanes and Mogollon Rims, in which the vertical scale is exaggerated, combine information obtained in the present investigation with information shown on the State geologic map. As only reconnaissance topographic maps are available for the Indian reservations, it is difficult to reconcile geology with topography in those areas. It is believed, however, that the general pattern of structural features and outcrops in relation to topography is properly illustrated.

Geologic controls in the Verde Basin remain puzzling. The depth to consolidated rock in the trough below the present land surface approaches 2,000 feet, inasmuch as Jenkins (1923) reported penetration of strata of the Verde formation to as much as 1,650 feet by wells which did not pass out of the Verde. Anderson and Creasey (1958, p. 84) reported faulting on the southwest side that caused elevation of the Black Hills relative to the valley block. They refer to the Verde Valley as a dropped block bounding the Black Hills horst. The senior author finds in these facts, and in the regionwide alinement of Pliocene and Pleistocene lake basins of which the Verde Valley is one, strong suggestion of a major structure bounding the Colorado Plateau. It seems reasonable to consider the Verde Valley as a probable graben.

Recent work in the Verde Basin (D. G. Metzger, written communication, 1960) has not shown the presence of boundary faults on the northeast side of the trough, however. Possibly there are faults on the northeast, concealed under cover of the Verde formation. An alternative possibility is that an ancestor of the modern Verde River carved a great canyon that was temporarily obstructed, causing the lake to form in which the Verde formation was deposited. Present information does not appear to be sufficient to resolve the problem.

In the eastern division, the stratigraphy and fault structures characteristic of the Mogollon Rim extend about 50 miles farther south than in the western and central divisions. The Natanes Rim (pl. 3, section B–B′) is therefore considered to be the structural equivalent of the Mogollon Rim as the latter is developed in the western and central divisions. In part of the eastern division the Mogollon Rim does not exist as a well-defined escarpment; the Natanes Rim does. The geologic sections in plate 3 have been prepared to illustrate the relations described above. Although the Apache group, exposed on the Natanes Rim, is far older than rocks at the base of the Mogollon Rim near Oak Creek, rocks of the Apache group are exposed at the base of the Mogollon escarpment, in the eastern part of the Tonto Basin (Wilson, 1939, p. 1148–1153) in an area near the middle of the central division.

The Payson-Ellison Creek sections (pl. 4) were drawn only across the traverse mapped and are not long enough to show the regional pattern in the Payson region, where 2 and perhaps 3 rims are present, probably as the result of repetition of structures and stratigraphy caused by faults paralleling the rim. They serve, however, to illustrate structures characteristic of many places in the Mogollon Rim region.

AGE OF REGIONAL STRUCTURES IN CENTRAL ARIZONA

Wilson (1939, p. 1161–1162) states in his summary that "long before [late Precambrian] Apache sedimentation, the [central Arizona] region underwent a profound crustal disturbance, termed the Mazatzal Revolution." The resulting structures included "subparallel folds, thrust faults, and imbricate, steeply dipping reverse faults, generally of northeastward to northward trend." The granite of Precambrian age that is exposed so widely, in the vicinity of Payson for example, represents a batholithic intrusion that, in the Mazatzal Mountains at least, "is definitely of post-Mazatzal—pre-Apache age." And he concludes: "The central Arizona region underwent no great deformation between the Mazatzal Revolution and the Tertiary Basin and Range orogeny." Creasey (1952), however, reported post-Cambrian but pre-Tertiary faults in the Black Hills, which form the southwestern boundary of the Verde Basin.

Fenneman's summary (1931, p. 324–325) of the physiographic history of the Colorado Plateau province includes periods of uplift as follows: (1) general uplift, local swells, and formation of the great monoclines in a period beginning with the close of the Cretaceous; (2) late Eocene or post-Eocene uplift; (3) another undated period of major uplift in Tertiary time; (4) inauguration of the canyon cycle of erosion by "great general uplift" at or after the beginning of Quaternary time.

Threet (1951, p. 1513) briefly described overthrust faulting in a block west of the Hurricane Cliffs adjacent to the western margin of the Colorado Plateau—an area structurally analogous to the area of interest in the present report. Threet's evidence indicates overthrusting in Late Cretaceous time. He considers the overthrusting to be related to Laramide flexures in the plateau.

In the eastern division of the Mogollon Rim, Upper Cretaceous strata appear to lie with angular unconformity upon the Kaibab limestone. This relationship was illustrated diagrammatically by Darton (1925, fig. 29, p. 202). East of Darton's section the Cretaceous strata are in depositional contact with Coconino sandstone of Permian age on the southwest and with the Moenkopi formation of Triassic age on the northeast. These relationships indicate northward or northeastward tilting of the area from post-Moenkopi to pre-Late Cretaceous time.

Widespread deposits of gravel along the Mogollon Rim are at least 200 feet thick in some areas. As these gravels are considered to be of Tertiary age, and as they are overlain in places by basalt of Tertiary or Quaternary age, the deposits provide evidence of very large-scale structural movements in the area south-southwest of the Mogollon Rim in late Tertiary or Quaternary time, or both.

Robinson (1913, p. 36) described faults in the Flagstaff region as post-Pliocene. More recently, Mears (1950b, p. 1557) speaks of the Oak Creek fault as Pliocene and indicates that gravels on the rim in the Oak Creek area are of Miocene age and are overlain by basalt of Pliocene age. McKee (1951, p. 498–500) summarized evidence suggesting that major uplift in the Prescott region, south-southwest of the rim, occurred in late Miocene or early Pliocene time.

Reconnaissance investigation of the lake deposits in the Payson Basin suggests that there is gradation from coarse clastic materials at the south end toward evaporites and finer grained clastic deposits at the north end, indicating a source area toward the south. However, these beds dip southward at angles ranging from less than 1° to perhaps as much as 3°, thus reversing what would be normal depositional slopes. It is probable, therefore, that the area was gently tilted southward after the lake beds were formed. By analogy with lacustrine strata at San Carlos, dated on fossil evidence as Pliocene(?) to early Pleistocene, the tilting must have occurred since early Pleistocene time.

Records of earthquakes in the Mogollon Rim region have been summarized by Heck (1947, p. 48–62). In the period 1868–1938 there were 25 earthquakes intense enough to be reported by inhabitants of the region. Of this number, 9 were felt in Flagstaff, Snowflake, Cottonwood, Whiteriver, or the Clifton-Morenci district. Most of them were in the 4 or 5 range on the Mercalli earthquake-intensity scale. One, however, on September 23, 1910, centered apparently north of Flagstaff, was of intensity 8 to 9. The earthquake evidence indicates that the rim region is still one of mild seismic activity, and therefore a region in which fault movement continues to some degree.

Information presented in the preceding paragraphs is interpreted to indicate that faulting has occurred in the Mogollon Rim region at various times from Wilson's (1939) Mazatzal Revolution to, and including, the present. There appear to have been four major periods of orogeny, namely Precambrian; Miocene(?), southwest of the rim; late Tertiary, possibly Pliocene; and at or near the beginning of Quaternary time. Structures formed during the Laramide revolution in Late Cretaceous and early Tertiary time, although dominant elsewhere in the Plateau province, appear to be of relatively minor significance in the history of the Mogollon Rim. The rim is still a region of structural activity, but on a greatly subdued level relative to the four major orogenic periods.

WATER RESOURCES

LAKES, PONDS, AND MARSHES

Both artificial and natural lakes are present in many localities on the plateau portion of the Mogollon Rim region. Lake Mary, near Flagstaff, and Lyman Reservoir, on the Little Colorado River near St. Johns, are examples of artificial lakes. Lake Mary has provided much of Flagstaff's muncipal water supply. Water stored in Lyman Reservoir is used for irrigation.

Mormon and Ashurst Lakes, near Flagstaff, are two of the larger natural lakes and are considered characteristic of natural lakes in the rim region. Mormon Lake is about 4 miles long and 2 miles wide. When full, it is reported to have a maximum depth of less than 6 feet. In periods of successive years of subnormal precipitation the lake dwindles to a muddy puddle, or dries up entirely. Ashurst Lake is less than half the size of Mormon Lake but tends to be more permanent; at the deepest point, however, it is still a shallow, reed-grown pond. Between Show Low and Springerville there are many dozen "cienagas" (swamps or marshes) of varying sizes, many occupied at times by ponds. In the fall of the year, or in other periods of deficient rainfall, these ponds become mud-coated areas. Their possible value as recharge areas is discussed later in this report.

GROUND WATER

SOURCE

The source of virtually all ground water discharged in the Mogollon Rim region is precipitation falling as rain or snow. Data for determining the volume of water falling on the region are only partly adequate. Similarly, data on runoff, discharge from springs, and pumping from wells are incomplete.

