Chemical Quality of the Water in the Tucson Basin, Arizona

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1939-D

Prepared in cooperation with the city of Tucson, the U.S. Bureau of Reclamation, and the University of Arizona

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By R. L. LANEY

WATER RESOURCES OF THE TUCSON BASIN

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CONTENTS

	Page
Abstract	D1
Introduction	2
Purpose and scope of investigation	3
Location and physiographic setting	4
Climate and streamflow	4
Previous investigations	5
Methods of investigation	5
Well-numbering system	6
Acknowledgments	8
Geologic units and their water-bearing properties	8
Pantano Formation	9
Tinaja rocks	9
Fort Lowell Formation	10
Quality of water	11
Surface water	11
Chemical constituents	11
Suspended sediment	11
Ground water	15
Areal distribution of dissolved solids in shallow ground water	15
Vertical distribution of dissolved solids	20
Changes in dissolved-solids concentrations with time	21
Calcium	22
Bicarbonate	23
Hardness	24
Sodium	25
Sulfate	26
Fluoride	27
Chloride	30
Nitrate	30
Iron	31
Magnesium	32
Potassium	32
Silica	32
pH values	33
Chemical-water types	34
Surface water	34
Chemical transition from precipitation to ground water	37
Ground water	37
Relation of water quality to particle size	40
Temperature of ground water	40
Summary	41
References cited	43
Index	45

ILLUSTRATIONS

[Plates are in separate case]

PLATE 1. Maps showing physical setting of the Tucson basin, southeastern Arizona.
2. Maps showing distribution of dissolved solids in ground water, Tucson basin, southeastern Arizona.
3. Graphs showing variation of dissolved constituents in ground water with depth, Tucson basin, southeastern Arizona.
4. Maps showing areal distribution of selected chemical constituents and hardness in shallow ground water, Tucson basin, southeastern Arizona.
5. Maps showing areal distribution of selected chemical constituents and chemical water types in shallow ground water, Tucson basin, southeastern Arizona.

Page

FIGURE 1. Map showing area of report ---- D3
2. Diagram showing well-numbering system in Arizona ---- 7
3. Maps showing changes in dissolved-solids concentrations with time in the ground water in T. 13 S., R. 13 E ---- 21
4. Graph showing relation of calcium-sodium ratios to depth below land surface ---- 23
5. Graph showing classification of major water types in the Tucson basin ---- 35

TABLES

Page

TABLE 1. Range and mean of chemical constituents, calcium to sodium ratios, and bicarbonate to sulfate ratios in surface water in major streams in the Tucson basin ---- D12
2. Water and suspended-sediment discharges, Tucson basin ---- 13
3. Chemical analyses of ground water from selected wells ---- 29
4. Changes in nitrate concentrations in ground water with increasing depth in the aquifer ---- 31
5. Silica concentrations in ground water with increasing depth in the aquifer ---- 33
6. Major types of ground water and their areal distribution ---- 36

CHEMICAL QUALITY OF THE WATER IN THE TUCSON BASIN, ARIZONA

By R. L. Laney

ABSTRACT

The Tucson basin is a broad mountain-rimmed area of about 1,000 square miles in the Basin and Range physiographic province in southeastern Arizona. The altitude ranges from 2,000 feet in the basin to as much as 8,000 feet in the mountains. The major streams in the area are the Santa Cruz River and its principal tributaries—Cañada del Oro, Rillito Creek, and Pantano Wash. The climate is semiarid, and the distribution and amount of precipitation vary greatly. The potential evapotranspiration is about four times the average annual precipitation.

The streamflow is of excellent chemical quality, although most of the flow occurs during floods and generally has large concentrations of suspended sediment. Because of the erratic occurrence and quantity of streamflow and because of the lack of surface-water storage reservoirs, all the water for municipal, industrial, and agricultural uses is obtained from the many wells that tap the permeable sedimentary deposits, which constitute the principal aquifer in the Tucson basin.

The aquifer consists of three sedimentary formations that range in age from middle Tertiary to Quaternary. The aquifer is as much as 2,000 feet thick and is composed mainly of sand, gravel, sandstone, and conglomerate. The upper part of the aquifer is more permeable than the lower part, and most wells obtain water at depths of less than 700 feet below the land surface.

Most ground water contains less than 500 mg/l (milligrams per liter) of dissolved solids and is of suitable chemical quality for most uses. The water to depths of as much as 700 feet is a calcium sodium bicarbonate type, is hard to moderately hard, and contains less than 1.0 mg/l fluoride. Water at greater depth is a sodium bicarbonate type, is soft, and is of excellent chemical quality; however, water below about 1,000 feet may contain fluoride in excess of the maximum allowable limit of 1.4 mg/l for public supply.

The ground water of poorest quality for public supply is at shallow depths along the major streams, in the Pantano Formation along the northeast margin of the basin, at depth in gypsiferous mudstone, and along a narrow zone that trends northwestward across the basin. Water from these hydrologic environ-

ments may contain as much as 500 mg/l dissolved solids and in places may contain more than 1,000 mg/l dissolved solids.

The anomalously large concentrations of calcium, bicarbonate, nitrate and sulfate in the ground water along the major streams, where the water table is from 25 to 150 feet below the land surface, are the result of near-surface phenomena. The large concentrations of these ions are derived from solution of relict salts, which were deposited in marshes along the streams prior to about 1900 by infiltrating surface water. In the narrow zone that trends northwestward across the basin, the large concentrations of calcium and sulfate are the result of the solution of limestone and gypsiferous mudstone in the sedimentary rocks in the headwaters area of Pantano Wash. The largest nitrate concentrations occur in the ground water along the Santa Cruz River; the nitrate probably is derived from irrigation return water, decayed vegetation from the marshes that occupied parts of the channel prior to 1900, and sewage effluent.

Anomalously large concentrations of sodium, sulfate, chloride, and fluoride occur in ground water along the Santa Cruz River near the major faults that displace the older formations. These anomalously large concentrations probably are derived from the upward leakage of deep water that has reacted with the gypsiferous mudstone in the center of the basin and moved along the faults into the near-surface deposits.

In the Tucson basin the water is divided into seven chemical types based on the relative amount of four major ions—calcium, sodium, bicarbonate, and sulfate—and the absolute amount of chloride. Most of the water is either a calcium sodium bicarbonate or a sodium bicarbonate type.

Ground-water temperatures in the upper few hundred feet of the aquifer are about 77°F (25°C). The normal temperature gradient is about 3°F (1.7°C) per 100 feet of depth. Hot water is present at relatively shallow depths near faults, where deep water is leaking upward; the temperature gradients are as much as 5°F (2.8°C) per 100 feet of depth.

INTRODUCTION

The ground water and surface water in the Tucson basin are of excellent chemical quality; however, in places excessive concentrations of dissolved solids are present in the ground water. The Tucson basin is a broad alluvial valley bordered by mountains in southeastern Arizona (fig. 1). The climate is semiarid, and because of the erratic occurrence and quantity of streamflow and the lack of surface-water storage facilities, most of the water is obtained from the many wells that tap the permeable sedimentary deposits.

The Tucson basin study was undertaken by the U.S. Geological Survey in cooperation with the city of Tucson, the U.S. Bureau of Reclamation, and the University of Arizona. The investigation was conducted under the general supervision of H. M. Babcock, district chief of the Water Resources Division of the U.S. Geological Survey in Arizona, and under the immediate supervision of E. S. Davidson, project chief.

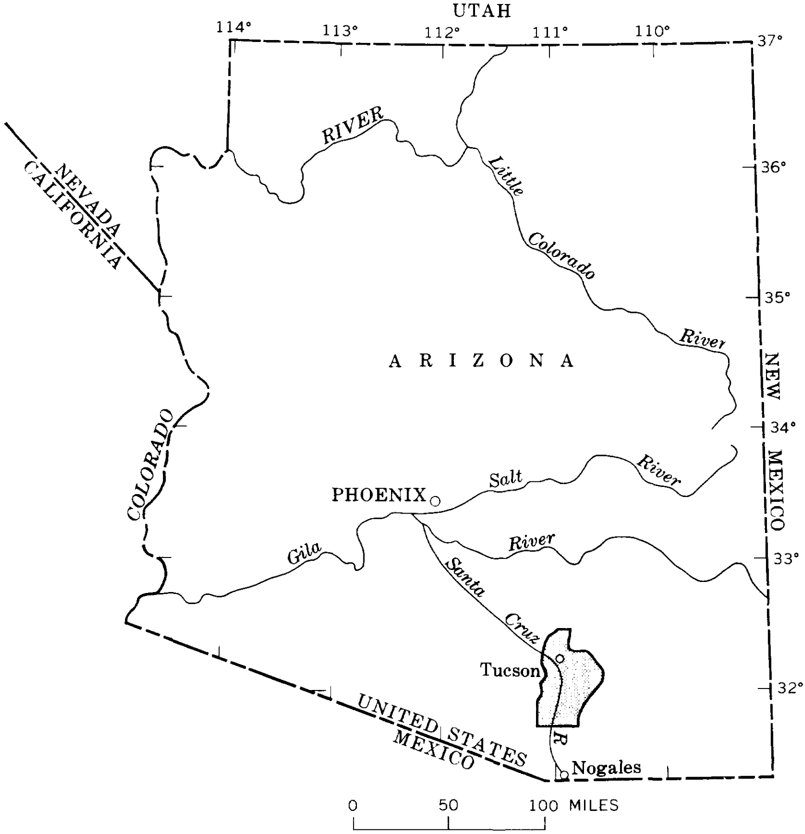

FIGURE 1.—Area of report (shaded).

PURPOSE AND SCOPE OF INVESTIGATION

The Tucson basin study was prompted by the need for a comprehensive knowledge of the water resources of the area. The study was designed to provide data for effective water use and management. This report is the fourth chapter of Water-Supply Paper 1939, which describes the hydrologic system in the Tucson basin.

The purpose of this phase of the Tucson basin study was to determine the areal and vertical distribution and source of the common chemical constituents in the ground water and surface water and the effects of the geohydrologic environment on the water in the Tucson basin. The common chemical constituents are silica, iron, calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, and fluoride. This report presents an analysis and evaluation of the chemical quality of the ground water in the basin in relation to its environment and delineates the depths above which potable water may be obtained in the aquifer. Changes in the concentration of dissolved constituents in the ground water in recent years are assessed by a comparison of chemical analyses made before and after 1950. Water-quality information is presented for chemical quality and suspended sediment in surface water in the major streams in the basin.

LOCATION AND PHYSIOGRAPHIC SETTING

The Tucson basin is a broad 1,000-square-mile area in the upper Santa Cruz River drainage basin in southeastern Arizona. The basin is a northwest-sloping plain and is in the Basin and Range physiographic province of Fenneman (1931). The city of Tucson is in the northern part of the basin; the city and its metropolitan area have a population of about a third of a million. The basin is bounded by mountains and is drained to the northwest by the Santa Cruz River and its major tributaries—Rillito Creek, Pantano Wash, and Cañada del Oro. The basin altitude ranges from about 2,000 feet at the northwest outlet to about 3,500 feet at the southernmost border. The basin is bounded on the north and east by the Tortolita, Santa Catalina, Tanque Verde, Rincon, Empire, and Santa Rita Mountains and on the west by the Tucson Mountains, Black Mountain, and the Sierrita Mountains (pl. 1*A*). The mountains on the north and east generally are at altitudes of 6,000 and 8,000 feet; the mountains on the west are from 3,000 to 6,000 feet in altitude.

As defined in this report, the boundary of the basin is along a line at the base of the mountains, where the steep mountain slopes become abruptly gentler. The line generally is along the contact between the water-bearing sedimentary rocks of the basin and resistant rocks of the mountains. The report area includes the basin and parts of the bordering mountains. In the valleys between the mountains, the boundary was arbitrarily selected—lat 31°45′ in the southern part of the area, lat 32°30′ in the Cañada del Oro drainage, and along a line between Black Mountain and the Sierrita Mountains in the southwestern part of the area.

CLIMATE AND STREAMFLOW

Because of the high temperatures and semiarid climate of the Tucson basin, the potential evapotranspiration is about 42 inches per year (Buol, 1964, p. 8) or four times the average annual precipitation. The mean annual temperature at Tucson is 67.3° F; the highest mean monthly temperature is in July (86.1° F), and the lowest is in January (50.0° F). The potential pan evaporation at the University of Arizona at Tucson is more than 80 inches per year or more than seven times the annual precipitation. (See Green and Sellers, 1964.)

Precipitation is extremely variable; the average annual precipitation is about 11 inches in the basin and as much as 30 inches in the mountains. High-intensity thunderstorms occur locally from July through September. The potential evaporation is greatest during these months. Occasional tropical storms, which usually occur in September, precipitate large amounts of rain in southeastern Arizona. Frontal storms produce widespread precipitation over the entire basin from December through March; the precipitation usually is less intense but of longer duration than summer precipitation.

Most streamflow in the basin occurs in direct response to precipitation. Condes (1970) stated that 93 percent of the flood peaks (above a selected base) along the Santa Cruz River occur in July, August, and September. For a given peak discharge, however, winter floods have larger flow volumes than summer floods because winter floods are of longer duration.

PREVIOUS INVESTIGATIONS

Hydrologic studies by several investigators were helpful in evaluating the chemical quality of the water in the Tucson basin. Smith (1910) discussed the chemical quality of the water in a few wells in the basin. Catlin (1926) classified the ground water in Arizona according to the purposes for which the supply was used and the distribution of the water in the State by major drainage basins. Catlin's (1926) report included a brief discussion on ground water in the Santa Cruz Valley and analyses of water from wells near the Santa Cruz River. More recent water-quality data for the Tucson basin were given by Smith and others (1963) and Smith, Draper, and Fuller (1964). Schwalen and Shaw (1957) discussed the areal distribution of dissolved solids and sulfate in the ground water and the areal distribution of water hardness. Feldman (1966) compiled the available water-quality data and presented distribution maps of the common constituents in ground water. Computer techniques were applied by Smoor (1967) to the areal distribution of the chemical constituents in the ground water in the basin.

METHODS OF INVESTIGATION

Sufficient water-quality data were available at the beginning of this study to establish a preliminary water-quality framework and to delineate the areas for which additional information was needed. Most of the water-quality data were collected between 1958 and 196?; however, some data were available for as early as the 1930's. Many of the chemical analyses were obtained from the files of the Department of Agricultural Chemistry and Soils at the University of Arizona.

Additional data were needed to show changes in chemical quality of ground water with depth in the aquifer. Most of the available analyses were from wells that were drilled to depths of less than 700 feet; well casings generally were perforated from the water table to the bottom of the well, which resulted in mixtures of water from different depths. As a part of the Tucson basin study, the city of Tucson drilled three test holes ranging from 1,800 to 3,000 feet deep, and the Bureau of Reclamation drilled six test holes ranging from 500 to 1,900 feet deep. Well cuttings and core samples were taken at selected intervals. The test holes drilled by the city were sealed with inflatable packers and were air-line pumped from selected intervals to produce water for chemical analysis. The holes drilled by the Bureau of Reclamation were fitted with 1¼-inch-internal-diameter piezometric tubes inserted in a coarse gravel-packed interval sealed at either end by concrete plugs. Water for chemical analysis was forced to the surface through the tubes by compressed air. In addition, water samples are collected by well drillers at specific depths during the drilling of industrial, municipal, and private wells. In general, the wells are drilled using cable-tool equipment, and water samples are collected from the bailer as the drill cuttings are removed.

Prior to this investigation, almost no information was available on the quality of natural recharge water. Samples of streamflow and rainfall in the mountains and of the streamflow in the basin were collected in order to determine the chemical quality of the natural recharge to the aquifer.

WELL-NUMBERING SYSTEM

The well numbers used by the Geological Survey in Arizona are in accordance with the Bureau of Land Management's system of land subdivision (fig. 2). 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 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

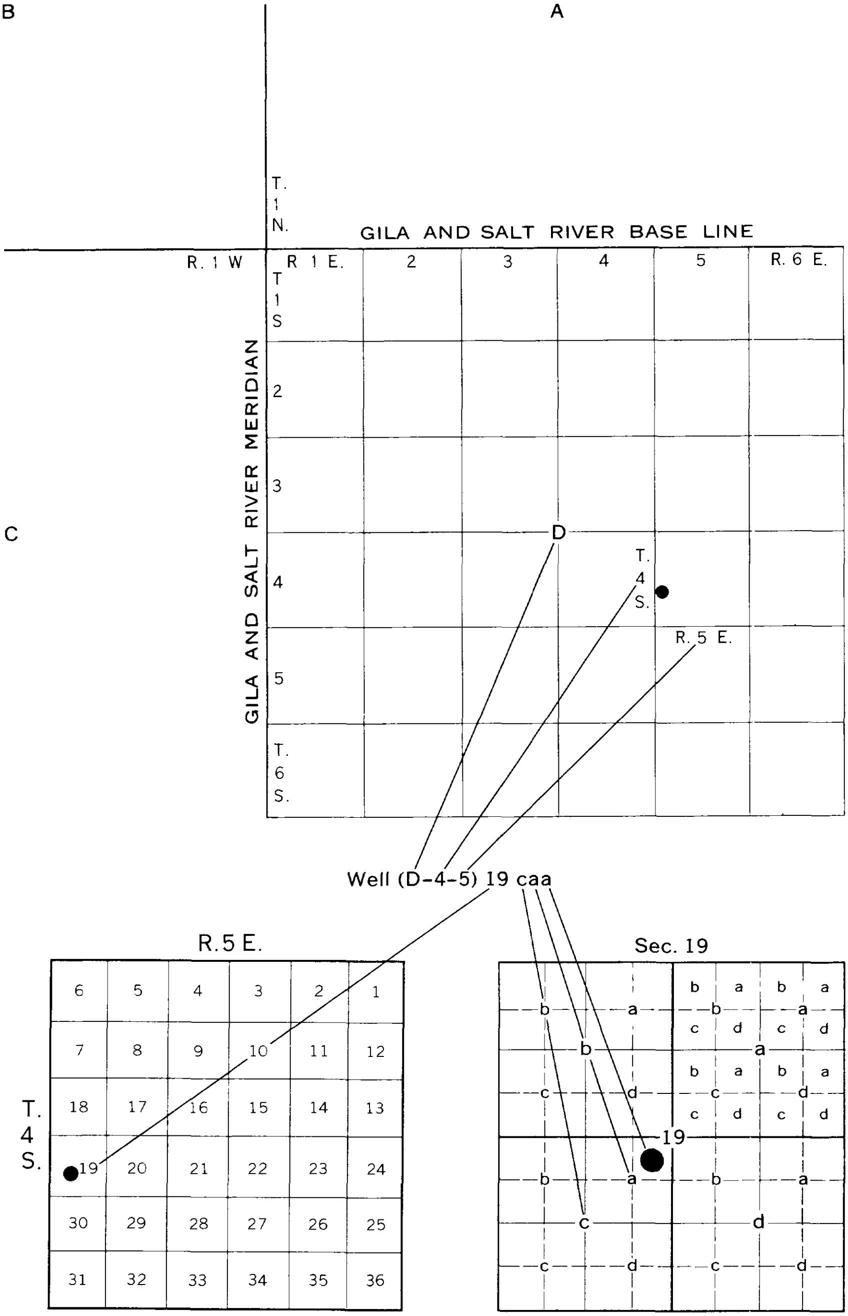

FIGURE 2.—Well-numbering system in Arizona.

