SUBSURFACE STRATIGRAPHY AND GEOTHERMAL RESOURCE POTENTIAL OF THE AVRA VALLEY, PIMA COUNTY, ARIZONA

by

W. Richard Hahman, Sr., and Timothy J. Allen

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416 W. Congress, Suite #100, Tucson, Arizona 85701

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Introduction

A subsurface stratigraphic study and preliminary investigation of the geothermal resource potential of the Avra Valley was undertaken in 1980. The area of investigation is situated in Pima County, Arizona, approximately five miles west of Tucson. The study area is bounded by $32^{\circ}6'$ to $32^{\circ}30'$ north latitude and $111^{\circ}7'$ to $111^{\circ}30'$ west longitude. Physiographically the area is bounded on the west by Ragged Top and Silver Bell mountains, the Waterman Mountains and the Roskruge Mountains. On the east side the area is bounded by the Tucson Mountains and the Tortolita Mountains. On the north the area is bounded by Cerro Prieto and the Marana Airpark and on the south by Dobbs Buttes and the San Xavier Indian Reservation. The study area comprises approximately 1575 km^2. With the exception of the mining activities in the Silver Bell Mountains and the Twin Peaks area the primary business in the valley is agriculture, cotton farming and minor cattle production. The majority of the domestic and irrigation wells belonging to the town of Marana and the city of Tucson are between 91.4 m and 457.2 m deep. The Avra Valley is a major source of water of the city of Tucson.

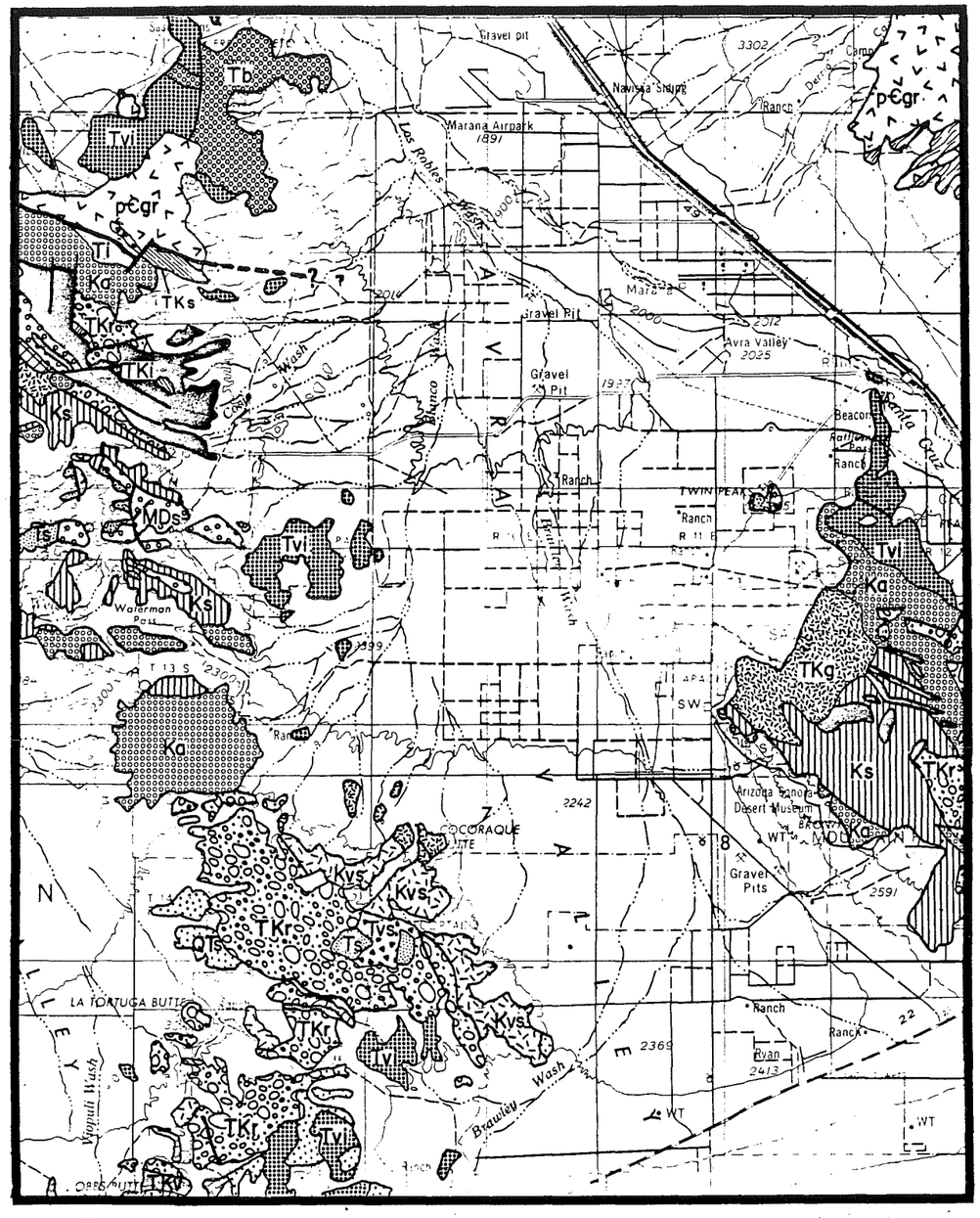
There are warm-water wells scattered throughout the valley but these wells appear to be concentrated in the southern half of the basin. In this study the warmest measured temperatures, 31.5°C, occurred in Tucson city water wells in the vicinity of Ryan Field in the southeast corner of the study area.

General Geology

The Avra Valley lies along the western edge of the Mexican Highland section of the Basin and Range province (Fenneman, 1931). Fenneman (1931) described this section of the Basin and Range province as "approximately half mountain and half plain" with a northwestward trend. Figure 1 is the regional geology of the study area compiled from the Geologic Map of Arizona (1969) by Wilson, Moore and Cooper. Figure 2 is the gravity map compiled from the Complete Residual Bouguer Gravity Anomaly Map, Tucson, Arizona, by Lysonski, Aiken and Sumner, 1981. The gravity data are contoured at 2 milligal intervals.

The geologic formations exposed in the mountains bounding the Avra Valley vary in age from Precambrian to late Tertiary. The igneous lithologies consist of felsic intrusive rocks with minor mafic dikes and felsic to mafic volcanic rocks. The sedimentary lithologies consist of conglomerate, arkose, sandstone, limestone and shale.

Structurally, the Avra Valley is a graben (Allen, 1981),



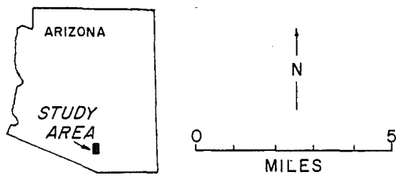


Figure I.
REGIONAL GEOLOGY
After Wilson, Moore, and Cooper, 1969.

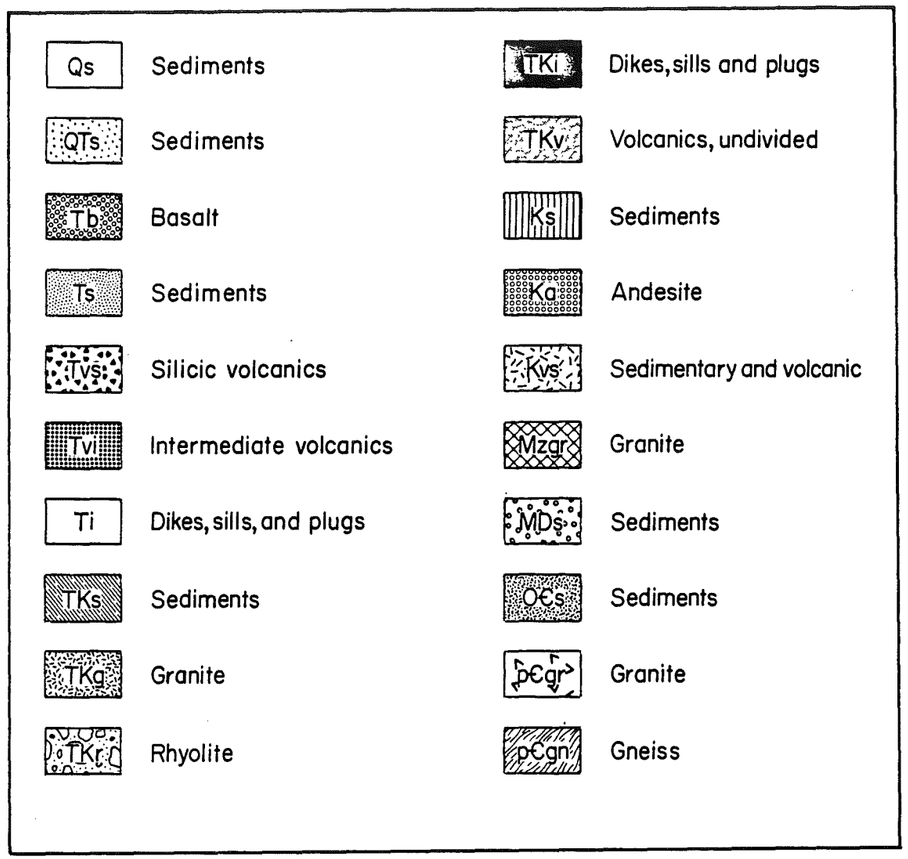


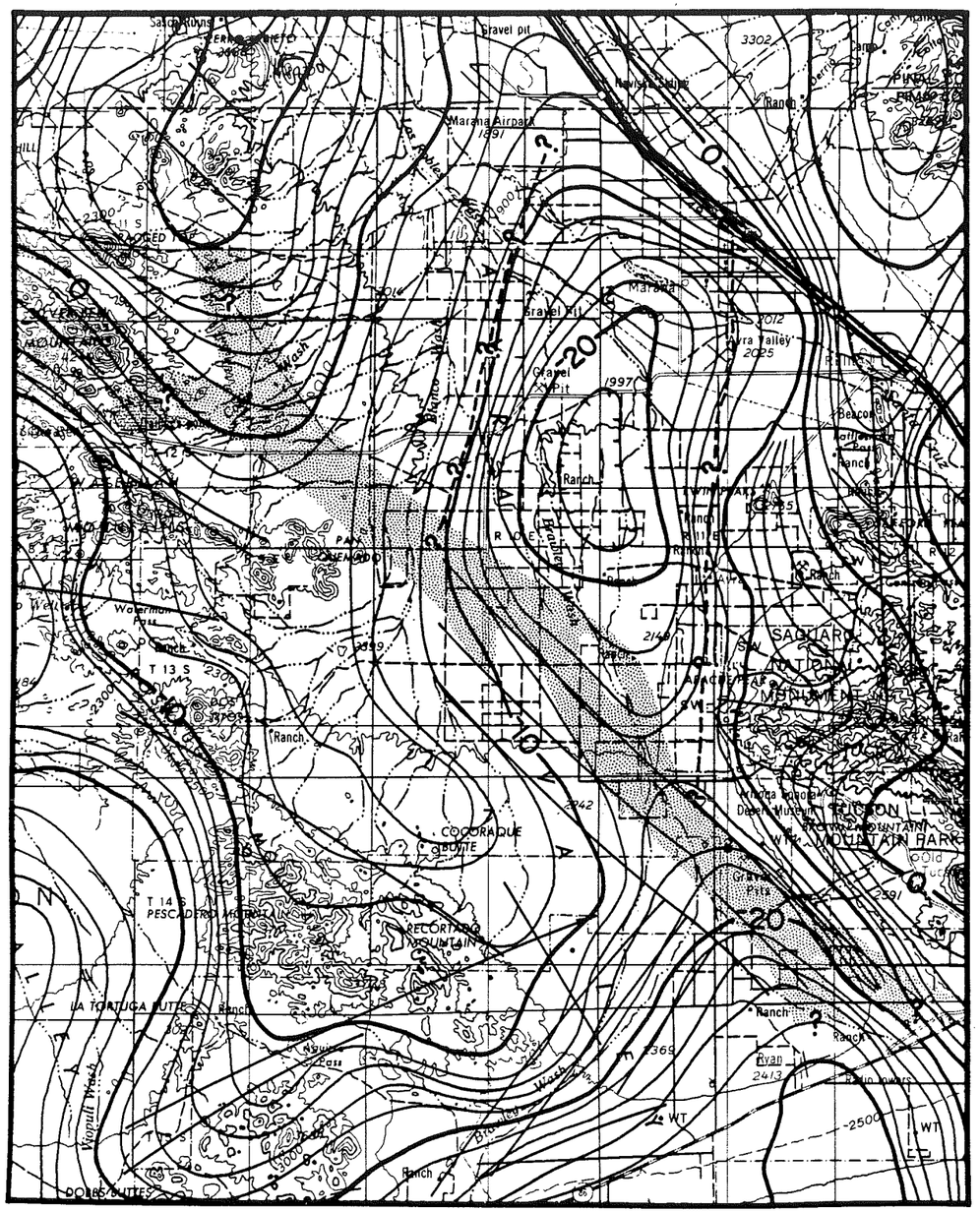
Figure I. Explanation of geologic units.