Despite the wide margin of error involved, the following analysis has been made to show the ratio between known spring discharge and average annual precipitation. The plateau part of the rim region lies north of the crest of the escarpment and is roughly 200 miles long and 50 miles wide. It is in approximately this area that the springs tabulated in table 2 receive recharge. Weather data (U.S. Weather Bureau, 1953) indicate that an assumed precipitation of 16 inches per year is conservative. By use of these figures, an annual precipitation of about 8,500,000 acre-feet may be computed. Table 2 shows that springs measured in the present investigation discharge a maximum of about 150,000 acre-feet annually. Thus, less than 2 percent of the

TABLE 2.—*Summary of maximum aggregate discharge of springs in the Mogollon Rim region visited prior to December 1952*

Area	Discharge (gallons per minute)	Source rock	Discharge (gallons per minute)
South-flowing springs:		Quaternary or Tertiary:	
Western division	37,500	Alluvium	5,200
Central division	31,400	Volcanic rocks	12,000
Eastern division	16,000	Verde formation	17,000
		Permian:	
Total	85,000	Kaibab limestone	20
North-flowing springs	[1] 5,500	Coconino sandstone	220
		Permian and Pennsylvanian: Supai	1,300
Total	[2] 91,000	formation (excluding spring in Grand Canyon)	11,300
		Pennsylvanian: Naco formation	22,000
		Mississippian: Redwall limestone (excluding springs in Grand Canyon)	5,200
		Devonian and Cambrian (excluding springs in Grand Canyon)	6,400
		Precambrian	80
		Total	[3] 79,400
		Flow in Oak Creek from unidentified sources	11,800
		Total	91,200

[1] Does not include discharge of 137,000 gpm from Indian Garden, Blue Spring, and the Havasu group, all which discharge in Grand Canyon far north of rim region.

[2] Equivalent to nearly 150,000 acre-feet per year.

[3] Does not include 11,000 gpm of flow in Oak Creek that was not assigned to identified sources, but is included in western division total in adjacent column of this table.

total precipitation on the rim region appears as spring flow in the region. It may be that the true figure is as little as 1 percent or as much as 4 percent, but the data serve to establish the smallness of the ratio of spring discharge to precipitation.

RECHARGE

Much of the recharge on the plateau portion of the Mogollon Rim region occurs by direct infiltration of rain and of snowmelt. Additional recharge takes place by seepage from runoff in the few permanent and the many intermittent streams that cross areas of permeable rock.

An outstanding feature of the geology of the recharge areas is the high recharge receptivity of the surface rocks. Most of the plateau is underlain by basalt, cinders, or the Kaibab limestone. Most of the basalt flows are jointed and shattered and conduct water downward rapidly, except where intercalated beds of clay or weathered ash provide local layers of relatively low permeability. The occurrence of springs in basalt is largely controlled by such low-permeability layers, although locally some basalt flows appear to be tight and thus to impede the downward movement of water. After emergence as spring discharge, the water in many places percolates downward again through fractures in the basalt.

In a few areas in the western division and in many in the eastern division, water falling on the volcanic rocks is temporarily impounded in open, unforested areas, locally referred to as "parks" or "prairies." In these areas the land surface generally is underlain immediately by clay, which greatly retards downward percolation of water, although the rocks on which the clay layers rest may be highly permeable. Temporary lakes and ponds exist in such localities for parts of most years. The origin of some of the parks and prairies in the Flagstaff region has been tentatively related to nearby geologic structures, and to extensive falls of volcanic ash (Feth, 1952). Parks and prairies are most common in the eastern division. Cienegas are numerous but are of little value even for grazing.

In the central division, the rocks exposed on the plateau are mostly the Kaibab limestone and the Coconino sandstone. Both formations are highly permeable, especially where they are jointed or otherwise broken along the rim. The degree to which fissures in the Kaibab limestone provide opportunity for recharge is suggested by Colton (1938, p. 29–32), who describes exploration to levels as much as 275 feet below the land surface in solution openings in the Kaibab limestone. Some of the fissures he examined extended below the base of the Kaibab into the Coconino standstone. Solution of limestone along faults of small displacement is cited by Colton as the origin of the fissures.

Conditions relating to recharge south of the rim have not been investigated. Patently, there is some recharge by infiltration of water from both permanent and intermittent streams where they cross areas underlain by permeable but unsaturated rocks. It is probable that interformational leakage, in zones in which water occurs under artesian pressure, constitutes a source of water for some rock units. The importance of such recharge in supplying shallow aquifers in the valleys below the escarpment may be great. A study of all sources of recharge in the Verde Basin would be especially worthwhile, as the potential for ground-water storage appears to be large.

POTENTIAL ARTIFICIAL RECHARGE

Possibilities for artificial recharge and resulting increases in the amount of ground water moving north and south from the rim appear to be particularly promising because of the high permeability of the surface rocks throughout the entire plateau portion of the rim region.

So far as is known, no attempts have been made to supplement natural recharge along the Mogollon Rim by artificial means. Structures to detain springtime snowmelt and water from summer rains in areas of jointed and shattered rocks should be considered. Some of the marshy areas offer another possibility worthy of examination, as they are natural water-catchment and surface-storage areas. It is thought that piercing of the clay seals would permit downward percolation to the underlying aquifers, at least in some localities. A program of artificial recharge would probably salvage water that cannot now be used beneficially. The geologic and hydrologic relations need to be worked out, however, and a complete program cannot be devised without consideration of the possible effects upon existing surface-water supplies.

A program of "prescribed burning" on the Fort Apache Indian Reservation is worthy of close examination. Designed to improve the use of forests for grazing and for timber growth, the burning program appears also to have a marked effect on the water crop derived from the burned areas. Older Indians report (H. F. Kallander, oral communication, 1952) that in burned-over areas springs that had been dry for as much as 30 years began to flow soon after the burning. Highly useful information could be collected by obtained streamflow and precipitation records in areas that are to be burned a few years in the future, and by continuing the records for a few years after burnings. Such records might reveal a method whereby the yield of an area in both surface runoff and ground-water recharge could be materially increased without damage to the watershed.

OCCURRENCE AND DISCHARGE

Discussion of occurrence of ground water in the rim region is concerned almost exclusively with its relation to the occurrence, localization, and discharge of springs. Table 5 presents the basic data on springs collected to the end of 1952. Some of the springs of larger discharge were measured several times in order to appraise their fluctuation. The springs of the region are classified as nonartesian or artesian. The nonartesian springs are classified as contact, fault, or conduit; the artesian as fault or conduit springs.

NONARTESIAN SPRINGS

Basalt flows are the aquifers supplying most of the contact springs. Williams Spring (table 1, No. 89), the spring at the head of Silver Creek (No. 71), and Concho Spring (No. 57) are among the largest in this category. Williams Spring on Williams Creek is tributary to the White River. The spring at the head of Silver Creek and Concho Spring are in the Little Colorado River drainage. In these three places, the water emerges at the contact between an impervious layer and the overlying basalt or intercalated gravel. All three are in the eastern division. Several other basalt springs in this division discharge from about 1 cfs to about 2½ cfs. A few nonartesian springs issue from volcanic rocks on the slopes of the San Francisco Mountain near Flagstaff; their discharges are reported to be rather large but they were not measured.

Contact springs emerge from sedimentary rocks of Paleozoic age in many canyons cut back into the rim. Yields range from less than 1 to about 200 gpm. The controlling contacts in some places are between a permeable sandstone and an underlying relatively impermeable siltstone. In other places the control was not determined. A number of springs of small discharge in the upper reaches of Oak Creek Canyon emerge along crossbedding planes in sandstone of the Supai formation.

Cassadore Spring, on the San Carlos Reservation, issues from jointed quartzite of Precambrian age along the contact with an underlying diabase sill. The springs at Tonto Natural Bridge emerge just above the contact between sandstone of Paleozoic age and Precambrian metarhyolite.

Springs that are localized by faulting but that do not show clear evidence of artesian head also are included in this category. Cold Spring, on Ellison Creek (pl. 4), emerges near the intersection of two faults. The low temperature of the water at Cold Spring, 55°F, suggests that the water table is intersected by faults that act as a barrier to movement. The wide fluctuation of discharge of this spring (table 3) indicates relatively small ground-water storage and a nearby recharge area.

