DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

Prepared in cooperation with the
ARIZONA DEPARTMENT OF WATER RESOURCES

WATER RESOURCES INVESTIGATIONS 86-4147
SHEET 1 OF 4

Figure 1. -- Location of Salt River Valley area and area of report.

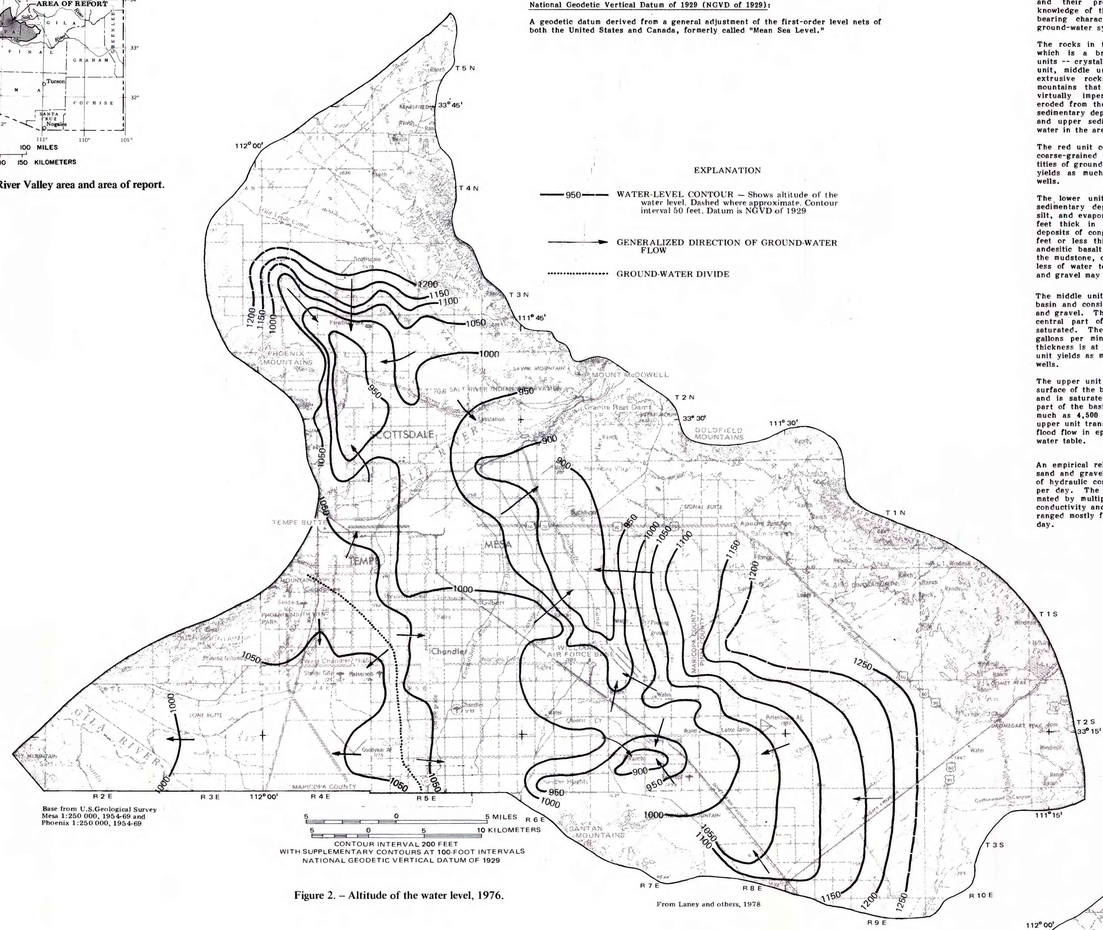
CONVERSION FACTORS

For readers who prefer to use metric units, the conversion factors for the terms used in this report are listed below:

Multiply	By	To obtain
inch (in)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
foot per day (ft/d)	0.3048	meter per day (m/d)
square foot per day (ft^2/d)	0.0929	square meter per day (m^2/d)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
degree Fahrenheit (°F)	°C=5/9 (°F-32)	degree Celsius (°C)

National Geodetic Vertical Datum of 1929 (NGVD of 1929):

A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level."



Base from U.S.Geological Survey
Mesa 1:250 000, 1954-69 and
Phoenix 1:250 000, 1954-69

Figure 2. – Altitude of the water level, 1976.

From Laney and others, 1978

HYDROLOGEOLOGY OF THE EASTERN PART OF THE SALT RIVER VALLEY AREA, MARICOPA AND PINAL COUNTIES, ARIZONA

By
Robert L. Laney and Mary Ellen Hahn

ABSTRACT

The Salt River Valley is a major agricultural and metropolitan area in semiarid south-central Arizona. Ground water in the permeable sedimentary deposits underlying the area is a major water supply for agricultural, municipal, and industrial users. The amount of ground water that has been pumped greatly exceeds recharge and, as a result, water levels have declined as much as 400 feet in recent years. Management of the remaining ground-water resources and their protection from contamination will require knowledge of the hydrogeologic framework and the water-bearing characteristics of the sedimentary units in the ground-water system.

The rocks in the eastern part of the Salt River Valley, which is a broad alluvial basin, are divided into six units -- crystalline rocks, extrusive rocks, red unit, lower unit, middle unit, and upper unit. The crystalline and extrusive rocks underlie the basin and make up the mountains that surround the basin. These rocks form virtually impermeable hydrologic boundaries. Detritus eroded from the crystalline and extrusive rocks forms the sedimentary deposits in the basin. The red, lower, middle, and upper sedimentary units contain most of the ground water in the area.