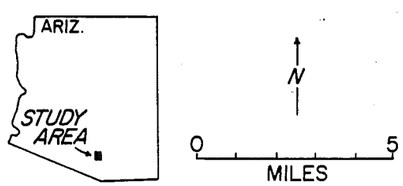
part of the horst and graben structure of the Basin and Range province. The Basin and Range orogeny commenced 15 million years ago (Shafiqullah and others, 1980) in the late Miocene at the close of the mid-Tertiary orogeny, late Oligocene to mid-Miocene, and may continue today. Figure 2 shows the probable graben faults inferred from the gravity data. The lineaments shown in the figure are from Lepley's 1977 Landsat lineament map. The northwest-trending stippled area on the map is apparently an expression of the Laramide Silver Bell-Bisbee discontinuity (Titley, 1976) which will be discussed later in this report.

The basin-fill sediments in the Avra Valley have been derived from the surrounding mountain ranges and vary in age from Miocene to Recent (Eberly and Stanley, 1978; Allen, 1981). The basin-fill sediments consist of surficial fine sands and silts and "younger" and "older" alluvial fill.

The surficial deposits are exposed on the valley floor and in the banks of washes. These deposits consist of fine-grained sand and silt, thickly interbedded with coarse sand and gravel. The coarse sands and gravels were deposited by laterally migrating channels and the fine-grained beds are sheet flood deposits. Some reworking of the silt by aeolian processes undoubtedly occurred.

The thickness of the surficial deposits is estimated to be about 10 m, based on values obtained for surficial deposits in the Tucson Basin (Davidson, 1973). In the Avra





Lepley Lineaments

Structural Trend

BOUGUER GRAVITY

10 mgal contour

2 mgal contour

BASE MAP:
U.S.G.S. Tucson
1:250,000

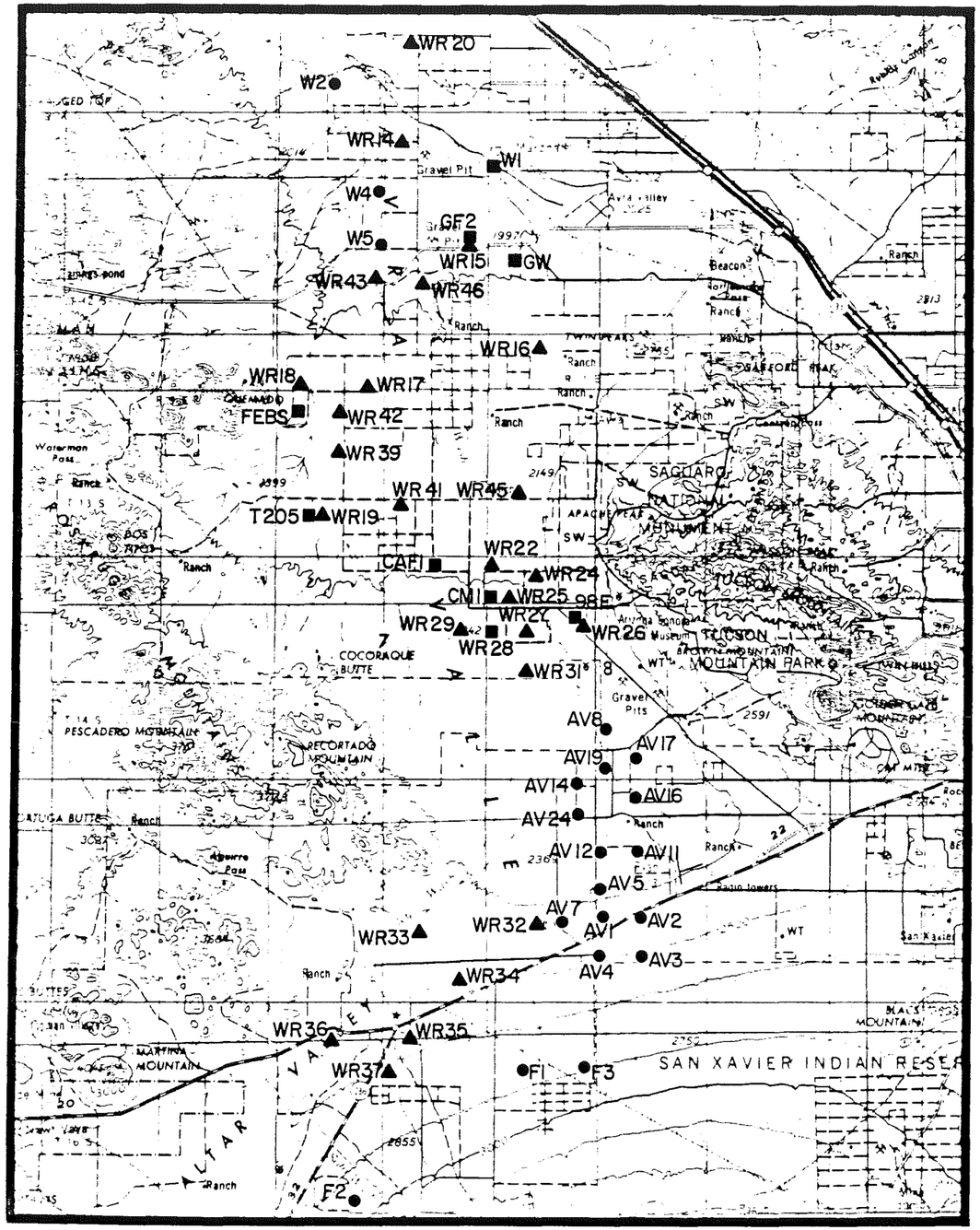
Probable faults inferred from gravity data.

Figure 2. GRAVITY MAP

Valley, pottery shards were found in silt beds five feet below the surface. According to Antevs (1962), pottery making was introduced in Arizona about 2,000 years B.P. This indicates that deposition of the top five feet of this unit occurred since that time. Based on this information, deposition of the entire unit during the Holocene seems reasonable.

Two subsurface units in the Avra Valley were defined by Allen (1981) based on analysis of drill-cutting samples and borehole geophysical logs from a ground-water exploration test hole program. Drilling was conducted by the city of Tucson Water Department in 1978-79. As part of this program, 28 small-diameter test holes were drilled throughout the valley to maximum depths of 396 m. Stratigraphic information from below this depth is available from only a small number of locations in the valley. Figure 3 is a location map of the test drill holes and producing water wells.

Within 396 m of the surface, two subsurface units were found. These units are called the younger and the older alluvium. They are not yet formally defined stratigraphic units. The upper unit, the younger alluvium, is believed to be correlative with the Ft. Lowell Formation. The lower unit, the older alluvium, is believed to be correlative with the Upper Tinaja Beds. The Ft. Lowell and Upper Tinaja units are the uppermost subsurface alluvial units in the



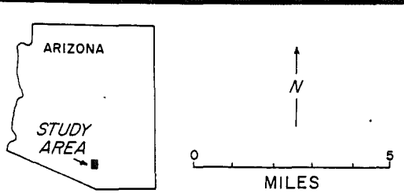


Figure 3. WELL LOCATION MAP
City of Tucson wells and test holes:

- ● Production wells
- ■ Retired farm wells
- ▲ Test holes

nearby Tucson Basin (Davidson, 1973). The younger alluvium immediately underlies the surficial deposits and extends to an average depth of 100 m below the surface. It is immediately underlain by the older alluvium. In locations where shallow bedrock was encountered, the bedrock was found directly beneath the older alluvium. In areas of deeper bedrock, the older alluvium extended to below the 396 m depth of investigation.

In the north and central parts of the valley the younger alluvium is characterized by very thickly interbedded layers of coarse and fine-grained sediments. These individual beds vary between 1.5 and 15 m in thickness. The fine-grained beds consist of silts and sandy silts, and probably some minor clay. The coarse-grained beds are sandy gravels and gravelly sands. In most cases, the fine-grained material is more abundant than the coarse-grained material.

In the southern part of the Avra Valley, the sediments of the younger alluvium exhibit more variability. In the vicinity of Three Points and along the northern slopes of the Sierrita Mountains, the younger alluvium is almost entirely sandy gravel and gravelly sand. West of Ryan Field, the unit has the same interbedded character seen further north, except there is a thick, widespread silt bed that makes up a large part of the thickness of the unit. This silt bed is shown in Fig. 4 in the upper sections of holes

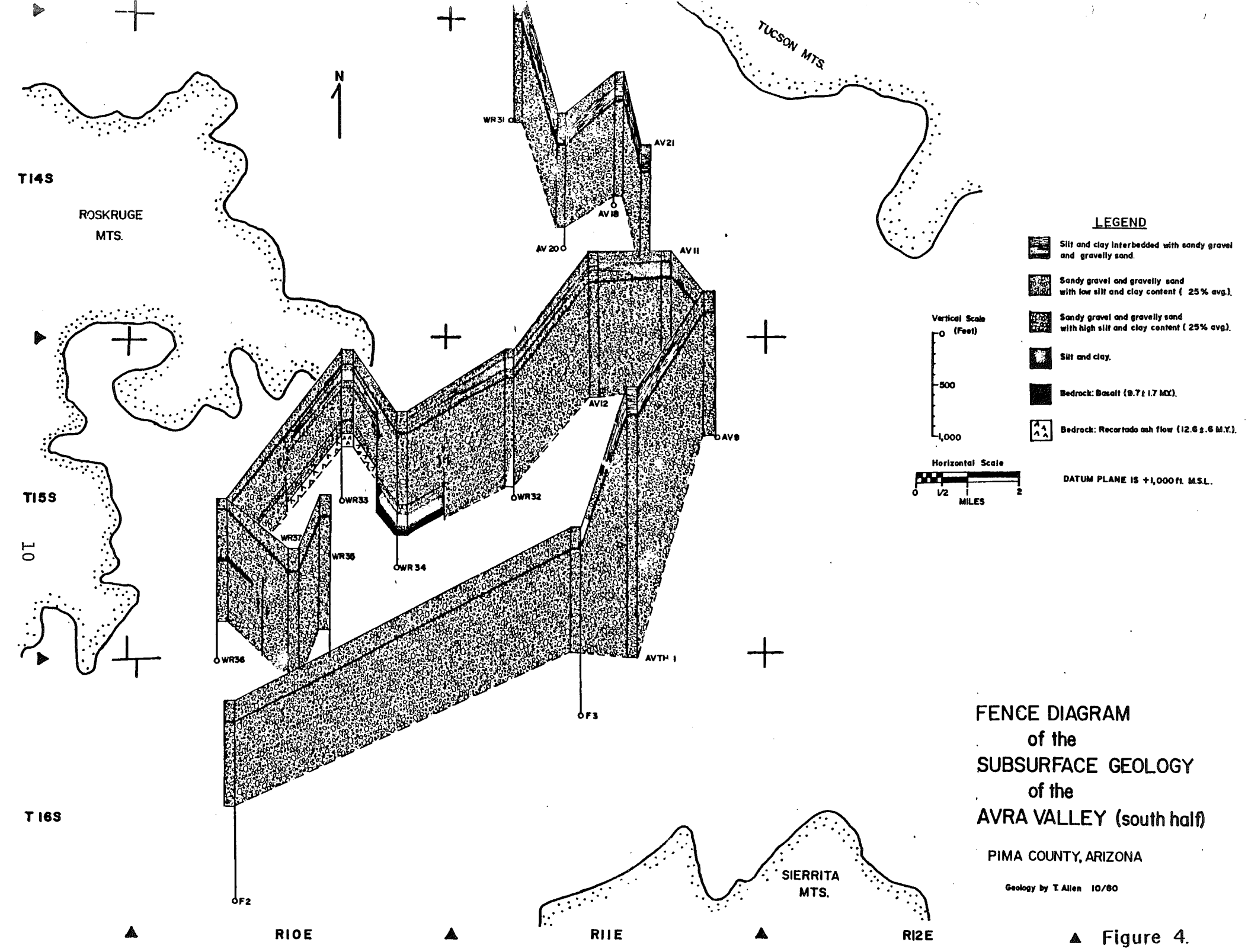

TUCSON MTS.
N
T14S
ROSKRUGE
MTS.
T15S
T16S
R10E
R11E
R12E
SIERRITA
MTS.
WR31
AV21
AV18
AV20
AV11
AV12
AV9
WR33
WR32
WR37
WR35
WR34
WR36
AVTH 1
F3
F2
LEGEND
Silt and clay interbedded with sandy gravel and gravelly sand.
Sandy gravel and gravelly sand with low silt and clay content (25% avg.).
Sandy gravel and gravelly sand with high silt and clay content (25% avg.).
Silt and clay.
Bedrock: Basalt (9.7 ± 1.7 M.Y.).
Bedrock: Recortado ash flow (12.6 ± .6 M.Y.).
Vertical Scale
(Feet)
0
500
1,000
Horizontal Scale
0
1/2
1
2
MILES
DATUM PLANE IS +1,000 ft. M.S.L.
FENCE DIAGRAM
of the
SUBSURFACE GEOLOGY
of the
AVRA VALLEY (south half)
PIMA COUNTY, ARIZONA
Geology by T. Allen 10/80

Figure 4.

