

## top of crystalline and extrusive rocks.

### INTRODUCTION

The Salt River Valley is a major population and agricultural center of more than 3,000 mi² in central Arizona (fig. 1). The western part of the Salt River Valley area (area of this report) covers about 1,500 mi<sup>2</sup>. The Phoenix metropolitan area with a population of more than 1.6 million in 1985 (Valley National Bank, 1987) is located within the valley. The watersheds of the Salt, Verde, and Agua Fria Rivers provide the valley with a reliable but limited surfacewater supply that must be augmented with ground water even in years of plentiful rainfall. Large-scale ground-water withdrawals began in the Salt River Valley in the early part of the 20th century; between 1915 and 1983, the total estimated ground-water pumpage was 81 million acre-ft (U.S. Geological Survey, 1984). Because of the low average annual rainfall and high potential evapotranspiration, the principal sources of ground-water recharge are urban runoff, excess irrigation, canal seepage, and surface-water flows during years of higher-than-normal rainfall. Withdrawals greatly exceed recharge and, in some areas, ground-water levels have declined as much as 350 ft (Laney and others, 1978; Ross,

300 ft have occurred in Deer Valley and from Luke Air Force Base north to Beardsley. As a result, a large depression of the water table has developed west of Luke Air Force Base (fig. 2). Ground-water use has decreased in recent years because precipitation and surface-water supplies have been large quantities of runoff to be released into the normally dry Salt and Gila River channels. From February 1978 to June 1980, streamflow losses of at least 90,000 acre-ft occurred between Jointhead Dam near the east boundary of the study area and Gillespie Dam several miles southwest of the west edge of the study area (Mann and Rhone, 1983). Consequently, groundwater declines in a large part of the basin have slowed, and ground-water levels in some areas have risen significantly. In many areas along the Salt River and northeast of the confluence of the Salt and Agua Fria Rivers, ground-water levels rose more than 25 ft between 1978 and 1984 (Reeter and Remick, 1986).

In the study area, ground-water declines of more than

## Purpose and Scope

The purpose of this investigation was to develop a better understanding of the hydrogeologic framework of the aquifer underlying the western part of the Salt River Valley. This report describes the lithologic, hydraulic, and water-quality characteristics of the hydrogeologic units that make up the basin-fill aquifer. The hydrogeology of the eastern part of the Salt River Valley is described by Laney and Hahn (1986).

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Glendale, Sun City, and other towns who supplied well, waterquality, and lithologic data. The Arizona Bureau of Geology and Mineral Technology provided assistance and a workspace in which to examine well cuttings. The Basic Data Unit of the Arizona Department of Water Resources provided a current data base of well information. Private consultants who provided drill cuttings, geophysical logs, and other hydrologic data included Kenneth D. Schmidt and Associates; Manera, Inc.; Water Resources Associates; and CH2M Hill. Odom Drilling, Prins Drilling, Layne Western, and many other drillers voluntarily provided drill cuttings. Special thanks are due to Travis Jones of Buckeye Irrigation Company, Jack Conovaloff of Roosevelt Irrigation District, and Dick Yancy of Maricopa County Municipal Water Conservation District. Their cooperation made possible the aquifer tests done during this

Salt River Valley is a broad alluvial basin within the Basin and Range physiographic province of the United States (Fenneman, 1931). The basin is almost completely surrounded by mountains composed primarily of granitic, metamorphic, and volcanic rocks and minor amounts of consolidated sedimentary rocks (fig. 3). The valley floor is underlain by unconsolidated to semiconsolidated basin-fill sediments that are more than 11,000 ft thick in the central part of the basin (Oppenheimer and Sumner, 1981). The valley floor ranges in altitude from 800 ft in the extreme southwest to about 2,000 ft in the northwest.

The western part of the Salt River Valley area is bounded on the south by the Buckeye Hills, South Mountain, and Sierra Estrella, which reach an altitude of 4,500 ft above sea level. The White Tank Mountains at the west boundary have a maximum altitude of 3,780 ft. The Hieroglyphic Mountains border the valley on the north and reach an altitude of 3,370 ft in the study area. Smaller mountains and hills lie along the northeast and east margins of the valley. The highest and most distinctive of these is Camelback Mountain, which reaches an altitude of 2,700 ft.