TABLE 3.—*Fluctuations in discharge of selected springs in the Mogollon Rim region*

Spring No.	Name	Date measured	Discharge (gpm)
(A-1-20) 12	Warm Springs [1]	Apr. 11, 1951	3,325
		Feb. 21, 1952	3,400
(A-8-23) 4ab	Pinetop Spring	June 19, 1946	350
		Feb. 19, 1952	265
(A-8-24) 23d	Boy Spring	Dec. 7, 1951	5
		May 19, 1952	200
(A-8-25) 3c	Gooseberry Creek Spring	May 22, 1952	1,200
		June 23, 1952	715
(A-9-22) 36a	Big Spring, near Lakeside	Feb. 20, 1952	1,100
		May 22, 1952	1,030
(A-11-10) 9b-1	The Grotto Spring	May 15, 1952	350
		July 10, 1952	10
9b-2	Big Spring, on Webber Creek	May 15, 1952	175
		July 10, 1952	100
(A-11-23) 20d	Silver Spring	Feb. 14, 1952	2,100
		June 12, 1952	3,220
(A-11½-11) 30dc	Cold Spring	May 17, 1952	4,200
		July 11, 1952	1,060
		Nov. 11, 1952	830
(A-12-7) 14	Fossil Creek, sum of many springs	June 12, 1946	[1] 19,125
		June 26, 1947	[1] 19,200
		Feb. 15, 1952	[2] 18,600
		July 10, 1952	[2] 18,620
(A-12-26) 19	Concho Springs [1]	June 17, 1946	1,325
		June 12, 1947	1,275
		June 22, 1948	1,125
		June 28, 1949	1,100
		July 17, 1950	1,175
		June 18, 1951	1,300
		Dec. 6, 1951	1,120
		June 19, 1952	1,120
		June 29, 1952	1,050
(A-16-4) 15da-1	Treeroot Spring	Feb. 12, 1952	380
		July 9, 1952	260
15da-2	Bubbling Pond	Dec. 11, 1951	4,125
		Feb. 12, 1952	3,500
		July 9, 1952	4,150
		Dec. 10, 1952	4,100
15dd	Turtle Pond	Feb. 12, 1952	160
		July 9, 1952	135
		Dec. 10, 1952	160
16ddd	Spring Creek, sum of many springs	Feb. 12, 1952	2,700
		July 9, 1952	2,400
		Dec. 10, 1952	2,950
(A-17-3) 5dbd	Summers Spring	Oct. 10, 1951	2,700
		Feb. 16, 1952	2,375
		June 19, 1952	2,350
		Dec. 12, 1952	2,275
(A-20-6) 13	Sycamore Creek at Packard Ranch [1]	July 10, 1946	5,125
		June 24, 1947	4,950
		June 28, 1950	4,875
		June 13, 1951	4,550
		June 18, 1952	5,000
13cc	Fulton Spring	July 29, 1949	8
		July 9, 1952	10

[1] Measurement by Surface Water Branch, U.S. Geological Survey.
[2] Measured about 10 miles upstream from 1946-47 measuring point.

Springs in lower Webber Canyon, near Payson, are shown in figure 5, in relation to faulting in the surrounding area. The fact that this major group of springs discharges within the area of a graben illustrates a regional characteristic that is considered important and is

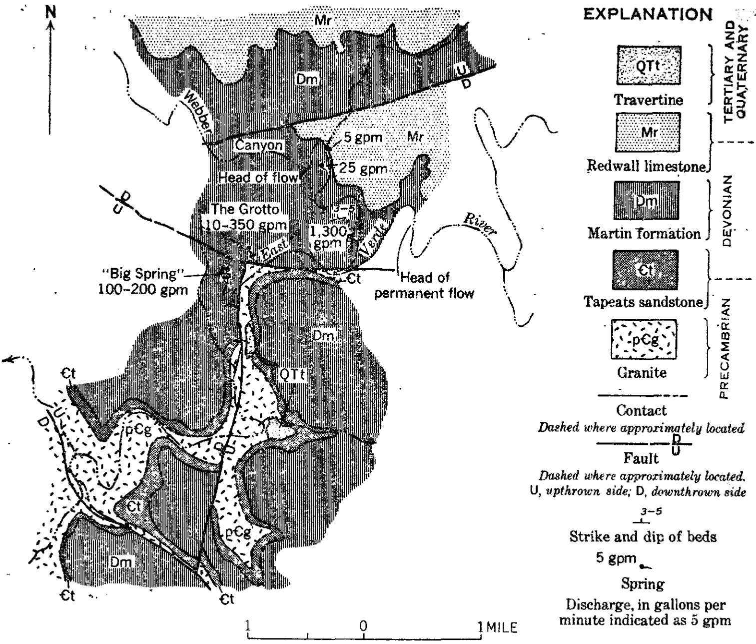

FIGURE 5.—Reconnaissance geologic map of Webber Canyon area near Payson, Ariz., showing occurrence of springs.

discussed in a following section on the relation of faulting to occurrence of springs.

The headwater springs in Oak Creek Canyon are classified as fault springs, as they emerge at the intersection of the water table with the Oak Creek fault and a westward-trending cross fault.

The clearest example of a limestone-conduit spring in the present study is Alchesay Spring on the White River. This spring issues from limestone of the Fort Apache member (of Stoyanow) of the Supai formation. The total discharge of the spring, which was determined as the difference in flow of the river above and below the spring-terrace area, aggregated about 7,500 gpm. At least two-thirds of the discharge emerges from a single orifice about 1 foot by 3 feet in cross section, as a dome of water several inches high. From this orifice the water flows about 250 feet across a travertine bench before cascading down the face of the terrace to the river. As only one discharge measurement was made, the range of fluctuation is not known.

Solution openings are prominent in exposures of the Redwall limestone. Summers Spring in Sycamore Canyon is probably a conduit spring, although it issues from soil and rubble and a direct relationship with the Redwall limestone must be inferred. As at Alchesay Spring, the Summers Spring waters emerge as low domes before cascading down a few feet to a channel in which they flow about 200 yards to Sycamore Creek. Three measurements in 1952 (table 3) indicate a relatively constant flow. Perhaps more significant are the measurements of the discharge of Sycamore Creek about 1½ miles downstream from the springs. The discharge was measured at the Packard Ranch on Sycamore Creek in June or July 1946, 1947, 1950, 1951, and 1952. The range in discharge was from 4,500 to 5,125 gpm. About half the total flow comes from Summers Spring; the remainder comes from springs and seeps in the Redwall in a reach extending up the canyon about 4½ miles beyond Summers Spring. The constancy and amount of discharge suggest a relatively large storage area for springs in Sycamore Canyon.

ARTESIAN SPRINGS

According to employees of the power company that utilizes the discharge of the springs at Fossil Creek, water from individual orifices tends to build travertine walls across the openings, thus raising the level of emergence. Occasionally, however, orifices become obstructed and new ones form at lower elevations. The springs issue from solution channels in limestone of the Naco formation, according to D. G. Metzger of the U.S. Geological Survey (written communication, 1960). The writer is indebted to D. G. Metzger and F. R. Twenter of the Ground Water Branch, Arizona district, for valuable indentification of formations in the western division especially, resulting from their studies in the Verde Valley and adjacent areas since 1952. The discharge of this group of springs was measured four times (table 3) and showed markedly little variation. The uniformity of flow suggests that a large storage area on the plateau is tributary to the Fossil Creek springs. The relative warmth of the water, about 71°F, indicates penetration to considerable depth before emergence.

A group of springs in the flood plain of Oak Creek together yield about 22,500 gpm. Their temperatures range from 67°F to 71°F, about 10° above the mean annual air temperature. The relatively high temperature suggests the possibility that the water percolates to considerable depth and is discharged under artesian pressure.

The springs at the Salt Banks on the Salt River, the White River Salt Springs, and those at Clifton discharge warm salty water under artesian pressure.

Warm Springs, on the San Carlos River about 15 miles northeast of San Carlos, emerge at 85°F from limestone in the Naco formation. A geologic reconnaissance map (fig. 6) shows the alinement of faults in the vicinity. It is probable that the fault shown trending northwestward, and approximately bisecting the area mapped, acts as a ground-water dam or barrier that causes the water to rise to the surface.

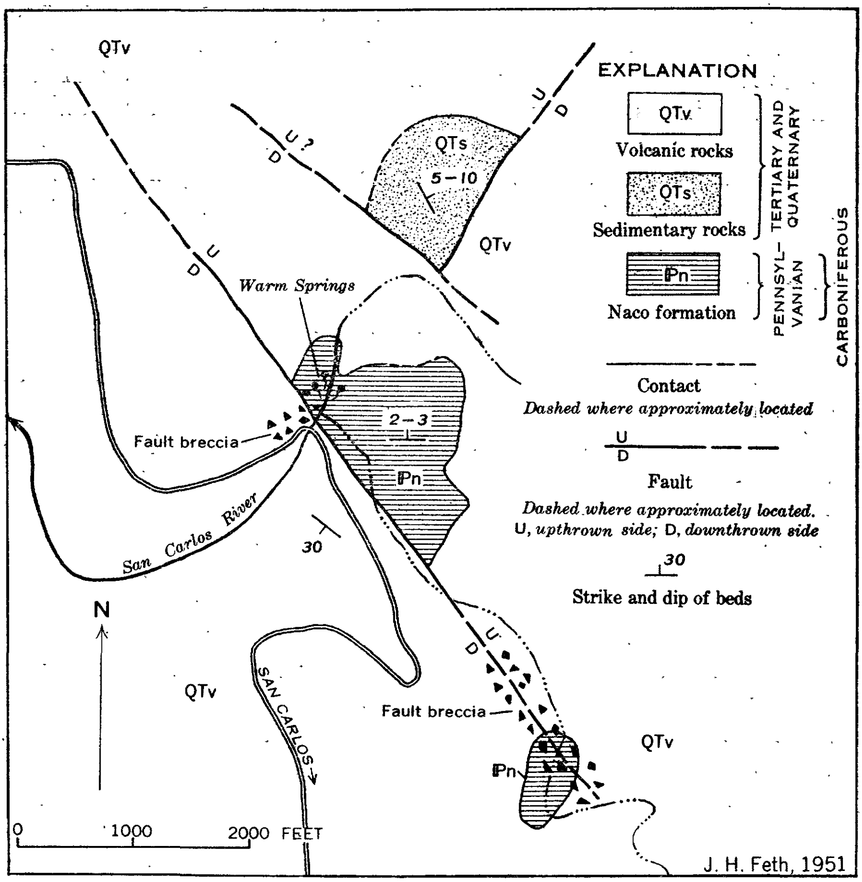

FIGURE 6.—Reconnaissance geologic map of Warm Springs area near San Carlos, Ariz.