The red unit consists mostly of well-cemented red beds of coarse-grained materials. The unit contains usable quantities of ground water, principally near Scottsdale, where it yields as much as 1,000 gallons per minute of water to wells.

The lower unit, which makes up the largest volume of sedimentary deposits, consists mostly of mudstone, clay, silt, and evaporite deposits that may be as much as 10,000 feet thick in the central part of the basin. Thinner deposits of conglomerate and sand and gravel are only 600 feet or less thick on the margins of the basin. Locally, andesitic basalt is interbedded in the unit. Wells tapping the mudstone, clay, and silt yield 50 gallons per minute or less of water to wells, but the conglomerate and the sand and gravel may yield as much as 3,500 gallons per minute.

The middle unit is the principal water-bearing unit in the basin and consists mostly of silt, siltstone, and silty sand and gravel. The unit is as much as 1,000 feet thick in the central part of the basin and as much as 700 feet is saturated. The unit generally will yield as much as 1,000 gallons per minute of water to wells where the saturated thickness is at least 500 feet. Locally, north of Mesa, the unit yields as much as 4,000 gallons per minute of water to wells.

The upper unit is gravel, sand, and silt and underlies the surface of the basin. The unit is as much as 800 feet thick and is saturated only in a small area in the southwestern part of the basin. Where saturated, the unit may yield as much as 4,500 gallons per minute of water to wells. The upper unit transmits recharge derived from sheet flow, from flood flow in ephemeral streams, and from irrigation to the water table.

An empirical relation of hydraulic conductivity and percent sand and of gravel was developed for the middle unit; values of hydraulic conductivity ranged from about 20 to 100 feet per day. The transmissivity of the middle unit was estimated by multiplying the graph-derived value of hydraulic conductivity and the saturated thickness to give values that ranged mostly from about 10,000 to 60,000 feet squared per day.

INTRODUCTION

The Salt River Valley area in central Arizona is a major metropolitan and agricultural area covering more than 3,000 mi^2. The eastern part of the Salt River Valley (area of this report) covers about 1,500 mi^2. The Phoenix metropolitan area near the center of the valley (fig. 1) contains a population of about 1.5 million (Valley National Bank of Arizona, 1981, p. 9). Large quantities of ground water are stored in permeable sedimentary deposits that underlie most of the area (Osterkamp and Ross, 1976). Between 1923 and 1980, about 78 million acre-ft of water was pumped from the saturated sedimentary deposits to supply irrigation, public supply, and industrial needs (U.S. Geological Survey, 1982). Between 1970 and 1980 an average of about 1.5 million acre-ft/yr of water was pumped, of which about 90 percent was used to irrigate crops and 10 percent was used for industry and public supply. The amount of ground water that is pumped in the Salt River Valley area is more than 30 percent of the total amount of water pumped annually in Arizona. Withdrawal of water from the ground-water reservoir greatly exceeds recharge, and as a result, water levels have declined as much as 400 ft since 1923. Water-level decline ranged from 2 to 8 ft/yr (Laney and others, 1978; Ross, 1978).

Large-scale withdrawal of ground water has caused reversal of the predevelopment ground-water gradient east of Mesa, north of the Santan Mountains, and in southern Paradise Valley near Scottsdale (fig. 2). Since 1978, the water table either rose or the rate of decline decreased, especially near the Salt River, because of four consecutive winters (1977-80) during which precipitation and runoff were above average (Mann and Rohne, 1983). During this period, pumping of ground water was reduced because excess surface water was available for irrigation, and higher-than-average amounts of recharge probably resulted from the increased surface flow. In some areas near the Santan Mountains, discharge rates of irrigation wells decreased markedly in the 1970's as water levels declined, indicating that the deeper parts of the aquifer system may be less productive. The rate of water-level decline per unit of pumpage may increase elsewhere in the area as water levels are lowered.

Purpose of Report

The purpose of this report is to describe the geologic and hydrologic characteristics of the water-bearing units in the eastern part of the Salt River Valley area. Large amounts of data on water levels, pumpage, and water quality have been collected since 1923; however, the hydrogeologic framework of the sedimentary deposits in the basin has not been well documented. Effective ground-water management requires knowledge of the hydrogeologic framework and the water-bearing properties of the sedimentary units in the aquifer system in order to make reliable predictions of the effects of future ground-water withdrawals.

Physical Setting

The eastern part of the Salt River Valley area is a broad alluvial basin surrounded by mountain ranges (fig. 3). The basin is underlain by several thousand feet of sedimentary deposits, and the mountains consist largely of igneous and metamorphic rocks. The basin floor ranges in altitude from about 1,100 ft above sea level in the southwest to as much as 1,900 ft in the east and north. The Phoenix, Scott, and Santan mountains reach altitudes as high as 2,500 ft; the McDowell and Superstition Mountains are about 4,000 and 5,000 ft high, respectively. The major streams in the area are the Salt and Gila Rivers and Queen Creek. The Salt River drains the northern part of the area and the Gila River drains only the southwesternmost part, but little flow occurs in either because of upstream diversions. Queen Creek, tributary to the Gila, drains the eastern part of the area. Queen Creek, as well as all smaller washes in the area, flows only intermittently in reponse to local heavy rainfall. The climate is semiarid; hot summers and mild winters are typical. Average daily temperatures in the summer exceed 90 °F from mid-June to early September (Sellers and Hill, 1974). Average annual precipitation ranges from about 8 in. on the basin floor to as much as 16 in. in the Superstition Mountains (University of Arizona, 1965). Annual evapotranspiration is 10 times greater than annual precipitation.