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 (fig. 2), well number (D–4–5) 19caa designates the well as being in the NE¼NE¼SW¼ sec. 19, T. 4 S., R. 5 E. Where there is more than one well within a 10-acre tract, consecutive numbers beginning with 1 are added as suffixes.

ACKNOWLEDGMENTS

Especial appreciation for their cooperation and assistance during the study is extended to the many employees of the city of Tucson, the Bureau of Reclamation, and the University of Arizona. Particular appreciation is expressed to the Hydrology Department of the University of Arizona for the extensive compilation of water analyses from the Tucson basin. The data were compiled by Mr. A. D. Feldman from the files of the Department of Agricultural Chemistry and Soils, University of Arizona. Supplemental water-quality data were furnished by the city of Tucson Water Department and by Mr. L. C. Halpenny, consulting engineer, Tucson, Ariz. Well drillers who have been very helpful in collecting water samples for chemical analyses and well-cutting samples are A. A. McDaniel, A. L. Cotton Boring, C. W. Pistor, Cecil Banghart, Buck Weber, Buckingham Drilling Co., and Layne Texas Co.

GEOLOGIC UNITS AND THEIR WATER-BEARING PROPERTIES

A comprehensive knowledge of the subsurface stratigraphy and structure is necessary in order to make a meaningful interpretation of the chemical quality of the ground water in the Tucson basin. The amount and kind of dissolved constituents in the ground water are governed by the distribution of the sedimentary facies, which, in turn, is controlled by the faulting and structural movements that affected the basin during its formation. In this report the rock units are grouped on the basis of age and origin (pl. 1*B*).

The rock units that bound the basin and form the mountains are mainly igneous, metamorphic, and tightly cemented sedimentary rocks, which store and transmit smaller quantities of water than the more porous and permeable sedimentary rocks of the basin (Davidson, 1970, p. 44). The intrusive igneous and metamorphic rocks generally have the lowest permeability; the permeability of the volcanic rocks is variable, but the older volcanic rocks generally contain water only along fractures. Although the rock units do not store or transmit large quantities of water to wells, they confine the ground water in sedimentary rocks that underlie the basin.

In the basin the uncemented to moderately cemented sedimentary deposits are as much as 2,000 feet thick (Davidson, 1970). The sedimentary deposits range from Tertiary to Quaternary in age. The Pantano Formation, Tinaja rocks, and Fort Lowell Formation are the most important deposits to the water resources in the basin. In this report the term "aquifer" is used when referring to these deposits as a single water-bearing unit. The descriptions of the rock units that form the aquifer are summarized from a report by Davidson (1970).

PANTANO FORMATION

The Pantano Formation (Finnell, 1970) is a thick sequence of conglomerate, gravel, sandstone, and mudstone of Oligocene age. The Pantano crops out around the edges of the basin (pl. 1*B*) and is more than 6,000 feet thick at the type locality near Davidson Canyon. In the center of the basin, the formation is from a few hundred to about 1,000 feet thick. The Pantano is composed of light- to medium-reddish-brown silty and pebbly sandstone and gravel and mudstone beds, which contain gypsum in places. Rock fragments consist of varying amounts of granite and diverse types of volcanic and sedimentary rocks set in an arkosic sand matrix. Landslide blocks are common in the lower part of the section. The mudstone crops out in the northern and eastern parts of the basin. Numerous faults offset the Pantano, and in many places near the mountains the beds are tilted as much as 30°. The Pantano is darker and more tightly cemented in exposures along the margins of the basin than in fresh cores from deep wells in the center of the basin.

The porosity of the sandstone and gravel in the Pantano Formation, as determined by borehole-formation-density logs, ranges from 20 to 27 percent, and the permeability ranges from very low to about 100 gpd (gallons per day) per square foot. The Pantano has not been developed extensively as a water supply, and only a few deep wells in the center of the basin penetrate the formation. The water in the coarse subsurface beds is of excellent chemical quality, although it may contain excessive amounts of fluoride. The water in the mudstone is of very poor quality.

TINAJA ROCKS

The Tinaja rocks are a weakly cemented to uncemented sedimentary deposit of gravel, sand, and mudstone of probable Miocene and Pliocene age. The unit unconformably overlies the Pantano Formation and is a major part of the aquifer in the Tucson basin. The unit is several hundred feet thick in much of the basin and is more than 2,000 feet thick in the triangular-shaped fault-bound depression in the center of the basin (pl. 1B). The Tinaja rocks grade from a fine-grained facies in the fault-bound depression to a coarse-grained facies between the depression and the surrounding mountains. The fine-grained facies is a reddish-brown sticky silt or mudstone in the lower part and a light-reddish-brown clayey gravel or clayey silt in the upper part. The mudstone is gypsiferous in places. The coarse-grained facies is a gravel or pebbly sand that commonly ranges from light gray to grayish brown and less commonly from medium brown to light reddish brown. The Tinaja rocks are made up of detritus derived from the surrounding mountains and were deposited in a closed basin. The unit is partially or completely penetrated by wells.

The porosity of the Tinaja rocks, which was calculated from borehole-formation-density logs, ranges from 24 to 35 percent, and the unit is less cemented and more permeable than the older deposits. The permeability ranges from about 10 to 400 gpd per square foot. Most of the water in the coarse-grained facies of the Tinaja rocks is of excellent chemical quality, although excessive amounts of fluoride may be present at depths of more than 1,000 feet below the land surface. Water in the fine-grained facies probably is of very poor chemical quality.

FORT LOWELL FORMATION

The Fort Lowell Formation, as named and defined by Davidson (1970), is a locally derived sedimentary deposit of Pleistocene age. The formation consists of dark- to light-reddish-brown gravel, sand, and silt and underlies most of the basin surface; the Fort Lowell is the most productive part of the aquifer in the Tucson basin. The Fort Lowell unconformably overlies the Tinaja rocks and older deposits and is partly concealed by thin surficial deposits; it is 300 to 400 feet thick in most of the basin and thins toward the mountains. The unit is an uncemented flat-lying depression-filling deposit. The detritus in the Fort Lowell was derived from the surrounding mountains and was deposited in alluvial fans. Granitic gneiss from the Santa Catalina and Rincon Mountains is most common in the deposits in the northern part of the basin, and volcanic, granitic, and sedimentary rock fragments are most common elsewhere. Volcanic rock fragments are especially abundant near the Sierrita and Tucson Mountains. The detritus in the Fort Lowell Formation is set in a montmorillonitic silty clay matrix. The distribution of detrital rock fragments and the relation between the silty gravel along the margins of the basin and the silty sand and clayey silt in the center of the basin indicate that the formation was deposited in an area of internal drainage. The center of deposition was in the northern part of T. 15 S., R. 14 E.

The porosity of the Fort Lowell Formation was computed from continuous-record borehole geophysical logs; the porosity ranges from 26 to 34 percent. The Fort Lowell Formation is the most permeable unit in the aquifer, and permeabilities range from about 150 to more than 700 gpd per square foot. The water in most of the unit is of excellent chemical quality.

QUALITY OF WATER

SURFACE WATER

In the Tucson basin the water in the major streams is of excellent chemical quality; the dissolved solids consist mainly of calcium, sodium, and bicarbonate. The streamflow, however, generally contains large amounts of suspended sediment; at times, the sediment concentration is almost 47,000 mg/l (milligrams per liter) in the Santa Cruz River. Surface water is not used for irrigation or public supply because of the erratic occurrence and quantity of the flow and because of the lack of storage reservoirs.

CHEMICAL CONSTITUENTS

In the Tucson basin, water in the major streams generally contains less than 400 mg/l of dissolved solids and commonly contains less than 200 mg/l of dissolved solids (table 1). Streamflow in the Santa Cruz River and Pantano Wash generally contains larger amounts of dissolved solids than the flow in Rillito Creek. Calcium and bicarbonate are the principal ions in solution, although flows in Pantano Wash and the Santa Cruz River may contain large amounts of sulfate. The flows in Rillito Creek and its tributaries have about the same dissolved-solids concentrations, except the tributary flows contain greater amounts of sodium and sulfate.

SUSPENDED SEDIMENT

Sediment data are vital in the design of flow-retarding structures intended to increase the amount of ground-water recharge from streamflow. In the Tucson basin the accumulation of fine sediment deposited by floodflows behind the structures probably would reduce the infiltration capacity of the streambed.

TABLE 1.—*Range and mean of chemical constituents, calcium to sodium ratios, and bicarbonate to sulfate ratios in surface water in major streams in the Tucson basin*

[Chemical constituents in milligrams per liter]

Constituent	Santa Cruz River		Pantano Wash	
	Range	Mean	Range	Mean
Silica (SiO_2)	11 - 46	24	21 - 24	22
Calcium (Ca)	25 - 90	47	47 -102	74
Magnesium (Mg)	2 - 14	7	8 - 22	15
Sodium (Na)	13 - 44	28	36 - 56	46
Bicarbonate (HCO_3)	98 -194	137	171 -264	218
Sulfate (SO_4)	18 -160	65	68 -218	143
Chloride (Cl)	8 - 38	16	12 - 16	14
Fluoride (F)	.4 - .7	.5	.4 - .8	.6
Dissolved solids	102 -585	198	133 -327	196
Ca/Na	1.32- 2.59	1.99	1.50- 2.69	2.10
HCO_3/SO_4	.95- 8.03	3.20	1.97- 9.73	5.85

Constituent	Rillito Creek		Tributaries to Rillito Creek except Pantano Wash	
	Range	Mean	Range	Mean
Silica (SiO_2)	12 - 15	14	7 - 25	16
Calcium (Ca)	13 - 42	32	6 - 30	18
Magnesium (Mg)	2 - 9	5	2 - 4	3
Sodium (Na)	7 - 16	11	11 - 33	20
Bicarbonate (HCO_3)	45 -181	119	26 - 98	59
Sulfate (SO_4)	17 - 20	19	19 - 58	37
Chloride (Cl)	4 - 5	4	4 - 24	10
Fluoride (F)	.3 - .4	.3	.3 - .8	.4
Dissolved solids	83 -273	145	81 -215	148
Ca/Na	1.51- 7.00	3.84	.30- 3.12	1.26
HCO_3/SO_4	2.11- 7.07	4.77	.56- 3.50	1.40

The major streams in the basin transport large amounts of suspended sediment. For the period of miscellaneous measurements, 1959–69, the sediment concentrations ranged from 110 mg/l in Bear Creek to 46,600 mg/l in the Santa Cruz River (table 2).

Streamflow that contains a sediment concentration of 46,600 mg/l is almost 5 percent particulate solids. The sediment concentrations in flows of 1,000 cfs (cubic feet per second) or more are equivalent to sediment discharges of from 100,000 to more than 700,000 tons per day. The sediment discharge, in tons per day, given in table 2 was calculated using the instantaneous stream-discharge rate at the time the sediment sample was collected. Although tons per day is a common measure for reporting sediment-discharge data, it may not represent the actual daily sediment discharge because the irregular streamflow may cause the sediment-discharge rate to decrease or increase considerably within a few hours. The actual sediment discharge for a given day would require many more measurements than were made during the sampling period.

TABLE 2.—*Water and suspended-sediment discharges, Tucson basin*

Location (See pl. 1*B*.)	Sampling point	Date of collection	Time (24-hour)	Water discharge (cfs)	Suspended sediment	
					Concentration (mg/l)	Discharge (tons per day)[1]
1	Santa Cruz River at Continental gaging station.	12-20-67	1700	13,500	32,000	1,170,000
2	Santa Cruz River at Tucson gaging station.	7-16-65	1920	543	13,200	19,400
		7-16-65	2150	135	7,180	2,620
		8- 2-65	1315	20	4,300	232
		12-23-65	1225	4,000	44,500	481,000
		2- 8-66	1535	1,100	30,100	89,400
		2-11-66	0945	350	20,300	19,200
		2-11-66	1800	430	20,200	23,500
		8-18-66	1145	1,200	39,000	126,000
		8-19-66	0915	1,900	44,300	227,000
		8-19-66	1100	1,700	46,600	214,000
		8-22-66	1445	160	28,600	12,400
		9-13-66	1035	120	18,800	6,090
		9-15-66	1200	41	15,100	1,670
		10- 3-67	1650	203	21,800	11,900
		8-20-68	1500	59	12,400	1,980
		8- 8-69	1530	76	25,600	5,250
		9- 5-69	1300	78	11,800	2,480
10	Santa Cruz River at Cortaro gaging station.	8-19-66	1015	3,390	45,700	418,000
		8-19-66	1015	3,260	45,400	400,000
		8-22-66	1615	165	29,000	12,900
9	Cañada del Oro near Tucson gaging station.	12-15-67	1605	207	33,600	18,800
4	Bear Creek near Tucson gaging station.	12-10-65	1515	301	110	89
3	Tanque Verde Creek near Tucson gaging station.	12-10-65	1330	550	460	683
5	Tanque Verde Creek at Sabino Canyon road.	2-14-68[2]	1530	300	894	724
		1-15-69[2]	1300	150	914	370
7	Rillito Creek near Tucson gaging station.	2-10-68	1430	215	3,720	2,160
		2-12-68	1125	4,560	20,800	256,000
		2-14-68[2]	1600	250	1,440	972
		1-15-69[2]	1100	158	6,240	2,660
		1-15-69[2]	1345	150	3,620	1,470

See footnotes at end of table.

TABLE 2.—*Water and suspended-sediment discharges, Tucson basin*—Continued

Location (See pl. 1B.)	Sampling point	Date of collection	Time (24-hour)	Water discharge (cfs)	Suspended sediment	
					Concentration (mg/l)	Discharge (tons per day)[1]
8	Rillito Creek at Oracle road.	7-27-59	0920	67	3, 140	568
		8-17-59	1800	6, 700	39, 500	715, 000
		8-18-59	0930	8. 6	5, 390	125
		12-22-65	1500	10, 200	23, 300	642, 000
		2- 8-66	1600	820	1, 910	4, 230
		9-13-66	2130	2, 500	11, 900	80, 300
		1-15-69 [2]	1415	100	5, 270	1, 420
6	Rillito Creek at Dodge Boulevard.	1-15-69 [2]	1330	300	2, 530	2, 050

[1] The sediment-discharge rate was calculated using the instantaneous stream-discharge rate at the time the sediment sample was collected.
[2] Pantano Wash was contributing no inflow. Except for the inflow from Sabino Creek, the amount of tributary inflow from the Santa Catalina Mountains is unknown.

On February 14, 1968, sediment samples were collected at Rillito Creek near Tucson and Tanque Verde Creek at Sabino Canyon road (pl. 1*B*, sampling points 7 and 5) ; the samples were collected at nearly the same time of day, and there was no flow entering the reach from Pantano Wash. Tanque Verde Creek had a sediment concentration of 894 mg/l, but at Rillito Creek near Tucson, about 7 miles downstream, the concentration had increased to 1,440 mg/l; the sediment concentration increases as a result of the contribution of silt and clay from the bed of Rillito Creek. The flow in this reach decreased from 300 cfs at Sabino Canyon road to 250 cfs near Tucson. The decrease in flow in this reach is due to infiltration.

On August 22, 1966, samples taken from the Santa Cruz River at Tucson and at Cortaro (pl. 1*B*, sampling points 2 and 10) had nearly equivalent sediment concentrations and sediment-discharge and water-discharge rates; this probably indicates a balance between sedimentation and erosion. Although the samples taken on August 19, 1966, had about equal sediment concentrations at the two sites, the concentrations were much larger than those on August 22; the water discharge also was greater on August 19 than on August 22. The sediment discharge on August 19 at Cortaro was almost double the sediment discharge at Tucson owing to the increase in water discharge downstream.

On January 15, 1969, five sediment samples were collected in Tanque Verde and Rillito Creeks, when the streamflow in Sabino Creek was being sustained by runoff from the Santa Catalina Mountains and when there was no flow in Pantano Wash at its confluence with Rillito Creek. The sediment concentration in the sample from Rillito Creek at Dodge Boulevard (pl. 1*B*, sampling point 6) was taken during a second flood pulse; the second flood pulse was determined by a comparison of the water discharge at Rillito Creek at Dodge Boulevard and that at Tanque Verde Creek at Sabino Canyon road (table 2). The three remaining samples taken downstream were from floodflow that preceded the second flood pulse. An analysis of the sediment data shows an increase in sediment discharge with water discharge and a large sediment discharge downstream even though the water discharge decreases because of infiltration. In the Tucson basin the miscellaneous measurements show that sediment concentrations tend to increase slightly in relation to an increase in water discharge and that large amounts of sediment are transported during periods of high flow.

GROUND WATER

Ground water in the Tucson basin is of suitable chemical quality for most purposes. As used in this report, the term "shallow ground water" applies to water to depths of as much as 700 feet below the land surface, and the term "deep ground water" applies to water at depths of more than 700 feet below the land surface. The shallow ground water generally contains less than 500 mg/l of dissolved solids, and the principal ions are calcium, sodium, and bicarbonate. The water is hard to moderately hard and contains small amounts of fluoride. The deep ground water generally contains less than 500 mg/l of dissolved solids, the principal ions are sodium and bicarbonate, and the water is soft; however, water at depths of more than 1,000 feet below the land surface contains fluoride concentrations in excess of the recommended maximum amounts for public supply.

The ground water of poorest quality is at shallow depth along the Santa Cruz River, in the Pantano Formation along the northeast margin of the basin, at depth in gypsiferous mudstone, and along a narrow zone that trends northwestward across the basin. Large concentrations of calcium, sulfate, nitrate, and bicarbonate occur in ground water along the major streams. The amounts of sodium, chloride, fluoride, sulfate, and bicarbonate increase in the ground water near the Santa Cruz fault because of the upward leakage of poor-quality water.

AREAL DISTRIBUTION OF DISSOLVED SOLIDS IN SHALLOW GROUND WATER

In general, the areal distribution of dissolved solids is related to the major sedimentary facies in the basin. In the northeastern half of the basin, much of the ground water contains less than 300 mg/l of dissolved solids (pl. 2*A*). The water is contained in deposits composed chiefly of gneissic and granitic detritus derived from the Tortolita, Santa Catalina, and Rincon Mountains. The gneissic and granitic detritus is mainly feldspar, muscovite, and quartz. Ground water in the rest of the basin contains more than 300 mg/l of dissolved solids (pl. 2*A*). The water is contained in deposits made up of varying amounts of volcanic, sedimentary, metamorphic, and granitic detritus derived from the Empire, Santa Rita, Sierrita, Black, and Tucson Mountains; this detritus contains more water-soluble material than the gneissic and granitic detritus. Some of the sedimentary rock detritus contains calcite and gypsum, which may contribute large amounts of dissolved solids to the ground water.

The shallow ground water contains less than 500 mg/l of dissolved solids in more than 75 percent of the basin (pl. 2*B*). Dissolved-solids concentrations of more than 500 mg/l are considered anomalous in the Tucson basin and exceed the recommended maximum amount of 500 mg/l established by the U.S. Public Health Service (1962) for public supply. The anomalously large concentrations of dissolved solids occur in the ground water along the major streams, in the Pantano Formation along the northeast margin of the basin, along a narrow zone that trends northwest across the basin, and along the Santa Cruz fault (pl. 2*B*).

Dissolved-solids concentrations are greater in ground water along the major streams than in ground water in the surrounding areas (pl. 2*B*). Ground water along the Santa Cruz River contains more than 500 mg/l of dissolved solids. The ground water along Rillito Creek, parts of Tanque Verde Creek, and Pantano Wash contains between 300 and 500 mg/l of dissolved solids; although these concentrations are less than 500 mg/l, they are considered anomalous because the ground water in the surrounding areas contains less than 300 mg/l of dissolved solids. The dissolved solids are mainly calcium and bicarbonate. Ground water along the Santa Cruz River contains greater concentrations of sulfate than ground water along other major streams. The anomalous concentrations of dissolved solids along the major streams may be the result of the solution of relict salts, which have been precipitated by the evaporation of water from the surficial deposits. In addition, irrigation return water may contribute dissolved solids to ground water in agricultural areas.