SUMMARY OF SPRING DISCHARGE

The aggregate discharge of springs in the rim region is shown in table 2. The table shows that, of the 85,000 gpm of spring flow draining southward, the western and central divisions contribute about five-sixths and the eastern division, one-sixth. The spring flow draining northward, about 5,500 gpm, is derived predominantly from basaltic aquifers in the eastern division. Approximately 10 times as much spring flow moves southward from the rim region as moves northward. However, considerable northward-flowing spring discharge occurs outside the Mogollon Rim region as defined in this report. A few of the springs that emerge in the canyons of the Colorado and Little Colorado Rivers are reported in table 5 (Blue Spring and springs in Havasu Canyon) for comparison. Blue Spring, in the canyon of the Little Colorado River about 13 miles upstream from its mouth, discharges about 200 cfs, an amount nearly equivalent to the combined discharge of all southward-flowing springs measured in the Mogollon Rim region. Discharge of Blue Spring was measured several times by the Geological Survey.

Table 3 shows fluctuations in discharge of springs that were measured more than once, either during the present investigation or previously by the Geological Survey. The wide range of fluctuation in discharge of some of the springs during a single year is related to snowmelt. The low range of fluctuations in the flow of Fossil Creek springs, Sycamore Canyon springs, and Bubbling Pond is believed to indicate large volumes of ground-water storage.

INFLUENCE OF FAULTING IN LOCALIZING SPRINGS

The influence of faulting in localizing points of discharge from springs is believed to extend beyond those areas where faults serve as channels or as dams that restrict ground-water movement. It is the senior author's impression that a significant number of springs along the Mogollon Rim occur in structural lows, although at points of discharge the springs may be classified as contact of fault-dam springs.

It has been noted that the springs in Webber Canyon (fig. 5) discharge in a graben. The presence of a small graben that controls the occurence of springs is indicated at Tonto Natural Bridge. Two series of step faults, having individual displacements ranging from a few feet to 25 feet and a total displacement of about 50 feet, form the graben, which has an axial trend approximately at right angles to Pine Creek Canyon.

Another type of relationship between faulting and the occurrence of ground water exists in the Payson area. During most of the year, the flow in Webber Canyon, Bray Creek, Chase Creek, and the East Verde River decreases to zero along a line roughly parallel to and about 3 miles south of the Mogollon Rim. This line is believed to coincide with a fault zone that brings the Redwall limestone to or near the surface. The cavernous nature of the Redwall limestone has already been described (p. H30). Within less than a mile downstream, the flow of the East Verde River again becomes perennial for several miles, receiving an increment from Ellison Creek downstream from Cold Spring. At an undetermined point the flow again decreases to zero, and final permanent flow is not attained until a short distance above the junction of the East Verde River and Webber Creek (fig. 5). It is thought that the points at which the East Verde River becomes intermittent represent outcrops of the Redwall limestone, repeated by faulting.

POTENTIALITIES FOR DEVELOPMENT OF SPRINGS

One purpose of the present investigation was to delineate areas in which detailed studies would provide information on the possibilities of increasing the development of the water resources. The more promising areas are those in which conduit springs occur.

At Fossil Creek the discharge area is on a bench in the canyon. There are two ways in which the yield might be increased. Wells could be drilled to intercept the ground water and, by pumping, the head could be lowered, resulting in a temporary increase in yield at least. A quarter of a mile downstream from the springs the stream channel is about 100 feet lower in altitude. If a tunnel were driven upstream from this point to intercept water in the cavernous area at the springs, a decrease in head would result and the yield should correspondingly increase temporarily by withdrawal from storage. Discharge southward to areas of large use of water would be increased permanently only if the developments suggested resulted in shifting the ground-water divide northward, thus in effect enlarging the recharge areas tributary to the southward-flowing springs. Such a shift, if accomplished, would reduce proportionately the amount of ground water moving northward beneath the plateau portion of the rim region. A thorough study of the geology of the recharge areas and of the canyon in which the springs emerge would be required before development could be properly planned.

Summers Spring, in Sycamore Canyon, is about 15 feet higher than the bed of the creek. Further examination of the area might reveal conditions favorable for development. Comparable conditions exist at Alchesay Spring on White River. There the discharge could be increased by lowering the outlet to increase the recharge area and eliminate wastage by evapotranspiration.

The reach on Oak Creek in which Page Fish Hatchery Springs, Bubbling Pond, and Turtle Pond occur appears to warrant careful study to determine whether the perennial flow could be increased.

The yields of many smaller springs in the region could be increased by clearing debris from spring orifices. In many places, much of the discharge is lost by seepage. It is estimated, for example, that about half the total discharge of Arsenic Cave Spring (table 5) bypasses the collecting box and does not enter the pipe in which water was carried several miles to point of use. The Bureau of Indian Affairs has undertaken a program of development at the spring.

Material improvement in the chemical quality of water reaching the surface reservoirs on the Gila and Salt Rivers would result if highly mineralized water could be diverted at its source. In this connection, careful geologic and engineering studies are needed at Clifton Hot Springs in the Gila drainage, and at the various saline springs on the Salt River. The concentration of dissolved solids is so high that the loss in volume of water, by diversion of flow from the salt springs, would be far outweighed by the resulting improvement in chemical quality. Approximate contributions of dissolved solids from these springs on which data are available are estimated as follows:

1. Discharge at Clifton Hot Springs averages about 1,000 gpm, and mineralization is such that Hem (1950, p. 34–35) estimated that the springs contribute about 50 tons of dissolved solids per day, or 18,000 tons per year, to the San Francisco River.
2. White River Salt Springs, near the junction with the Black River, have a combined flow of about 950 gpm and add about 12¼ tons of salts per day, or 4,500 tons per year, to the White River. Additional volumes of salts are discharged into the White River from sources as yet undetermined.
3. The contribution of salts reaching the Salt River from the Salt Banks is not precisely known. Earlier estimates (Feth, 1954, p. 38) were that 140 tons per day, or about 50,000 tons per year of dissolved solids, mostly sodium, was added to the river at Salt Banks.

The area was revisited on March 30–31, 1959, and samples were taken from the river above and below Salt Banks and from the highly mineralized springs themselves. These data suggest the possibility of an entirely different order of magnitude of discharge from Salt Banks from the unsupported estimate of 2 cfs used in the calculations in 1954.

On March 30, 1959, discharge of Salt River near Chrysotile, Ariz., about 7 miles upstream from the Salt Banks, was 180±10 cfs (U.S. Geological Survey, unpublished data) and at the gage, Salt River near Roosevelt, Ariz., approximately 30 miles downstream from Salt Banks, 195 cfs. The following table shows the significant relations.

Chemical-quality and discharge data, salt-load study, Salt River and Salt Banks, Ariz., March 1959

	Salt River, 1 mile upstream from Salt Banks	Salt Banks waters sampled			Salt River near Roosevelt, Ariz.
		Springs on top of Salt Banks	Slough, east end of Salt Banks	Spring at river's edge	
Sodium: (ppm)	500	8,400	11,600	13,100	500
Sulfate: (ppm)	84	758	968	1,100	126
Chloride: (ppm)	843	13,000	17,600	20,100	794
Dissolved solids: (ppm)	1,660	24,000	31,600	36,400	1,640
Discharge: (cfs)	[1] 180±10	0.02	0.01	0.002	195

[1] Salt River near Chrysotile, Ariz.; gage is 6 miles upstream from water-sample point.

In addition to the data shown, water enters Salt River below the gage near Chrysotile and above Salt Banks from Cibique Creek. The discharge on March 30 was estimated to be less than 5 cfs. The quality of water is not known, but the flow is mixed with Salt River water above the upstream sample point. Additional water reaches the river below Salt Banks from Canyon Creek and Cherry Creek. Discharge relations reported above suggest that the combined flow of the two on March 30, 1959, was about 10 cfs.

The analytical data show little change in the chemical quality of the Salt River in the reach from the gaging station near Chrysotile to the gage near Roosevelt. The sum of changes, including increments of salts from the Salt Banks and increments of water from Canyon and Cherry Creeks, suggests that there is actually a very slight improvement in terms of total mineralization and a significant reduction in chloride content.

A detailed study of chemical and discharge relations in Salt River canyon is clearly needed before full interpretation can be made. Present evidence is strong, however, that at least in March 1959 the discharge of saline water from the Salt Banks was sufficiently small that its influence on the chemical quality of the Salt River was negligible. It appears from this that the larger sources of mineralization that affect the chemical quality of water in the Salt River may be located elsewhere.