Methods of Investigation

An informal drill-cuttings collection program was started in the 1970's in cooperation with well drillers in the Salt River Valley. Cuttings were collected from 10- or 20-ft intervals of the drill holes. Laboratory determinations of size, color, and amount of cementation, were made and a geologic description for each set of cuttings was prepared. A graphic lithologic log for each set of cuttings was prepared for correlation purposes. The drill-cuttings analysis methods were used in investigations in the Tucson basin by Pashley (1966) and Davidson (1973) and have been described by Matlock and others (1976). A joint U.S. Geological Survey-U.S. Bureau of Reclamation investigation of land subsidence and earth fissures, begun in the late 1970's, provided subsurface information for the eastern part of the study area. Results of surface-geophysical surveys, test drilling, and borehole-geophysical logging increased the knowledge about the hydrogeology of the sedimentary deposits.

Acknowledgments

Appreciation is extended to the many well drillers whose unpaid efforts contributed to the investigation. Without their cooperation in the collection of drill cuttings, the interpretations in this report would have been less complete. Personnel of the water departments of the cities of Phoenix, Scottsdale, Mesa, and Tempe and private water companies also were helpful in providing information on existing and proposed wells. The Salt River Project provided the opportunity to conduct aquifer tests using many of their irrigation wells. Special thanks are due Bobby L. Wallace and J. Wesley Smith of the U.S. Geological Survey for their efforts in coordinating the drill-cuttings collection program with the well drillers and obtaining other well data.

HYDROGEOLOGY

The rocks and sedimentary deposits in the eastern part of the Salt River Valley are divided into six units -- crystalline rocks, extrusive rocks, red unit, lower unit, middle unit, and upper unit (fig. 3). Crystalline and extrusive rocks make up the mountains that border the basin. The mountains form virtually impermeable hydrologic boundaries and are the sources of most of the sedimentary deposits that fill the basin. These deposits--the red, lower, middle, and upper units--contain most of the ground water in the area. A summary of the hydrogeologic characteristics of the units is shown on table 1.

The present-day Basin and Range physiography was formed as a result of a period of mostly high-angle block faulting that began about 15 million years (m.y.) ago. The red unit predates the period of high-angle block faulting. The lower, middle, and upper units were deposited during and after the faulting. The older part of the lower unit is more faulted than the younger part, and little obvious faulting affected the deposition of the middle and upper units. Subsidence of the basin continued during deposition of the middle and upper units but at a less rapid rate than during deposition of the lower unit. Relief of the surrounding mountains has changed with time and probably affected the rates of sedimentation and types of sediments in the basin.

Rocks of the Mountains

Crystalline Rocks

The crystalline rocks comprise granitic rocks of Late Cretaceous to early Tertiary age, and schist, gneiss, granite, quartzite, and metavolcanic rocks of Precambrian age (Wilson and others, 1957; Wilson and Moore, 1959; Christenson and others, 1978; Cordy and others, 1978; and Schulten and others, 1979). Crystalline rocks are exposed along the margins of the mapped area (fig. 3) and have been penetrated by some water wells near the edge of the sedimentary deposits. These rocks may yield as much as 10 gal/min (gallons per minute) of water to wells depending on the number and distribution of fractures. The rocks form a virtually impermeable boundary around most of the basin.

Extrusive Rocks

The extrusive rocks comprise rhyolitic to basaltic pyroclastic and flow rocks of middle to late Tertiary age (Wilson and others, 1957; Wilson and Moore, 1959). These rocks are exposed in the Goldfield and Superstition Mountains and may be present at shallow depths near these mountains (fig. 3). Volcanic rocks in the Superstition-Superior volcanic field are dated about 29 to 15 m.y. ago (Sheridan, 1978, p. 85-86). Probable correlative volcanic rocks to those in the Superstition-Superior volcanic field and older volcanic rocks have been encountered at depth within the basin (see fig. 6a, wells (D-2-01)ada and (D-2-01)daa; see fig. 5 for well-numbering system). The older volcanic rocks are not exposed in the study area. The volcanic rocks are of minor hydrologic significance; however, they were a principal source of detritus for the sedimentary deposits in the eastern part of the study area.

Rocks of the Basin

Red Unit

The red unit is present locally in both the mountains and the basin. Hydrologically, it is the most important in the basin and is grouped with rocks of the basin for convenience of discussion. The red unit comprises reddish-colored, well-cemented breccia, conglomerate, sandstone, and siltstone containing granitic and rhyolitic detritus. The breccia and conglomerate are poorly sorted; particle sizes range from clay to boulders as much as 15 ft in diameter. Bedding generally is poorly defined, and a large part of the unit is probably made up of debris flows. Siltstone and sandstone deposits generally are better stratified and sorted than the coarser grained deposits, and, in places, are interbedded with poorly sorted breccia and conglomerate. Locally, mafic to felsic volcanic-flow rocks and some pyroclastic rocks are interbedded with the sedimentary rocks at the top of the unit.