Prior to about 1900, most of the present-day recharge areas were discharge areas in the Santa Cruz River and Rillito Creek flood plains, and lakes, swamps, and springs were common in the wet seasons. The stream channels were indefinite (Hastings, 1958, p. 30;

Smith, 1910, p. 98), and in places the flood plains were covered with dense growths of trees and grass. During times of flood, the Santa Cruz River spread over the lowlands in a shallow sheet. In the late 19th century the Santa Cruz bottom land between Tucson and the San Xavier Mission (pl. 1*B*) was a "grassy bottom, much covered with saline efflorescence * * *" (H. M. T. Powell, in Hastings, 1958, p. 30). In places in the valley north of Sentinel Peak (pl. 1*B*), the soil was too alkaline for the cultivation of crops.[1] Salts did not accumulate in the surficial deposits along streams where the water table was deep, such as along Pantano Wash. The large concentration of dissolved solids in the ground water along Pantano Wash in the western part of T. 14 S., R. 15 E. (pl. 2*B*) is the result of the solution of calcium carbonate in the Tinaja rocks rather than the solution of salts in the surficial deposits.

Water is of poor chemical quality in the Pantano Formation where it crops out in the northeastern part of the basin (pl. 1*B*). Dissolved-solids concentrations are greater than 500 mg/l and in places are greater than 2,000 mg/l. The dissolved solids are mainly sodium and sulfate. In its area of outcrop the volume of poor-quality water in the Pantano is small and is insignificant in terms of the total water resources of the basin.

A zone of poor-quality water extends northwestward across the basin from near Vail (pl. 2*B*); the zone narrows and the dissolved-solids concentrations decrease northwestward in the direction of ground-water movement. The dissolved-solids content ranges from 500 mg/l to more than 1,000 mg/l and is about 860 mg/l near Vail, 730 mg/l between Vail and the west edge of T. 15 S., R. 15 E., and 550 mg/l from the west edge of T. 15 S., R. 15 E., to the west edge of T. 14 S., R. 14 E. The principal constituents are calcium, sulfate, and sodium. Dissolved-solids concentrations in water in two small areas in and near the zone increase, rather than decrease, in the direction of ground-water movement, probably because of upward leakage of poor-quality water along an indefinite northeast-trending fault in the western part of T. 15 S., R. 15 E. (See pl. 4.)

In the northwest-trending zone the largest concentrations of dissolved solids are in the ground water at shallow depths. Available well data indicate that the largest concentrations are in water at depths of less than 700 feet below the land surface—about 250 to 400 feet below the water table—and that a large concentration, which does

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[1] W. Allison, undated manuscript, "Arizona the Last Frontier," Arizona Pioneers' Historical Society.

not parallel stratigraphic boundaries, is present northwest of the northeast-trending fault in T. 15 S., R. 15 E. The large concentration of dissolved solids northwest of the fault is in the water between 400 and 700 feet below the land surface (see wells D–15–14) 3bac and (D–15–15)16cbb, pl. 3*B*); unless gypsiferous mudstone is penetrated, the dissolved-solids concentrations in water generally decrease to depths of as much as 2,000 feet below the land surface.

The zone of poor-quality water probably is caused by the movement of water through the Pantano Formation and (or) older rocks in the headwaters of Pantano Wash at the eastern margin of the basin. The Pantano and older rocks range from gypsiferous mudstone to conglomerate and include some limestone. An approximate parallelism exists between the zone of poor-quality water and the direction of ground-water movement. The decreases in dissolved-solids concentrations and in the width of the zone in the direction of ground-water movement are probably the result of dilution and mixing of the water of poor quality with water of better quality.

A possible alternate source of the poor-quality water in the zone is the ancestral Pantano Wash. E. S. Davidson (oral commun., 1969) noted the parallelism between the band of poor-quality water and the probable ancestral course of Pantano Wash on the Cemetery terrace of Smith (1938). The present-day headwaters of Pantano Wash drain an area underlain by sedimentary rocks northeast, east, and south of the Empire Mountains. At one time, the drainage basin probably was restricted to the area northeast of the Empire Mountains; this area is underlain by sedimentary rocks that contain gypsum beds. Surface water in the restricted basin may have contained large amounts of dissolved solids, and the precipitation of salts from intermittent flow may have caused infiltration of poor-quality water and an accumulation of salts in the near-surface deposits. Pantano Wash was captured and was diverted to nearly its present course by Rillito Creek more than 30,000 years ago (E. S. Davidson, oral commun., 1969), which is a sufficient length of time for the poor-quality water to move out of the basin; however, remaining salts in the deposits may be contributing dissolved solids to the ground water at the present time.

Dissolved-solids concentrations range from more than 1,000 mg/l to more than 2,000 mg/l in the shallow ground water near the Santa Cruz River in Tps. 13 and 14 S., R. 13 E. The large dissolved-solids content is caused by the upward leakage of ground water along the Santa Cruz fault; the poor-quality water originates in the gypsiferous mudstone in Tps. 15 and 16 S., R. 14 E. The evidence that substantiates upward leakage along the Santa Cruz fault is (1) the coincidence of the southeast edge of the zone of water that contains more than 1,000 mg/l of dissolved solids and the intersection of the Santa Cruz fault and a northwest-trending fault (pl. 2*B*); (2) the similarity of the chemical characteristics of the water from gypsiferous mudstone, water from wells near some of the major faults, and the shallow ground water (see table 6, chemical water type 7); and (3) an increase in water temperatures in a few wells near the Santa Cruz fault (see section entitled "Temperature of Ground Water"). The faults act as conduits for the poor-quality water from the gypsiferous mudstone; the water is forced upward through the faults by the constriction of the basin between the Tucson and Santa Catalina Mountains. The gypsiferous mudstone in Tps. 15 and 16 S., R. 14 E., may be considered as a body of salt in the ground-water flow regimen. Water that contains less than 500 mg/l of dissolved solids moves through and along the body of salt, which increases the dissolved-solids content of the water in the aquifer in the direction of ground-water movement.

Another area of poor-quality water is in the western part of T. 16 S., R. 14 E. Wells drilled east of the Santa Cruz fault penetrate mudstone at less than 500 feet below the land surface. The poor-quality water may be derived directly from the mudstone or may be moving upward along the Santa Cruz fault.

The dissolved-solids content decreases greatly in the ground water along the Santa Cruz River in a small area in the northwestern part of T. 13 S., R. 13 E., probably because of dilution of the poor-quality water by recharge of effluent from the city of Tucson sewage-treatment plant. Dissolved-solids concentrations are as small as 500 mg/l in ground water along the Santa Cruz River downstream from the sewage-treatment plant in the SW¼SW¼ sec. 21, T. 13 S., R. 13 E.; whereas, the dissolved-solids concentrations are more than 1,000 mg/l in the ground water in the surrounding areas. The treated sewage effluent generally contains from 500 to 700 mg/l of dissolved solids (City of Tucson, 1966). The estimated amount of water released to the streambed of the Santa Cruz River from 1951–65 averaged 5,600 acre-feet per year (Davis and Stafford, 1966).

In the northern part of T. 14 S., R. 13 E., the area of ground water that contains more than 1,000 mg/l of dissolved solids forms a fork-shaped indentation that opens to the south and straddles the Santa Cruz River. The water in the fork-shaped area is of better chemical quality because of recharge from the Santa Cruz River (pl. 2*B*).

VERTICAL DISTRIBUTION OF DISSOLVED SOLIDS

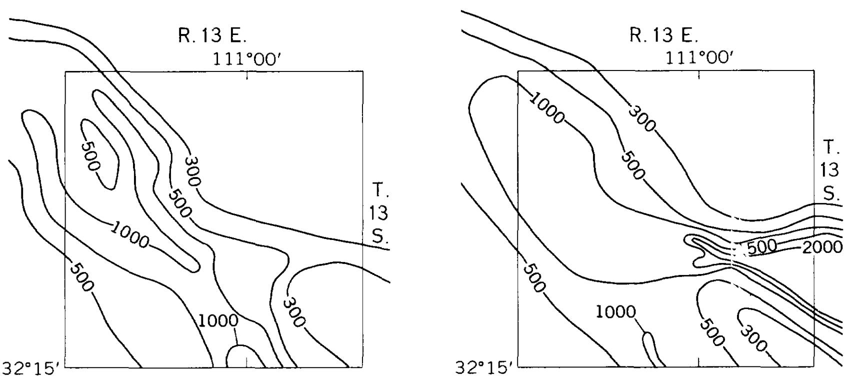
Dissolved-solids concentrations are less than 500 mg/l in water at depths of more than 1,000 feet below the land surface, where the aquifer is coarser than mudstone (pl. 3). The dissolved-solids content is generally more than 500 mg/l and in places is more than 3,000 mg/l in water in gypsiferous mudstone. (See well (D–13–14) 31dba, pl. 3*A*.) The dissolved-solids content decreases in the water with increasing depth in the parts of the aquifer where the material is coarser than mudstone, particularly in the north-central, eastern, and southwestern parts of the basin (pl. 3, *B* and *C*). Unfortunately, most of the chemical analyses of water from increasing depth are from wells that were drilled in or near the areas of anomalously large dissolved-solids concentrations in shallow ground water—that is, near the major streams or in and near the northwest-trending zone in which dissolved-solids concentrations are more than 500 mg/l. Based on the available data, it is uncertain whether or not the dissolved solids decrease with increasing depth outside the areas containing anomalously large concentrations of dissolved solids.

In the Tucson basin the depths to which potable water may be obtained range from less than 500 to more than 2,000 feet below the land surface (pl. 2*B*). The solid lines on plate 2*B* show the top of a mudstone unit, which in places is gypsiferous, and the dashed lines show the maximum depths for which chemical-quality-of-water data are available; water that contains less than 500 mg/l of dissolved solids may be present at greater depths for which data are not available. Near Rillito Creek in the northern part of the basin and in Tps. 15 and 16 S., R. 14 E., mudstone is from 200 to 500 feet below the land surface, and the dissolved-solids concentrations in the ground water may exceed 2,000 mg/l. Along the Santa Cruz River in the southwestern part of the basin and in the eastern and north-central parts of the basin, water to depths of 2,000 feet below the land surface contains less than 500 mg/l of dissolved solids; however, in places the shallow ground water contains more than 500 mg/l of dissolved solids. Along the Santa Cruz River north of T. 16 S., R. 14 E., there is no apparent improvement in water quality to about 500 feet below the land surface, the maximum depth for which water-quality data are available. Volcanic bedrock or mudstone, which contain poor-quality water, are present in parts of this area at depths of less than 500 feet.

Plate 2*B* may be used to determine optimum well depth and location in order to obtain water of good chemical quality. It should be realized, however, that the hydrologic characteristics of the aquifer vary both areally and with increasing depth; therefore, other hydrologic data must be considered in the location of wells in addition to the quality-of-water data shown on plate 2*B*.

CHANGES IN DISSOLVED-SOLIDS CONCENTRATIONS WITH TIME

Changes in dissolved-solids concentrations with time were determined by comparing post-1950 chemical-quality data with pre-1950 data; most of the pre-1950 data are for the middle 1940's. The most significant changes in dissolved-solids concentrations with time have been in the shallow ground water along Rillito Creek and the Santa Cruz River in T. 13 S., R. 13 E. (fig. 3)—from more than 2,000 mg/l prior to 1950 to about 300 mg/l at present (1968). A comparison of the dissolved-solids and well-depth data shows that the large dissolved-solids concentrations were a near-surface phenomenon. In this area the changes in dissolved-solids concentrations with time probably are the result of ground-water pumping and lowering of the water table, which has declined as much as 60 feet since 1940 (Davidson, 1970, fig. 8), and the infiltration of streamflow, which is of good chemical quality. Continued flushing by fresh infiltrating streamflow may remove the relict ground water and accumulated salts and reduce the anomalously large concentrations of dissolved solids in the deposits along the major drainages elsewhere in the basin.



A.
POST-1950 DATA
More than 50 percent of the data are for 1960-66

B.
PRE-1950 DATA
Most of the data are for the middle 1940's

EXPLANATION

———300———
Line of equal dissolved-solids concentration
Interval 200 and 500 mg/l

FIGURE 3.—Changes in dissolved-solids concentrations with time in the ground water in T. 13 S., R. 13 E.

The areal distribution of dissolved solids shown on plate 2*B* is based on chemical analyses of water samples collected in 1932–67. More than 85 percent of the samples analyzed were collected after 1950, and most of these samples were collected after 1958. Except in the area along the Santa Cruz River and Rillito Creek in T. 13 S., R. 13 E. (fig. 3), the differences between the data obtained prior to 1950 and the data obtained after 1950 generally are not significant and do not change the dissolved-solids distribution shown on plate 2*B*.

CALCIUM

In most of the basin the ground water contains less than 50 mg/l of calcium and is suitable for most uses (pl. 4*A*). Water that contains more than 50 mg/l of calcium occurs in the narrow zone that trends northwest across the basin, along the Santa Cruz River, in places in the Pantano Formation where it is exposed along the northeast margin of the basin, and in small areas along Rillito Creek and Pantano Wash. The calcium content generally decreases with increasing depth in the aquifer.

The ground water in the gneissic detritus in the northeastern part of the basin contains small amounts of calcium, generally less than 30 mg/l. Ground water south of Cañada del Oro in Tps. 12 and 13 S., R. 13 E. contains calcium concentrations as small as 15 mg/l. The ground water contains more than 50 mg/l of calcium in areas where the dissolved-solids content is more than 500 mg/l (pls. 2*B* and 4*A*). Ground water in the east-central part of the basin and along parts of the Santa Cruz River contains from more than 100 to more than 300 mg/l of calcium.

Calcium decreases in the ground water with increasing depth where the aquifer is composed mainly of gravel, sand, and silt (pl. 3). Water in gypsiferous mudstone generally contains large amounts of calcium, often more than 400 mg/l. (See well (D–13–14)31dba, pl. 3*A*.) Calcium and sodium are the principal cations in most of the shallow ground water, but the calcium decreases and the sodium increases with increasing depth. Calcium concentrations generally are less than 15 mg/l, and sodium is the dominant cation below depths of from 800 to 1,000 feet (fig. 4). The decrease in calcium may be caused by ion exchange of calcium in the water for sodium adsorbed on montmorillonite, which is the principal clay mineral in the aquifer. Some calcium also may be removed from ground water by precipitation of calcium carbonate.

Calcium in the ground water in the Tucson basin is derived from the silicic minerals feldspar, pyroxene, and amphibole and from the

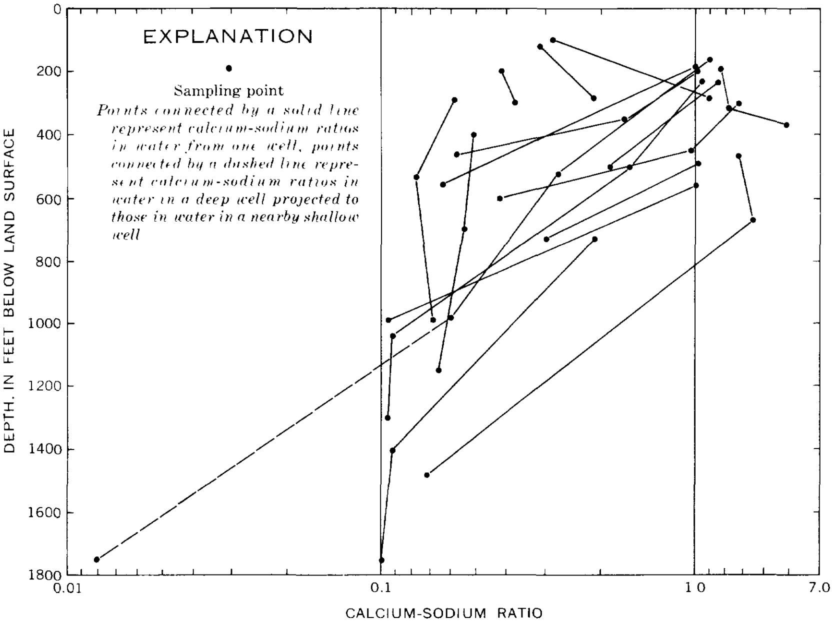


FIGURE 4.—Relation of calcium-sodium ratios to depth below land surface.

nonsilicic minerals calcite, dolomite, anhydrite, and gypsum. Silicic minerals are more resistant to solution than nonsilicic minerals, which probably is the reason why the smallest concentrations of calcium are in the ground water in the gneissic and granitic deposits.

The large amounts of calcium and bicarbonate in the ground water along the major streams probably are caused by the solution of relict calcite. Part of the calcium and bicarbonate is contributed by infiltrating streamflow; flow in the major streams has a calcium bicarbonate composition (table 1). In the zone of poor-quality water that trends northwest across the basin, gypsum or anhydrite may be responsible for the large calcium concentrations.

BICARBONATE

Bicarbonate is the dominant anion in ground water in the Tucson basin where the dissolved-solids concentrations are less than 500 mg/l. The areal distribution of bicarbonate and dissolved solids in shallow ground water is similar (pls. 2B and 4A), although, in places, bicarbonate concentrations vary independently from the dissolved solids with increasing depth in the aquifer (pl. 3). Bicarbonate concentrations range from less than 100 mg/l in ground water in the southeastern part of T. 12 S., R. 13 E., to more than 400 mg/l along the

Santa Cruz River in the southern part of T. 14 S., R. 13 E. (pl. 4A). In most of the basin bicarbonate concentrations generally are less than 200 mg/l and have little effect on water for public supply.

The bicarbonate concentrations in the ground water are derived from the solution of carbonate minerals, such as calcite and dolomite, and from the conversion of dissolved carbon dioxide to bicarbonate during the weathering of minerals. Along Rillito Creek, Pantano Wash, and the Santa Cruz River south of Black Mountain, the large bicarbonate and calcium concentrations probably are related to the infiltration of streamflow, in which bicarbonate is the principal anion and calcium is the principal cation (table 1). In addition, bicarbonate and calcium may be added to ground water by the solution of relict salts by streamflow infiltrating into the deposits along parts of the Santa Cruz River and Rillito Creek. Along the Santa Cruz River between Sahuarita and Cortaro, the bicarbonate concentrations of more than 300 mg/l in the ground water probably are derived from upward leakage of water along the Santa Cruz fault from gypsiferous mudstone in Tps. 15 and 16 S., R. 14 E. (pl. 4*A*). In the eastern part of the basin the large bicarbonate concentrations in the northwest-trending zone of poor-quality water are derived from the solution of sedimentary rocks by streamflow infiltration in the area where Pantano Wash enters the basin.

HARDNESS

The hardness of water is manifested by the formation of soap curd or scum, and very hard water is undesirable for use as a public supply because the excessive polyvalent cations—most commonly calcium and magnesium—react with soap and form an insoluble residue. Very hard water causes incrustation in pipes and household fixtures and on cooking utensils. The U.S. Geological Survey reports water hardness in milligrams per liter of calcium carbonate.