QUALITY OF WATER

By J. D. Hem

SCOPE OF CHEMICAL-QUALITY STUDIES

Samples of water have been collected for chemical analysis from more than 100 springs and a few wells during this investigation. Additional chemical-quality data are available in the files of the Geological Survey for many of ground-water and surface-water sources within the Mogollon Rim region. These additional data were collected during earlier investigations by the U.S. Geological Survey. These older analyses have been found useful because they provide some information on areas where fieldwork was not done in the present study. A few chemical analyses of interest in the study of the rim region are contained in published U.S. Geological Survey reports.

The results of a few of the chemical analyses are given in table 4. Only a few were selected for the purposes of this report, to show the chemical character of water in the principal aquifers and the constitutents of some of the more saline springs waters in the region in a general way. Some of these analyses are shown graphically in figure 7.

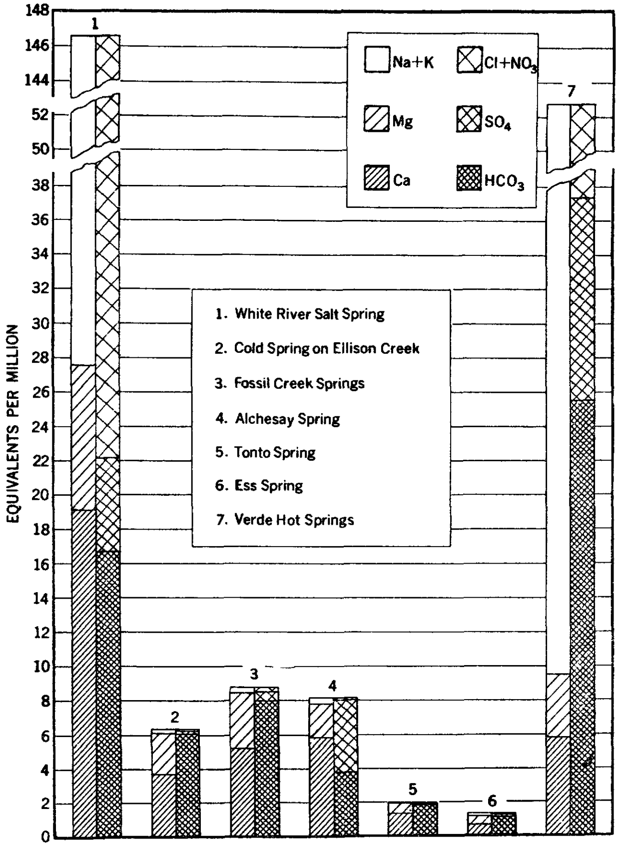

FIGURE 7.—Graphic representation of analyses of water from seven springs in Mogollon Rim region, Arizona.

RELATION OF CHEMICAL CHARACTER OF WATER TO AQUIFERS

PRECAMBRIAN ROCKS

Salty water emerges from quartzite of Precambrian age along the Salt River, notably at the junction of the Black and White Rivers and at the Salt Banks. The water from springs at the Salt Banks has a concentration of dissolved solids approximating that of sea water. With the exception of chloride, however, the proportions in which the constituents appear in the spring water are very different from those of sea water.

TABLE 4.—*Analyses of water from representative springs in the Mogollon Rim region*

[Analyses by U.S. Geological Survey]

Spring No.[1]	Name	Date of collection	Parts per million											Percent sodium	Specific conductance (micromhos at 25° C)
			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 (calculated)	Hardness as $CaCO_3$		
Western division															
(A-16-4) 15da	Frey Ranch Springs	2-12-52	15	61	26	16	287	6.4	36	0.0	1.4	303	259	12	545
15da	Bubbling Pond	12-11-51	17	56	24	9.2	275	5.1	18	.2	1.1	266	238	8	470
(A-17-3) 5dbd	Summers Spring	10-10-51	15	72	27	5.8	341	7.6	10	.2	1.5	307	290	4	543
Area of major spring inflow along Oak Creek															
(A-16-4) 23d	Page Fish Hatchery Springs.	8- 4-49	18	42	19	8.7	227	3.7	8	0	.8	212	183	9	364
33b	Sheepshead Canyon Springs.	7- 9-52	17	70	29	17	341	5.6	31	.2	.8	339	294	11	595
34bb	Hells Canyon Spring	7- 9-52	17	78	32	13	366	6.6	34	0	.2	361	326	8	641
Eastern division															
(D-4-30) 30db	Clifton Hot Springs	1-10-44	58	860	41	[2] 2,750	109	153	5,800	3.0	7.5	[3] 9,790	2,310	70	16,500
(A-4-27) 20b	Ess ("S") Spring	6-18-52	25	13	5.7	4.1	69	5.6	1	.4	.1	89	56	14	116
(A-4½-20) 35ad	White River Salt Springs.	9-20-51	22	384	103	[4] 2,730	1,020	265	4,420	.5	--------	8,450	1,380	80	13,900
(A-6-23) 4c	Alchesay Spring	6-24-52	16	117	24	7.8	230	204	4	.4	.0	486	390	4	717

Central division

(A-2-19) 18	Cassadore Spring	3-13-51	30	51	21	20	285	5.8	10	.4	1.9	280	214	17	464
(A-5-16) 13	Salt Banks-Green Seep.	12- 8-51	45	496	286	[5] 10,000	1,490	882	15,900	----	----	[6] 28,400	2,410	89	41,500
13	Salt Banks-Orange Spring.	12- 8-51	15	549	249	[7] 13,500	2,020	1,130	20,800	----	----	[8] 37,300	2,390	92	52,300
(A-11-6) 3b	Verde Hot Springs	12-10-51	60	116	45	996	1,560	566	545	1.5	.3	[9] 3,100	474	82	4,660
(A-11-12) 20	Indian Garden	5-17-52	8.9	68	27	[10] 3.2	333	4.1	2	.2	.1	278	280	2	497
(A-12-7) 14	Fossil Creek Springs	2-16-52	14	104	40	6.9	485	27	9	.1	.5	440	424	3	753
(A-12-8) 35c	Cottonwood Spring	7-18-46	----	56	34	18	370	2.9	8	.4	.5	302	280	----	557
(A-11-12) 26d	R-C Spring	5-14-52	8.9	43	9.0	2.3	163	13	1	.1	.4	158	144	3	275
(A-10½-12) 24aaa.	Bear Flat Spring	10-20-52	15	54	13	2.3	227	2.3	3	.2	.0	202	188	3	348
(A-12-10) 11cc	McGee Spring	10-18-52	11	58	17	0.5	250	6.6	2	.1	.2	218	214	----	383
14a	East Verde Spring	10-18-52	11	30	10	1.6	136	5.8	1	.2	.1	127	116	3	207
(A-12-12) 33baa	Tonto Spring	10-17-52	8.7	26	7.6	.7	111	3.1	2	.2	.3	104	96	2	174

North flowing

(A-9-23) 18ad	Paige Spring	6- 6-52	35	16	9.4	4.6	96	4.9	3	.2	.8	121	78	11	162
(A-9-24) 21ddd	Danstone Spring	6-13-52	24	10	5.8	2.3	56	4.7	1	.4	.4	77	49	9	99.7
(A-32-7)	Blue Spring	6-14-50	19	264	79	527	964	147	815	.2	3.2	2,340	984	----	3,940

[1] See table 2 for other pertinent data.
[2] Includes equivalent of 142 ppm of potassium (K).
[3] Includes 0.19 ppm of iron (Fe) and 0.74 ppm of boron (B).
[4] Includes equivalent of 63 ppm of potassium (K).
[5] Includes equivalent of 167 ppm of potassium (K).
[6] Includes 17 ppm of boron (B).
[7] Includes equivalent of 208 ppm of potassium (K).
[8] Includes 26 ppm of boron (B).
[9] Includes 7.2 ppm of boron (B).
[10] Includes equivalent of 0.7 ppm of potassium (K).

Sodium and chloride greatly exceed other components of the Salt Banks spring inflow, giving the flow practically the character of a solution of common salt. The other components are of interest, however, because they are present in comparable proportions in other saline springs along the Salt River. Characteristically, the bicarbonate content is high, being equivalent to or considerably in excess of the sulfate, whereas in sea water sulfate exceeds bicarbonate by a factor of nearly 20. Calcium and magnesium are present in large and nearly equivalent amounts. In sea water magnesium is more than 30 times as abundant as calcium. Boron concentrations are relatively high in the sources for which this component was determined.

The strata from which these saline springs issue are deeply buried in the area north of the Salt River canyon and in the lower reaches of some of its tributaries. It seems likely, therefore, that the saline waters have a complex history and may derive much of their dissolved matter from rocks other than the ones from which the springs flow.

The concentration of dissolved mineral matter in waters from the White River Salt Springs, (A–4½–20)35ad (fig. 7), is only about one-fourth as great as that in the Salt Banks, but the proportion of the constituents present is much the same at both sites.

Saline water is not everywhere typical of the rocks in which the Salt Banks springs occur, as is shown by the analysis for Cassadore Spring (table 4). This spring yields water containing moderate amounts of dissolved solids, mostly calcium, magnesium, and bicarbonate, and emerges from quartzite of Precambrian age.