The western part of the Salt River Valley area lies in the northeastern part of the Sonoran desert and has hot summers and cool winters. The average maximum daily temperature in July is 105° F; the average minimum is 80° F. The average maximum and minimum daily temperatures in December are 65° F and 39° F, respectively (Sellers and others, 1985). Average rainfall on the valley floor is about 7.5 in./yr but may be

Base from U.S. Geological Survey 1:250,000

Mesa, 1954-69 and Phoenix, 1954-69

## north of Sun City and 11 in. at Cave Creek, which is 10 mi

significantly higher in the surrounding mountains. Average

annual rainfall is about 9.5 in. at Lake Pleasant, about 10 mi

northeast of the study area (Sellers and others, 1985). Most

of the precipitation occurs during two rainy seasons. During

the winter, occasional storm systems move inland from the

Pacific Ocean and result in rains that generally are

widespread and light to moderate in intensity. During the

summer, rain results from moist air masses moving northward

from the Gulf of Mexico and the west coast of Mexico. Summer

rains are more localized than winter rains and may vary

greatly in intensity. The average annual pan evaporation

measured a few miles east of the study area in Tempe was

72 in. for 1969-73 (Sellers and Hill, 1974, p. 44). Potential

evapotranspiration may equal pan evaporation and therefore may

The Salt, Gila, and Agua Fria Rivers are the main streams

in the western part of the Salt River Valley area. Most of

the low flow in these rivers is sewage effluent and irrigation

return flow. High flows occur during or following periods of

intense or prolonged rainfall when large amounts of water are

released from upstream reservoirs into the normally dry river

channels. The Salt River enters the study area at Tempe and

flows into the Gila River about 15 mi southwest of downtown

Phoenix. The Gila River enters the study area through the gap

between Sierra Estrella and South Mountain and flows to the

extreme west boundary of the study area about 8 mi west of

Buckeye. The Agua Fria River enters the valley from the

Hieroglyphic Mountains, flows south, and joins the Gila River

Most of the smaller streams, including the New River,

Waterman Wash, and Skunk Creek, are dry most of the time and

flow only during and after intense or prolonged rains. The

New River and its main tributary, Skunk Creek, enter the

valley from the north and flow into the Aqua Fria River

southwest of Glendale. Waterman Wash flows northward into the

Methods of Investigation

test, specific-capacity, specific-yield, and water-quality

data were inventoried and compiled to provide a complete data

base. Well drilling was monitored during 1983-85 to obtain

drill cuttings in data-deficient areas. In addition, drill

cuttings from more than 110 wells drilled over the last

40 years were inspected at the office of the Arizona Bureau of

in defining the lithologic character of the basin-fill

deposits. Aquifer tests were done at 23 existing

large-capacity wells from May 1984 to September 1985. Tests

were limited mostly to wells that were perforated in a single

hydrogeologic unit in order to provide transmissivity,

perforated in narrow zones within a particular unit.

HYDROGEOLOGY

part of the Salt River Valley area are divided into six

unit, and the lower, middle, and upper units of the basin fill

with the sedimentary units. Metamorphic, granitic, and

extrusive rocks make up the mountains that border the basin

and underlie the basin fill. These rocks form virtually

impermeable hydrologic boundaries and are the sources of most

significance. The basin-fill units contain most of the

The present-day Basin and Range physiography was formed as

ground water in the area. A summary of the hydrogeologic

a result of a period of high-angle block faulting that

occurred mostly between 15 and 8 million years (m.y.) ago

(Shafiqullah and others, 1980). The red unit predates the

period of high-angle block faulting. The lower unit of basin

fill contains an older part that was deposited during faulting

and basin subsidence and a younger part that was deposited

during the waning stages of faulting. Little discernable

faulting has disturbed the units above the older part of the

lower unit, although subsidence of the basin continued during

activity and size of the drainage area with time have affected

the rates of sedimentation and distribution of fine-grained

sediments in the basin fill. Active tectonism resulted in the

of closed basins during deposition of the lower unit. During

deposition of the middle and upper units, the lack of

tectonism and the development of regional drainage resulted in

coarsening upward in grain size and changes in the areal

location of fine-grained deposits.

deposition of fine-grained sediments in the subsiding centers

deposition of the middle and upper units. Changes in tectonic

characteristics of the units is in table 1.

of the sedimentary deposits that fill the basin. The red unit

is a discontinuous sedimentary deposit of minor hydrologic

units metamorphic and granitic rocks, extrusive rocks, red

(fig. 3). Basalts interbedded with sediments are included

Geology and Mineral Technology in Tucson. These samples aided

Available lithologic, geophysical, particle-size, aquifer-

be about 10 times the average annual rainfall.

originates outside the study area.

Gila River several miles east of Buckeye.

individual units.

The occurrence and movement of ground water in the study area are controlled partly by the structure of the crystalline and the sedimentary rocks. The crystalline rocks delineate the areal and vertical extent of the aquifer. Primary hydraulic properties of the aquifer are influenced by the thickness, areal distribution, and tilting of the sedimentary units. Faulting and fracturing may form barriers to groundwater flow or provide avenues of increased permeability.

The study area is divided into northeast and southwest regions by a major structure that extends from Wittman in the northwest corner of the basin to Papago Buttes in the southeast corner. This structure, which probably is a major fault within the crystalline rocks, is defined by steep gravity gradients and the pronounced gravity low that is southwest of the structure (fig. 3).