The shallow ground water in the Tucson basin is moderately hard to very hard. In general, moderately hard water is present in the aquifer northeast of the Southern Pacific Railroad Co. tracks, and hard and very hard water is present southwest of the tracks (pl. 4B). Water is usually very hard when the amount of dissolved calcium is greater than 50 mg/l. The areas having very hard water are along the Santa Cruz River, along the narrow zone that trends northwestward across the basin, and along parts of Rillito Creek and Pantano Wash (pl. 4B).

Water hardness generally decreases with increasing depth in the aquifer because concentrations of calcium are less in the deep water than in the shallow water (pl. 3); however, water in gypsiferous mudstone contains large amounts of calcium and is very hard. Most of the water at depths of less than 600 feet below the land surface is hard to very hard, and water at depths of more than 1,000 feet below the land surface is soft.

SODIUM

In most of the Tucson basin, sodium concentrations are less than 50 mg/l in the shallow ground water where the dissolved-solids content is less than 500 mg/l (pls. 2 *B* and 4*C*). Concentrations of sodium increase with increasing depth in the aquifer, and below about 800 feet sodium is the principal cation (fig. 4). Because calcium decreases in water with increasing depth in the aquifer, deep water is sodium-rich and soft. The sodium concentrations have little or no effect on water for domestic use. Water for use in boilers, however, should contain less than 50 mg/l of sodium, and water in which sodium is the major dissolved cation may not be desirable for irrigation.

The smallest sodium concentrations—less than 15 mg/l—occur in the ground water in the southeastern part of T. 12 S., R. 13 E. Along the Santa Cruz River north of Black Mountain and in the Pantano Formation along the northeast margin of the basin, ground water contains from more than 100 mg/l to more than 300 mg/l of sodium. The areal distribution of sodium, dissolved solids, and calcium is closely related in the shallow ground water along the Santa Cruz River north of Black Mountain. The relation is particularly good in and northwest of sec. 13, T. 14 S., R. 13 E., where poor-quality water has moved into the shallow deposits from gypsiferous mudstone in Tps. 15 and 16 S., R. 14 E. via the Santa Cruz fault (pl. 4*C*). Elsewhere in the basin, the distribution of sodium and dissolved solids in shallow ground water does not coincide as well as the distribution of calcium and dissolved solids. Sodium may have a different source than calcium in at least part of the basin; in some areas where the dissolved-solids and calcium concentrations are relatively large, sodium concentrations are not proportionately large. For example, in most of the zone of poor-quality water that trends northwestward across the basin and in the western part of T. 16 S., R. 14 E., dissolved-solids and calcium concentrations may be more than 1,000 and 200 mg/l, respectively, but sodium concentrations generally are less than 70 mg/l. Along the Santa Cruz River northwest of Tucson, dissolved-solids and calcium concentrations are more than 1,000 and 200 mg/l, respectively, and the sodium concentrations are as much as 200 mg/l.

Sodium is the dominant cation in ground water below a depth of about 800 feet (fig. 4) in material coarser than mudstone, and concentrations may be more than 100 mg/l. The increase in sodium relative to calcium probably is the result of ion exchange between water and montmorillonite.

SULFATE

Excess sulfate, particularly when associated with large concentrations of sodium and magnesium, imparts an unpleasant taste to water and may be cathartic if consumed by humans. Therefore, the U.S. Public Health Service (1962) recommends that drinking and culinary water contain no more than 250 mg/l of sulfate. In most of the ground water in the basin sulfate concentrations are less than 150 mg/l; only a small part of the water contains more than 250 mg/l sulfate.

The smallest sulfate concentrations occur in the shallow ground water in the northeastern part of the basin, where the aquifer is mainly gneissic detritus; the concentrations in this area are less than 50 mg/l (pl. 4*C*) and are as small as 10 mg/l in the southeast part of T. 12 S., R. 13 E., the northeast part of T. 13 S., R. 13 E., and the southwest part of T. 14 S., R. 15 E. Sulfate concentrations are generally more than 150 mg/l in ground water in which the dissolved-solids concentrations are more than 500 mg/l. Sulfate concentrations are more than 250 mg/l in places along the Santa Cruz River, near the Santa Cruz fault, in the narrow zone that trends northwest across the basin, and in the Pantano Formation along the northeast margin of the basin (pl. 4*C*).

The principal sources of the large sulfate concentrations are gypsum and anhydrite, which may be chemical precipitates that were deposited in mudstone or a constituent of rock detritus that was brought into the basin from surrounding areas. Gypsum and anhydrite have been identified in well cuttings and cores of mudstone at depths of more than 700 feet below the land surface in the center of the basin and in surface exposures of the Pantano Formation in the northern and eastern parts of the basin. In the center of the basin, upward leakage of water from gypsiferous mudstone contributes large amounts of sulfate to the shallow ground water near the Santa Cruz fault. In the zone of poor-quality water that trends northwest across the basin, the large concentrations of sulfate probably are derived from gypsum and anhydrite; although these minerals have not been identified in the aquifer material in this area, gypsum beds are exposed in the headwaters area of Pantano Wash along the eastern margin of the basin. Water recharged to the ground-water reservoir probably derives sulfate and other chemical constituents from these beds. Large amounts of sulfate may be derived from the oxidation and leaching of metallic-sulfide minerals in and near ore deposits, and the smaller amounts of sulfate in the ground water may be caused by a similar breakdown of minor amounts of sulfide in the rock detritus.

FLUORIDE

The determination of fluoride is an important consideration in selecting water supplies for domestic and municipal uses. The recommended average optimum fluoride concentration for a water supply differs according to the annual average maximum daily air temperatures (U.S. Public Health Service, 1962). In the Tucson basin the optimum concentration in drinking water is 0.7 mg/l. The presence of fluoride in average concentrations greater than two times the optimum value, or an upper limit of 1.4 mg/l, constitutes grounds for rejection of a water supply (U.S. Public Health Service, 1962).

Most of the shallow ground water in the Tucson basin contains only small amounts of fluoride (pl. 5*A*), and concentrations are below the maximum recommended concentrations for public water supplies. Excessive amounts of fluoride are present only in places along the Santa Cruz River and in the Pantano Formation. Fluoride concentrations, however, increase with increasing depth in the aquifer, and concentrations may exceed the maximum recommended values in parts of the basin.

Ground water in the Fort Lowell Formation and in the upper part of the Tinaja rocks generally contains less than 1.0 mg/l of fluoride; however, in places along the Santa Cruz River and in the Pantano Formation, which is exposed in the northeastern part of the basin near the Santa Catalina Mountains, ground water contains more than 1.0 mg/l fluoride (pl. 5*A*). The Pantano Formation, however, contains only small quantities of water and is insignificant in terms of the total water resources of the basin. Anomalously large amounts of fluoride are present in the water in some of the wells near the major faults. The large concentrations probably are the result of the upward leakage of poor-quality water from depth.

Along the Santa Cruz River, the areas that contain large amounts of fluoride are offset to the west from the areas that contain the greatest concentrations of the other dissolved constituents (pls. 2*B*, 4, and 5*A*). Therefore, the fluoride may have a source different from that of the other dissolved constituents. Large concentrations of fluoride and other constituents—as much as 5 mg/l fluoride and 2,000 mg/l dissolved solids—occur in water in gypsiferous mudstone; large amounts of fluoride also may be present at depth in material coarser than mudstone, where the dissolved-solids concentrations are not unusually high. Near the east edge of T. 16 S., R. 13 E., the areas of large fluoride concentrations are separated from the areas of large dissolved-solids concentrations by the Santa Cruz fault. East of the fault the large dissolved-solids concentrations probably are from gypsiferous mudstone; west of the fault, the large fluoride concentrations probably are caused by water that has moved upward from the thick accumulation of coarse material to the south.

Although fluoride concentrations generally increase with increasing depth in the aquifer, the increase is not uniform. Plate 5*A* shows the depths to which ground water contains less than 1.0 mg/l fluoride. In the north-central and eastern parts of the basin and west of the Santa Cruz fault in the southwestern part of the basin ground water contains less than 1.0 mg/l fluoride to depths of more than 1,000 feet below the land surface. In the eastern part of the basin, the water in well (D–16–15)10ccc contains 0.5 mg/l fluoride at a depth of 1,900 feet below the land surface; water from most of the other deep wells in the basin contains from 1 to 5 mg/l fluoride. The fluoride concentrations in water in three deep wells drilled to depths of 2,500 to 3,145 feet in secs. 2 and 3, T. 15 S., R. 14 E., range from 4.0 to 11 mg/l, which is the largest reported fluoride value in the basin; the water is pumped from an interval between 1,000 and 2,500 feet below the land surface. (See well (D–15–14)2cac, table 3.)

In the Tucson basin, fluoride is related to the minerals in the aquifer material and to the chemical composition of the water. Although fluorite and apatite contain fluoride as a structural constituent, significant amounts of these minerals are not common in the aquifer material. Fluoride may substitute for as much as 5 percent of the hydroxyl ion in silicate minerals, such as mica and amphibole, but solution of fluoride from these minerals occurs at a very slow rate. Clay minerals, especially montmorillonite, may have fluoride weakly attached to crystal-edge (exchange) sites. Fluoride on the exchange sites is replaced readily by the hydroxyl ions in water, and the replacement is enhanced by water that has a high pH (table 3). The association between high pH and large concentrations of fluoride in ground water is common in the Tucson basin and elsewhere in southern Arizona. Volcanic rocks, especially tuff derived from glassy volcanic ash, may contain large amounts of fluoride. Tuff is common in the Tinaja rocks and in the Pantano Formation and may be a significant source of the large fluoride concentrations in water in parts of the basin.

The solubility of fluorite may exert a control on the amount of fluoride in solution. The largest concentrations of fluoride generally occur in water in which calcium concentrations are less than 10 mg/l.

TABLE 3.—*Chemical analyses of ground water from selected wells*

[Analyses in milligrams per liter except as indicated; analyses by Tucson Gas and Electric Co. except as indicated; E, estimated]

Well No.	Date of collection	Depth (feet)	Temperature (°C)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Sum of dissolved solids	Hardness as $CaCO_3$	Specific conductance (micromhos at 25°C)	pH	Remarks
(D-15-14) 2cac.	4-61	2,500	43.0		4.0	0.7	192	78	5	290	39	11	580	13		9.0E	Analysis by Department of Agricultural Chemistry and Soils, University of Arizona; silica not included in dissolved solids.
	9-62	2,500		30	3.4	.4	159	66	30	188	32		476	10	650	9.2	
	8-63	2,500			0	0	207	61	10	260	61	10	578	0	1,000	>9.6E	Analysis by Department of Agricultural Chemistry and Soils, University of Arizona; silica not included in dissolved solids.
2dbc	1-60	3,145	52.0	46	4.3	.4	155	120		182	31	5.7	485	12	733	9.1	Dissolved solids include 1.4 mg/l nitrate.
3abb	9-62	848		28	51	8	46	165	0	100	14		328	162	490	7.8	
	8-68	848										.54					
3abc	9-62	820		25	51	10	49	159	0	120	13		345	171	325	7.8	
	8-68	820										.44					
3bbb	9-62	868		31	79	13	38	177	0	160	16		424	252	600	7.7	
	8-68	868										.45					
3bdb	9-62	1,115		28	66	7	49	171	0	140	13		387	197	550	7.8	
	8-68	1,115										.60					
3dad	8-63	2,505		26	0	0	171	110	0	195	49	4.0	499	0	820	>9.4E	Analysis by Department of Agricultural Chemistry and Soils, University of Arizona.

Theoretical fluoride calculations were made using a solubility product for fluorite and concentrations of calcium in the range of those in ground water in the basin. The theoretical fluoride values are greater than the actual concentrations for the same amount of calcium. The solubility of fluorite may establish the theoretical upper limit of fluoride in the water, and the pH of the water and the availability of fluoride in exchange sites on clay minerals may control the actual amount found in ground water.

CHLORIDE

Chloride is a minor chemical constituent in the ground water in the Tucson basin except in places along the Santa Cruz River west, northwest, and south of Tucson and in the Pantano Formation along the northeast margin of the basin, where concentrations are more than 50 mg/l (type 7 water, pl. 5C). Chloride concentrations generally are less than 30 mg/l in the basin. The smallest chloride concentrations—in places less than 10 mg/l—occur in ground water northeast of the Southern Pacific Railroad Co. tracks. Along the Santa Cruz River northwest of Tucson, chloride concentrations are more than 130 mg/l. The U.S. Public Health Service (1962) recommends that chloride should not exceed 250 mg/l in drinking and culinary water. Very little ground water in the basin contains more than 250 mg/l chloride.

The distribution of large concentrations of chloride and dissolved solids in ground water is similar except along the Santa Cruz River south of Sahuarita and in the zone of poor-quality water that trends northwest across the basin. In the zone of poor-quality water the dissolved-solids content is generally more than 500 mg/l and in places is nearly 1,000 mg/l; however, chloride concentrations are less than 30 mg/l. Chloride concentrations generally do not increase with increasing depth, except in water in gypsiferous mudstone where the chloride content may be more than 100 mg/l. (See well (D–13–14) 31dba, pl. 3A.) Because the largest chloride concentrations are in the ground water in gypsiferous mudstone, the anomalous concentrations of more than 50 mg/l chloride in the shallow ground water along the Santa Cruz River delineate the areas where water is moving upward from the mudstone along the Santa Cruz fault (pl. 5C).

NITRATE

Nitrate is a minor chemical constituent in most of the ground water in the basin, and concentrations are less than 10 mg/l, except in places along the Santa Cruz River where nitrate concentrations are more than 40 mg/l (pl. 5*B*). Drinking water that contains excessive nitrate has been reported to cause methemoglobinemia or cyanosis in infants, and the U.S. Public Health Service (1962) recommends that water containing more than 45 mg/l of nitrate should not be given to infants.

In the north-central and southern parts of the basin, ground water contains less than 5 mg/l nitrate (pl. 5*B*). Large nitrate concentrations are present in the ground water northwest of Tucson where treated sewage effluent is used for irrigation and released to the Santa Cruz River. Although data are not available for changes in nitrate concentration in ground water with increasing depth along the Santa Cruz River, nitrate decreases with increasing depth in other parts of the basin and is near zero about 600 feet below the land surface (table 4). Most of the nitrate in ground water has an organic origin and is considered the final product of the decomposition of organic matter (Hem, 1959, p. 117). The large nitrate concentrations in the ground water along the Santa Cruz River probably are from the decomposition of organic matter in the former marsh areas, fertilizers applied in the agricultural areas along the river, and contamination by sewage effluent.

TABLE 4.—*Changes in nitrate concentrations in ground water with increasing depth in the aquifer*

Well	Sampling depth (feet)	Nitrate (mg/l)
(D-13-14)31dba	184	18
	554	.1
	656	0
(D-12-12)5cbc	200	13
	345	6
	470	2
(D-16-15)5bcc	557	0
	989	.1
(D-15-15)16cbb	470	2.0
	674	.3
	1,480	0

IRON

In most of the Tucson basin, the iron content in shallow ground water is very small, but at depth the concentrations may be so large that the iron must be removed from the water for use as a public supply. Water that contains less than 0.3 mg/l of iron is suitable for most domestic purposes; more than 0.3 mg/l iron stains laundry and cooking utensils and imparts an unpleasant taste to the water (U.S. Public Health Service, 1962). Most industries require water having less than 0.1 mg/l iron. When iron and manganese are present in concentrations of less than 0.5 mg/l, the addition of a small amount of metaphosphate will prevent the precipitation of these constituents (American Water Works Association, 1951, p. 365). In the Tucson basin, shallow ground water generally contains less than 0.05 mg/l iron. On the basis of the few available analyses, iron concentrations increase to as much as 0.50 mg/l with increasing depth in the aquifer.

MAGNESIUM

Magnesium is present in minor amounts in ground water in the Tucson basin, and no water was analyzed in which magnesium was the dominant cation. In most of the basin, ground water contains less than 10 mg/l magnesium. Magnesium concentrations usually are less than 2 percent of the dissolved solids and range from zero to as much as 35 mg/l. The behavior of magnesium in ground water is similar to that of calcium; in the upper part of the aquifer magnesium concentrations tend to vary directly in relation to the dissolved-solids concentrations and decrease with increasing depth in the aquifer.

Magnesium is derived from ferromagnesian silicate minerals, such as the olivine, pyroxene, amphibole, and dark-colored mica that are common in the detritus in the southwestern part of the basin. Magnesium also is derived from nonsilicate-magnesium-bearing minerals, such as the dolomite in the Paleozoic limestone beds that crop out in places in the mountains, and from calcite, which may contain as much as 10 percent magnesium.

POTASSIUM

Potassium is a minor constituent in ground water in the Tucson basin and makes up less than 1 percent of the dissolved solids. Potassium concentrations generally are less than 5 mg/l in the ground water. The most common potassium-bearing mineral is potassium feldspar, which makes up a considerable part of the basin detritus. Only small amounts of potassium are present in the water because potassium feldspar is resistant to solution and some potassium may be adsorbed by the clay minerals.

SILICA

Silica concentrations generally are less than 40 mg/l in the ground water in the Tucson basin and do not vary in relation to the dissolved-solids concentrations. Silica is not physiologically significant to humans and livestock and is not an important constituent in irrigation water; the silica concentrations in the water are within tolerable limits for most industrial uses.

The areal distribution of silica in the shallow ground water does not form a definable pattern. Silica concentrations do not vary greatly in an aquifer of uniform mineralogical content; silica tends to approach an upper limit of concentration that is determined by the type of rock that makes up the aquifer (Davis, 1964, p. 885). The mean and median silica concentrations are about 30 mg/l from the water table to a depth of about 800 feet below the land surface; below 800 feet, the mean and median concentrations are less than 30 mg/l (table 5). Silica concentrations are largest in ground water within 200 feet of the surface.

TABLE 5.—*Silica concentrations in ground water with increasing depth in the aquifer*

Depth (feet)	Concentrations (milligrams per liter)		
	Median	Mean	Range
<200	35	33	20–42
200–400	30	30	20–40
400–600	30	29	11–59
600–800	30	30	17–38
800–1,000	24	24	15–32
1,000–1,200	22	22	18–27
1,200–1,400	27	27	26–28
1,400–1,600	23	23	23
>1,600	25	25	22–29

The decrease in silica with increasing depth in the aquifer seems anomalous because the increases in temperature, pH, and sodium favor greater solubility of silica. In addition, silica-rich tuff, which is present in places in the Tinaja rocks and the Pantano Formation, should be a significant source of silica.

The anomalous silica concentrations in ground water less than 200 feet below the land surface may be the result of leaching of tuff. In southeastern Arizona, tuff is present near the top of units equivalent to the Fort Lowell Formation (E. S. Davidson, oral commun., 1969); however, tuff has not been recognized at shallow depths in the Fort Lowell in the Tucson basin.

pH VALUES

The pH is a measure of the acidity of water—a neutral water has a pH of 7.0, an alkaline water has a pH of more than 7.0, and an acidic water has a pH of less than 7.0. The pH of most natural water has no significant physiological effects on humans; however, water that has a pH of more than 10 or less than 3.0 may not be as palatable as water that has a neutral pH. Most of the ground water in the Tucson basin

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is slightly alkaline to alkaline. The pH values range from 7.0 to 8.0 in the shallow ground water and may be more than 9.0 in water at depths of more than 1,000 feet below the land surface.

CHEMICAL-WATER TYPES

The water in the Tucson basin has been divided into seven types based on the relative amounts of four major ions—calcium, sodium, bicarbonate, and sulfate—and the absolute amount of chloride. The types of water are related to the geohydrologic environments in the basin.