The red unit was described first by Cooley in Arteaga and others (1968). It has been referred to informally as the Papago Buttes deposits by Christenson and others (1978), the Tempe beds by Schulten and others (1979), and the "Camel's Head Formation" by Cordy and others (1978). The red unit is exposed mainly north of the Salt River along the east and west boundaries of the study area (fig. 3). As much as 2,000 ft of the deposits are exposed on the west side of the area (Arteaga and others, 1968, fig. 4) but faulting may have caused repetition of beds (Schulten and others, 1979). Most of the unit is tilted 20 to 45 degrees. Near Scottsdale, as much as 500 ft of the unit is present at depths that range from about 300 to 1,100 ft, where it is directly overlain by either the middle or lower unit. The red unit is in fault contact with parts of the lower unit, and faulting probably is the cause of the irregular upper surface of the unit near Scottsdale (fig. 3).

The red unit was deposited before the high-angle normal faulting that formed the present-day sedimentary basins and isolated mountain ranges in southern Arizona. The period of faulting and basin subsidence began no earlier than about 16 m.y. ago (Peirce, 1976, p. 325; Eberly and Stanley, 1978, p. 938; and Shafiqullah and others, 1980, p. 223). As a result, the sedimentary facies of the red unit are not related to the present-day mountain ranges and basins.

Radiometric ages of the volcanic rocks in the upper part of the red unit indicate that the unit is, in part, equivalent to the extrusive rocks of the Superstition-Superior volcanic field (fig. 3). Volcanic rocks in the upper part of the red unit have been dated at about 17.5 m.y. near Tempe Butte and about 18 to 18.5 m.y. near Mount McDowell.

The red-bed sequence may not be much older than about 19 m.y. About 2,400 ft of red beds in drill hole (D-2-01)daa are younger than about 19 m.y. (fig. 6A). The red beds in drill hole (A-4-04)8edc in Paradise Valley (fig. 4) are older than 22 m.y. Widespread red beds in the Tucson area--the Pantano Formation (Brennan, 1957; Finnell, 1970) and its equivalents--range in age from about 38 to 26 m.y. (Davidson, 1973, p. E17). In drill hole (D-2-01)daa, basaltic andesite at a depth of 8,922 to 8,971 ft has an age of 39.4 ± 0.9 m.y. (Shafiqullah and others, 1980, p. 249). The rocks may correlate with the Rillito andesite (38.5 ± 1.3 m.y., Eberly and Stanley, 1978, p. 924) which formerly was used for rocks now assigned to the base of the Pantano Formation. No red beds were reported associated with the volcanic rocks below a depth of 8,104 ft.

The red unit in the study area may represent more than one depositional sequence. The radiometric dates from the volcanic rocks near Mount McDowell, and to a lesser extent the dates from Tempe Butte, indicate that the red beds at these locations are younger than the Pantano Formation and its equivalents. The red beds in drill hole (A-4-04)8cdc in Paradise Valley are older than 22 m.y. and could be equivalent to the Pantano Formation. Parts of the red unit in the study area are clearly Miocene in age, but the available data do not permit a determination of a maximum age of the unit and possible correlation to parts of the Pantano Formation and its equivalents.

Where the red unit is exposed, it generally is well cemented with calcium carbonate and probably has a low hydraulic conductivity. Near Scottsdale, the red unit yields more water to wells than do the overlying lower or middle units (Arteaga and others, 1968, p. 23); however, data are insufficient to determine the hydraulic conductivity. Fractures and faults in the red unit may yield as much as 1,000 gal/min of water to wells.

SELECTED POTASSIUM-ARGON ROCK AGES IN SOUTHERN ARIZONA

QTs ?
3.3 m.y. (mean of multiple samples)–Gillespie basalt flow overlying second highest of 3 terraces along the Gila River near Gillespie Dam, about 40 miles southwest of Phoenix (8)(9)

Tsu / Ts / Tsl
8.12 ± 0.64 m.y.–Basalt, interbedded with gravel and conglomerate at Poston Butte, 2 miles northwest of Florence (7)

8.87 ± 0.26 m.y.–Basalt, displaced 10-20 ft by high-angle fault; overlies fine-grained basin-fill sediments; overlain by Gila River gravel; about 4 mi east of Florence (7)

10.52 ± 0.61 m.y.–Basalt near top of thick evaporate sequence, in drill hole about 1,030 ft below land surface in west part of Salt River Valley area, 10 to 12 mi. west of Phoenix (7)

15.8 ± 0.34 m.y.–Trachyte, 9,060 ft below land surface in drill hole near Eloy; overlain by 740 ft of conglomerate, which is overlain by 6,000 ft of anhydrite (6)

Tv / Lc
17.56 ± 0.37 m.y.–Basaltic andesite, overlies fine-grained beds of red unit on Tempe Butte (5)

17.71 ± 0.43 m.y.–Rhyolitic ash flow on Mt McDowell; overlies red beds (7)

18.01 ± 0.43 m.y.–Trachyte breccia that overlies about 900 ft of red conglomerate at Mt. McDowell near Granite Reef Dam (7)

18.40 ± 0.50 m.y.–Dacite, top of Picketpost Mountain near Superior (7)

18.70 ± 0.44 m.y.–Trachyte boulder in red beds, Mt. McDowell (7)

19.40 ± 0.47 m.y.–Poorly welded pyroclastic rock in drill hole, sec. 1, T 2 S, R 6 E, 7,672 to 7,938 ft below land surface (7) [see sheet 2, section A-A' well (D-2-06)1daa]

20.60 ± 0.62 m.y.–Dacite, Superstition Mountains (7)