The northeast region is dominated by several structural

blocks of crystalline rocks that are oriented in a northwest direction and slightly tilted to the northeast. The predominant stratigraphic sequence of each block consists of middle to upper Tertiary volcanic rocks overlying Precambrian schist and granite. Structurally high surfaces of crystalline rock occur at the southwest edge of each block. Structural lows and large basin-fill thicknesses occur at the northeast edge of each block. The most pronounced of these blocks is indicated by a buried northwest-trending structural high near Glendale. Gravity data and several drillers' logs indicate that crystalline rocks are at shallow depths and the thickness of the basin fill increases to the northeast.

The crystalline rocks in the southwest region consist mainly of Tertiary gneiss and granite and Precambrian granite. In this region, South Mountain, the White Tank Mountains, and Sierra Estrella may lie within separate structural blocks, as indicated by steep gravity gradients between the mountains. South Mountain is a northeast-trending arch structure. The northwest limb of the arch dips basinward at less than 30°. and the nose plunges beneath basin fill at dips of 10° to 15° (Reynolds, 1985). The arch is overlain by a detachment fault and highly faulted and tilted middle to upper Tertiary rocks including the red unit. Similar arch structures are not known to exist in the White Tank Mountains or Sierra Estrella.

A large structural depression that forms the down-faulted core of the basin is well defined by an extensive gravity low in the southwest region (fig. 3). Steep gravity gradients, which probably represent steep-angle normal faults, bound the depression on three sides—northeast, west, and south—forming a graben. The graben is roughly triangular in shape and includes the area of Luke Air Force Base, the Luke salt body (Eaton and others, 1972) in the center of the gravity low, and the east- and west-trending region of low-gravity values from

The characteristics of the basin-fill aguifer vary between storage-coefficient, and hydraulic-conductivity data for the northeast and southwest regions. The northeast region contains basin fill that generally is less than 2,000 ft thick. The lower unit of the basin fill is the main water-Water-quality samples were collected at 56 sites during the bearing unit in the northeast region because the overlying summers of 1984 and 1985 to augment the existing data base. units generally are thin and depths to water are great. Samples were taken only from wells in which the depth and Ground-water flow in the lower unit is influenced by perforated intervals were known in order to correlate waterrelatively shallow bedrock and secondary permeabilities. The quality characteristics with aquifer lithology. An effort was southwest region contains the greatest thickness of sediments, made to collect samples from wells open to a single zone or and all the basin-fill units are significant water-bearing parts of the aquifer. Ground-water flow is influenced mainly by the location of fine-grained deposits. Surface-bedrock topography is rugged and similar to the topography of the mountains, but, generally, the bedrock surface on the basin margin slopes toward the basin center at a low angle. Crystalline rocks and sedimentary deposits in the western

> In general, the basin fill gently dips toward the basin center. Continual subsidence during basin-fill deposition has resulted in greater thickness in the graben and an increased dip of beds near the graben-bounding faults. The lower part of the lower unit of the basin fill probably is displaced by faults and may be tilted in much of the basin; however, the greatest degree of structural deformation occurs at depth within the graben. The upper part of the lower unit may be slightly displaced by faults, especially near the graben boundaries. The middle and upper units probably are not

faulted except possibly near the Luke salt body. Movement of the Luke salt body during basin-fill deposition has affected the structure of the basin-fill units. A structural high within the lower unit near the salt body indicates vertical displacement of several hundred feet in that unit. Upward salt movement probably was accompanied by subsidence at the margins of the salt body, as indicated by a thickening of younger basin-fill units around the salt body. Faulting of the lower unit of the basin fill near the salt body is likely, but similar faulting of younger units is uncertain. Outcrops of undifferentiated basin fill near the salt body contain fractures, but no displacement is obvious.

Crystalline rocks are composed of metamorphic and granitic rocks. Metamorphic rocks, which are composed of schist and gneiss of Precambrian to middle Tertiary age, make up most of the surrounding mountains (Wilson and others, 1957; Cordy and others, 1978; Reynolds, 1985; Schulten and others, 1979). Granitic rocks of Precambrian to middle Tertiary age crop out mostly along the north and west margins of the study area

<u>Crystalline Rocks</u>

(fig. 3). Metamorphic and granitic rocks have been penetrated by wells near the edge of the basin. The rocks form a virtually impermeable boundary at the basin margins and beneath the basin fill.