WR 32, AV 11 and AV 12.

The thickness of the younger alluvium averages about 100 m throughout most of the basin. The thinnest section (21 m) was drilled in test hole WR 36 in the south end of the valley, near Three Points. The thickest section (137 m) was encountered in the north, near Marana.

The younger alluvium is for the most part uncemented, although some weak carbonate cementation may occur. The sand and gravel particles in the unit show little sign of rounding. They are predominantly in the subangular to angular range.

The sands and gravels of the unit are made up mostly of mixed volcanic rock fragments. Volcanic rock is also the dominant rock type found in the surrounding mountain ranges, from which the sediments were derived. Granitic rock fragments also occur to some degree in the sediments, but only become especially common in the vicinity of the Sierrita and Tortolita mountains, where large amounts of granitic rock crop out. No materials were observed in the sediments that could have been derived from outside the confines of the present day drainage system. This fact, and the angularity of the sediments, indicate that the sediments were locally derived and that their deposition postdates the Basin and Range faulting.

The depositional environment of the younger alluvium is interpreted to be the same as that of the surficial de-

Figure 5

CORRELATION CHART

FOR

AVRA VALLEY

TIME UNITS	REGIONAL UNITS Eberly and Stanley (1978)	AVRA VALLEY UNITS (This paper)	TUCSON BASIN UNITS Davidson (1973)	TUCSON BASIN UNITS Pashley (1966)	SAN PEDRO UNITS Gray (1967)
PLEISTOCENE	UNIT II	? YOUNGER ALLUVIUM	FT. LOWELL FM.	BASIN FILL DEPOSITS	ST. DAVID FM.
PLIOCENE		? OLDER ALLUVIUM	UPPER TINAJA BEDS	RILLITO III BEDS	QUIBURIS FM.
MIOCENE	UPPER UNIT I	BASIN FAULTING ?	LOWER TINAJA BEDS	RILLITO II BEDS	

Chart showing the correlation of the basin fill units of the Avra Valley to the regional units and the units of the Tucson Basin and San Pedro Valley.

posits. The coarse-grained beds are interpreted to be lateral accretion deposits from migrating channels and the fine-grained material is believed to be overbank silt deposits resulting from sheet flooding.

This unit is correlated with the Ft. Lowell Formation based on the following factors: (1) the similar thickness and stratigraphic position of both units, (2) a similar degree of induration, and (3) a similar color change and increase in cementation that occurs at the lower contact of both units (Allen, 1981). Figure 5 is a correlation chart that shows the relation of the Avra Valley units to the units from other basins in southern Arizona. In terms of Eberly and Stanley's (1978) classification of Cenozoic units from southern Arizona, both the younger and older alluvium would be correlative with Unit II, which includes all the basin sediments deposited after the Basin and Range fualting occurred 15-8 m.y. ago (Shafiqullah and others, 1980).

Based on the correlation with the Ft. Lowell Formation, the younger alluvium is interpreted to be late Pliocene through middle Pleistocene in age. This same age determination for the Ft. Lowell Formation was made by Davidson (1973) by regional correlation with the St. David Formation of the San Pedro Valley. The St. David Formation has been dated by mammalian fossil remains.

Two facies of the older alluvium have been noted. These have been named the fanglomerate and the mudstone facies. The

RECORD NUMBER	LOCATION	LATITUDE	LONGITUDE	DATE	TEMP (°C)	PH	HCO3 (MG/L)	CO3 (MG/L)	CA (MG/L)	MG (MG/L)	NA (MG/L)	K (MG/L)	CL (MG/L)	SO4 (MG/L)	F (MG/L)
53	D121221DCC	32 22.033	111 7.283	65-12-20		7.3	303.0	0.0	115.0	17.0			80.0	220.0	0.5
79	D141221CAA	32 11.867	111 7.417	40-03-15			389.0		40.0	36.0			24.0	135.0	1.3
48	D121216BAD	32 23.483	111 7.417	30-06-14			154.0	0.0	30.0		20.0		16.0	0.0	
47	D121216BAA	32 23.650	111 7.417	55-09-08	24.0	7.1	134.0	0.0					16.0		
52	D121221BAB	32 22.800	111 7.533	65-12-16		7.3	244.0	0.0	132.0	17.0			86.0	254.0	0.3
49	D121216BBA	32 23.700	111 7.617	65-12-20			171.0	0.0	54.0	10.0			30.0	50.0	0.4
51	D121220AAD	32 22.700	111 7.917	65-12-20		7.4	285.0	0.0	108.0	15.0			70.0	200.0	0.5
46	D121208DBB	32 24.100	111 8.300	65-12-03			220.0	0.0	98.0	12.0			64.0	163.0	0.3
96	D151217BBB	32 7.967	111 8.800	40-03-01			203.0		32.0	4.4			10.0	16.0	
78	D141217BBB	32 13.183	111 8.800	40-03-15			316.0		45.0	29.0	76.0		45.0	67.0	1.5
44	D121205CBC	32 24.867	111 8.817	66-12-01		7.7	228.0	0.0	69.0	16.0			56.0	120.0	0.3
45	D121208BBB	32 24.533	111 8.833	65-12-03			208.0	0.0	98.0	12.0			64.0	160.0	0.3
77	D141206BBD	32 14.700	111 9.750	46-03-07	24.5		282.0	0.0	182.0	40.0			3.8	485.0	1.9
50	D121219CBB	32 22.283	111 9.833	48-06-29	35.0	7.9	199.0	0.0	41.0	7.2			42.0	119.0	0.5
69	D141124AAD	32 12.117	111 10.033	40-03-15			157.0		48.0	15.0	197.0		95.0	331.0	1.3
60	D131113CD	32 17.533	111 10.100	41-12-01			177.0	0.0	32.0	9.8			9.0	14.0	
84	D151111BBB	32 8.783	111 11.933	79-09-14	31.0	7.9			23.0	3.3	38.0	2.7	13.0	12.0	0.4
94	D151122DDD	32 6.283	111 12.033	76-08-12				0.0	26.0	5.0	37.0		10.0	9.0	0.6
91	D151115DDD	32 7.133	111 12.050	79-09-14	31.0	7.8			23.0	4.5	33.0	2.5	7.9	7.2	0.7
85	D151115AAA	32 7.900	111 12.050	76-01-29				0.0	28.0	6.0	35.0		9.0	8.0	0.6
75	D141134AAD	32 10.350	111 12.083	75-10-02				0.0	27.0	4.0	39.0		9.0	8.0	0.3
70	D141127AAD	32 11.183	111 12.100	75-10-21				0.0	27.0	4.0	40.0		14.0	11.0	0.3
72	D141127DCB	32 10.683	111 12.450	78-07-27				0.0	24.0	3.0	37.0		10.0	8.0	0.3
62	D131134CDD	32 14.967	111 12.617	64-03-30		7.7	181.0	0.0	31.0	7.4	44.0	3.2	21.0	24.0	0.3
86	D151115BBB	32 7.700	111 12.817	76-08-12				0.0	24.0	2.0	41.0		10.0	8.5	0.3
76	D141134BBC	32 10.367	111 12.867	77-11-26				0.0	30.0	5.0	48.0		42.0	9.0	0.5
43	D121134CC	32 20.183	111 12.867	40-03-27			185.0		44.0	14.0			54.0	93.0	
90	D151115CCC	32 7.133	111 12.900	76-01-29				0.0	26.0	5.0	35.0		9.0	10.0	0.4
88	D151115BBB	32 7.883	111 12.917	66-11-13	30.0	8.4	154.0	4.0	21.0	3.3			10.0	12.0	0.3
87	D151115BBB	32 7.883	111 12.933	65-04-28	42.0	8.0	150.0	0.0	9.2	0.5			39.0	37.0	3.5
93	D151122CCC	32 16.267	111 12.950	76-11-26				0.0	26.0	5.0	40.0		11.0	8.5	0.6
71	D141127BCC	32 11.033	111 12.967	75-10-21				0.0	58.0	3.0	42.0		14.0	9.0	0.4
68	D141122CBB	32 11.733	111 12.967	79-02-19				0.0	26.0	3.0	37.0		18.0	2.5	0.5
61	D131134CCC	32 14.883	111 13.000	64-03-19	30.5										0.3
56	D131104AB	32 20.000	111 13.033	40-03-26			126.0	12.0	26.0	12.0			46.0	77.0	0.0
83	D151109BAB	32 8.333	111 13.067	40-03-14	25.5		176.0	0.0		7.4			11.0	15.0	0.0
82	D151109AAA	32 8.800	111 13.100	78-07-21				0.0	26.0	4.0	36.0		10.0	11.0	0.2
67	D141109BBD	32 13.417	111 13.367	54-04-16			181.0	0.0	37.0	1.5			9.0	7.2	0.8
97	D121109ACC	32 24.167	111 13.417	79-09-14	24.0	7.3			86.0	15.0	82.0	3.2	79.0	200.0	0.5
73	D141128DCC	32 10.567	111 13.467	75-10-02				0.0	69.0	7.0	56.0		104.0	36.0	0.3
57	D131104CDD	32 19.300	111 13.567	40-04-15	28.5		200.0		35.0	12.0	52.0		31.0	41.0	
95	D151123BBB	32 6.167	111 13.967	75-10-16				0.0	42.0	6.0	44.0		50.0	19.0	0.6
74	D141133CCC	32 9.733	111 13.983	71-05-06	31.0	8.1	166.0	0.0	28.0	3.7	37.0	1.6	13.0	18.0	0.6
42	D121120DDA	32 22.133	111 14.050	71-05-13	28.0	8.0	161.0	0.0	30.0	4.0	71.0	3.7	55.0	50.0	0.4
92	D151120AAA	32 7/050	212 24/077	77-18.13				0.0	29.0	3.0	45.0		10.0	15.0	0.3
39	D121117ACD	32 23.317	111 14.283	71-05-13		7.9	159.0	0.0	38.0	4.1	79.0	3.3	45.0	97.0	1.2
38	D121108CBA	32 24.017	111 14.800	40-03-27			235.0		39.0	8.3			14.0	22.0	
14	D141105CCD	32 14.067	111 14.900	71-05-07	30.0	7.5	138.0	0.0	31.0	4.2	34.0	1.6	15.0	13.0	0.7