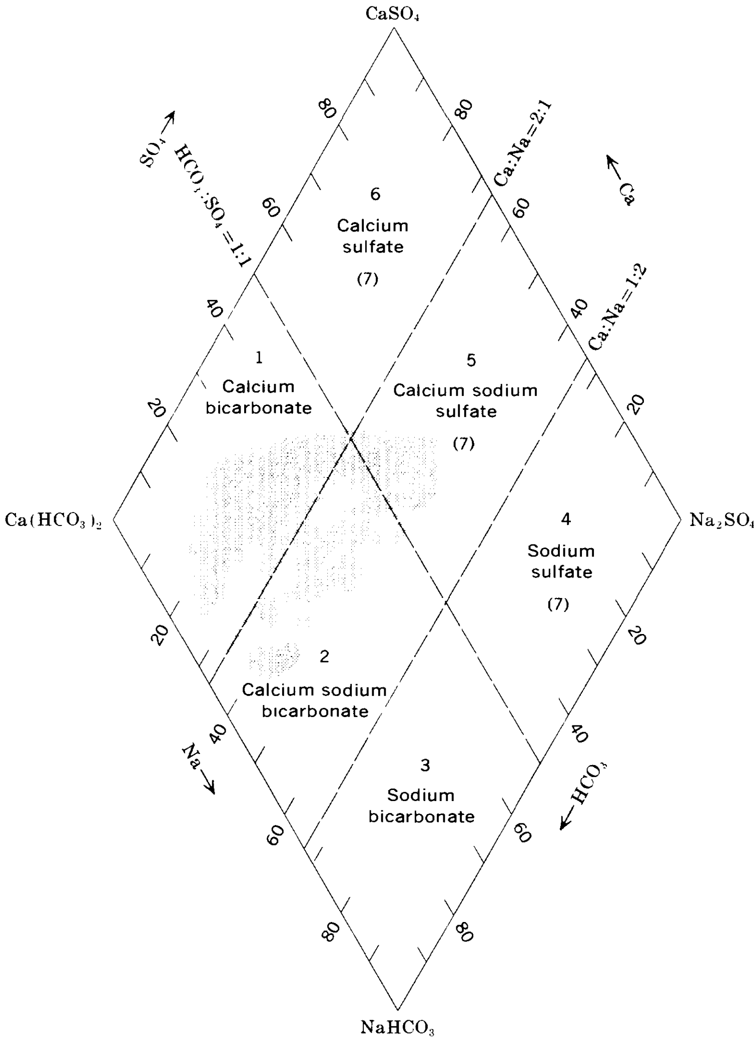
The milliequivalents of the major ions were recalculated to 100 percent, and the ratios of calcium to sodium and bicarbonate to sulfate were used to divide the water into major types (fig. 5 and table 6). Most of the water in the basin falls into the first six of the seven water types. Locally, water that contains more than 50 mg/l chloride has hydrologic significance and makes up the seventh water type.

The first six water classifications divide the water into bicarbonate and sulfate types, each of which are further subdivided into three types by the ratios of calcium to sodium. Generally, bicarbonate water contains less than 500 mg/l dissolved solids, and sulfate water contains more than 500 mg/l dissolved solids (table 6). Streamflow in the main channels generally is a calcium bicarbonate or calcium sodium bicarbonate type (fig. 5). The main types of ground water are calcium bicarbonate, calcium sodium bicarbonate, and sodium bicarbonate.

SURFACE WATER

In the Tucson basin, most of the water in the main stream channels has a calcium bicarbonate to calcium sodium bicarbonate composition (table 1, fig. 5). The water in Rillito Creek is mainly a calcium bicarbonate type. The composition of the water in Pantano Wash and the Santa Cruz River is more variable than that of water in Rillito Creek; the water in Pantano Wash and the Santa Cruz River is a calcium bicarbonate type, a calcium sodium bicarbonate type, or occasionally a calcium sodium sulfate type. Sulfate and dissolved-solids concentrations are greater in water in Pantano Wash and the Santa Cruz River than in Rillito Creek.

The water in the tributaries to the main streams undergoes a chemical transition from the type common to runoff on the rocks of the mountains to the type common to runoff on the material in the basin; therefore, tributary flow does not have the calcium bicarbonate composition typical of the water in the main streams. For example, in the northeastern part of the basin, the water tributary to Rillito Creek



EXPLANATION

3
Major water type that contains less than 50 mg/l of chloride
Number corresponds to types in table 6

(7)
Major water type that contains more than 50 mg/l of chloride
Number corresponds to type in table 6

Chemical composition of streamflow (recharge water) in Santa Cruz River, Rillito Creek, and Pantano Wash

FIGURE 5.—Classification of major water types using ratios of calcium to sodium and bicarbonate to sulfate and absolute amount of chloride.

TABLE 6.—*Major types of ground water and their areal distribution*

Water type (ratio of milliequivalents per liter)	Areal distribution of water types in the aquifer	Dissolved solids (milligrams per liter)	Remarks
1. Calcium bicarbonate (Ca:Na>2:1) (HCO_3:SO_4>1:1).	Occurs within 2 miles of major recharge areas in the Fort Lowell Formation and the upper part of the Tinaja rocks. Similar in chemical composition to recharge water.	200–400 along Rillito Creek and Pantano Wash; 300–700 along Santa Cruz River south of Black Mountain.	Contains less than 50 mg/l chloride.
2. Calcium sodium bicarbonate (Ca:Na=2:1 to 1:2) (HCO_3:SO_4>1:1).	In about 70 percent of the basin in the Fort Lowell Formation and the upper part of the Tinaja rocks. Typical of water in material derived from granitic rocks.	<350 in northeast; <500 elsewhere	Do.
3. Sodium bicarbonate (Ca:Na<1:2) (HCO_3:SO_4>1:1).	Areal distribution similar to that of type 2; occurs in the lower part of the Tinaja rocks and in the Pantano Formation, where gypsiferous mudstone is not present, and in places in the upper part of the Tinaja rocks.	200–500	Do.
4. Sodium sulfate (Ca:Na<1:2) (HCO_3:SO_4<1:1).	Mainly in the lower part of the Tinaja rocks and in the Pantano Formation in the central and southwestern parts of the basin; in the Fort Lowell Formation and Tinaja rocks in places along the Santa Cruz River near Tucson.	300–600	Do.
5. Calcium sodium sulfate (Ca:Na=2:1 to 1:2) (HCO_3:SO_4<1:1).	In the Fort Lowell Formation and the upper part of the Tinaja rocks in the narrow zone that trends northwest across the basin and along the Santa Cruz River mainly west and northwest of Tucson.	400–1,500	Do.
6. Calcium sulfate (Ca:Na>2:1) (HCO_3:SO_4<1:1).	Mainly in the Fort Lowell Formation and the upper part of the Tinaja rocks in the zone that trends northwest across the basin and in places along the Santa Cruz River south of Tucson.	400–1,500	Do.
7. Calcium sulfate to sodium sulfate (Ca:Na>2:1 to <1:2) (HCO_3:SO_4<1:1).	In the Fort Lowell Formation and the Tinaja rocks along the Santa Cruz River southwest, west, and northwest of Tucson; in gypsiferous mudstone in the Tinaja rocks; along some of the major faults; and also in the Pantano Formation where it is exposed along the northeast margin of the basin.	500–3,000	Contains more than 50 mg/l chloride.

has a lower calcium to sodium and bicarbonate to sulfate ratio than the water in Rillito (table 1). Sufficient data are not available to determine the chemical composition of tributary flow in other parts of the basin.

CHEMICAL TRANSITION FROM PRECIPITATION TO GROUND WATER

In the northeast part of the Tucson basin, the chemical transition of precipitation on the Santa Catalina Mountains to ground water near Rillito Creek may be traced through four steps (Laney, 1968, p. 561): precipitation on the mountains is a calcium sodium sulfate bicarbonate water; runoff on the granitic bedrock of the mountains is a sodium sulfate to sodium bicarbonate water; streamflow in the washes tributary to Rillito Creek is a calcium sodium sulfate and calcium sodium bicarbonate to calcium bicarbonate water; and streamflow in Rillito Creek is a calcium bicarbonate water. After the streamflow from Rillito Creek is recharged to the material in the creekbed, calcium sodium bicarbonate water results within a mile of Rillito Creek. The change from calcium bicarbonate to calcium sodium bicarbonate may be due to ion exchange.

During the chemical transition of precipitation to ground water, the dissolved-solids content progressively increases—from about 5 mg/l in precipitation to more than 300 mg/l in the ground water near Rillito Creek. The chemical composition of the ground water remains fairly uniform in the direction of ground-water movement to the outlet of the basin, because the composition of the material through which it moves does not change significantly.

GROUND WATER

Calcium sodium bicarbonate water makes up nearly 75 percent of the shallow ground water in the Tucson basin (pl. 5*C*). Calcium bicarbonate ground water is present along Rillito Creek and Pantano Wash and along the Santa Cruz River south of Black Mountain. Calcium bicarbonate water is the result of infiltration of surface water in which calcium and bicarbonate are the principal constituents and the solution of relict calcite in the near-surface deposits along Rillito Creek and the Santa Cruz River.

Sodium bicarbonate water is present in the sand and gravel units in the lower part of the Tinaja rocks and in the Pantano Formation. The chemical transition from a calcium sodium bicarbonate to a sodium bicarbonate water occurs between 600 and 1,000 feet below the land surface. The change is caused by an increase in sodium and a decrease in calcium in the water in sand and gravel units; ion exchange between montmorillonite and the water may remove calcium from the water and replace it with sodium, and additional calcium may be removed from the water by precipitation of calcite.

Calcium sulfate and calcium sodium sulfate water is present in the narrow zone that trends northwest across the basin, and calcium sodium sulfate water is present along the Santa Cruz River northwest of Tucson and near Black Mountain. The source area for the sulfate in the northwest-trending zone is along the east edge of the basin, as shown by the sulfate distribution on plate 4*C*; additional evidence for the source area is that the dissolved-solids concentrations decrease northwestward in the zone from about 860 mg/l near Vail to about 550 mg/l in T. 14 S., R. 14 E. In the headwaters area of Pantano Wash calcium and sulfate are derived by water that infiltrates through the Pantano Formation and older rocks. Gypsiferous mudstone may exist at depth where the zone widens in the eastern part of T. 16 S., R. 15 E., and in the western part of T. 16 S., R. 16 E. The presence of the gypsiferous mudstone is indicated by the bedded gypsum deposits in the Pantano Formation along the east margin of the basin, the gypsiferous mudstone penetrated at about 1,700 feet below the land surface in well (D–15–15)16cbb, and the reported "yellow cemented clay," which may be gypsiferous, penetrated at more than 1,000 feet below the land surface in well (D–15–15)25caa. Very few wells have been drilled in the eastern part of the zone, but well (D–16–15)14acb was drilled to a depth of 900 feet in gravel and did not penetrate gypsiferous deposits. The sulfate concentrations increase from 315 mg/l at about 450 feet to 345 mg/l at 900 feet, and the dissolved solids increase from 665 to 739 mg/l, respectively. (See well (D–16–15)14acb, pl. 3*B*.)

In the center of the basin, sodium sulfate water generally is associated with the coarse-grained facies in the lower part of the Tinaja rocks and with the Pantano Formation, where they are near the boundaries of the fine-grained facies of the Tinaja. In the center of the basin, water quality may deteriorate in wells that bottom in the coarse-grained facies; if these wells are pumped for prolonged periods, the increased ground-water gradient toward the wells may cause movement of poor-quality sulfate water from the fine-grained facies. Sodium sulfate water occurs along the Santa Cruz River south of Black Mountain, west of the Santa Cruz fault, and in the zone of poor-quality water that trends northwest across the basin. Sodium sulfate water also is present at shallow depths in small areas along the river west and northwest of Tucson. Sodium sulfate water is present near some fault zones, where water moving upward from the deeper parts of the aquifer has been mixed with shallow ground water. The sodium sulfate water probably is the result of the solution of calcium sulfate in gypsiferous mudstone and the subsequent modification by ion exchange. In the coarse facies near the boundaries of the mudstone, sufficient calcium sulfate is dissolved to give the water a sulfate "flavor," although the amount of sulfate may be only slightly greater than the amount of bicarbonate. (See table 3, wells at depths of 2,500 feet and deeper.) Subsequent movement of ground water in the coarse facies causes the exchange of the calcium in the water for the sodium in the aquifer material and possibly causes the precipitation of calcium carbonate, which result in a sodium sulfate composition.

Sulfate water that ranges in composition from calcium sulfate to sodium sulfate is present in the aquifer along the Santa Cruz River from north of Sahuarita to Rillito. In most of the area the water contains more than 50 mg/l chloride, which generally is associated with gypsiferous mudstone. The distribution of the calcium sulfate to sodium sulfate water is related to the Santa Cruz fault; the anomalous concentrations of sulfate and chloride in the water near the fault denote the upward leakage from the gypsiferous mudstone in the Tinaja beds in Tps. 15 and 16 S., R. 14 E. The Santa Cruz fault intersects a northwest-trending fault in sec. 13, T. 14 S., R. 13 E. (pl. 5*C*), which probably is the area of major discharge of water into the near-surface deposits. In the direction of ground-water movement, the dissolved-solids content increases from less than 600 mg/l southeast of the fault intersection to as much as 2,000 mg/l northwest of the intersection. Calcium sulfate to sodium sulfate water is present in a small area north of Sahuarita and east of the Santa Cruz fault in T. 16 S., R. 14 E., where wells probably derive part of their water directly from mudstone; in this area the mudstone is less than 500 feet below the land surface (pl. 2*B*). The Santa Cruz fault is the approximate western boundary for the calcium sulfate to sodium sulfate water, and the water from the mudstone in this area has a higher ratio of calcium to sodium than that of the same water type along the Santa Cruz River north of Black Mountain (pl. 5*C*). The higher ratio of calcium to sodium in water in this area may be caused by mixing with calcium-rich water from along the Santa Cruz River in T. 16 S., R. 14 E., or may be the result of the presence of smaller concentrations of sodium in water in the upper part of the mudstone in the western part of T. 16 S., R. 14 E., than elsewhere in the mudstone.

Along the Santa Cruz River north of Sahuarita, much of the calcium sulfate to sodium sulfate water probably is the result of upward leakage of water along the Santa Cruz fault. Some sulfate, however, may be derived from the older Tertiary and Cretaceous volcanic and sedimentary rocks in the Tucson Mountains, particularly in the western part of T. 15 S., R. 13 E. In addition, the area along the river north of Black Mountain was swampy and poorly drained prior to 1900, and remnants of salt from evaporated water may be responsible for some of the sulfate water. Calcium sulfate to sodium sulfate water is present in the Pantano Formation along the northeast margin of the basin. In this area the Pantano is a gypsiferous mudstone to a tightly cemented conglomerate, has very poor water-bearing properties, and does not significantly affect the quality of water in the adjacent parts of the aquifer.

RELATION OF WATER QUALITY TO PARTICLE SIZE

The particle size of the aquifer material is variable. The percentage of sand and gravel in the aquifer ranges from 30 to 80, and the dissolved-solids content of the water ranges from 150 to more than 3,000 mg/l; no apparent relation exists between the particle size and chemical quality of the water.

The water in the gypsiferous mudstone is of poor chemical quality. Well (D–13–14)31dba penetrated gypsiferous mudstone at 660 feet (see well (D–13–14)31dba, pl. 3*A*); 40 percent of the mudstone is coarser than silt (0.062 mm in diameter), and water in the upper part of the mudstone contains 3,120 mg/l dissolved solids. The well penetrated sandstone and sand at a depth of 554 feet; 80 percent of the material is coarser than silt, and the water contains 261 mg/l dissolved solids. In other places in the basin, less than 40 percent of the aquifer material is coarser than silt, although the ground water contains less than 400 mg/l dissolved solids. In parts of the basin, fine-grained aquifer material at depth contains water of better quality than that of the water in the overlying coarser sediments. (See well (D–15–15) 16cbb, pl. 3*B*.) Therefore, it is apparent that the mineralogy of the aquifer material, which is determined by source and depositional environment and not the particle size, controls the chemical composition of the water in the Tucson basin.

TEMPERATURE OF GROUND WATER

The temperature of ground water generally is about 77°F (25°C) in the upper few hundred feet of the aquifer. The temperature normally increases about 3°F (1.7°C) per 100 feet of depth, and at 2,000 feet below the land surface water temperatures are about 130°F (54.5°C). Hot water occurs at relatively shallow depths near faults, which indicates upward leakage and circulation of water from depth along fault zones. Temperature gradients along fault zones are as much as 5°F (2.8°C) per 100 feet of depth.

SUMMARY

Most of the ground water in the Tucson basin is of excellent chemical quality and is suitable for most uses. In places, ground water contains excessive amounts of dissolved solids and fluoride, and the fluoride content may be large in the water in the deep parts of the aquifer.

About 75 percent of the shallow ground water—water at depths of less than 700 feet below the land surface—contains less than 500 mg/l of dissolved solids, which is the maximum recommended concentration for public water supplies. Dissolved-solids concentrations generally are less than 300 mg/l in the ground water in most of the Cañada del Oro drainage south of the Pima-Pinal County line and in the area bounded by Rillito and Tanque Verde Creeks, the Southern Pacific Railroad Co. tracks, and the Rincon and Tanque Verde Mountains. Dissolved-solids concentrations of more than 500 mg/l occur in ground water along the Santa Cruz River and in the narrow zone that trends northwestward across the center of the basin. In places along the Santa Cruz River northwest, west, and southwest of Tucson, ground water contains more than 1,000 mg/l dissolved solids.

The dissolved-solids content of the deep ground water—water at depths of more than 700 feet below the land surface—is comparable to that of the shallow ground water and in some areas may be less than that of the shallow ground water where the aquifer is mainly sand- and gravel-sized material. In the southwestern part of the basin west of the Santa Cruz fault and in the eastern and north-central parts of the basin, water at depths of more than 2,000 feet below the land surface contains less than 500 mg/l of dissolved solids. The dissolved-solids concentrations may exceed 2,000 mg/l in the water in the gypsiferous mudstone in Tps. 15 and 16 S., R. 14 E., and in the southern part of T. 13 S., R. 14 E., along Rillito Creek.

In general, shallow ground water that contains less than 500 mg/l dissolved solids is a calcium sodium bicarbonate type, and deep ground water that contains less than 500 mg/l dissolved solids is a sodium bicarbonate type. Shallow ground water that contains more than 500 mg/l of dissolved solids is either a calcium sulfate or calcium sodium sulfate type, and deep ground water that contains more than 500 mg/l of dissolved solids is a sodium sulfate type.

Most of the ground water contains fluoride concentrations that are below the maximum recommended limit for public water supplies.

The maximum recommended fluoride concentration, which varies indirectly with the annual average of maximum daily air temperature, is 1.4 mg/l. The optimum fluoride concentration is half the maximum, or 0.7 mg/l. In most of the basin, fluoride concentrations in shallow ground water are less than 0.5 mg/l; along the Santa Cruz River, fluoride concentrations generally are more than 0.5 mg/l, and northwest of Tucson they are more than 1.5 mg/l. Deep ground water contains more fluoride than shallow ground water. In the central and northern parts of the basin, fluoride concentrations increase from less than 0.5 mg/l in the upper part of the aquifer to as much as 5.0 mg/l at depth in the mudstone. In the rest of the basin, water contains less than 1.0 mg/l fluoride to depths of as much as 1,000 feet below the land surface.