## Extrusive rocks are volcanic rocks that include rhyolitic

to basaltic rocks of middle to late Tertiary age and basalt flows of middle Tertiary to Quaternary age (Wilson and others, 1957). Most of the volcanic rocks are of minor hydrologic significance; however, some of the rocks may contain permeable zones where they are highly vesicular or fractured. Volcanic rocks older than middle Miocene age are exposed in

1957) and are commonly encountered by wells in the north and northeast parts of the study area. Younger basalt flows of middle Miocene age are intercalated with sediments that probably are equivalent to the lower unit of basin fill north of the study area (fig. 3) (Scarborough and Wilt, 1979). Younger mafic volcanic units of late Miocene age have been encountered at depth by well drilling near the center of the basin. Basalts of late Tertiary and Quaternary age are interbedded with basin sediments in the extreme southwestern

The red unit is present mainly in the southeastern part of the study area and is not a significant source of water. The red unit, described by Cooley in Arteaga and others (1968), consists of reddish-colored, well-cemented breccia, conglomerate, sandstone, and siltstone and contains granitic and rhyolitic detritus. The size of the particles in the breccia and conglomerate range from clay to boulders as large as 15 ft in diameter. Bedding generally is poorly defined, and a large part of the unit probably is debris flows. Siltstone and sandstone deposits generally are better stratified and sorted than the coarse-grained deposits and, in places, are interbedded with poorly sorted breccia and conglomerate. Locally, mafic to felsic flow rocks and some pyroclastic rocks are interbedded with the sedimentary rocks at the top of the unit.

The red unit was deposited prior to high-angle normal faulting and formation of the late Tertiary sedimentary basins. Most of the unit has been tilted 20 to 45 degrees by earlier structural events (Laney and Hahn, 1986). Age determinations of volcanic flows within the red unit range from about 17.5 to 22 m.y. (Laney and Hahn, 1986). 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. About 2,400 ft of red beds in a drill hole near Higley in the eastern part of the Salt River Valley area, about 20 mi southeast of the study area, are younger than about 19 m.y. Red beds in a drill hole in Paradise Valley a few miles east of the study area are older than

Several wells encounter the red unit in the southeastern part of the study area. Test well (A-01-03)13dbb penetrates 599 ft of the red unit that contains gypsum and is tilted about 45°. An explanation of the well-numbering system used in this report is given in figure 4. Drilling of several other wells terminated in lesser thicknesses of red sediments. Red sediments found in two wells in deeper parts of the basin may be equivalent to the red unit. Red-brown sand and silt and traces of calcite were found at the bottom of well (B-03-01)25bbb at depths of 760 to 805 ft. At well (A-03-02)27bad, about 90 ft of red sand at depths of 1,750 to 1,840 ft is overlain by 580 ft of diabase.

Fractures and faults in the red unit may yield as much as 1,000 gal/min of water to wells in the eastern part of the Salt River Valley area (Laney and Hahn, 1986). Near Scottsdale, the red unit yields more water to wells than does the overlying basin-fill units (Arteaga and others, 1968, p. 23). The red unit is not known to be a significant source of ground water in the western part of the Salt River Valley

The lower unit of basin fill overlies or is in fault contact with the red unit and older crystalline rocks and underlies the middle and upper units (fig. 6). The lower unit consists of playa, alluvial-fan, fluvial, and evaporite deposits. The unit generally is fine grained with coarsegrained facies at the basin margins and at depth. The finegrained deposits may be massive or thinly bedded and may range from reddish-brown and buff silt, clay, mudstone, and siltstone to grayish-brown and grayish siltstone and finegrained sandstone. The coarse-grained deposits are poorly sorted sand, gravel, and conglomerate that are grayish brown or gray. Reddish-brown sand and gravel are found at the base of the lower unit in the southeastern part of the basin and are associated with detritus of the red unit. Calcium carbonate may form cement that reduces the porosity of some of the coarse-grained deposits.

The lower unit is divided into lower and upper parts. Both parts are generally fine grained but differ in consolidation, homogeneity, types of evaporite deposits, and structure. The

lower part is more consolidated and more homogeneous in terms of clast type and stratigraphy than the upper part. Evaporite deposits in the lower part generally are massive and consist of anhydrite, gypsum, and halite. Gypsum is the only evaporite found in the upper part and occurs as interbedded layers or is finely disseminated within the sediments. Lateral changes in stratigraphic facies and in thickness of both parts of the unit are associated with basin structures. Some of the lateral changes represent discontinuities that have been caused by faulting, especially in the lower part.

The lower part of the lower unit is moderately to wellcemented mudstone, siltstone, gypsiferous and anhydritic mudstone, sand, gravel, conglomerate, halite, gypsum, and anhydrite and includes basalt flows. The lower part is as much as 1,000 ft thick near the basin margins and may be more than 10,000 ft thick in the graben. The Luke salt body is an evaporite facies of the lower part. The base of the unit may contain several hundred feet of sand and gravel or conglomerate at the basin margins. The lower part includes fanglomerates, mudstones, and intercalated basalts, andesitic pasalts, and tuffs of middle Miocene age that are exposed in the Hieroglyphic Mountains and found in the northern and northeastern parts of the basin.