RECORD NUMBER	LOCATION	DATE	SIO2 (MG/L)	B (UG/L)	LI (MG/L)	TDS (MG/L)	DEPTH (FEET)	ID
53	D121221DCC	65-12-20				893.0	280.0	
79	D141221CAA	40-03-15				542.0		
48	D121216BAD	30-06-14				227.0		
47	D121216BAA	55-09-08					280.0	
52	D121221BAB	65-12-16				846.0	235.0	
49	D121216BBA	65-12-20				364.0	270.0	
51	D121220AAD	65-12-20				818.0	386.0	
46	D121208DBB	65-12-03				651.0	500.0	
96	D151217BBB	40-03-01				208.0	450.0	
78	D141217BBB	40-03-15				420.0		
44	D121205CBC	56-12-01	32.0			476.0	517.0	
45	D121208BBB	65-12-03				632.0	300.0	
77	D141206BBD	46-03-07				987.0		
50	D121219CBB	48-06-29	42.0			451.0	360.0	
69	D141124AAD	40-03-15				764.0		
60	D131113CD	41-12-01				184.0		
84	D151111BBB	79-09-14	30.0	60.0		205.0		
94	D151122DDD	76-08-12						
91	D151115DDD	79-09-14	28.0	40.0		200.0		
85	D151115AAA	76-01-29						
75	D141134AAD	75-10-02						
70	D141127AAD	75-10-21						
72	D141127DCB	73-07-27						
62	D131134CDD	64-03-30	29.0	100.0		253.0		
86	D151115BBB	76-08-12						
76	D141134BBC	77-11-26						
43	D121134CC	40-03-27				368.0	313.0	
90	D151115CCC	76-01-29						
88	D151115BBB	66-11-13	30.0			200.0	993.0	
87	D151115BBB	65-04-28					2000.0	
93	D151122CCC	76-11-26						
71	D141127BCC	75-10-21						
68	D141122CBB	79-02-19						
61	D131134CCC	64-03-19					555.0	
56	D131104AA	40-03-26				306.0		
83	D151109AB	40-03-14				182.0		
82	D151109AAA	78-07-21						
67	D141109BD	54-04-16	34.0			223.0		
97	D121109ACC	73-09-14	33.0	100.0		632.0		
73	D141128DCC	75-10-02						
57	D131104CDD	40-04-15				270.0		
95	D151128BB	75-10-16						
74	D141133CCC	71-05-06	35.0	40.0		226.0		
42	D121120DDA	71-05-13	27.0	140.0		328.0		
92	D151120AAA	76-08-12						
39	D121117ACD	71-05-13	28.0	150.0		382.0		
38	D121108CBA	40-03-27				247.0	210.0	
14	D141105CCD	71-05-07	35.0	40.0		210.0		

RECORD NUMBER	LOCATION	LATITUDE	LONGITUDE	DATE	TEMP (°C)	PH	HCO3 (MG/L)	CO3 (MG/L)	CA (MG/L)	MG (MG/L)	NA (MG/L)	K (MG/L)	CL (MG/L)	SO4 (MG/L)	F (MG/L)
27	D111120CCC	32 27.233	111 14.967	76-10-05	25.0										0.4
16	D141108CCC	32 13.167	111 15.000	71-05-07	31.0	7.9	174.0	0.0	30.0	4.3	37.0	1.4	11.0	20.0	0.7
41	D121118DDD	32 22.867	111 15.050	40-03-27			167.0	19.0	30.0	10.0			22.0	31.0	
26	D111107DDD	32 28.967	111 15.100	71-05-12	25.0	8.0	144.0	0.0	39.0	6.1	41.0	2.2	19.0	39.0	0.6
32	D121009BAB	32 24.333	111 15.250	40-04-17	25.5		196.0		38.0	7.0	39.0		16.0	24.0	
40	D121118CDD	32 22.850	111 15.667	71-05-13	25.5	7.9	144.0	0.0	50.0	13.0	54.0	3.0	110.0	46.0	0.2
15	D141107BAD	32 13.800	111 15.733	71-05-07	31.0	7.7	157.0	0.0	29.0	4.0	39.0	1.9	12.0	22.0	0.7
28	D111131CBC	32 21.017	111 16.100	76-09-08				0.0	90.0	14.0	85.0		103.0	150.0	0.6
12	D131025ACD	32 16.217	111 16.450	71-05-07	30.5	7.6	151.0	0.0	31.0	4.2	33.0	1.8	13.0	17.0	0.6
11	D131024DCB	32 16.833	111 16.633	71-05-07	29.0	8.0	164.0	0.0	39.0	5.3	37.0	1.6	34.0	21.0	0.6
65	D141025CAA	32 10.883	111 16.700	40-04-16	32.0		139.0		118.0	8.3			90.0	317.0	0.9
2	D121012CCD	32 23.650	111 17.000	71-05-11	28.0	7.9	175.0	0.0	86.0	19.0	59.0	3.9	76.0	120.0	0.3
4	D121023DDC	32 21.933	111 17.383	71-05-11	30.0	7.9	165.0	0.0	31.0	4.5	33.0	2.3	16.0	21.0	0.2
59	D131110BB	32 19.017	111 17.917	40-04-19			152.0	19.0	32.0	12.0			44.0	111.0	
35	D121026BBA	32 21.817	111 17.950	40-03-27			129.0	16.0	29.0	6.6			10.0	15.0	
58	D131109AAD	32 19.100	111 18.067	40-04-17			146.0	14.0	43.0	14.0			57.0	156.0	
61	D151023CBC	32 6.317	111 18.100	71-05-12	34.0	9.2	92.0	34.0	1.2	0.3	73.0	0.4	13.0	12.0	1.9
18	D111002CBA	32 29.900	111 18.167	71-05-14	23.5	8.0	207.0	0.0	140.0	21.0	51.0	3.3	74.0	260.0	0.2
8	D131015DDD	32 17.533	111 18.250	71-05-10	30.0	7.9	161.0	0.0	33.0	5.1	39.0	1.6	20.0	21.0	0.7
10	D131022DDD	32 16.650	111 18.267	71-05-07	31.0	7.9	172.0	0.0	28.0	4.7	45.0	1.6	17.0	25.0	0.8
21	D111015AAD	32 28.617	111 18.283	71-05-14	24.0	7.8	210.0	0.0	80.0	12.0	61.0	2.6	30.0	100.0	0.4
20	D111010DDD	32 28.850	111 18.283	77-01-10	25.0										0.3
1	D121003DCD	32 24.500	111 18.500	71-05-11	29.5	8.0	153.0	0.0	27.0	4.3	36.0	2.4	17.0	15.0	0.3
24	D111022BDD	32 27.533	111 18.783	71-05-14	26.0	8.3	203.0	0.0	46.0	7.4	73.0	3.0	28.0	100.0	0.3
66	D141034BAD	32 10.367	111 18.833	56-09-28	25.0	7.3	559.0	0.0	88.0	29.0			7.5	21.0	0.8
17	D151016DAD	32 7.167	111 19.250	71-05-06		7.7	187.0	0.0	4.6	0.4	87.0	0.7	15.0	22.0	0.8
55	D131021AA	32 17.400	111 19.267	40-04-15	23.0		184.0		36.0	6.6			15.0	25.0	
7	D131009DDD	32 18.400	111 19.283	71-05-10	30.0	7.8	144.0	0.0	30.0	4.7	35.0	2.0	11.0	26.0	0.5
9	D131016DDD	32 17.533	111 19.300	71-05-10	31.0	7.6			29.0	4.0	40.0	2.1	12.0	20.0	0.6
37	D121033DDD	32 20.150	111 19.300	71-05-10	29.0	8.1	162.0	0.0	26.0	2.7	35.0	2.2	8.4	14.0	0.4
34	D121009DDD	32 23.650	111 19.317	75-12-12				0.0	45.0	10.0	35.0		33.0	18.0	0.6
30	D121004ACD	32 25.150	111 19.533	79-09-14	28.5	7.8			35.0	4.7	41.0	2.3	32.0	22.0	0.7
25	D111028BAD	32 26.900	111 19.783	71-05-14	30.0	8.0	142.0	0.0	45.0	6.6	57.0	3.2	74.0	33.0	0.6
31	D121004BDD	32 24.917	111 19.817	71-05-11	35.5	8.1	144.0	0.0	19.0	2.0	48.0	2.6	14.0	32.0	0.9
6	D131005DDD	32 19.283	111 20.333	71-05-10		7.9	171.0	0.0	36.0	5.9	34.0	2.1	19.0	18.0	0.3
3	D121020ADD	32 22.300	111 20.350	71-05-10	27.0	8.0	165.0	0.0	32.0	5.4	32.0	1.9	15.0	17.0	0.4
19	D111008DDD	32 28.867	111 20.350	71-05-14	27.0	8.0	173.0	0.0	40.0	5.7	56.0	2.9	24.0	61.0	0.7
23	D111020DDC	32 24.317	111 20.417	76-04-12				0.0	34.0	5.0	59.0		42.0	48.0	0.6
36	D121029ABB	32 21.800	111 20.717	42-08-04	25.5		181.0	0.0	36.0	7.0			14.0	18.0	0.8
22	D111020DCC	32 27.133	111 20.850	76-04-02				0.0	24.0	3.0	84.0		25.0	120.0	0.5
13	D141008CCA	32 13.300	111 21.000	40-04-16	23.5		393.0	18.0	68.0	30.0			58.0	32.0	
64	D141020CCC	32 11.417	111 21.183	56-09-28	26.5	7.9	321.0	0.0	20.0	1.7			24.0	15.0	2.2
80	D150912ACB	32 8.350	111 22.767	56-09-20	25.0	7.6	199.0	0.0	14.0	5.0			20.0	18.0	0.6
29	D120923DDD	32 21.833	111 23.333	52-04-10			166.0		263.0	45.0			82.0	1046.0	0.6
54	D130927CAD	32 16.033	111 25.000	56-11-19		7.3	376.0	0.0	124.0	34.0			103.0	61.0	0.6
63	D140933CCC	32 9.550	111 26.383	56-12-06	22.0	7.4	302.0	0.0	77.0	25.0			28.0	15.0	0.6
5	D130917CAA	32 17.900	111 26.967	55-09-07	25.5	7.3	409.0	0.0	77.0	40.0			119.0	87.0	0.6

Total number of records: 95.
ALL
25-FEB-81

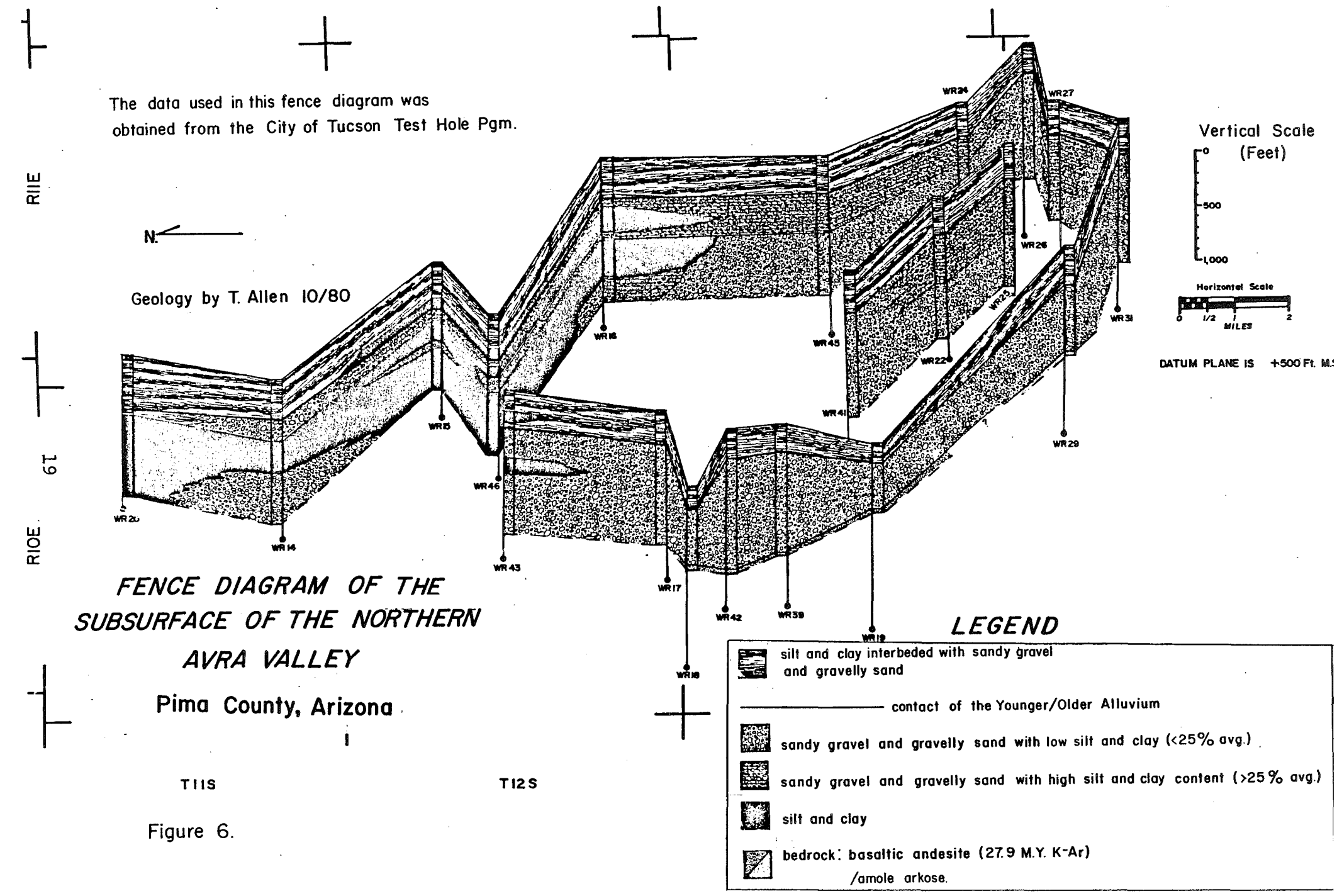
RECORD NUMBER	LOCATION	DATE	SIO2 (MG/L)	B (µG/L)	LI (MG/L)	TDS (MG/L)	DEPTH (FEET)	ID
27	D111120CCC	76-10-05					442.0	
16	D141108CCC	71-05-07	36.0	20.0		231.0		
41	D121118DDD	40-03-27				247.0	218.0	
26	D111107DDD	71-05-12	37.0	50.0		276.0		
32	D121009BBB	40-04-17				221.0		
40	D121118CDD	71-05-13	35.0	160.0		404.0		
15	D141107AAD	71-05-07	35.0	100.0		227.0		
28	D111131CBC	76-09-08						
12	D131025ACD	71-05-07	36.0	40.0		219.0		
11	D131024DCB	71-05-07	35.0	20.0		267.0		
65	D141025CAA	40-04-16				715.0		
2	D121012CCD	71-05-11	35.0	90.0		517.0		
4	D121023DDC	71-05-11	33.0	50.0		233.0		
59	D131110AB	40-04-19				387.0		
35	D121026BBA	40-03-27				170.0		
58	D131109AAD	40-04-17				458.0		
81	D151023CBC	71-05-12	31.0	120.0		216.0		
18	D111002CBA	71-05-14	37.0	60.0		746.0		
8	D131015DDD	71-05-10	35.0	30.0		241.0		
10	D131022DDD	71-05-07	34.0	30.0		247.0		
21	D111015AAD	71-05-14	38.0	80.0		520.0		
20	D111010DDD	77-01-10						
1	D121003DCD	71-05-11	33.0	60.0		218.0		
24	D111022BDD	71-05-14	33.0	110.0		399.0		
66	D141034AAD	56-09-28	66.0			580.0		
17	D151016DAD	71-05-06	30.0	190.0		267.0		
55	D131021AA	40-04-15						
7	D131009DDD	71-05-10	37.0	30.0		223.0		
9	D131016DDD	71-05-10	34.0	60.0		225.0		
37	D121033DDD	71-05-10	34.0	60.0		208.0		
34	D121009DDD	75-12-12						
30	D121004ACD	79-09-14	33.0	60.0		253.0		
25	D111028BAD	71-05-14	35.0	60.0		339.0		
31	D121004BDD	71-05-11	37.0	50.0		232.0		
6	D131005DDD	71-05-10	36.0	70.0		253.0		
3	D121020ADD	71-05-10	36.0	70.0		232.0		
19	D111008DDD	71-05-14	35.0	90.0		331.0		
23	D111020DDC	76-04-12						
36	D121029ABB	42-08-04				198.0		
22	D111020DCC	76-04-02						
13	D141008CCA	40-04-16				480.0		
64	D141020CCC	56-09-28	40.0			392.0		
80	D150912ACB	56-09-20	16.0			244.0	400.0	
29	D120923DDD	52-04-10				2626.0	412.0	
54	D130927CAD	56-11-19	71.0			750.0		
63	D140933CCC	56-12-06	76.0			381.0	30.0	
5	D130917CAA	55-09-07	44.0			723.0	130.0	