22 ± 1.2 m.y.–Basaltic andesite overlying red beds at about 4,730 ft below land surface in drill hole in sec. 8, T 4 N, R 4 E (5)(10)

22.65 ± 0.54 m.y.–Trachyte, overlies red beds, drill hole sec. 8, T 4 N, R 4 E (7)

24.4 ± 2.6 m.y.–Andesite porphyry in Pantano Formation, Davidson Canyon, east of Tucson (3)

26.3 ± 0.8 m.y.–Andesite porphyry over San Xavier Conglomerate southwest of Tucson (4)

27.9 ± 2.6 m.y.–Tuff from Helmet Panglomerate, Sierrita Mountains, southwest of Tucson (2)

28.0 ± 2.6 m.y.–Andesite porphyry on Sentinel Peak near Tucson (2)

38.5 ± 1.3 m.y.–Rhyolite at base of Pantano Formation near Tucson (2)

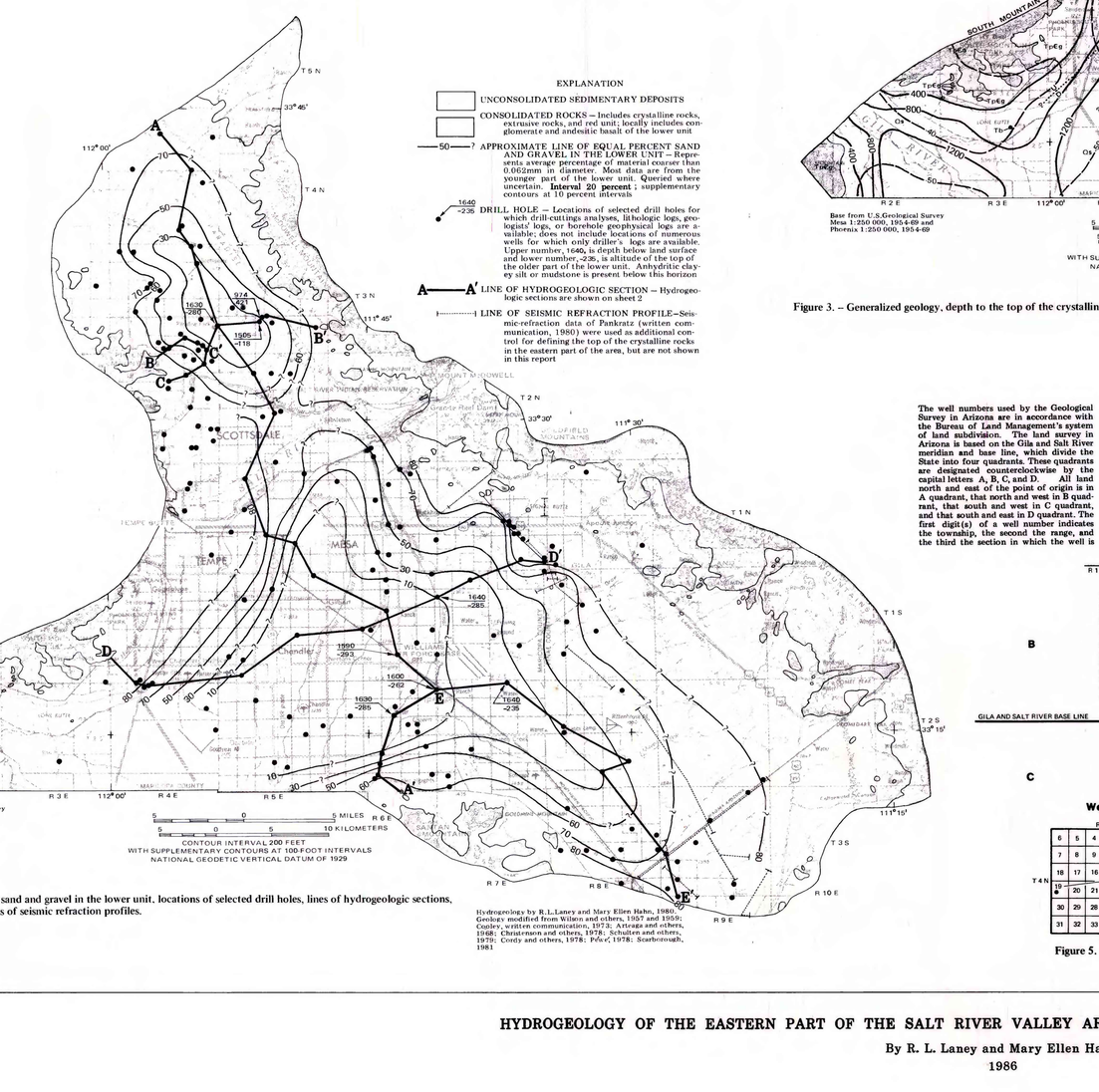
39.4 ± 0.9 m.y.–Basaltic andesite in drill hole, sec. 1, T 2 S, R 6 E, 8,922 to 8,971 ft below land surface (7) [see sheet 2, section A-A', well (D-2-06)1daa]

SOURCES OF DATA

(1) Bikerman and Damon, 1966
(2) Damon and Bikerman, 1964
(3) Finnell, 1970
(4) Pereious, 1968
(5) Scarborough and Wilt, 1979
(6) Shafiqulla and others, 1976
(7) Shafiqulla and others, 1980
(8) Lee and Bell, 1975
(9) Euge and others, 1978
(10) Eberly and Stanley, 1978