Much of the lower part of the lower unit probably was deposited prior to 10 m.y. ago on the basis of the age of drill cuttings from a basalt within a gypsum and anhydrite sequence near the top of the unit (Peirce, 1973, 1976; Eaton and others, 1972). The lower part of the unit correlates, at part of the Salt River Valley area (Laney and Hahn, 1986), 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 some of the middle fine-grained unit and the lower conglomerate unit described by the U.S. Bureau of Reclamation

A transition from the red unit to the lower unit of the basin fill and some low-angle faulting of the lower unit is indicated by the age and tilting of the lower unit at several locations. Tilted tuff, mudstone, and basalt dated at 16.6 m.y. occur west of Lake Pleasant (Scarborough and Wilt, 1979) and are equivalent to the lower unit. Core data from U.S. Bureau of Reclamation test well (B-03-01)32dda indicate that the fine-grained lower unit is tilted 20 to 45 degrees below a depth of 1,965 ft. In well (B-03-01)25bbb, the lower unit consists of red sediments with calcite and salty water. Red sediments and gypsum in well (A-01-03)13dbb are tilted 45 degrees and interpreted as red unit; however, the lithologic description is similar to that of the lower part of the lower unit. Age dating of drill cuttings from a mafic volcanic unit within the lower unit at well (B-02-01)09bdd indicated an age of 23 m.y. The volcanic unit was encountered at depths of 800 to 850 ft in a moderately fine-grained sequence of the lower part of the lower unit. The presence of salty water beneath the volcanic unit and high electrical resistivities below a depth of 900 ft indicate the presence of halite, although no halite was recovered in drill cuttings.

Average particle size in the lower part of the lower unit ranges from less than 20 to more than 80 percent sand and gravel (fig. 5). Generally, the coarsest grained deposits occur along the basin margin and become increasingly finer toward the center of the basin. Deposits containing more than 80 percent sand and gravel occur along the south end of White Tank Mountains at the west edge of the study area. Similarly, a broad arc of sediments containing more than 80 percent sand and gravel occur at the base of the Phoenix Mountains in Tps. 1 and 2 N., R. 3 E. Sediments of the lower part of the lower unit contain less than 20 percent coarse materials in the basin graben except for an area of several square miles almost directly over the Luke salt body. The salt body is overlain by about 400 ft of anhydritic, gypsiferous, and clastic sediments of the lower part. The clastic sediments contain more than 20 percent coarse materials and are surrounded by fine-grained sediments (fig. 5).

The break between the lower and upper parts of the lower unit is gradational in the basin center and is characterized by increased heterogeniety upward in geophysical and particle-size logs. The break may be abrupt on the basin margins, especially where the lower part is coarse grained. The upper part of the lower unit is weakly to moderately

cemented and consists of silt, clay, mudstone, siltstone,

gypsiferous mudstone, gypsum, sand, and gravel. The upper

part is an extensive fine-grained deposit that contains interbedded sand and gravel. In places, the unit abuts or overlies crystalline rocks at the basin margins. Deposits of the upper part of the lower unit containing less than 10 percent sand and gravel occur in a generally arcuate pattern from northwest Phoenix to Tolleson and southeast of the White Tank Mountains (fig. 7). This pattern is somewhat atypical of the particle-size distribution generally found in closed basins where the fine-grained deposits are found in the deepest part of the basin. Doming of the Luke salt body apparently has had a major influence on

distribution of particle size in the upper part of the lower

unit. Deposits over the salt body contain from 20 to 50

percent sand and gravel. These deposits are surrounded on the

containing from 10 to 30 percent sand and gravel. This

pattern suggests that doming of the salt body was occurring

west, south, and east by a zone of fine-grained materials

during deposition of the upper part of the lower unit and resulted in the deposition of fine-grained materials southwest and southeast of the salt body. Deposits containing more than 80 percent sand and gravel occur in the south half of T. 1 N., R. 3 W., and the north half of T. 1 S., R. 3 W., and become finer to the east and

deposits from the Agua Fria River and New River drainages. The unit becomes finer grained south of the major northwest-trending structure in the basin. Thickness of the upper part of the lower unit is controlled by basin structure, subsidence, and locally by the Luke salt body. The unit is more than 1,000 ft thick in a trough that trends north and south along the west side of the basin between the Luke salt body and the White Tank Mountains. The unit is less than 500 ft thick in Buckeye Valley (fig. 8) and is absent along the mountain fronts in some areas.

west. This area of coarse material coincides with an area of

high gravity values that delineate a shallow part of the basin

in the Buckeye Valley (fig. 3). Deposits containing more than

60 percent sand and gravel also occur in the Sun City area.