Total number of records: 95.
ALL
25-FEB-81

fanglomerate facies is a sandy gravel to gravelly sand, which is moderately to well cemented. The mudstone facies is a brown silt and clay containing very little sand or gravel. Some deeper sections of the mudstone are gypsiferous. The mudstone facies is found in the northern and northeastern part of the valley (Fig. 6) where depth of bedrock is in excess of 1219 m. The fanglomerate facies is found in the northwestern part of the valley and throughout the central and southern part where bedrock depths are shallower. In most of the area the fanglomerate facies contains less than 30 percent silt and clay. An exception to this occurs immediately north of the bedrock saddle in the middle of the basin, where the fines content of the fanglomerate is between 30 and 50 percent. The sands and gravels of the older alluvium, like those of the younger, are angular to subangular.

Like the younger alluvium, the older alluvium was deposited within the confines of the present basin, after the Basin and Range faulting of 15-8 m.y. ago occurred. This is indicated by the pebble lithologies, which are the same as the rock types exposed in the surrounding mountain ranges. There are no readily discernable changes in pebble lithology between the younger and older alluvium.

The distribution of the facies in the older alluvium shows evidence of being fault controlled. The lateral changes in sediment types coincide with the zones where the depth to bedrock information (Oppenheimer, 1980) indicates probable



FENCE DIAGRAM OF THE SUBSURFACE OF THE NORTHERN AVRA VALLEY

Pima County, Arizona

Figure 6.

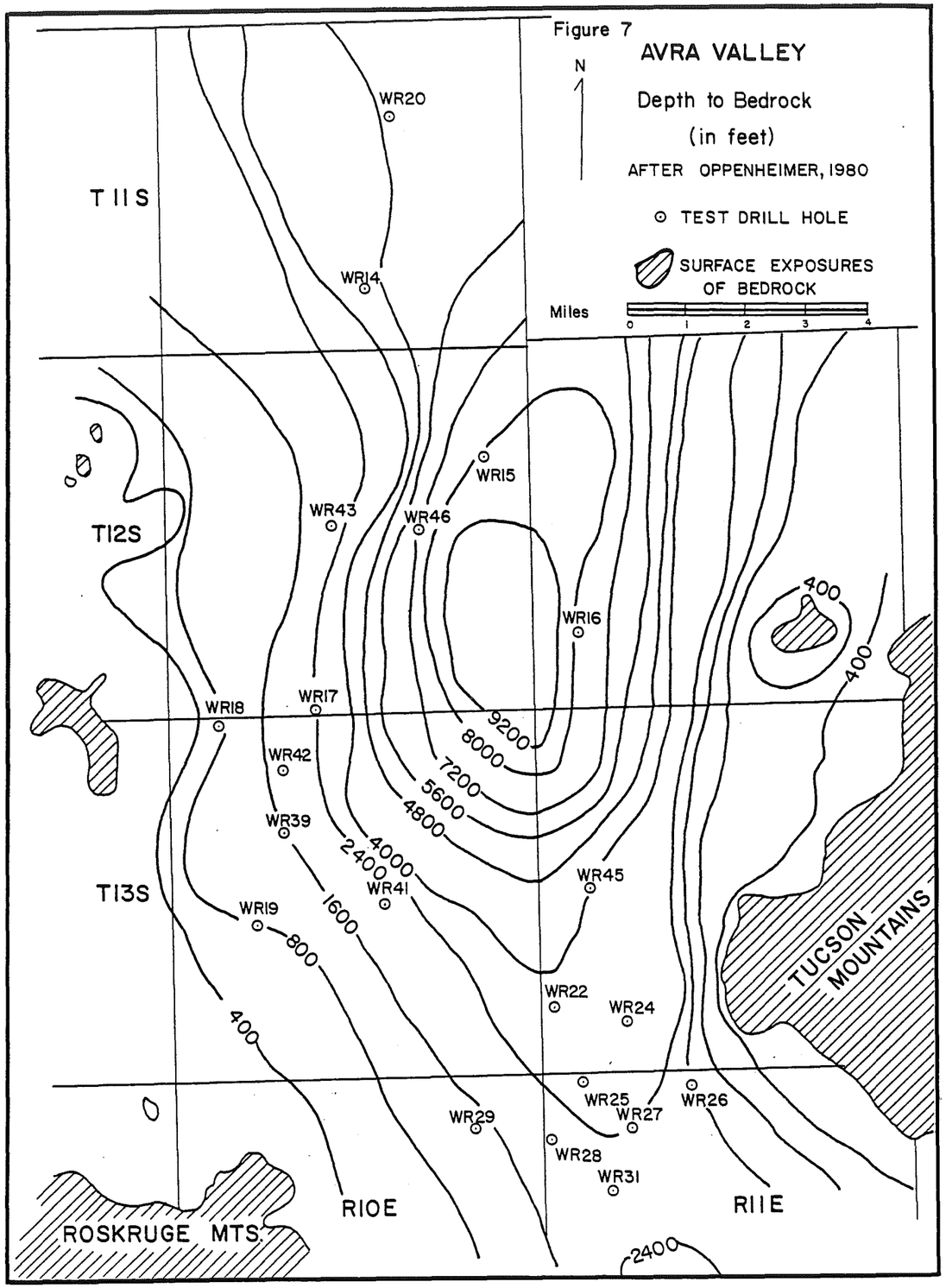


Figure 7
AVRA VALLEY
Depth to Bedrock
(in feet)
AFTER OPPENHEIMER, 1980
TEST DRILL HOLE
SURFACE EXPOSURES OF BEDROCK
N
Miles
0 1 2 3 4
T11S
T12S
T13S
R10E
R11E
WR20
WR14
WR15
WR43
WR46
WR16
WR17
WR18
WR42
WR39
WR41
WR45
WR19
WR22
WR24
WR25
WR27
WR26
WR29
WR28
WR31
9200
8000
7200
5600
4800
4000
2400
1600
800
400
400
400
2400
TUCSON MOUNTAINS
ROSKRUGE MTS.

tern to that seen in the Tucson Basin.

The time of deposition of the older alluvium is interpreted as somewhere between late Miocene and middle Pliocene. This determination is made based on the correlation of these sediments with the Upper Tinaja Beds of the Tucson Basin and on the relation of the older alluvium to volcanic flows of known age. The deposition of the older alluvium after the Basin-and-Range faulting establishes the maximum possible age of this unit as 12 m.y. (Eberly and Stanley, 1978). Basaltic andesite and the Recortado Ash flow, which date from this period (Bikerman, 1967), underlie the older alluvium along the west side of the basin. City test holes WR 18, 19, 39 and 42 were terminated in basaltic andesite; WR 33 was terminated in Recortado Ash. In a hole drilled west of Three Points (WR 36), a basalt flow was penetrated between 171 and 177 m depth. Older alluvium was drilled above, as well as 183+ m below the flow. Similar basalt in the area has been dated at 9.7 $\pm$ 1.7 m.y. (Bikerman, 1967). This date indicates that deposition of the older alluvium had been occurring since the beginning of the Pliocene. The middle Pliocene date for the upper time limit on the deposition is highly tenuous. Davidson (1973) based his minimum age determination for the Upper Tinaja Beds on regional correlation with units having a similar stratigraphic position from other basins. These units in other basins were dated based on their vertebrate faunas.

If these correlations are correct and the age assignments of the Tucson Basin sediments are correct, then the younger alluvium is late Pliocene to mid-Pleistocene in age and the older alluvium is upper Miocene to mid-Pliocene in age.

Geothermal Resource

In the summer of 1980 a geological reconnaissance to determine the geothermal potential of Avra Valley was undertaken. The study area in Pima County extended from just north of Marana Airpark to just north of the town of Three Points. In addition to a study of the pre-existing literature, a reconnaissance field study was conducted during which 21 water samples were collected, 14 wells were temperature logged for thermal gradient, and over 80 km of mercury (Hg) soil sample geochemistry lines were run.

The water sampling program did not yield results because of analytical errors in the water analyses. Partial analyses are reported for these samples (Table 1). Current U.S. Geological Survey WATSTORE data have been used to define the chemical regime of the water. While the writers have some confidence in the results reported as partial analyses they have elected not to combine the data with the U.S.G.S. WATSTORE data because of the element of doubt that exists with the results of the survey.

For the WATSTORE data the Avra Valley area was defined

TABLE 1

PARTIAL ANALYSES

Water Samples, Avra Valley

	Li	Cl	B	OH	SiO_2	SO_4	F	pH
AV- 1	0.1	93	<0.01	0	40	110	0.80	7.94
2	0.1	39	<0.01	0	35	9	<0.01	8.74
3	<0.01	24	0.18	0	36	10	1.40	8.63
4	0.1	28	<0.01	0	30	60	0.93	8.83
5	0.1	49	0.55	0	34	50	0.68	8.07
6	0.1	8	<0.01	0	39	9	<0.01	8.33
7	0.1	33	0.29	0	36	20	0.90	8.34
8	0.1	25	0.55	0	36	19	0.53	8.77
9	0.1	104	0.29	0	36	62	<0.01	8.24
10	<0.01	22	0.15	0	33	4	0.68	8.64
11	<0.01	9	0.36	0	35	4	0.90	8.42
12	<0.01	17	<0.01	0	36	10	0.75	8.65
13	<0.01	9	<0.01	0	35	4	0.85	8.71
14	<0.01	14	<0.01	0	37	5	0.10	8.52
15	<0.01	14	<0.01	0	34	6	0.18	8.36
16	<0.01	13	<0.01	0	35	3	0.45	8.44
17	<0.01	11	<0.01	0	37	7	0.52	8.26
18	<0.01	25	<0.01	0	35	3	0.28	8.42
19	<0.01	86	0.55	0	38	28	0.95	8.11
20	<0.01	31	<0.01	0	36	12	0.50	8.21
21	<0.01	39	0.18	0	34	4	0.45	8.19

All data are reported as milligrams per liter except pH.

by the following latitude and longitude: $32^{\circ}6'$ to $32^{\circ}30$N and $111^{\circ}7'$ to $111^{\circ}30'$W. The boundary is shown as tic marks on the gravity map. In this area, 95 analyses are available for different wells. Where there was more than one analysis for a well, the most recent analysis was used. Not all the analyses have recorded temperatures and not all the analyses are complete. However, there is sufficient data to characterize the water in the Avra Valley.