ROCKS OF PALEOZOIC AGE

Cold Spring, (A–11½–11)30dc, issues from the Martin formation of Devonian age. Water from this spring is typical of waters from limestone and does not show any other characteristics of importance. Silica is comparatively low, and calcium, magnesium and bicarbonate make up nearly all the dissolved matter.

REDWALL LIMESTONE

Some of the larger springs along the Mogollon Rim, and Blue Spring which flows into Little Colorado River about 13 miles above its mouth, issue from the Redwall limestone. The springs near the rim, which include Summers and Indian Gardens (table 4), yield waters containing moderate amounts of dissolved solids, largely calcium, magnesium, and bicarbonate. Some of the spring waters appear to be supersaturated with carbon dioxide and calcium bicarbonate at atmospheric pressure and are actively depositing travertine. Blue Spring and associated springs which emerge for several miles along the Little Colorado River also are depositing travertine. The water of Blue Spring is rather highly mineralized, containing particularly large amounts of sodium and chloride. The water of Blue Spring is considerably less saline, however, than the waters of somewhat similar composition that issue along the Salt River, for example. The sodium and chloride in the water of Blue Spring are undoubtedly derived from sources outside the Redwall limestone.

SUPAI FORMATION

Springs issuing from the Supai formation are characterized generally by moderate concentrations of dissolved solids, comparable to those of water from springs in the Redwall and Martin formations that yield water of good quality. Waters from the Supai, however, usually are slightly higher in chloride and sodium and have a lower calcium-magnesium ratio. No very highly mineralized water has yet been found in the Supai in this area. The water from Alchesay Spring, which issues from limestone in the Fort Apache member (of Stoyanow) of the Supai formation, differs in quality from other waters from the Supai. The Alchesay Spring water is rather high in sulfate, which suggests that it may have dissolved some gypsum, possibly from within the Supai formation.

COCONINO SANDSTONE

Available data indicate that water from the Coconino sandstone along the rim is low in dissolved solids and contains mostly calcium, magnesium, and bicarbonate. It has been previously pointed out (Hem, J. D., *in* Babcock and Snyder, 1947, p. 11–12) that the water in the Coconino sandstone is of good quality near the rim but increases in mineral content as it moves downdip toward the north. It is believed that this formation has been partly leached of soluble matter near the rim where circulation of ground water has been more active than elsewhere. Saline water is reported in wells in the Coconino in areas north of the rim (Babcock and Snyder, p. 10), but its origin in these areas is not yet known. The salt water seems to be most prevalent in areas where the Moenkopi formation overlies the Coconino, and, as the Moenkopi is known to contain salt, genetic relationship may exist.

EXTRUSIVE ROCKS

Available analyses of samples of water from basalt indicate that the least mineralized water of the area occurs in this rock. The water is low in dissolved solids, has a low calcium-magnesium ratio that may approach unity, and is proportionally high in silica. These characteristics are commonly found in water associated with basalt in other areas. The basalt in this area is near or at the surface and is fissured; therefore, ground water in it circulates rapidly. These factors and the rather insoluble nature of the rock result in water having a low content of dissolved solids.

The water of the Clifton Hot Springs issues from alluvium in an area of volcanic rocks, probably is of deep-seated origin, and may be in part juvenile. This water differs in chemical quality in several important respects from the salt-spring waters issuing along the White and Salt Rivers. The Clifton spring water is mostly a solution of sodium and calcium chloride. Bicarbonate, sulfate, and magnesium all are very low in comparison with the other components, and much lower than are those constituents in the Salt Banks or White River salt springs.

The Verde Hot Springs, which issue from volcanic rocks, yield a water different from that of the other salt springs mentioned previously. The Verde Hot Springs water contains more sodium and bicarbonate than anything else, although both sulfate and chloride concentrations are high. This water also contains 7.2 ppm of boron.

Neither the Clifton nor the Verde Hot Springs yields water the quality of which would be considered typical for igneous rocks. The increased solvent power of hot water over cold may be the cause of the high mineralization of waters.

SOURCES OF CERTAIN CONSTITUENTS OF DISSOLVED MATTER IN GROUND WATERS

SILICA

Pure silica in the form of quartz and chert is one of the less soluble mineral substances. Most of the silica contained in natural waters is probably derived from the decomposition of more complex silicate minerals. Because such silicate minerals, other than quartz, make up a large part of igneous rock but are minor constituents of limestone and most sandstones, the waters high in silica—both on an absolute basis and in proportion to the total mineral content in solution—are commonly those coming from igneous acquifers such as basalt. This relationship is apparent in table 4, although there are some exceptions.

CALCIUM AND MAGNESIUM

Calcium and magnesium, two of the alkaline-earth metals, are among the more abundant mineral constituents of natural waters. Both elements are abundant in igneous rocks. Limestone is made up largely of calcium carbonate, but some magnesium carbonate is characteristically present. In dolomite the quantity of magnesium is about equivalent to the calcium. In many sandstones calcium carbonate, probably containing some magnesium, is the principal cementing material. Solution of these carbonates is the most common source of the calcium and magnesium in waters from limestone and sandstone.

Calcium carbonate is dissolved readily in water containing carbon dioxide. The dissolution of the mineral may be written as the following chemical equilibrium:

$$CaCO_3 + H_2O + CO_2 \leftrightharpoons Ca^{++} + 2HCO_3^-$$

The equilibrium point is usually dependent upon the supply of carbon dioxide available. Whether the carbon dioxide is retained in solution or escapes is in part dependent upon the temperature and pressure. Ordinarily the quantities of calcium carbonate and water available are comparatively large. Calcium is derived also from direct solution of gypsum ($CaSO_4 \cdot 2H_2O$), anhydrite ($CaSO_4$), and other minerals.

SODIUM

Sodium is present in small proportions in some of the silicate minerals in igneous rocks but is not usually in a form that is readily soluble. Localized beds of salt or sodium sulfate exist in some of the rock formations in this part of Arizona, but their effect on the quality of ground water is not fully known.

BICARBONATE

The principal anion in the less mineralized waters in the area is bicarbonate. It is produced principally by the solution of carbonate minerals in water containing carbon dioxide. Some of the more saline waters in the area have unusually high concentrations of bicarbonate. As pointed out in the preceding discussion of solution of calcium carbonate, the equilibrium can be shifted toward the formation of more bicarbonate when large amounts of carbon dioxide are in solution. Apparently a large supply of carbon dioxide is available to the water circulating at depth in certain of the rock formations in this area. Under the conditions of high pressure existing far below the surface, the carbon dioxide dissolves in the water in much greater amounts than under atmospheric pressure, and the resulting solution can dissolve increased amounts of carbonates of calcium and magnesium.

Several sources of carbon dioxide are possible within the rock formations. Carbon dioxide is given off in soil by the action of plants and during the decay of plant materials. These sources are probably not sufficient to account for the high bicarbonate concentrations found in the saline waters of this area. Carbon dioxide is produced also in the biochemical reduction of sulfate. This reaction is of common occurrence deep below the land surface; and, as sulfates probably exist in most of the sedimentary rocks of the area, sulfate reduction may produce enough carbon dioxide to give high bicarbonate concentrations. Another possible source of carbon dioxide, mentioned by Foster (1950, p. 40–41), is the decomposition of organic debris included in the sediments. Owing to the great age of most of the sediments in the area, however, this reaction is likely to have been completed long ago, and the resulting carbon dioxide removed by percolating water.

SULFATE

The most probable source of sulfate in ground water of the rim region is gypsum, which is commonly found in sedimentary rocks. Bedded sodium sulfate exists near Camp Verde and is a source of sulfate in ground waters in that vicinity. Oxidation of pyrite and other sulfides may be a source of sulfate in a few localities in the region.

CHLORIDE

Chloride minerals are present in igneous rock in relatively minor amounts but are generally soluble, so that they can be taken up in circulating water if the rock structure is such that the water can come into contact with the minerals. Chloride may be contributed by magmatic or juvenile water also, and this source may be a partial explanation of the high chloride concentrations observed in some of the springs.

DEPOSITION OF TRAVERTINE

Many springs in the rim region are actively depositing travertine. To deposit calcium carbonate in quantity, the spring water must be supersaturated with respect to calcium bicarbonate when the water issues from the spring opening. The presure on the water, especially in an artesian system, is greatly reduced when it issues from the ground, the lower pressure allows carbon dioxide to escape into the air, and the reaction—

$$CaCO_3+H_2O+CO_2 \leftrightarrows Ca^{++}+2HCO_3^-$$

proceeds to the left. The excess of calcium carbonate is deposited until a new equilibrium characterized by a lower content of calcium and bicarbonate in solution is reached. From a few seconds to several hours may elapse from the time when the water issues from the ground to the time when a new point of equilibrium is reached. Evaporation, turbulence and the activity of some forms of algae also contribute to travertine deposition. Spring waters that reach adjacent river channels are mixed with waters of lower mineralization, and little or no further deposition takes place. The conditions that favor a high content of calcium bicarbonate and deposition of travertine when pressure is relieved would seem to include high pressure and large supplies of carbon dioxide and calcium carbonate. Such conditions commonly exist in deep-seated limestone aquifers.