This coarse-grained material is associated with alluvial-fan

The basin was closed and subsiding during the deposition of the lower unit on the basis of the following observations: (1) Fine-grained basin-center deposits of mudstone, silt, clay, and evaporites are dominant within the graben structure (fig. 6); (2) structural contours of the base of the upper part of the lower unit coincide closely with gravity contours; and (3) abrupt lateral changes in lithology increase wit

The upper part of the lower unit is fully saturated in most of the basin. Minor amounts of dewatering have occurred east of the White Tank Mountains and to a lesser extent in small areas south of Luke Air Force Base and in Deer Valley. Middle Unit

The middle unit of the basin fill includes playa, alluvialfan, and fluvial deposits of silt, clay, siltstone, and silty sand and gravel (figs. 6A-E). Most of the unit is weakly consolidated, but moderately to well-cemented siltstone occurs locally. Calcium carbonate cement is common. Generally. grain size decreases downward in the middle unit. Depth to the base of the middle unit ranges from zero near the mountains to about 800 ft west of Luke Air Force Base and south of Glendale. The thickest parts of the unit are in the central areas of the valley near gravity lows (fig. 10). The thickness of the middle unit is related to and controlled by basin structure and subsidence as well as by a structural high at the Luke salt body.

The distribution of fine-grained sediments in the middle unit is much less extensive and irregular than in the lower unit. The unit contains more than 40 percent sand and gravel throughout most of the basin (fig. 9). The fine-grained parts of the middle unit are localized, and the locations appear to be highly influenced by the large influx of sediment from the major drainages. Local fine-grained zones of less than 20 percent sand and gravel are present near Glendale and Goodyear. The drainage basins of the Agua Fria, Salt, and Gila Rivers were the principal sources of sediment for the middle unit. Presence of gravel and sand from the Salt River drainage indicates the development of a through-flowing drainage system during this period of deposition.

The contact between the upper part of the lower unit and the middle unit is gradational, and available geophysical logs indicate that the two units are similar. The middle unit can be distinguished from the lower unit by a greater bedding frequency or heterogeniety, a buff or brown color as opposed to red brown, slightly higher resistivity on electric logs, greater variety of clast types near inflow areas of major drainages, general lack of mudstone, and lack of gypsum or gypsiferous sediments. Near Sun City, both units are coarse grained and are lithologically similar. This similarity probably is due to a consistent source area and similar environments during deposition of the two units. In the center of the basin where the lower and middle units are fine grained, the following criteria were used to select the contact: (1) A downward decrease in grain size (increase in clay content); (2) a general decrease in resistivity on borehole-electric logs at the same horizon as the textural change; (3) a decrease in bedding frequency, indicated by geophysical logs; (4) the presence of gypsum or gypsiferous mudstone; and (5) a downward change in color from brown to red

Near the margin of the basin, the middle unit contains more silt and clay than the lower unit, and the contact was placed near a marked downward increase in particle size. The color changes from shades of light brown in the middle unit to grayish brown in the lower unit. Where both units are coarse grained, the contact could be identified in geophysical logs by a downward increase in density and a correlative decrease

Clast types could be used to distinguish the middle and lower units in places. Near Luke Air Force Base, the middle unit contains a larger amount of several types of volcanic clasts. South of Glendale near the Salt River, rounded quartzite gravel and intervals of well-sorted sand occur near the top of the middle unit. In most areas, the clasts in the lower unit are more monolithologic than those in the middle

The age of the middle unit is constrained to between 8 and 3.3 m.y. before present on the basis of radiometric age dates on volcanic flows in the underlying units and near the top of the unit. About 600 ft of sedimentary deposits that contain 8 to 9 m.y. old volcanic flows underlie a similar stratigraphic unit near Florence (Laney and Hahn, 1986). Near Gillespie Dam on the Gila River a few miles west of the report area (fig. 1), 10 basalt samples that range in age from 4.2 to 1.3 m.y. and have a mean age of 3.3 m.y. were collected from rocks that overlie rounded quartzite gravel (Lee and Bell, 1975; Euge and others, 1978). The presence of this gravel indicates that the Salt and (or) Gila River was a throughflowing stream at this early time (Laney and Hahn, 1986) and

places an upper age limit on the unit.

The middle unit is equivalent, in part, to the middle unit of Laney and Hahn (1986), the middle unit of Cooley (Arteaga and others, 1968), the basin fill of Davidson (1961) and Cooley and Davidson (1963), the Fort Lowell Formation of Davidson (1973b), and, in part, the upper alluvial unit of the U.S. Bureau of Reclamation (1977).