Excessive hardness of water is a near-surface phenomenon and, as a result, the shallow ground water is moderately hard to very hard. The deep ground water is soft in most of the basin. Most of the moderately hard ground water is in the northeastern part of the basin. Hard ground water occurs in the south-central part of the basin and along Pantano Wash and Rillito Creek. Very hard water is in the upper part of the aquifer along the Santa Cruz River, in a zone of poor-quality water that trends northwestward across the basin, and along parts of Rillito Creek and Pantano Wash. Most of the deep ground water is soft to depths of more than 1,000 feet below the land surface, where the aquifer material is coarser than mudstone. Deep water in the mudstone, however, generally contains large amounts of calcium and is extremely hard.

Most of the water in the aquifer contains less than 0.3 mg/l iron, which is the maximum recommended limit for public water supplies. Shallow ground water generally contains less than 0.05 mg/l iron, and deep ground water generally contains less than 0.3 mg/l iron; in places, however, deep ground water may contain as much as 0.5 mg/l iron.

Sulfate concentrations are less than 150 mg/l in most of the aquifer. In a small part of the basin, sulfate concentrations in ground water exceed the recommended upper limit of 250 mg/l for public supplies. The distribution of sulfate in ground water is similar to that of the dissolved solids. Sulfate concentrations are less than 50 mg/l in the shallow ground water in the southern and northeastern parts of the basin and may be as small as 10 mg/l in the northeastern part. Sulfate concentrations are more than 250 mg/l in the ground water in places along the Santa Cruz River northwest and south of Tucson and in the zone of poor-quality water that trends northwestward across the basin. In these areas, shallow ground water is not suitable for use as a public supply. Sulfate concentrations generally are not more than

150 mg/l in deep ground water, except where the aquifer material is gypsiferous mudstone. In these deposits water may contain as much as 2,000 mg/l sulfate.

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INDEX

[Italic page numbers indicate major references]

	Page
Acknowledgments	D*8*
Aquifer, particle size	40
use of term in this report	9
Bibliography	*43*
Bicarbonate in ground water	*23*
Calcium in ground water	*22*
Chemical constituents in surface water	*11*
Chemical-water types	*34*
Chloride in ground water	*30*
Climate	*4*
Dissolved solids, anomalous concentrations in ground water	16
areal distribution in shallow ground water	*15*, 41
changes in concentrations with time	*21*
vertical distribution in ground water	*20*, 41
Fluoride in ground water	*27*, 41
Fort Lowell Formation	*10*
fluoride concentrations in ground water	27
Ground water, chemical-water types	*37*, 41
quality	*15*
Ground-water pumping, changes in dissolved-solids concentrations	21
Hardness of ground water	*24*, 41
Iron in ground water	*31*, 41
Location	*4*
Magnesium in ground water	*32*
Methods of investigation	*5*
Nitrate in ground water	*30*
Pantano Formation	*9*, 28, 38, 40
calcium concentrations in ground water	22
chemical-water types	37, 40
chloride concentrations in ground water	30
fluoride concentrations in ground water	27
poor water quality	15, 17
sodium concentrations in ground water	25
silica	33
sulfate concentrations in ground water	26
Pantano Wash, anomalous concentrations of dissolved solids in nearby ground water	16
bicarbonate in nearby ground water	24
chemical type of nearby ground water	37
chemical-water type	34
hardness of nearby ground water	24
nearby zone of poor-quality water	18, 24
Particle size of aquifer material	D*40*
pH	28, *33*
Physiographic setting	*4*
Population, metropolitan Tucson	4
Potable water, depth to	20
Potassium in ground water	*32*
Precipitation	5
chemical transition to ground water	37
Quality of water	*11*
Rillito Creek, anomalous concentrations of dissolved solids in nearby ground water	16
changes in dissolved-solids concentrations in nearby ground water	21
chemical type of nearby ground water	37
chemical-water type	34
hardness of nearby ground water	24
sediment concentrations	14
Santa Cruz fault, bicarbonate in nearby ground water	24
fluoride concentrations in nearby ground water	28
sulfate concentrations in nearby ground water	26
upward leakage of poor-quality water	18, 24, 25, 30, 39
Santa Cruz River, bicarbonate in nearby ground water	24
calcium concentrations in nearby ground water	22
changes in dissolved-solids concentrations in nearby ground water	21
chemical type of nearby ground water	37
chemical-water type	34
chloride concentrations in nearby ground water	30
dissolved-solids concentrations in nearby ground water	16, 19
fluoride concentrations in nearby ground water	27
hardness of nearby ground water	24
nitrate concentrations in nearby ground water	30
poor quality of nearby ground water	15
sediment concentrations	14
sodium concentrations in nearby ground water	25
sulfate concentrations in nearby ground water	26
Silica in ground water	*32*
Sodium in ground water	*25*

	Page
Streamflow, chemical constituents	D11
chemical water types	34
response to precipitation	5
suspended sediment	11
Sulfate in ground water	*26*, 41
Summary	*41*
Surface water, chemical water types	*34*
quality	*11*
Suspended sediment, surface water	*11*
Tanque Verde Creek, anomalous concentrations of dissolved solids in nearby ground water	16
sediment concentrations	14
Temperature of ground water	D*40*
Temperature, Tucson	4
Test holes	*6*
Tinaja rocks	*9*, 28, 38
chemical-water types	37
fluoride concentrations in ground water	27
silica	33
Vail, nearby zone of poor-qual'ty water	17, 38
Water-quality data, years of record	5
Well-numbering system	*6*

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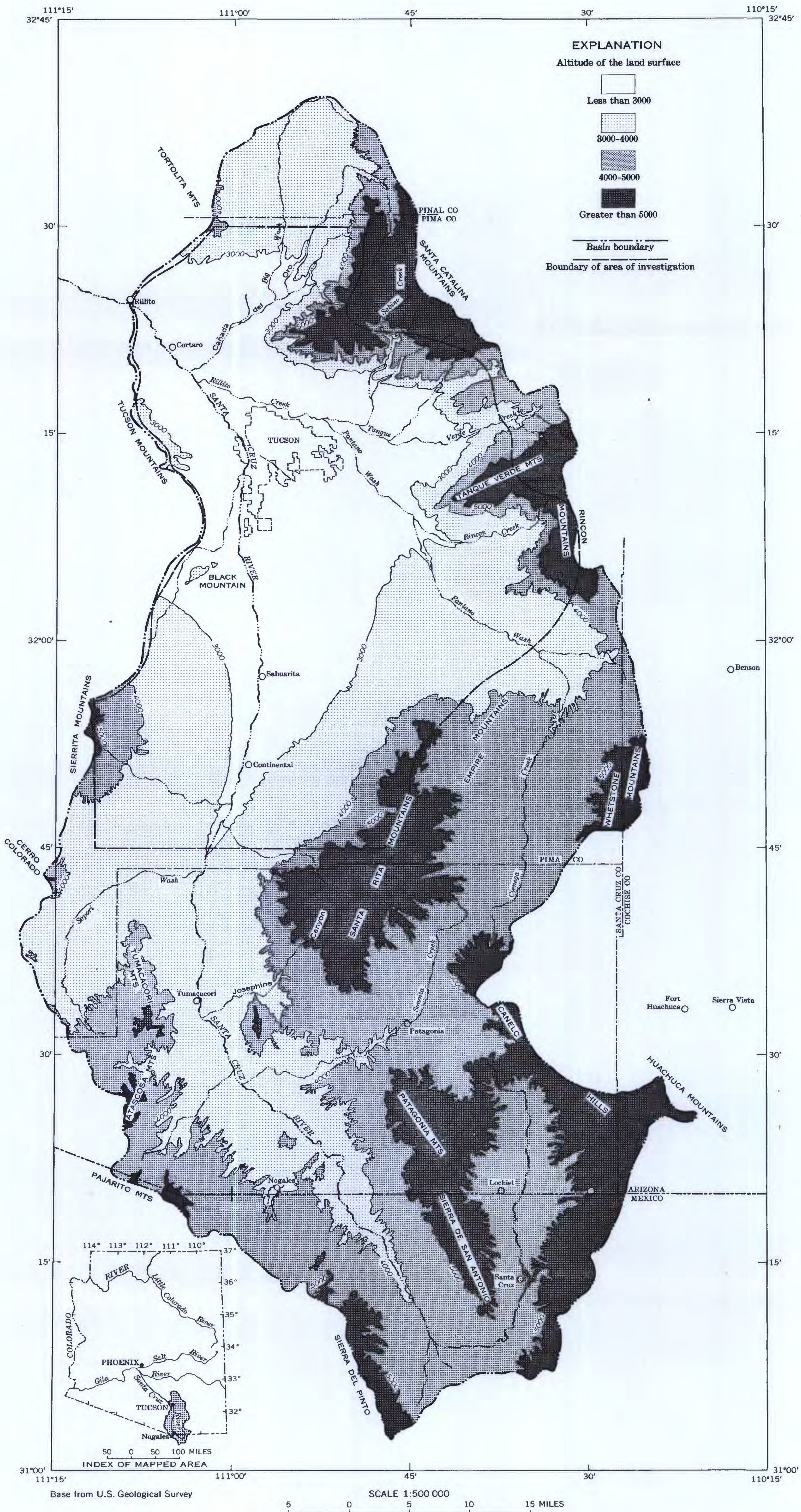
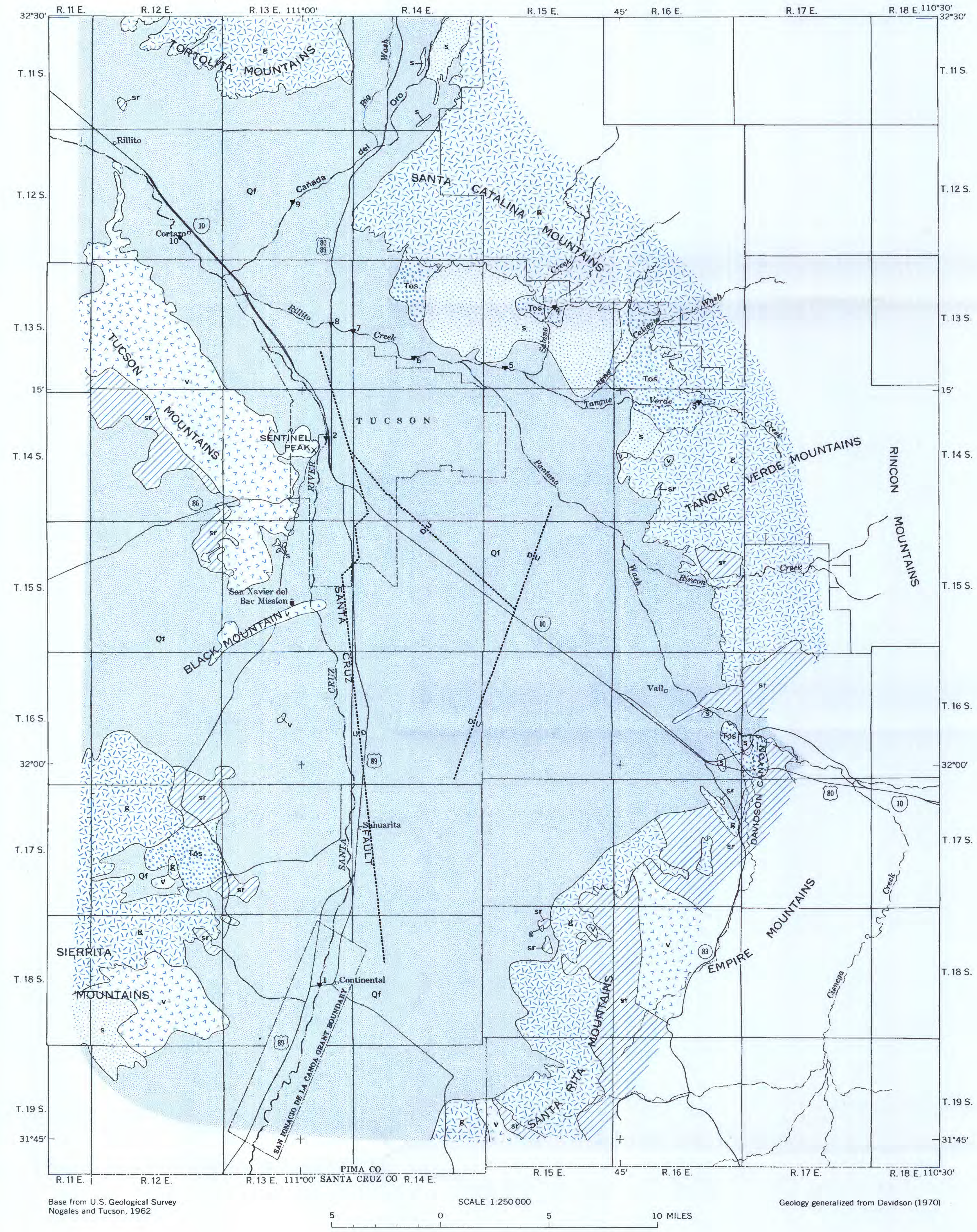


A. TOPOGRAPHY OF THE UPPER SANTA CRUZ RIVER BASIN AND BOUNDARY OF AREA OF INVESTIGATION



B. GENERALIZED DISTRIBUTION OF ROCK TYPES

EXPLANATION

ROCK UNITS OF THE AQUIFER

Pleistocene	Qf	**Fort Lowell Formation** — *Gravel to clayey silt; also includes thin surficial alluvial deposits*		QUATERNARY
		UNCONFORMITY		
Miocene and Pliocene	Ts	**Tinaja rocks** — *Gravel and conglomerate to clayey silt and mudstone; include some basaltic andesite flows and dacite tuff*		TERTIARY
		UNCONFORMITY		
Oligocene	Tos	**Pantano Formation** — *Conglomerate, sandstone, mudstone, and gypsiferous mudstone; includes some tuff*		TERTIARY

ROCK UNITS ALONG THE MARGIN OF THE BASIN (PRECAMBRIAN TO TERTIARY)

sr	**Sedimentary rocks undifferentiated** — *Conglomerate, sandstone, mudstone, shale and quartzite, some limestone, interbedded volcanic flows, tuffs, and agglomeratic tuff*
g	**Granitic rocks** — *Granite, quartz monzonite, granodiorite diorite, monzonite, and quartz latite porphyry; include granitic gneiss and schist*
v	**Volcanic rocks** — *Flows, necks, dikes, and plugs; tuff, welded tuff, agglomerate, and breccia; basaltic andesite to rhyolite; include some interbedded conglomerate, sandstone, and siltstone*

Contact

U/D — Concealed fault
U, upthrown side; D, downthrown side

▼1 — Suspended-sediment sampling point
Number refers to location given in table 2

MAPS SHOWING PHYSICAL SETTING OF TUCSON BASIN, SOUTHEASTERN ARIZONA

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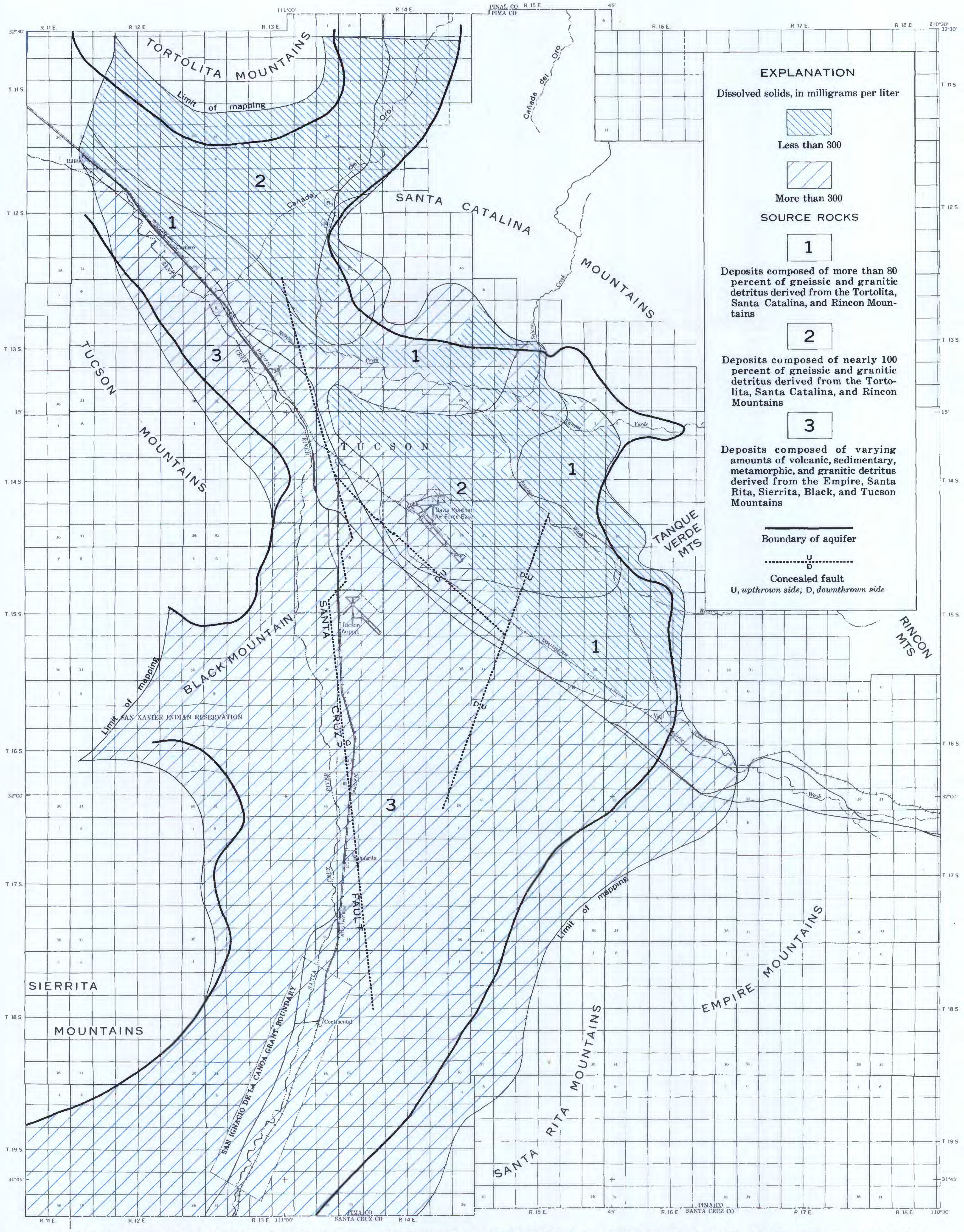
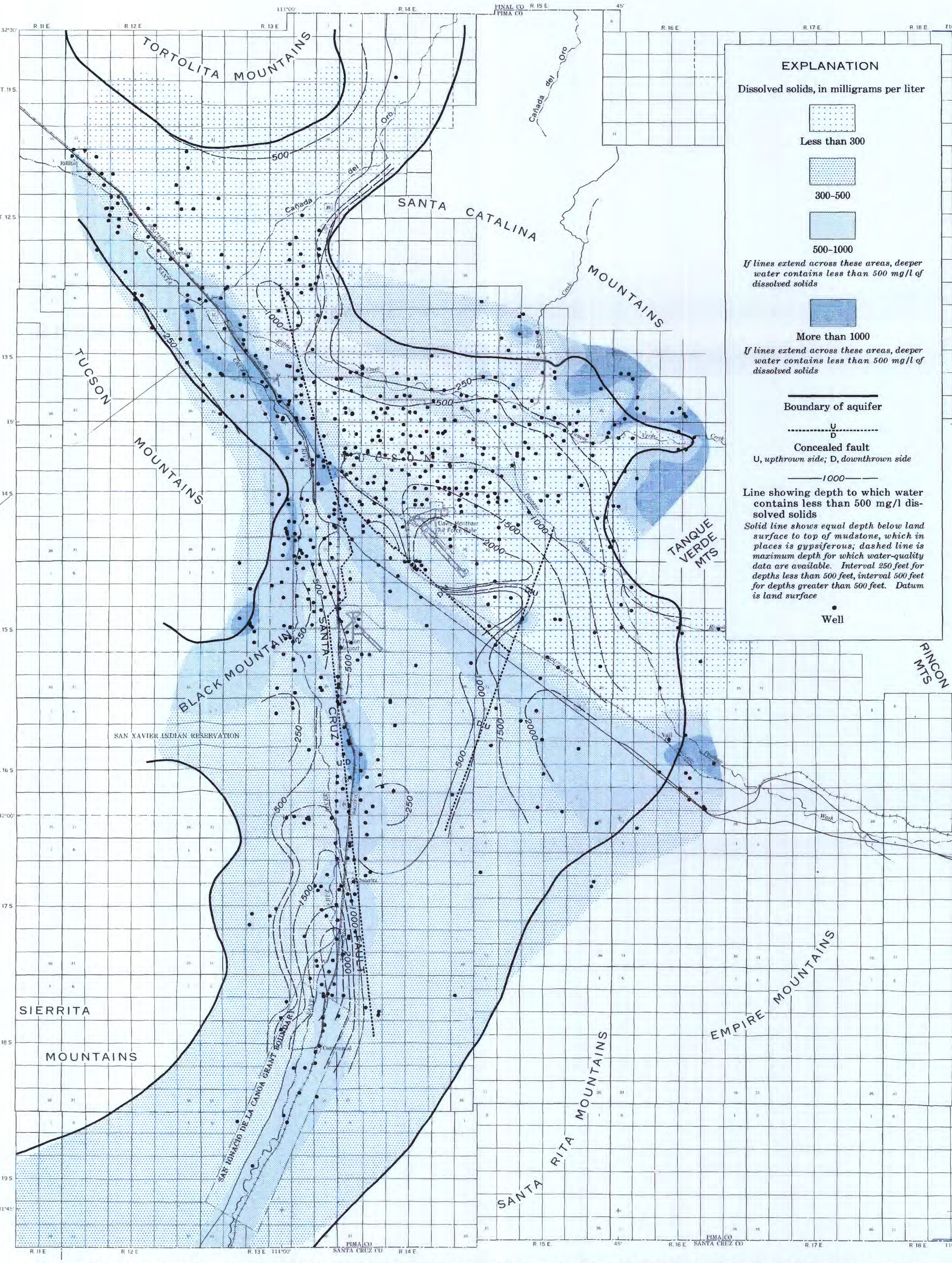