SUGGESTED LINES OF FURTHER GEOCHEMICAL INVESTIGATION

The quality of water of the entire region should be more completely investigated, and samples should be taken from more sources. Several uses for these data are suggested as follows:

1. The chemical quality of water from all aquifers should be more closely determined. These data may aid in identifying the source of the water of springs.
2. The use of analytical results to trace ground-water movement may be capable of a considerable development in this area and would be a helpful supplement to other hydrologic data in studying the water movement.
3. Correlation of quality-of-water and other data for the area near the rim with data gathered farther to the north will help determine which areas may be hydrologically related.
4. Closer study of the salt-spring inflows along the Salt River and tributaries will provide basic data for any possible action program aimed at reducing these inflows to improve salt-balance conditions downstream.
5. Collection of samples at seasonal intervals from certain springs, especially those of large discharge and wide fluctuation, might provide data of value in determining rates of water movement underground, and the volumes of water retained in storage in the aquifers, provided that periodic changes in chemical quality could be correlated with periods of heavy precipitation or of drought, for example. Studies of aquifer characteristics and of geologic controls must be made to correlate with data derived from chemical analyses.

TABLE 5.—*Records of springs in or near the Mogollon Rim region visited to 1952*

Spring No.: "A" refers to NE quadrant of the State; the first number to township, north; second to range east; third to section; thus (A-16-4)15da is T. 16 N., R. 4 E., sec. 15. The lowercase letters refer to quarter-sections, a, the NE¼; b, the NW¼; c, the SW¼; d, the SE¼.

Type of spring: F, fault spring; C, contact spring.
Discharge: M, measured; E, estimated; R, reported.
Remarks: A, see analysis in table 4.

Spring No.	Name	Date first examined	Water-bearing unit	Type of spring	Discharge (gpm)	Temperature (° F)	Remarks
			Western division				
(A-16-4) 14d	Oak Creek, sum of many springs not individually reported.	12-15-52			11,800 M	48	
15da	Frey Ranch Springs	2-12-52	Alluvium	C	60 M	66	A.
15da	Treeroot Springs	7- 9-52	do	C	260 M	71	
15da	Bubbling Pond	12-11-51	do	C	4,125 M	67	A.
15dd	Turtle Pond	2-12-52	do	F	160 M	66	A.
16ddd	Springs on Spring Creek	2-12-52	Alluvium, Verde formation, and basalt.	C	2,700 M	67	A.
(A-16-4) 23d	Page Fish Hatchery Springs	2-13-52	Verde formation and volcanics	F(?)	8,000-14,000 M	68	A.
33b	Sheepshead Canyon Springs	7- 9-52	Verde formation	C	65 M	71	A.
34bb	Hells Canyon Spring	7- 9-52	do		5 E	66	A.
(A-17-3) 5		10-10-51	Redwall limestone		15 E	66	
5dbd	Summers Spring	10-10-51	do		2,700 M	67	A. Discharge measured Dec. 12, 1952, 2,275 gpm.
(A-18-3) 32a	Parson Spring	10-10-51	do			77	Seep; too small to measure.
(A-18-6) 5a		8-18-49	Supai formation		750 E	55	Record by P. W. Hughes.
5b	Hummingbird Spring	8-18-49	do	F	25 E	55	Do.
5bc		8-18-49	do		50 E	55	Do.
7a		8-18-49	Supai formation	F	15 E	55	Record by P. W. Hughes.
27ccc	Indian Gardens	2-14-52	Supai(?) formation	F	115 M	58	
34bb	Thompson Pasture Springs	2-14-52	do	F	180 M	57-60	
(A-19-4) 2ac	Dorsey Spring	8-11-49	Basalt				Reported by P. W. Hughes.
(A-19-5) 9aa	Lockwood Spring	8- 5-49			1 E	50	Reported by D. G. Metzger.
13cc		8-25-49	Coconino(?) sandstone		1 E	52	Reported by P. W. Hughes and J. H. Feth.
22ba		8-30-49		F		54	Reported by J. H. Feth and D. G. Metzger.
30c	Barney Spring	8-25-49	Coconino sandstone		⅛ M	47	Reported by D. G. Metzger.

(A-19-6) 15d(2)		8-13-49	Coconino sandstone	C	21 M	52	Reported by D. G. Metzger.
15d(3)	No. 3 in Oak Creek	8-13-49	do		15 E	52	Do.
22d		8-13-49	do		182 M	54	Do.
34b	Grassy Meadow Spring	8-17-49	Supai formation		1 E	54	Reported by P. W. Hughes.
34c	Lelani Spring	8-17-49	Supai(?) formation	F	30 E	55	Do.
(A-20-4) 3bc	Lower Hulls Spring	8-10-49	Basalt			51	Reported by D. G. Metzger and P. W. Hughes.
9aab	Poison Spring	8-31-49	do		20 E	52	
10c	Greys Spring	7-29-49	Alluvium and basalt			60	
35a	Babes Hole Spring	7-29-49	Kaibab limestone	F	1 E	50	
35aa	Kelsey Spring	8-10-49	Basalt				Reported by D. G. Metzger and P. W. Hughes.
(A-20-6) 3b	Woody Spring	8- 1-49	Basalt and tuff				Reported by J. H. Feth and D. G. Metzger.
8ca	Aspen Spring	7-29-49	Basalt			46	Reported by D. G. Metzger.
12dc	Landon Spring	7-29-49					Do.
(A-21-4) 32daa	Little L. O. Spring	8-31-49	Alluvium and basalt		1E	52	
(A-21-5) 3bcc	Navajo Ordinance depot Spring in "O" area.	8- 9-49	Basalt		5 E	50	Reported by D. G. Metzger and P. W. Hughes.
4ba	Navajo Ordinance Depot, Indian Camp. Springs.	8- 9-49	do				Do.
10aa(1)	Navajo Ordinance Depot Spring No. 2.	8- 9-49	Volcanic rocks		60 E	48	Do.
10aa(2)	Navajo Ordinance Depot Spring No. 3.	8- 9-49	Volcanic rocks				Reported by D. G. Metzger and P. W. Hughes.
11ab	Navajo Ordinance Depot Spring No. 1.	8- 9-49	Basalt and Recent gravel	C	100 R	48	
(A-21-6) 21bc		8-18-49	Volcanic rocks		3 E	48	Reported by D. G. Metzger
21bd		8-18-49	do		1 E	47	Do.
28ca	Fisher Spring	8-18-49	do		1 E	51	Do.
31cc	Patterson Spring	7-29-49	Basaltic soil		(1)		
			Eastern division				
(D-1-24) 16	Tule Spring	3-20-51			20 E		
(D-1-25) 30	Arsenic Cave Spring	3-20-51	Volcanic agglomerate		2 E	71	
(D-4-30) 30db	Clifton Hot Springs	10-29-40	Volcanic rocks	F	1,100 R	120	A. Reported by J. D. Hem.
(A-4-27) 20b	Ess ("S") Springs	6-18-52	Basalt	C	200 M	58	A.
(A-4½-20) 35ad	White River Salt Springs	9-20-51	Sandstone of Cambrian age and quartzite of Apache group.	F(?)	10 E	83	A. Salty taste.
36b	do	9-20-51	do	C	30 E		
36c		9-20-51	Devonian(?) limy sandstone	C	875 M	76	
(A-5-24) 18		2-19-52	Supai formation		40 M	45	Reported by S. F. Turner and J. H. Feth.
(A-5-29) 27aa	Gillard Hot Springs	11-18-40	Alluvium	F	100 E	181	Reported by J. D. Hem.
(A-6-23) 4c	Alchesay Spring	5-21-52	Supai formation (Fort Apache limestone of Stoyanow).		9,000 E		A. Discharge measured June 1952, 7,650 gpm.
17	"Old Farm Springs"	5-20-52	Alluvium			53	
(A-7-23) 3	Bull Cienega Spring	5-21-52	Basalt	C	2 E	54	
(A-8-22) 11ccc	Amos Ranch "Big Spring"	6-20-52	do	C	150 E	54	

See footnote at end of table.