The Na-K-Ca geothermometer was calculated according to Fournier and Truesdell (1973) and no magnesium correction was necessary. The SiO_2 geothermometer was calculated according to Fournier and Rowe (1966) and the chalcedony geothermometer was used because of the greater tendency for correlation with the known geological conditions in the basins in southern Arizona.

Both the SiO_2 and Na-K-Ca geothermometers were developed to estimate reservoir temperatures for high-temperature (>150°C) geothermal resources. The geothermometers are not accurate when dealing with low- to moderate-temperature resources in a sedimentary alluvial basin. It is quite probable that numerous chemical reactions take place as the water migrates through the somewhat diverse lithologies that occur in the basins. Hence the results of the geothermometers should only be considered a very rough approximation and may be too high or too low.

Mercury in soil may be used to delineate geological

structure and thermal areas of igneous origin (Matlick III, 1975). Mercury soil anomalies are known to occur over buried faults or fault zones. Apparently these mercury anomalies are the result of mercury vapor rising along open portions of fault zones and passing through the alluvial cover to the surface. Soil samples taken over buried faults or zones will generally have a higher concentration of mercury than soil not associated with open, "leaking" fractures.

The geothermal resource in the Arizona Basin and Range province is primarily structurally controlled (Hahman, Sr., 1979). Therefore, a reconnaissance mercury soil sampling program was undertaken as part of this study in an attempt to delineate buried structure in the valley. Table 2 is the analytical results of the soil-sampling program. Figure 8 is the plot of the mercury analyses on the gravity map for the area. Background mercury values for the area would be between 10 and 75 parts per billion (ppb). Values 150 ppb and above are considered anomalous. A northwest-southeast trend (stippled area on map) is readily apparent. The 300 ppb value just west of Apache Peak is in the vicinity of mineralized outcrop as is the 525 ppb value at the eastern-most point on the southern line (Snyder Hill). Other than these two points no field explanation can be given for the other anomalous values. Therefore, the writers assume that the northwest trending linear mercury anomaly is indicating a fault-zone structure at depth. This zone parallels a

TABLE 2

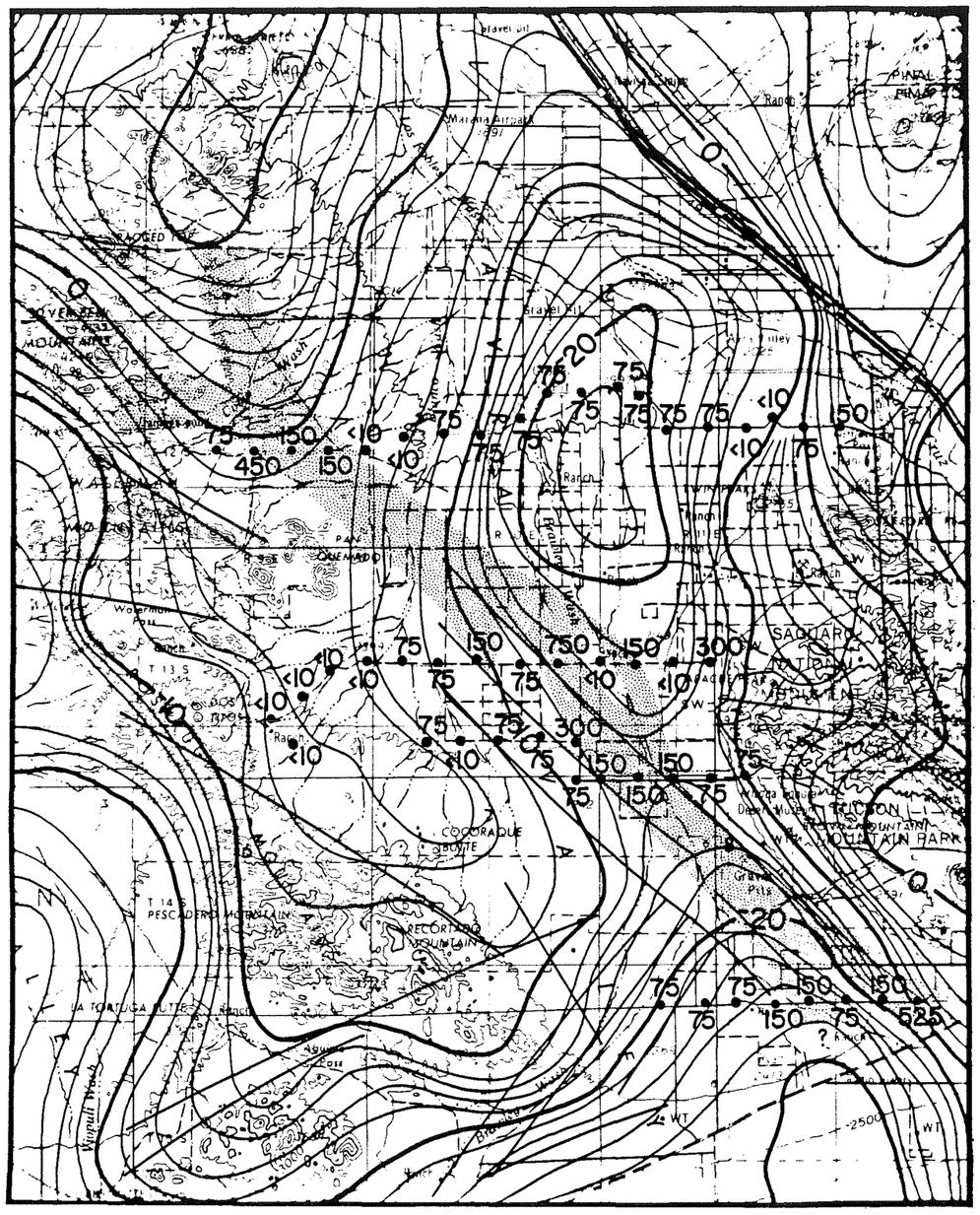
AVRA VALLEY

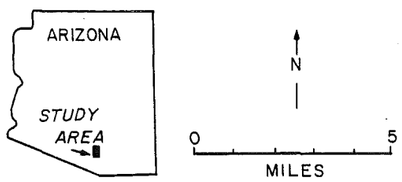
Mercury Geochemical Soil Samples

Sample Number	Hg ppb	Sample Number	Hg ppb	Sample Number	Hg ppb
AV-1	525	AV-19	75	AV-36	-10
2	150	20	300	37	-10
3	75	21	-10	38	150
4	150	22	150	39	150
5	150	23	-10	40	450
6	75	24	750	41	75
7	75	25	75	42	75
8	75	26	150	43	75
9	75	27	75	44	75
10	75	28	75	45	75
11	150	29	-10	46	75
12	150	30	-10	47	75
13	150	31	-10	48	75
14	75	32	-10	49	-10
15	300	33	-10	50	-10
16	75	34	75	51	75
17	75	35	-10	52	150
18	-10				

Mercury analyses in parts per billion

A minus in front of 10 means less than





75 MERCURY CONTENT (ppb)

Lepley Lineaments

Structural Trend

BOUGUER GRAVITY

10 mgal contour

2 mgal contour

BASE MAP:
U.S.G.S. Tucson
1:250,000

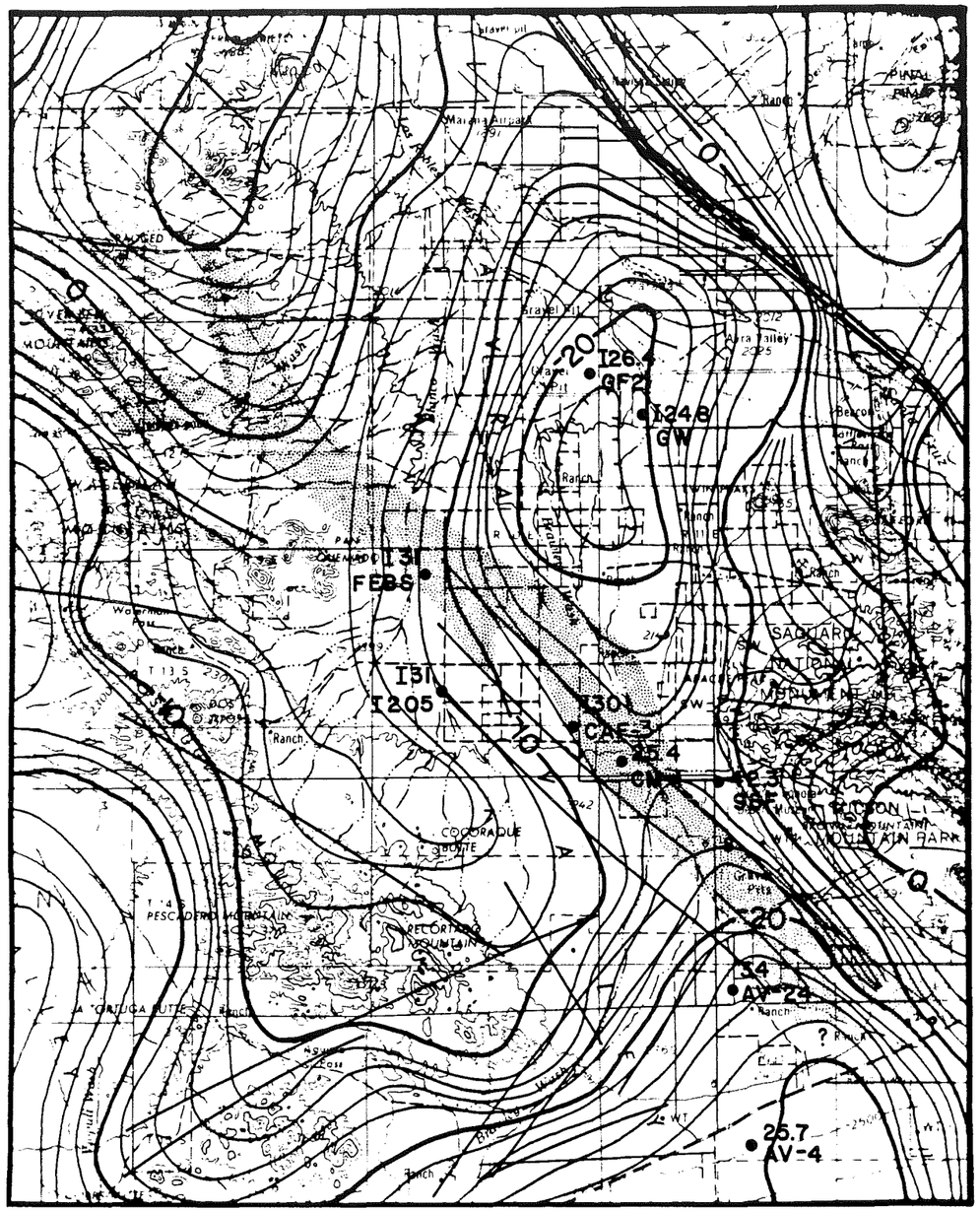
Figure 8.

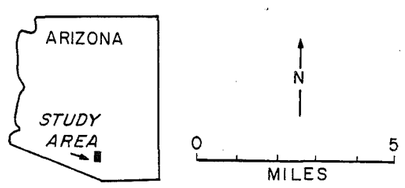
series of northwest lineaments (Lepley, 1977) and some type of linear structure is indicated by the gravity contours, especially in the southeast and northwest corners of the map. In addition the linear mercury anomaly lies astride the Silver Bell-Bisbee discontinuity (Titley, 1976) that was apparently active in the Laramide and probably again active in the late Tertiary (Rehrig and Heidrick, 1976). Oppenheimer (1980) indicated (Fig. 7) a sudden deepening of the basin to the northeast in the general vicinity of this linear feature. Therefore, the writers feel that this mercury anomaly is the surficial expression of the Silver Bell-Bisbee discontinuity and that this structure is still "open" and might well be contributing warm water at depth in the basin.