Water-level declines in parts of the study area have significantly dewatered the middle unit. The unit has been completely dewatered in a large area east of the White Tank Mountains and in two smaller areas—one south of Luke Air Force Base and one in Deer Valley in secs. 9 and 10, T. 3 N.,

The upper unit of the basin fill includes channel, floodplain, and alluvial-fan deposits that consist largely of gravel, sand, and silt. Most of the unit is unconsolidated; however, alluvial-fan deposits near the mountain fronts and the deposits underlying terraces near the major stream courses may be strongly cemented by caliche. Deposits that contain as much as 80 percent sand and gravel occur near the Salt and Gila Rivers. The unit was deposited after the development of integrated drainage and a large decrease in rates of basin subsidence and basin deposition. The unit has a maximum thickness of nearly 400 ft near the confluence of the Salt and Gila Rivers. The middle unit grades upward into the upper unit in the southern part of the basin where both units are thickest and finest grained. The upper unit thins to 200 ft or less toward the basin margins (fig. 11) where the contact with underlying units is abrupt and is likely to be an erosional surface.

The principal sources of sedimentary material for the upper unit were the drainages of the Salt, Gila, and Aqua Fria Rivers. The mountains that border the basin also contributed sediment to the upper unit. The sediments derived from the Salt and Gila River drainages contain sand- to boulder-size clasts of quartzite, granite, and intermediate to mafic volcanic rocks as well as variable amounts of quartz feldspar, gneiss, and schist. Many of the clasts, especially the quartzite clasts, are well rounded. Sediments derived from the Aqua Fria River drainage consist mainly of subround to subangular granitic and volcanic clasts.

Deposits that contain more than 80 percent sand and gravel occur in a continuous band along the Salt and Gila Rivers from the east to west edge of the study area (fig. 12). Smaller areas of more than 80 percent sand and gravel occur northeast of Grand Avenue between Skunk and Cave Creeks and immediately northeast of Luke Air Force Base. This latter deposit probably is related to gravels deposited by the Agua Fria River. Delineations of the actual extent of subsurface Agua Fria gravels north and east of this area is difficult because of the lack of particle-size data. Deposits that contain less than 40 percent coarse materials occur southwest of the Phoenix Mountains, in small isolated areas east of the White Tank Mountains, and at the extreme west edge of the study

Subsidence of the Salt River Valley area—and (or) uplift of the area to the northeast of the Salt River Valley—is indicated by the relation of terrace levels along major streams and a comparison of the thickness of the upper unit in the Salt River Valley area with equivalent deposits along the lower reaches of the Salt and Gila Rivers (Laney and Hahn, 1986). Three terraces along the Salt River and other major streams converge downgradient toward the Salt River Valley and are buried by deposits in the upper part of the upper unit (Pewe, 1978). The Salt River Valley is the only region of southern Arizona where the upper unit along the Salt and Gila River drainages exceeds 100 ft in thickness (Cooley, 1977,

The upper unit is equivalent to the upper alluvium as

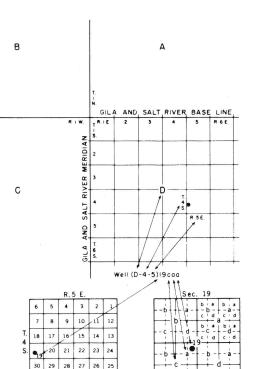
defined by Cooley (Arteaga and others, 1968). The unit may be as old as the 3.3 m.y. basalt flows that overlie rounded quartzite gravel along the Gila River west of the study area; however, most of the unit probably is Quaternary in age. Overdraft of the ground-water system has significantly dewatered the upper unit over large parts of the study area. Complete dewatering has occurred to the north and west of Luke Air Force Base (fig. 12), in T. 3 N., Rs. 2, 3, and 4 E., and

in the area between Phoenix and Deer Valley. Saturated

thickness along and adjacent to the Salt and Gila Rivers

ranges from about 100 to more than 300 ft.

Figure 5.--Percent sand and gravel in the lower part of the lower unit, selected drill holes, and lines of hydrogeologic sections. GILA AND SALT RIVER BASE LIN.



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 designate counterclockwise by the capital letters A, B, C, and D. All land north and east of the point of origin is in A quadrant that north and west in B quadrant, that south and west in C quadrant, and that south and east in D quadrant. The first digit of a well number indicates the township, the second the range, and the third the section in which the well is situated. The lowercase letters a, b, c, and d after the section number indicate the well location within the section. The first letter denotes a particular 160-acre tract, the second the 40-acre tract, and the third the 10-acre tract. These letters also are assigned in a counterclockwise direction, beginning in the northeast quarter. If the location is known within the 10-acre tract, three lowercase letters are shown in the well number. In the example shown well number (D-4-5)19caa designates the well as being in the NE NE NE SW sec. 19, T. 4 S., R. 5 E. Where more than one well is within a 10-acre tract, consecutive numbers beginning with 1 are added as suffixes.

Figure 4.--Well-numbering system in Arizona.