A. DISTRIBUTION IN SHALLOW GROUND WATER AS RELATED TO SOURCE ROCKS



B. DISTRIBUTION IN SHALLOW GROUND WATER AND DEPTH TO WHICH GROUND WATER CONTAINS LESS THAN 500 MG/L OF DISSOLVED SOLIDS

Base from U.S. Geological Survey

Compiled by R. L. Laney, 1968

SCALE 1:250 000

5 0 5 10 15 20 25 MILES

5 0 5 10 15 20 25 KILOMETERS

APPROXIMATE MEAN DECLINATION, 1972

MAPS SHOWING DISTRIBUTION OF DISSOLVED SOLIDS IN GROUND WATER, TUCSON BASIN, SOUTHEASTERN ARIZONA

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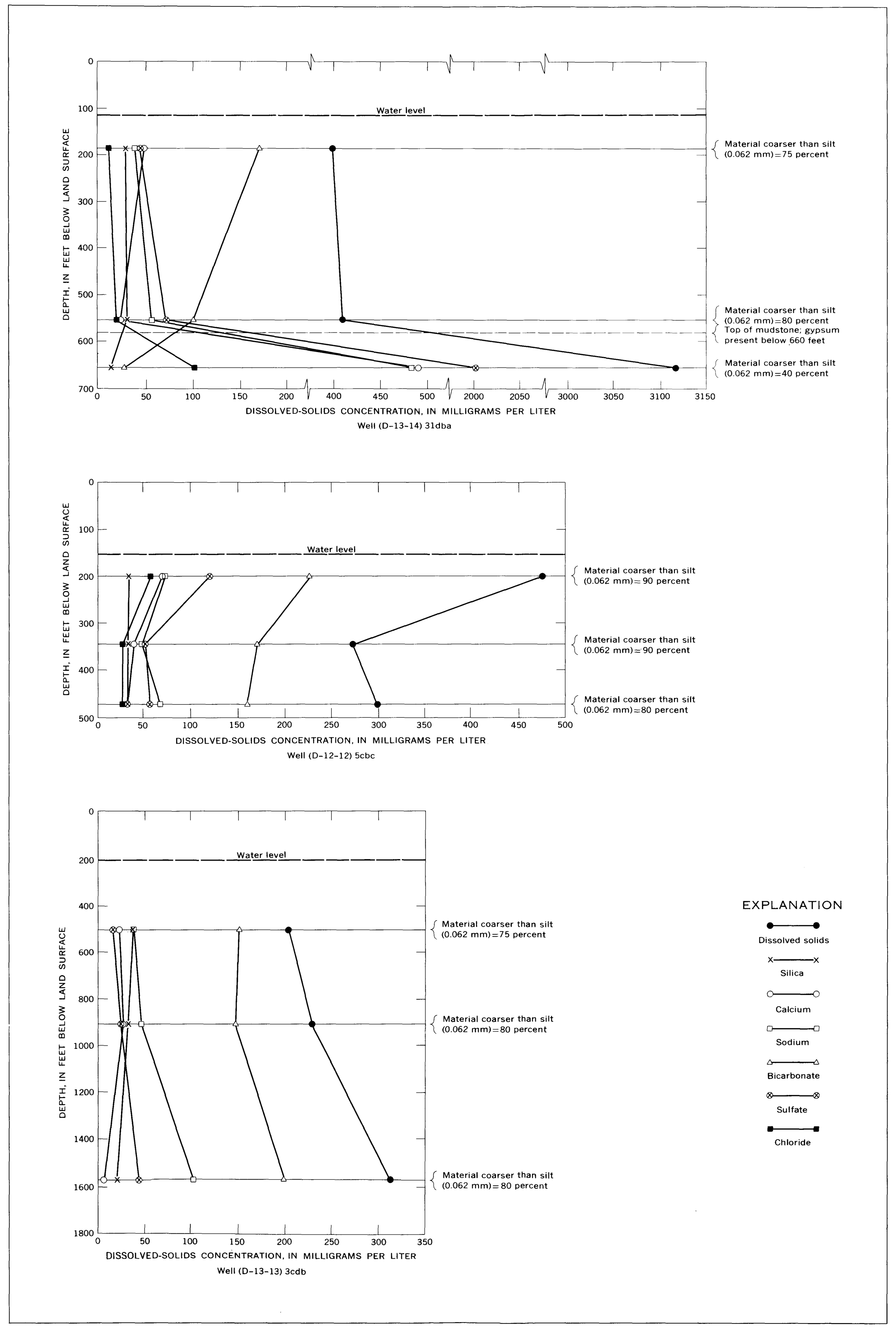
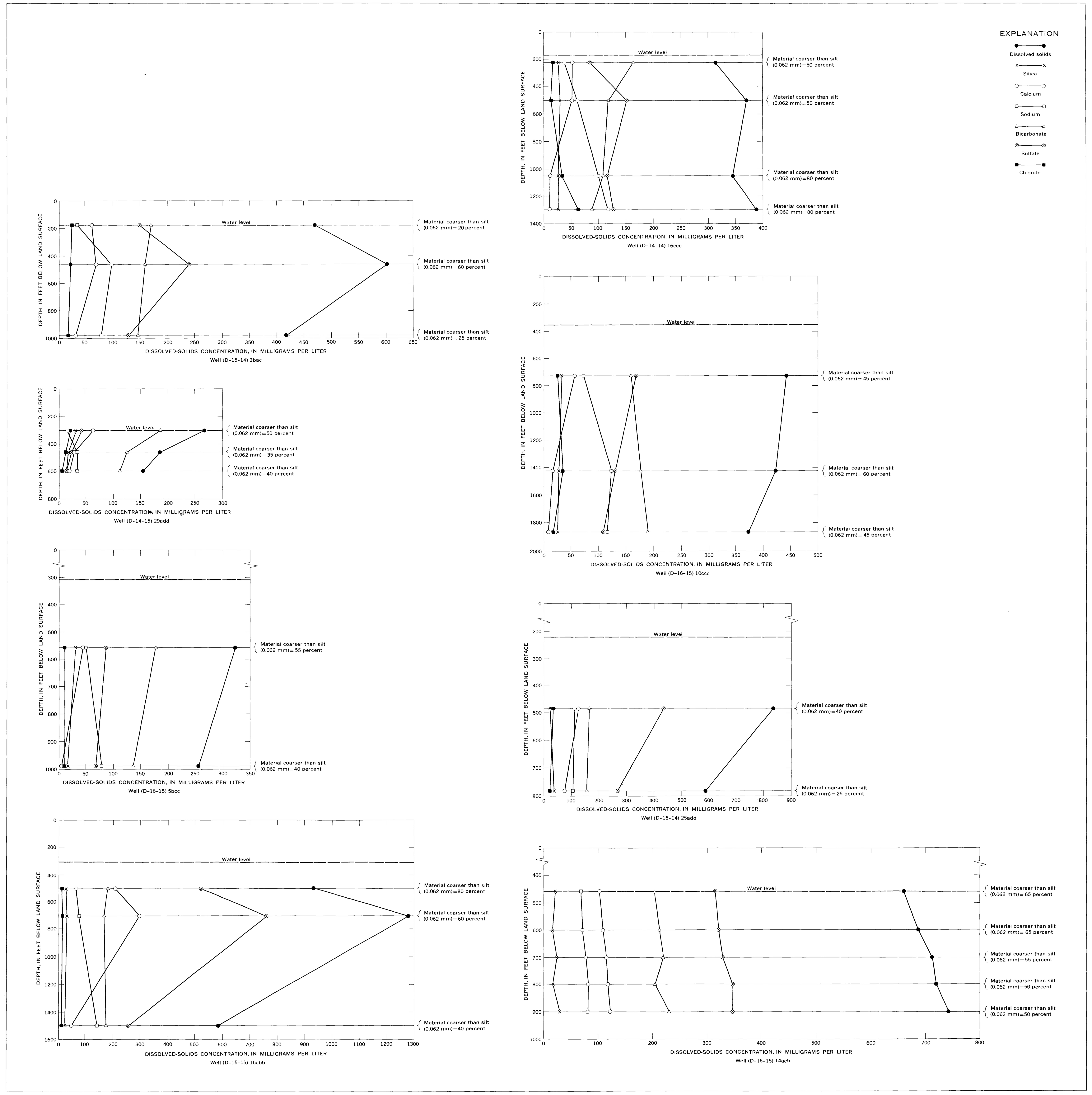
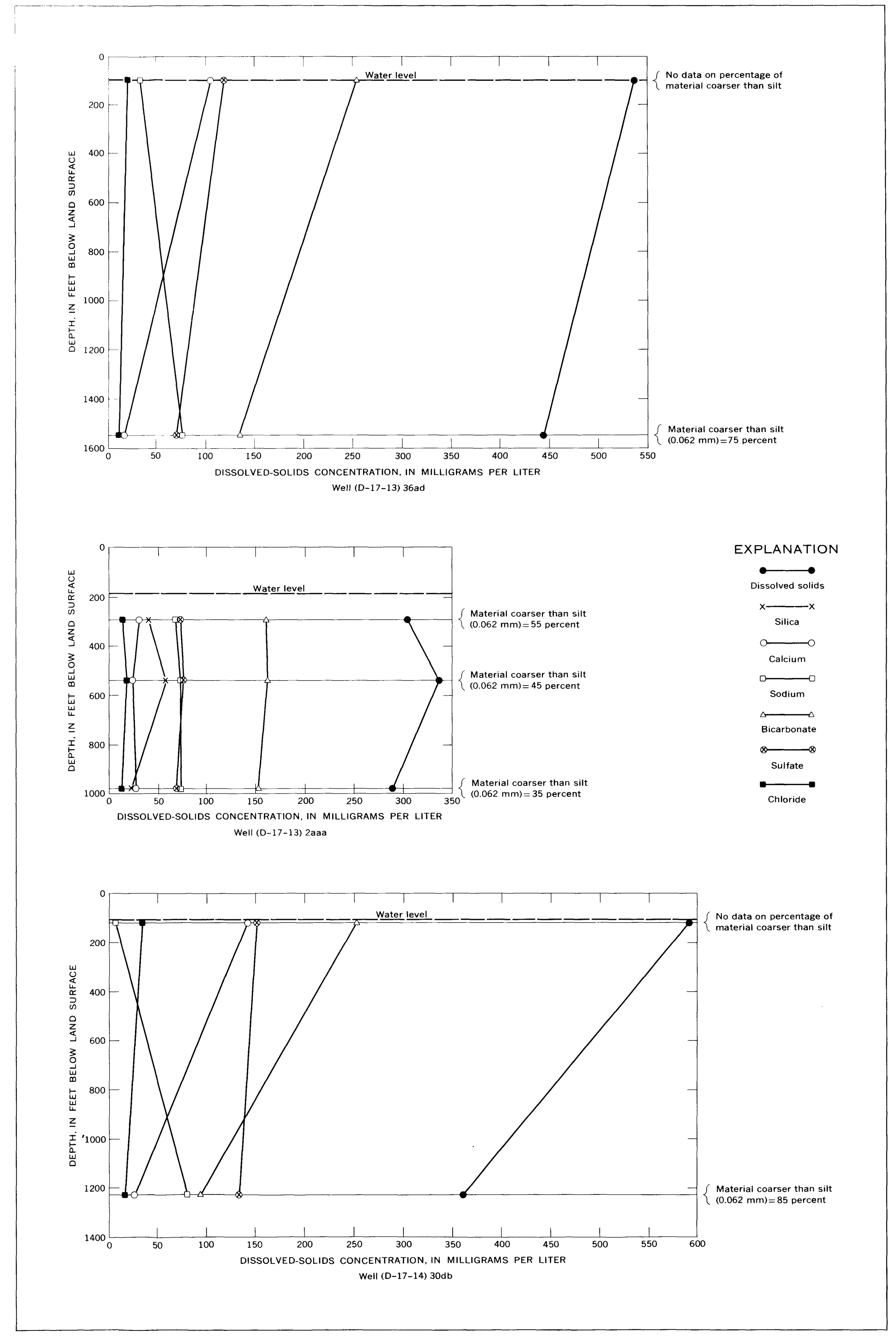