Table 1. – Summary of rock units and their hydrogeologic characteristics

Rock unit	Rock type	Depositional conditions	Sediment sources	Thickness (feet)	Saturated thickness (feet)	Hydraulic conductivity (feet per day)	Transmissivity (square feet per day)	Potential yield to wells (gallons per minute)	Type of aquifer	Remarks
Upper unit	Gravel, sand and silt	Open basin (through drainages) – channel, floodplain, alluvial fan	Drainage areas of Salt River and Queen Creek, the area north of Paradise Valley, and local mountain ranges	0 to 300	0 to 150	50 to 500 (estimated)	2,500 to 75,000 (estimated)	1,000 to 4,500	Unconfined	Most permeable unit. Saturated only in the southwest part of the area
Middle unit	Silt, siltstone silty sand and gravel	Closed basin: playa, alluvial fan, fluvial	Same as above, except local mountain ranges contributed relatively more during early part of depositional period	<100 to 1,000	100 to 700	20 to 100	10,000 to 60,000	200 to 4,000	Unconfined, leaky confined	Contains the most recoverable ground water and is the most productive unit basinwide. Values of hydraulic conductivity are based on aquifer-test data
Lower unit	Clay, silt, mudstone, evaporites sandstone, gravel, conglomerate and andesitic basalt	Similar to above	Local mountain ranges	600 to 10,000+	600+	0.001 to 100 (estimated)	1,000 to 50,000 (estimated)	<50 to 3,500	Unconfined, leaky confined	Highest yields where coarse-grained. Most recoverable water in the upper 500 feet of the unit
Red unit	Breccia, conglomerate, sandstone, and siltstone; locally basaltic to rhyolitic flows and pyroclastic rocks	Alluvial fan, fluvial	Mountains that predate the modern basins and ranges	2,000+	500+ near Scottsdale	0.001 to 100 (estimated)	0 to 50,000 (estimated)	0 to 1,000	Confined (?)	Basin configuration during deposition not known. Yield depends on the amount of fracturing. Known to be productive only near Scottsdale
Extrusive rocks	Rhyolitic to basaltic pyroclastic and flow rocks	---	---	3,500+	---	---	---	---	---	Present mainly in the Superstition Mountains. Principal source of detritus to the younger sedimentary units near the mountains
Crystalline rocks	Granitic intrusive rocks, schist, gneiss, quartzite, metavolcanic rocks	---	---	---	---	< 0.001 (estimated)	---	0 - 10	Unconfined	Underlie the basins and mountains. Form virtually impermeable boundaries.



Base from U.S.Geological Survey
Mesa 1:250 000, 1954-69 and
Phoenix 1:250 000, 1954-69

Figure 4. -- Percent sand and gravel in the lower unit, locations of selected drill holes, lines of hydrogeologic sections, and lines of seismic refraction profiles.

Hydrogeology by R.L.Laney and Mary Ellen Hahn, 1980. Geology modified from Wilson and others, 1957 and 1959; Cooley, written communication, 1973; Arteaga and others, 1968; Christenson and others, 1978; Schulten and others, 1979; Cordy and others, 1978; Pelw, 1978; Scarborough, 1981

CORRELATION AND DESCRIPTION OF MAP UNITS

Qs	UPPER UNIT – Gravel, sand, and silt	QUATERNARY
QTs	MIDDLE UNIT – Silt, siltstone and silty sand and gravel; overlain by the upper unit and not exposed in the study area	QUATERNARY AND TERTIARY
Tsu / Ts / Tsl	LOWER UNIT – Consists of two parts. The upper and younger part (Tsu) is clay, silt, mudstone, gypsiferous mudstone, sand and gravel, and conglomerate; andesitic basalt (Ts) locally crops out and is interbedded with and overlies the older part and underlies the younger part in the southeast part of the area. The lower and older part (Tsl) is mudstone, gypsiferous and anhydritic mudstone, anhydrite, conglomerate, and basalt. Undifferentiated conglomerate of the unit (Ts) crops out locally on the east and west sides of Paradise Valley	TERTIARY
Tr	RED UNIT AND EXTRUSIVE ROCKS – Red unit (Tr) consists of breccia, conglomerate, sandstone and siltstone and locally basaltic to rhyolitic flows and pyroclastic rocks in upper part. Extrusive rocks (Tv) consist of rhyolitic to basaltic pyroclastic and flow rocks	TERTIARY
TpCg	CRYSTALLINE ROCKS – Granite, schist, gneiss, quartzite and metavolcanic rocks	TERTIARY TO PRECAMBRIAN