# CONVERSION FACTORS For readers who prefer to use International System (SI) units, rather than the inch-pound terms used in this report, the following conversion factors may be used: To obtain SI unit Multiply inch-pound unit

25.40

0.3048

1.609

0.001233

0.3048

0.09290

0.06309

Sea level: In this report "sea level" refers to the National

datum derived from a general adjustment of the first-order

Geodetic Vertical Datum of 1929 (NGVD of 1929)—A geodetic

level nets of both the United States and Canada, formerly

millimeter (mm

kilometer (km)

cubic hectomete:

meter per day

meter squared per

liter per second

liter per second

 $day (m^2/d)$ 

per meter

[(L/s)/m]

 $^{\circ}C = 5/9(^{\circ}F-32)$  degree Celsius

meter (m)

EXPLANATION

upper, middle, and lower units

than 5,500 feet below land surface at edges,

DRILL HOLE—Location of selected drill hole

geophysical logs are available

near center

20 percent

UNCONSOLIDATED SEDIMENTARY DEPOSITS—Includes

RED UNIT, EXTRUSIVE ROCKS, AND CRYSTALLINE

may be less than 500 feet below land surface

AREA WHERE DEPTH TO VOLCANIC ROCK OVERLYING

LUKE SALT BODY IS LESS THAN 1,000 FEET-Full

areal extent of deeper volcanic rocks is

LOWER PART OF THE LOWER UNIT-Represents

average percentage of material coarser than

0.062 millimeter in diameter. Queried where

uncertain. Hachures indicate closed areas of lower percent sand and gravel. Interval

for which cuttings analysis, lithologic

logs, geologic logs, and (or) borehole-

LINE OF HYDROGEOLOGIC SECTION—Hydrogeologic

sections are shown in figure 6 on sheet 2

AREAL EXTENT OF LUKE SALT BODY—Top is more

called "Sea Level Datum of 1929."

foot (ft)

mile (mi)

acre-foot

(acre-ft)

foot per day

foot squared per

 $day (ft^2/d)$ 

(gal/min)

per foot

gallon per minute

gallon per minute

[(gal/min)/ft]

degree Fahrenheit

(ft/d)

square mile

## Table 1.--Summary of rock units and their hydrogeologic characteristics

[>, greater than; <, less than; mg/L, milligrams per liter]

Rock unit	Rock type	Depositional conditions	Sediment source	Thickness, in feet	Saturated thick- ness, in feet	Hydraulic conductivity, in feet per day	Trans- missivity, in feet squared per day	Potential well yield, in gallons per minute	Aquifer	Water-quality characteristics	Remarks
Jpper unit	Gravel, sand, and silt	Open basin (through drainages) channel, flood plain, and alluvial fan	Drainage areas of Salt, Gila, Agua Fria, and Verde Rivers; local mountain ranges	0 to 400	0 to 350	180 to 1,700	1 <sub>20,000</sub> to 150,000	1,500 to 5,500	Unconfined	Dissolved solids from >1,000 mg/L near Salt River to <4,000 mg/L east of Buckeye	Most permeable unit. Saturated only in southern part of basin
Middle unit	Silt, clay, silt- stone, silty sand, and gravel	Closed basin; playa, alluvial fan, fluvial; establishment of through drainages	Drainage areas of Salt, Gila Agua Fria, and Verde Rivers; local mountain ranges	0 to 800	0 to 400	4 to 60	<sup>1</sup> 0 to 20,000	350 to 2,200	Unconfined, leaky confined	>10 mg/L nitrates near Glendale	High bedding frequency
per part of ower unit	Silt, clay, mud- stone, siltstone, gypsiferous mud- stone, gypsum, sand, and gravel	Playa, alluvial fan, fluvial, and evaporite	Local mountain ranges	0 to >1,000	0 to >1,000	3 to 25	0 to 7,000	400 to 1,700	Unconfined, leaky confined	>10 mg/L nitrates near Glendale. Dissolved solids, <500 mg/L in northern part of basin	Combines with middle unit to compose main water-bearing unit in basin. Disseminated evaporites
wer part of ower unit	Mudstone, silt- stone, gypsifer- ous and anhydritic mudstone and silt- stone; sand, gravel, and con- glomerate, halite, anhydrite, and interbedded basalts	Playa, alluvial fan, fluvial, and evaporitic	Local mountain ranges	<1,000 to >10,000	<1,000 to >10,000	6 to 14	<sup>1</sup> 6,000 to (?)	200 to 2,100	Leaky confined	>2 mg/L fluoride in Buckeye Valley. May be highly saline near Luke salt body	Most recoverable yields in upper-most part of unit. Contains massive evaporites, including Luke salt body
Red unit	Breccia, conglom- erate, sandstone, siltstone, and interbedded volcanic rocks	Playa, alluvial fan, and debris flows	Pre-Basin and Range mountains	>600	>600						Deposition predates Basin and Range disturbance
Extrusive rocks	Rhyolitic to basaltic flow and pyroclastic rocks										Present along northern and northeastern margin of basin
rystalline rocks	Schist, gneiss, granite, quartzite, and metavolcanic rocks										Forms impermeable barrier beneath the basin