A. EAST OF THE SANTA CRUZ RIVER IN THE NORTHWESTERN PART OF THE TUCSON BASIN



B. IN THE NORTH-CENTRAL AND EASTERN PARTS OF THE TUCSON BASIN



C. NEAR THE SANTA CRUZ RIVER IN THE SOUTHWESTERN PART OF THE TUCSON BASIN

GRAPHS SHOWING VARIATION OF DISSOLVED CONSTITUENTS IN GROUND WATER WITH DEPTH, TUCSON BASIN, SOUTHEASTERN ARIZONA

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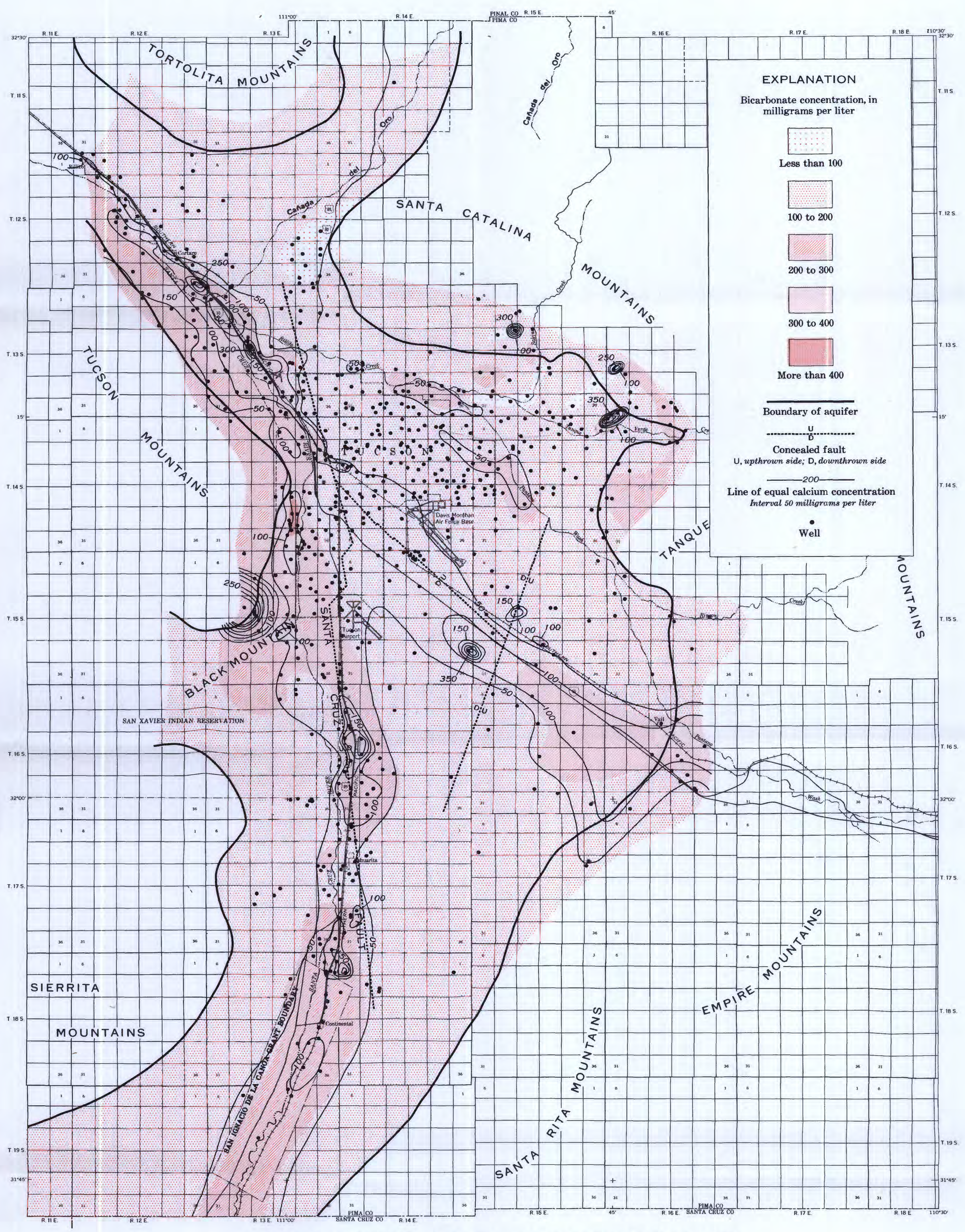
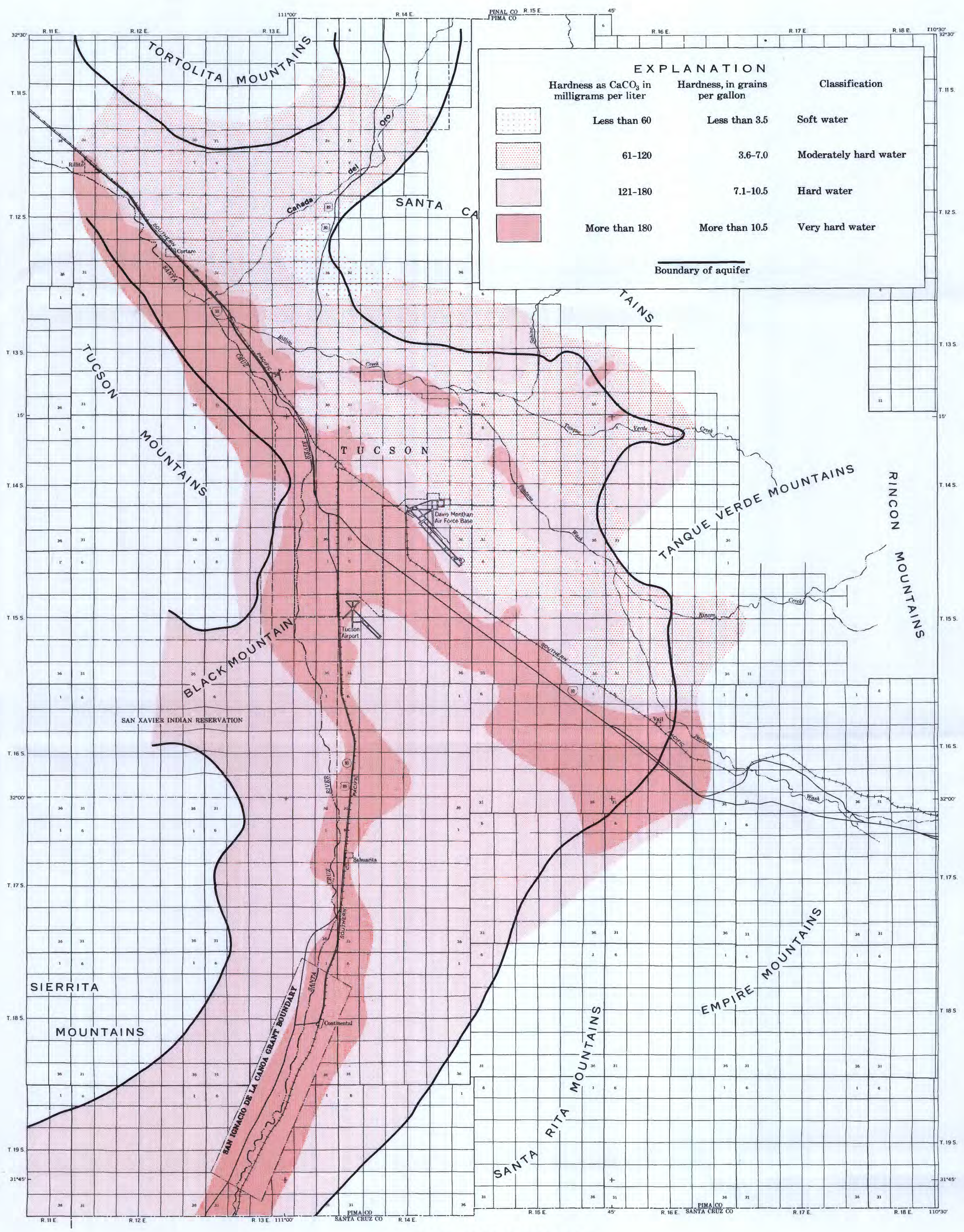
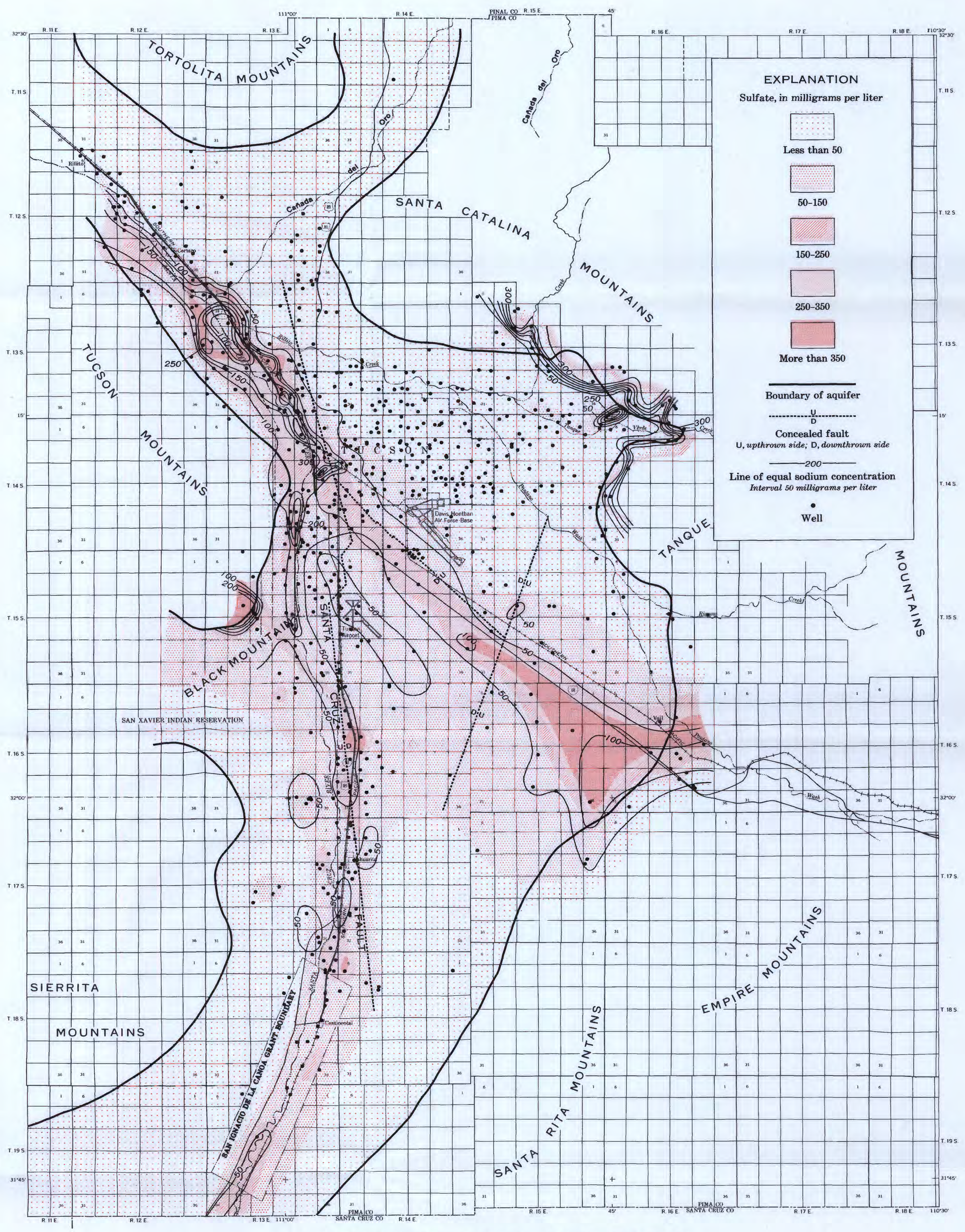


A. CALCIUM AND BICARBONATE



B. HARDNESS



C. SODIUM AND SULFATE

Base from U.S. Geological Survey

APPROXIMATE MEAN DECLINATION, 1972

SCALE 1:250 000

5 0 5 10 15 20 25 MILES

5 0 5 10 15 20 25 KILOMETERS

Compiled by R. L. Laney, 1968

MAPS SHOWING AREAL DISTRIBUTION OF SELECTED CHEMICAL CONSTITUENTS AND HARDNESS IN SHALLOW GROUND WATER, TUCSON BASIN, SOUTHEASTERN ARIZONA

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UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
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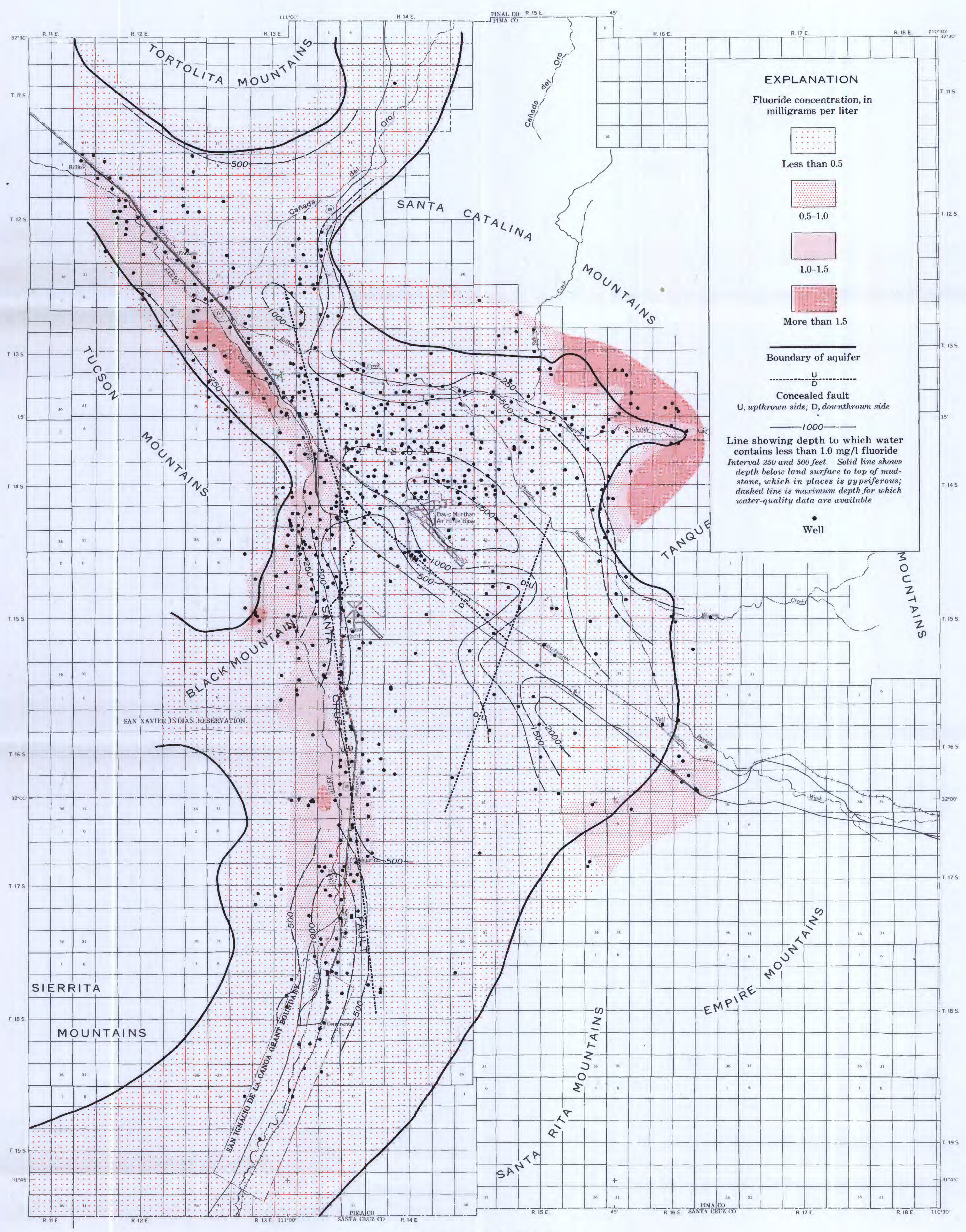
WATER-SUPPLY PAPER 1939-D
PLATE 5



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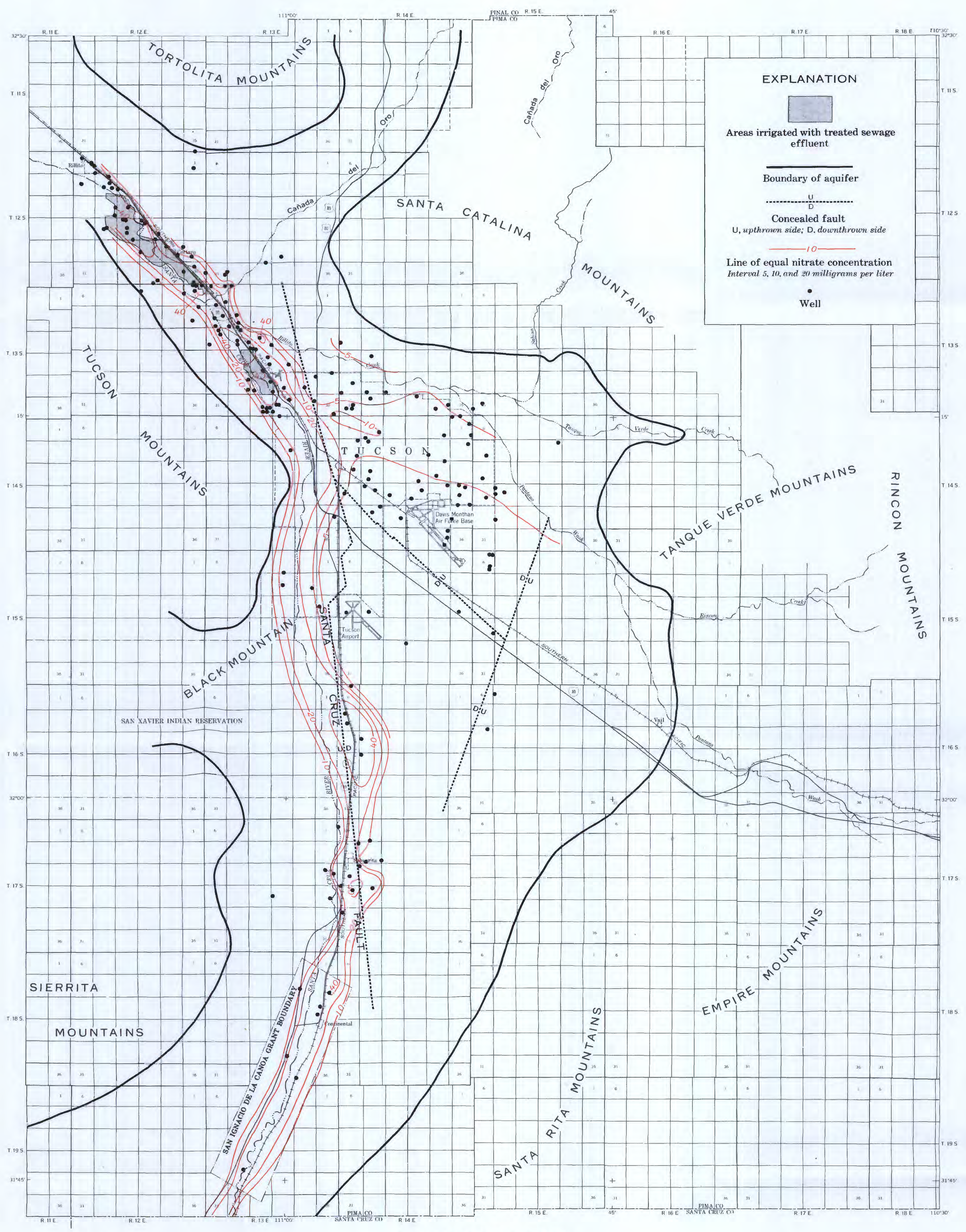
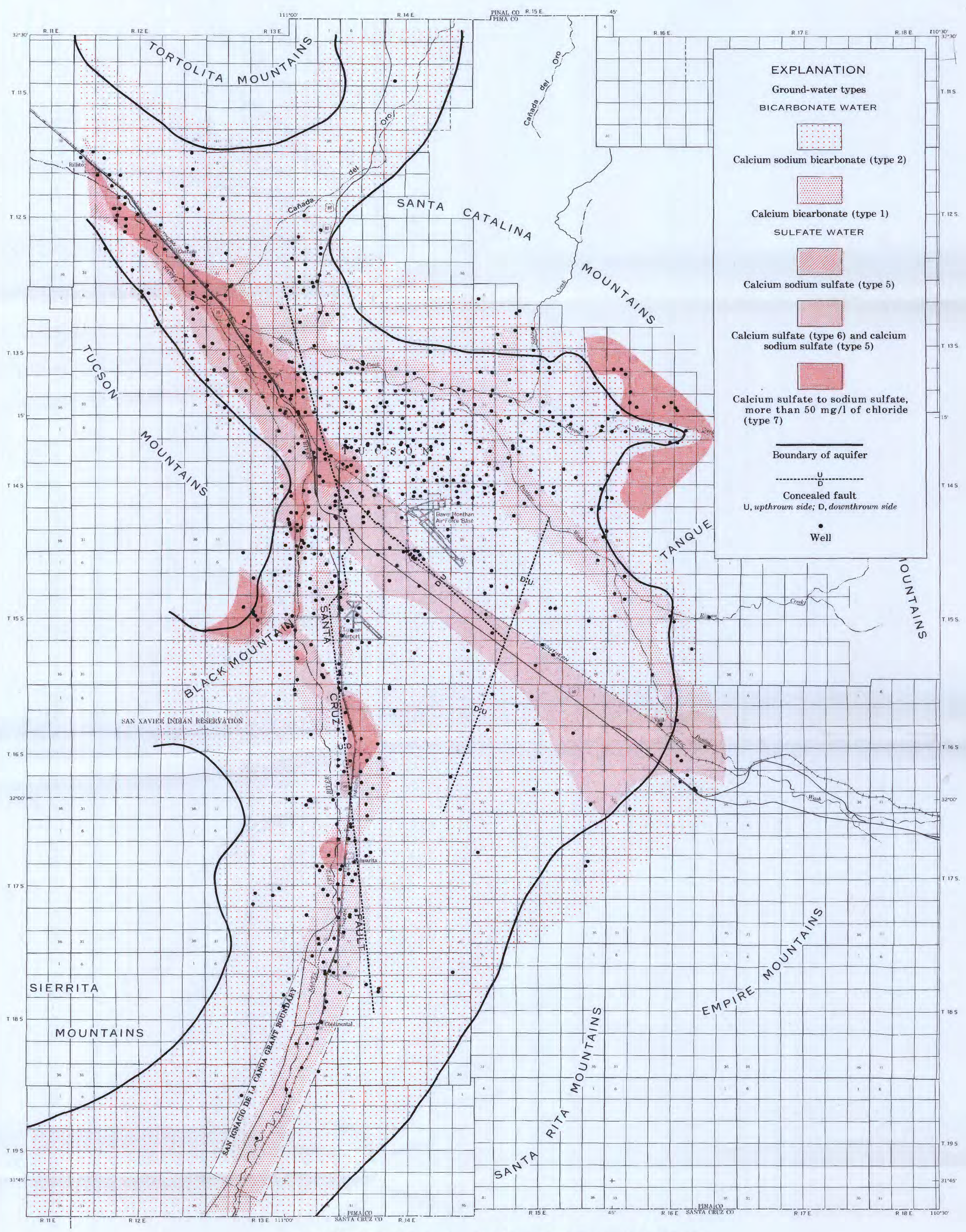


B. NITRATE



C. CHEMICAL WATER TYPES

Base from U.S. Geological Survey

APPROXIMATE MEAN DECLINATION, 1972

SCALE 1:250 000

5 0 5 10 15 20 25 MILES

5 0 5 10 15 20 25 KILOMETERS

Compiled by R. L. Laney, 1968

MAPS SHOWING AREAL DISTRIBUTION OF SELECTED CHEMICAL CONSTITUENTS AND CHEMICAL WATER TYPES IN SHALLOW GROUND WATER, TUCSON BASIN, SOUTHEASTERN ARIZONA

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