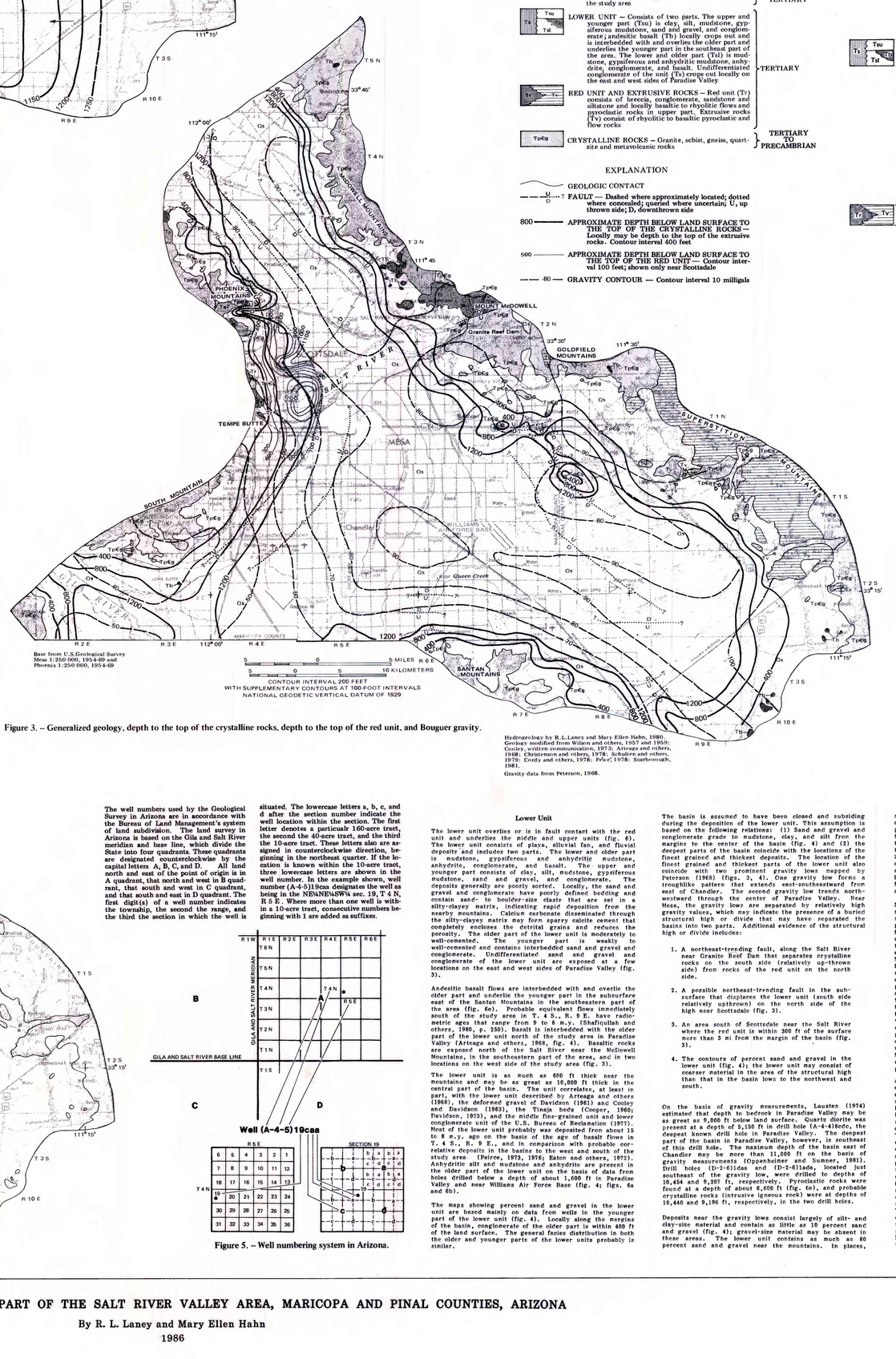


Figure 3. – Generalized geology, depth to the top of the crystalline rocks, depth to the top of the red unit, and Bouguer gravity.

Hydrogeology by R.L.Laney and Mary Ellen Hahn, 1980. Geology modified from Wilson and others, 1957 and 1959; Cooley, written communication, 1973; Arteaga and others, 1968; Christenson and others, 1978; Schulten and others, 1979; Cordy and others, 1978; Pelw, 1978; Scarborough, 1981.

Gravity data from Peterson, 1968.

The well numbers used by the Geological Survey in Arizona are in accordance with the Bureau of Land Management's system of land subdivision. The land survey in Arizona is based on the Gila and Salt River meridian and base line, which divide the State into four quadrants. These quadrants are designated counterclockwise by the capital letters A, B, C, and D. All land north and east of the point of origin is in A quadrant, that north and west in B quadrant, that south and west in C quadrant, and that south and east in D quadrant. The first digit(s) of a well number indicates the township, the second the range, and the third the section in which the well is situated. The lowercase letters a, b, c, and d after the section number indicate the well location within the section. The first letter denotes a particualr 160-acre tract, the second the 40-acre tract, and the third the 10-acre tract. These letters also are assigned in counterclockwise direction, beginning in the northeast quarter. If the location is known within the 10-acre tract, three lowercase letters are shown in the well number. In the example shown, well number (A-4-01)19caa designates the well as being in the NE¼NE¼SW¼ sec. 19, T 4 N, R 5 E. Where more than one well is within a 10-acre tract, consecutive numbers beginning with 1 are added as suffixes.

Figure 5. – Well numbering system in Arizona.

Lower Unit

The lower unit overlies or is in fault contact with the red unit and underlies the middle and upper units (fig. 6). The lower unit consists of playa, alluvial fan, and fluvial deposits and includes two parts. The lower and older part is mudstone, gypsiferous and anhydritic mudstone, anhydrite, conglomerate, and basalt. The upper and younger part consists of clay, silt, mudstone, gypsiferous mudstone, sand and gravel, and conglomerate. The deposits generally are poorly sorted. Locally, the sand and gravel and conglomerate have poorly defined bedding and contain sand- to boulder-size clasts that are set in a silty-clayey matrix, indicating rapid deposition from the nearby mountains. Calcium carbonate disseminated through the silty-clayey matrix may form sparry calcite cement that completely encloses the detrital grains and reduces the porosity. The older part of the lower unit is moderately to well-cemented. The younger part is weakly to well-cemented and contains interbedded sand and gravel and conglomerate. Undifferentiated sand and gravel and conglomerate of the lower unit are exposed at a few locations on the east and west sides of Paradise Valley (fig. 3).