Measured gradients in $^{o}C/km$ (Fig. 9) for the Avra Valley were calculated using a least squares fit. The data are plotted on a map showing the gravity, lineaments and the mercury anomaly trend. The designation I in front of a gradient means the well is isothermal.

Nine wells were successfully temperature logged. The Tucson city wells that were logged were not in service and had no pumps in the hole. The five unsuccessful attempts were caused by extreme turbulence in the well, cable hanging-up in the well, and (or) trash in the well.

Well AV-4, the southernmost well logged in the study area, was essentially isothermal (T ~31°C) from 120 m (water





•25.4 GRADIENT IN °C/KM
•CM-1 WELL DESIGNATION

Lepley Lineaments
Structural Trend

BASE MAP
U.S.G.S. Tucson
1:250,000

BOUGUER GRAVITY
10 mgal contour
2 mgal contour

Figure 9.

table) to 250 m. From 250 m to the bottom (295 m) the well had a gradient of 25.7°C/km.

Moving northward, well AV-24 has a temperature gradient of 34°C/km. In this well the gradient increased significnatly, to 72.6°C/km, between 180 and 205 m (bottom). In this well cooler water intrusion was noted at depths of 135 m, 167 m, and 180 m.

The next two wells, 98 Farms (98F) and Cactus Milewide #1 (CM-1), are on the east side of the valley in the vicinity of the mercury trend and are less than 200 m deep. The 98 Farms well had a bottom hole temperature of 30°C at a depth of 175 m and a gradient of 42.3°C/km. Cactus Milewide #1 had a bottom hole temperature of approximately 31.4°C at a depth of 195 m and a gradient of 25.4°C/km. No cool water intrusion was noted on either log.

In the central part of the valley, but west-southwest of the mercury trend, Cactus Avra Farms #3 (CAF-3), Trust 205 (T205), and Flying E Bar South (FEBS) are isothermal with temperatures of 30°, 31°, and 31°C respectively.

In the northern part of the area the Glover West Well (GW) is isothermal with a temperature of 24.8°C and the Gin Farm #2 (GF-2) well is isothermal with a temperature of 26.4°C. Both of these wells are shallow having depths of 118 m and 124 m respectively.

While the data are somewhat biased by abundance to the south and southwest in the area of investigation, it does ap-

pear that the warm temperatures and higher gradients are situated either in the vicinity of, or south-southwest of the mercury anomaly. The isothermal wells indicate complete mixing of the water column and probably reflect a ground-water convection system in the basin-fill sediments. The warmer water at shallow depth appears to be along or south-southwest of the Silver Bell-Bisbee discontinuity.

One possible explanation for this phenomenon is that the basement rock with its higher heat flow is closer to the surface on the south-southwest side of the lineament, thereby applying more heat to the near surface waters. Phrased another way, quite possibly there is very little or no thermal insulating blanket of sediments shielding the near surface waters south-southwest of the Silver Bell-Bisbee discontinuity.

The Tucson Mountains and the Silver Bell Mountains have been evaluated for heat flow. The west side of the Tucson Mountains has recorded heat flow of 2.56 heat flow units (HFU) (Sass and others, 1971). The Silver Bell Mountains have recorded heat flow of 2.36 HFU (Roy and others, 1968). A heat flow unit is defined as 1×10^{-6} calories per square centimeter per second (1×10^{-6} cal/cm^2/sec). Lachenbruch and Sass (1977) gave an average heat flow for the Basin and Range province as 2.2 HFU. Hence the heat migrating upward through the mountain blocks is somewhat higher

than normal and by inference the heat flow in the basement of the basin (graben) is assumed to be somewhat higher than normal. Therefore, the hypothesis of a probable lack of a thermal insulating blanket of sediments and (or) a heat source closer to the near-surface waters seem reasonable.

A somewhat less reasonable possibility would be the migration of warm water upwards along the "open" Silver Bell-Bisbee discontinuity. The warm water would have to migrate south and southwest up slope and against the groundwater flow, which is from south to north (White and others, 1966; Matlock and Morin, 1976).

If the Silver Bell-Bisbee discontinuity were supplying warm water to the basin in Avra Valley, in all probability the warm water would migrate upward along the structure until it encountered permeable aquifers. The warm water would then move into the aquifer and migrate northward downdip into the basin, following the path of least resistance.

As previously stated, the water geochemistry program was not successful because of analytical problems. Table 3 is the U.S.G.S. water data for Avra Valley, obtained from the WATSTORE file. Table 4 is the correlation of the Avra Valley water-sample numbers with the City of Tucson water-well designation. Table 5 is the silica geothermometers calculated from the water samples taken in this study. Figure 10 is a map showing the location of the water samples and the silica geothermometers. The silica geothermometers do not

reflect a "hot" reservoir and probably reflect the ground-water temperatures within 1000 m of the ground surface. Also the geothermometers do not reflect any "hot" water migrating upward along faults.

Table 6 is the Na-K-Ca geothermometers calculated from the WATSTORE file, and Figure 11 is a computer-plotted map generated from these data. For low-temperature resources, <90°C, there is fairly close agreement between the chemical geothermometers. The Na-K-Ca geothermometers appear to more closely reflect the measured discharge temperature of the wells than do the silica geothermometers. Therefore it is assumed that the Na, K and Ca are in approximate equilibrium with the well-water discharge temperature. Figure 12 shows the well water discharge temperature and indicates that the warmer water is confined south and southwest of the Silver Bell-Bisbee discontinuity.

In an attempt to define the water of the Avra Valley, two triangular diagrams and five x-y plots were generated by the computer. Geothermal waters will often have excessive concentrations of boron, fluorine, chlorine and sulfate. Comparisons of these elements and compounds will often designate different waters and mixed waters in the same geographical area, as well as indicate geothermal water.

Figure 13 is a computer plot of the cations Na, Ca, and Mg. Each vertex represents 100 percent of each of the three cations. Where complete analyses are available, the

TABLE 4

CORRELATION OF WELL SAMPLE NUMBERS

Sample designation this report	City of Tucson Dept. of Water and Sewers Well Designation
AV-1	
AV-2	W-5
AV-3	W-4
AV-4	W-2
AV-5	W-1
AV-6	
AV-7	
AV-8	
AV-9	Mile Wide Farm domestic well
AV-10	AV-11
AV-11	AV- 3
AV-12	AV- 7
AV-13	AV- 1
AV-14	AV- 5
AV-15	AV-12
AV-16	AV-16
AV-17	AV-17
AV-18	AV-19
AV-19	AV-14
AV-20	AV- 2
AV-21	AV-18

Sample numbers AV-1, AV-6, AV-7, and AV-8 are irrigation wells on land not owned by the City of Tucson.

TABLE 5

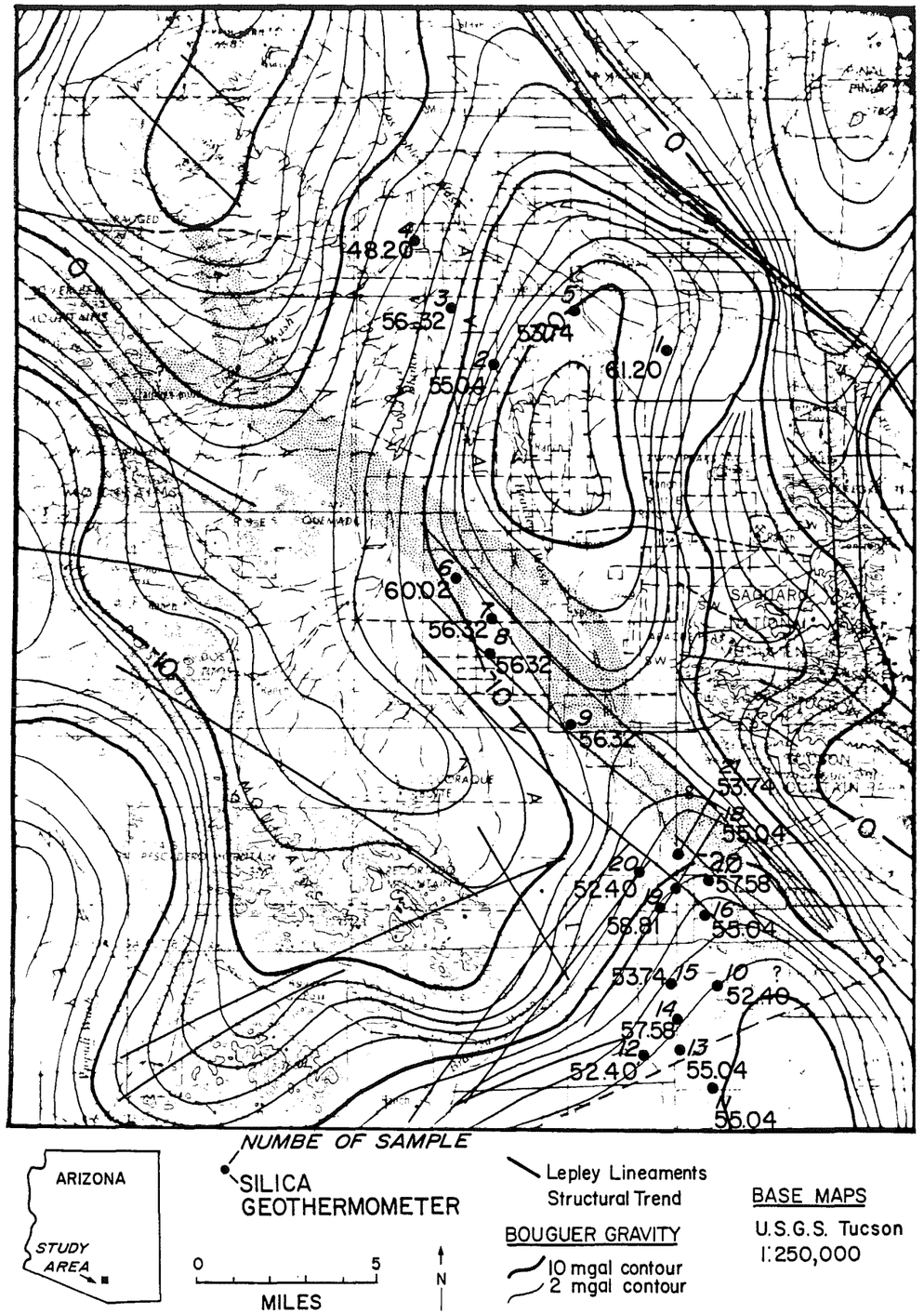
AVRA VALLEY

Silica Geothermometers

Sample #	SiO_2 (ppm)	Geothermometer Chalcedony °C
AV-1	40	61.20
2	35	55.04
3	36	56.32
4	30	48.20
5	34	53.74
6	39	60.02
7	36	56.32
8	36	56.32
9	36	56.32
10	33	52.40
11	35	55.04
12	36	52.40
13	35	55.04
14	37	57.58
15	34	53.74
16	35	55.04
17	37	57.58
18	35	55.04
19	38	58.81
20	36	52.40
21	34	53.74

Calculated from the following formula:

$$t_{oC} = \frac{1032}{4.69 - \log SiO_2} - 273$$



48.20
56.32
53.74
55.04
61.20
60.02
56.32
56.32
56.32
53.74
55.04
52.40
57.58
58.81
55.04
53.74
52.40
57.58
52.40
55.04
55.04
SAGUARO
NUMBE OF SAMPLE
SILICA GEOTHERMOMETER
Lepley Lineaments
Structural Trend
BOUGUER GRAVITY
10 mgal contour
2 mgal contour
BASE MAPS
U.S.G.S. Tucson
1:250,000
ARIZONA
STUDY AREA
0
5
MILES
N

Figure 10.