TABLE 5.—*Records of springs in or near the Mogollon Rim region visited to 1952*—Continued

Spring No.	Name	Date first examined	Water-bearing unit	Type of spring	Discharge (gpm)	Temperature (° F)	Remarks
Eastern division—Continued							
(A-8-23) 24cd	Government Spring Sump	6-18-46			75 M	49	Reported by L. C. Halpenny and R. S. Jones.
24cd(2)	Government Spring	do	Basalt		40 E		Do.
24cd(3)	Government Spring No. 4	do	do		20 E		Do.
24cd(4)	Government Spring	do	do		20 E		Do.
25aa	Gomez Spring	do	Recent mud		200 R	70	Reported by L. C. Halpenny and R. S. Jones.
27aa	Upper Bull Cienega Spring	6-20-52	Basalt		100 E	50	
(A-8-24) 19aa	Haystack No. 1	6-18-46	do		40 E	52	Reported by L. C. Halpenny and R. S. Jones.
19ab	Haystack No. 2	do	do		20 M	49	Do.
19cb	Earl Spring No. 3	do	do	C	20 E	49	Do.
21aa		6-20-46	do		100 E	47	Do.
23d	Boy Spring	12-7-51	do	C	5 M	42	Discharge measured May 20, 1952, 200 gpm (snowmelt).
27ab	Blue Lake	6-13-52	do			63	
27ac		5-19-52	do		260 M	51	
27ac	Williams Springs	6-18-46	do		1,260 R	52	Discharge measured May 20, 1952, 2,350 gpm.
(A-8-25) 3c	Gooseberry Creek Spring	5-22-52	Basalt	C	1,200 M	43	Discharge measured June 23, 1952, 715 gpm.
(A-8-26) 26dc	Sheep Springs	do	do	C	60 M	44	
Central division							
(D-2-16) 14	Spring Branch Ranch Creek	5-8-51	Limestone and basalt		2 E	72	
(A-1-15) 26aa	Maurel Spring	4-11-46	Alluvium		50 M	64	Reported by L. C. Halpenny.
(A-1-20) 12	Cold Spring at Warm Springs	3-2-51	do		2 E	60	
12	Warm Springs	3-13-51	Naco formation		3,350-3,400 M	85	Reported by R. L. Cushman and W. H. Wilson.
(A-2-19) 10b		11-6-51				67	Reported by R. L. Cushman and W. H. Wilson.
18	Cassadore Spring	3-13-51	Quartzite of Apache group	C	35 E	67	A. Do.
(A-3-16) 6	Rock Spring	5-18-52	(See "Remarks")		5 E	59	A. Issues from area of granite, diabase and alluvium.
(A-5-16) 13	Salt Banks (on Salt River)	12-8-51	Quartzite of Apache group intruded with diabase.			70-78	A.
(A-5-19) 34	Warm Spring on Salt River	9-21-51	Redwall limestone	F	1,180 M	70	

(A-10½-12) 24aaa	Bear Flat Spring	10-20-52	Volcanic rocks		6 M	62	A.
(A-11-6) 3b	Verde Hot Springs	12-10-51	do	F	10 E	100-106	A. Saline. Resort lodge; bathing, drinking.
(A-11-9) 5cd	Natural Bridge	7-26-46	Sandstone of Cambrian age			63	Reported by K. K. Kendall.
5dc		do	do			67	
(A-11-10) 4c	Springs in lower Webber Canyon.	10-22-52	Redwall limestone	F	1,300 M	49	
9b1	The Grotto Spring	5-15-52	Martin formation		350 M	58	Discharge measured July 10, 1952, 10 gpm.
9b2	Big Spring	do	Alluvium		175 M	58	A. Discharge measured July 10, 1952 100 gpm.
(A-11-11) 13dcc	Wildcat (Arsenic) Spring	10-20-52	Martin formation		5E	60	
(A-11-12) 16bac	Henturkey Spring	10-17-52	do		60M	51	
20	Indian Gardens	5-17-52	Redwall limestone			58	A.
26d	R-C Spring	5-14-52	Troy quartzite		800E	48	A.
34dd	Columbine Spring	10-20-52	Precambrian volcanic rocks		5E		
(A-11½-9) 23	Red Rock Spring	7-22-46	Supai formation		3E	60	Reported by K. K. Kendall
30	Oak Spring	7-25-46			3E	66	Do.
(A-11½-11) 30dc	Cold Spring	5-17-52	Martin formation	F	4,200 M	55	A. Discharge measured July 11, 1952, 1,060 gpm; Nov. 11, 1952, 830 gpm.
(A-12-7) 14	Fossil Creek Springs	2-15-52	Naco formation (limestone)	C	18,600 M	70	A.
22		7-28-46			5 E	69	Reported by K. K. Kendall.
(A-12-8) 23	Strawberry Spring	7-24-46	Coconino(?) sandstone		1 E	58	Do.
26da		do	Supai formation		1 E	60	Do.
35c	Cottonwood Spring	7-18-46	do		1 E	56	A. Reported by K. K. Kendall.
(A-12-9) 8	Parsnip Spring	7-23-46	Supai(?) formation		10 E	52	Reported by K. K. Kendall.
30ddl	Dripping Springs	7-19-46	do		3 E	56	Do.
(A-12-10) 11cb	Washington Park Spring	10-18-52	Supai formation		10 E	52	
11cc	McGee Spring	do	Alluvium		2 E	51	A.
14a	East Verde Spring	do	Supai formation		125 E	52	A.
34	"Burned House Springs"	do	Martin formation		100 E	58	
(A-12-12) 32(1)	Winters No. 1—Domestic	5-16-52	Supai(?) formation		1 E	47	
32(2)	Winters No. 2	do	do		2 E	51	
32(3)	Winters No. 3	do	do		20 M	47	
33baa	Tonto Spring	10-17-52	Fort Apache member (of Stoyanow) of Supai formation.		900 M	48	A.
(A-16-8) 16a	Foster Spring	10-11-51	Basalt	C			
(A-8-23) 4ab	Pinetop Spring	6-19-46	Basalt	C	350 E	50	Reported by L. C Halpenny and R. S. Jones.
4ba	Hallack Spring	6-22-52	do	C	5 E	49	
(A-8-26) 5c	C. C. Hall spring	6-23-52	do		6 M	43	
5ccb	C. C. Cabin spring	do	do		5 M	43	
(A-9-22) 36a	Big Spring (near Lakeside)	2-20-52	do		1,100 M	53	
36ad	Walnut Spring	6-23-52	do		225 M	52	
(A-9-23) 18ad	Paige Spring	6-16-52	do		300 M	54	A.
23c	Pat Mullen Spring	6-11-52	Cinders				Seep; water in pools, no visible flow.
26db	Whitcomb Spring	do	Basalt	C(?)	40 E	50	
26dc	Chipmunk Spring	6-11-52	Basalt		4 M	48	
34cba	Thompson Spring	do	do		20 E	49	

TABLE 5.—*Records of springs in or near the Mogollon Rim region visited to 1952*—Continued

Spring No.	Name	Date first examined	Water-bearing unit	Type of spring	Discharge (gpm)	Temperature (° F)	Remarks
Central division—Continued							
(A-9-24)21ddd	Danstone Spring	6-13-52	do	C	38 M	48	A.
26bdc	McCormick Spring	do	do		1 E	50	
26cc	Los Burros Springs	6-11-52	do		25 M	46	
28cb	Telephone Spring	6-13-52	do		2 E	48	
(A-11-18)27ab	Trough Springs	11- 7-52	Alluvium		1 E	54	
(A-11-23)19a	Bourdon Ranch Spring	6-25-52	Basalt	C	100 E	59	Weedy and covered with tules.
20d	Silver Spring	2-14-52	do	C	2,100 M	60	A. Discharge measured June 12, 1952, 3,220 gpm.
(A-12-21)25da	Old Mill Spring	3-12-51		F		65	
(A-12-22) 31bd	East Shumway Spring	3-12-51				63	
33ac		12-12-50	Basalt				
(A-12-26) 19	Concho Springs	12- 6-51	do		1,100 M	59	
(A-13-9) 14	Clover Spring	11-10-52	Kaibab limestone		20 E	46	
21	Little Pivot Rock Spring	7-28-46	do			48	Reported by K. K. Kendall.
(A-20-6) 13cc	Fulton Spring	7-29-49	Basalt		8 M	50	Reported by D. G. Metzger.
(A-20-7) 7ad	Black Spring	8- 1-49	do			50	Reported by J. H. Feth and D. G. Metzger.
(A-21-3) 23acb	Buck Springs	8-31-49	do	F	(1)		
(A-22-6) 13a	Little Leroux Spring	9-30-49	Basalt				Reported by P. W. Hughes.
14a	Leroux Spring	do	do		25 R	48	Do.
18d	Maxwell Spring	do	do	C			Do.
18dc		9-26-49	Alluvium			51	Do.
(A-22-7) 25dd		8-27-49	Redwall(?) limestone	C	1 E		Reported by field party.
(A-22-8) 19db	Little Elden Spring	10-11-50	Latite, porphyry				Stagnant puddle.
31b		do	Supai formation	F	1 E		
(A-31-2) 13	Indian Gardens	2-21-51	Muva limestone		150-200 R		
(A-32-7)	Blue Spring	6-14-50	Redwall limestone		90,000 M	69	A. Reported by P. W. Hughes and J. A. Baumgartner.
(B-33-4)	Havasu Springs	6-14-51	Redwall limestone	F	26,700 M		Reported by J. A. Baumgartner, D. G. Metzger, and J. L. Hatchett.
9		5-20-50	do		200 E	70	Reported by P. W. Hughes and J. A. Baumgartner.
10		do	do		10 E	68	Reported by P. W. Hughes.
15		do	Supai formation		100 E	67	Do.
26	Headwater Spring (Havasu)	5-21-50	Alluvium		20,000 E	66	Do.

[1] Dry when visited.

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