Andesitic basalt flows are interbedded with and overlie the older part and underlie the younger part in the subsurface east of the Santan Mountains in the southeastern part of the area (fig. 6e). Probable equivalent flows immediately south of the study area in T. 4 S., R. 9 E. have radiometric ages that range from 9 to 8 m.y. (Shafiqullah and others, 1980, p. 250). Basalt is interbedded with the older part of the lower unit north of the study area in Paradise Valley (Arteaga and others, 1968, fig. 4). Basaltic rocks are exposed north of the Salt River near the McDowell Mountains, in the southeastern part of the area, and in two locations on the west side of the study area (fig. 3).

The lower unit is as much as 600 ft thick near the mountains and may be as great as 10,000 ft thick in the central part of the basin. The unit correlates, at least in part, with the lower unit described by Arteaga and others (1968), the deformed gravel of Davidson (1961) and Cooley and Davidson (1963), the Tinaja beds (Cooper, 1960; Davidson, 1973), and the middle fine-grained unit and lower conglomerate unit of the U.S. Bureau of Reclamation (1977). Most of the lower unit probably was deposited from about 15 to 8 m.y. ago on the basis of the age of basalt flows in T. 4 S., R. 9 E., and in comparison with probable correlative deposits in the basins to the west and south of the study area (Peirce, 1973, 1976; Eaton and others, 1972). Anhydritic shale and anhydrite are present in the older part of the lower unit on the basis of data from holes drilled below a depth of about 1,600 ft in Paradise Valley and near Williams Air Force Base (fig. 4; figs. 6a and 6b).

The maps showing percent sand and gravel in the lower unit are based mainly on data from wells in the younger part of the lower unit (fig. 4). Locally along the margins of the basin, conglomerate of the older part is within 400 ft of the land surface. The general facies distribution in both the older and younger parts of the lower units probably is similar.

The basin is assumed to have been closed and subsiding during the deposition of the lower unit. This assumption is based on the following relations: (1) Sand and gravel and conglomerate grade to mudstone, clay, and silt from the margins to the center of the basin (fig. 4) and (2) the deepest parts of the basin coincide with the locations of the finest grained and thickest deposits. The location of the finest grained and thickest parts of the lower unit also coincide with two prominent gravity lows mapped by Peterson (1968) (figs. 3, 4). One gravity low forms a troughlike pattern that extends east-northeastward from east of Chandler. The second gravity low trends northwestward through the center of Paradise Valley. Near Mesa, the gravity lows are separated by relatively high gravity values, which may indicate the presence of a buried structural high or divide that may have separated the basins into two parts. Additional evidence of the structural high or divide includes:

1. A northeast-trending fault, along the Salt River near Granite Reef Dam that separates crystalline rocks on the south side (relatively up-thrown side) from rocks of the red unit on the north side.
2. A possible northeast-trending fault in the subsurface that displaces the lower unit (south side relatively upthrown) on the north side of the high near Scottsdale (fig. 3).
3. An area south of Scottsdale near the Salt River where the red unit is within 300 ft of the surface more than 3 mi from the margin of the basin (fig. 3).
4. The contours of percent sand and gravel in the lower unit (fig. 4); the lower unit may consist of coarser material in the area of the structural high than that in the basin lows to the northwest and south.

On the basis of gravity measurements, Lausten (1974) estimated that depth to bedrock in Paradise Valley may be as great as 9,000 ft below land surface. Quartz diorite was present at a depth of 5,150 ft in drill hole (A-4-04)8cdc, the deepest known drill hole in Paradise Valley. The deepest part of the basin in Paradise Valley, however, is southeast of this drill hole. The maximum depth of the basin east of Chandler may be more than 11,000 ft on the basis of gravity measurements (Oppenheiner and Sumner, 1981). Drill holes (D-2-01)daa and (D-2-01)ada, located just southeast of the gravity low, were drilled to depths of 10,454 and 9,207 ft, respectively. Pyroclastic rocks were found at a depth of about 6,606 ft (fig. 6a), and probable crystalline rocks (intrusive igneous rock) were at depths of 10,440 and 9,196 ft, respectively, in the two drill holes.

Deposits near the gravity lows consist largely of silt- and clay-size material and contain as little as 10 percent sand and gravel (fig. 4); gravel-size material may be absent in these areas. The lower unit contains as much as 80 percent sand and gravel near the mountains. In places, such as northwest of the Santan Mountains, grain size changes laterally within a short distance. In the younger part of the lower unit the lateral change in grain size may be caused by sedimentary facies change and (or) faulting--the central parts of the basin were downdropped relative to the the margins (figs. 3 and 4). Faulting is the most likely cause of abrupt lateral changes in particle size in the older part of the lower unit because of greater structural activity during the deposition of the older part. These lateral discontinuities -- regardless of whether they are a fault of facies change -- are hydrologic boundaries that affect storage, transmitting properties, and well yields.

Sediment in the lower unit was derived from the mountains surrounding the basin. The lower unit generally is more monolithologic than the overlying middle unit and is composed largely of granitic material--granite, quartz, feldspar, and granitic gneiss. Locally, the lower unit contains clasts of schist, quartzite and volcanic rocks where these rocks are present in the nearby mountains. In the east