TABLE 6

AVRA VALLEY

Na-K-Ca Geothermometers

USGS WATSTORE RECORD #	GEOTHERMOMETER
84	45.59°C
91	42.30
62	46.12
97	33.90
74	28.76
42	55.14
39	48.56
14	26.47
16	24.50
26	31.96
40	37.87
15	32.80
12	29.04
11	23.54
2	36.10
4	35.06
81	69.21
18	23.05
8	26.56
10	30.33
21	27.61
1	39.21
24	41.90
17	76.11
7	32.62
9	35.50
37	37.39
30	34.85
25	41.82
31	50.14
6	30.60
3	29.59
19	41.14

Calculated from the following formula:

$$t_{oC} = \frac{1647}{\log(Na/K)+\beta\log(\sqrt{Ca}/Na) + 2.24} - 273$$

$\beta = 4/3$
No Mg correction

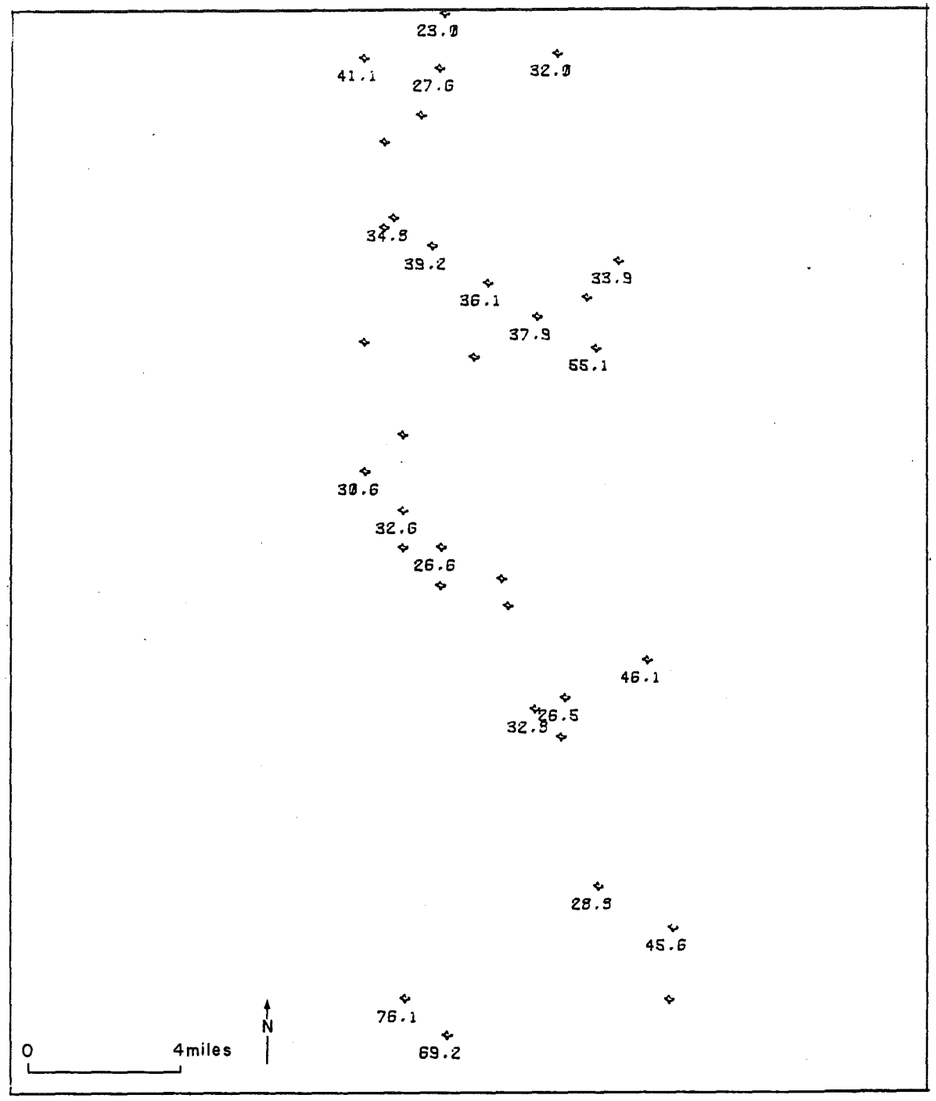
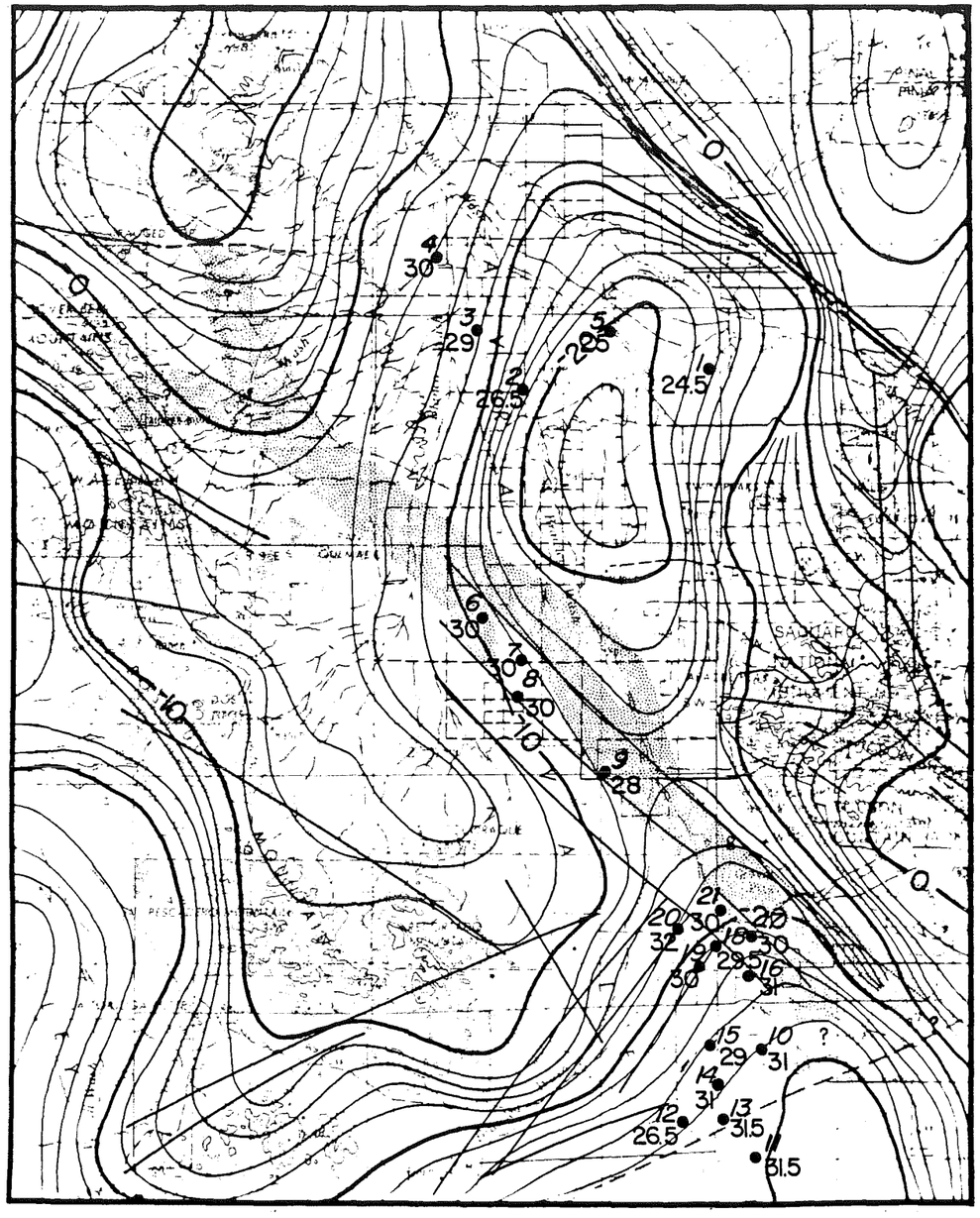
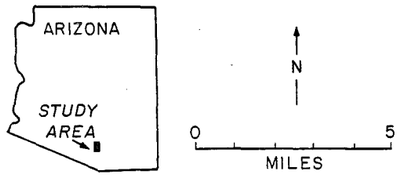


Figure 11. Computer plotted map of the Na-K-Ca geothermometer in °C. All numbers over 30° plotted in addition to every 10th number.





N

0 5
MILES

10 NUMBER OF SAMPLE
31 DISCHARGE TEMPERATURE (°C)

Lepley Lineaments
Structural Trend

BOUGUER GRAVITY
10 mgal contour
2 mgal contour

BASE MAP
U.S.G.S. Tucson
1:250,000

Figure 12.

water is sodium-calcium (Na-Ca) water low in magnesium.

Figure 14 is a computer plot of the anions, Cl, HCO_3, and SO_4. It shows that where complete analyses are available, the water is primarily a bicarbonate (HCO_3) water.

From the two triangular diagrams the water in the Avra Valley may be classified as a sodium-calcium-bicarbonate water. This type of water appears, from prior work in Arizona, to be one of the more common types of ground water in the Basin and Range province of the state.

The following x-y plots were generated by the computer: SiO_2 geothermometer vs. Na-K-Ca geothermometer; SiO_2 geothermometer vs. measured temperature; chlorine vs. measured temperature; boron vs. measured temperature; and fluorine vs. chlorine. These diagrams contributed no information concerning the geothermal resource in Avra Valley.

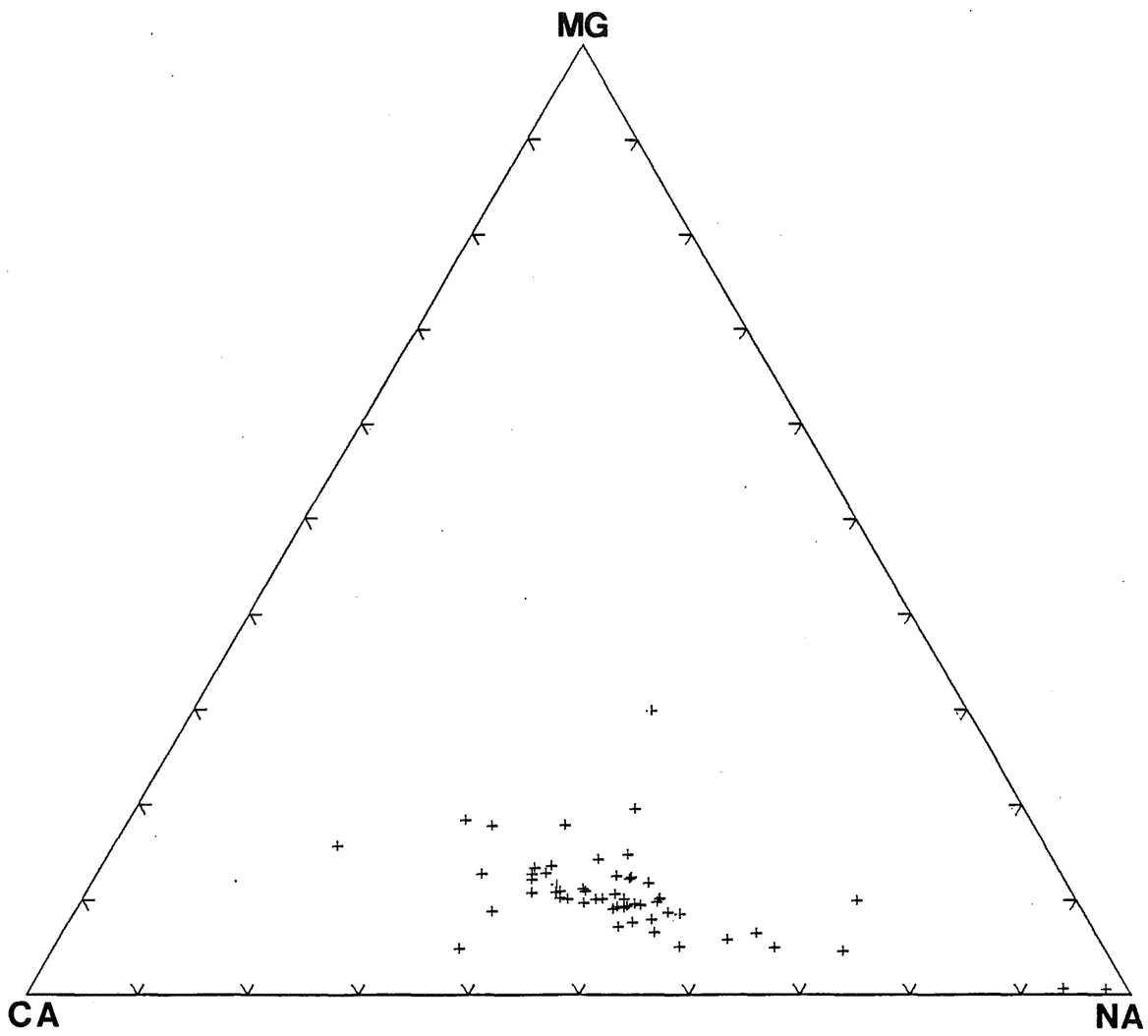


Figure 13. Computer plot of the major cations, Na, Ca and Mg. Each apex equals 100%. The results indicate fairly equal amounts of Na and Ca and a very low concentration of Mg.

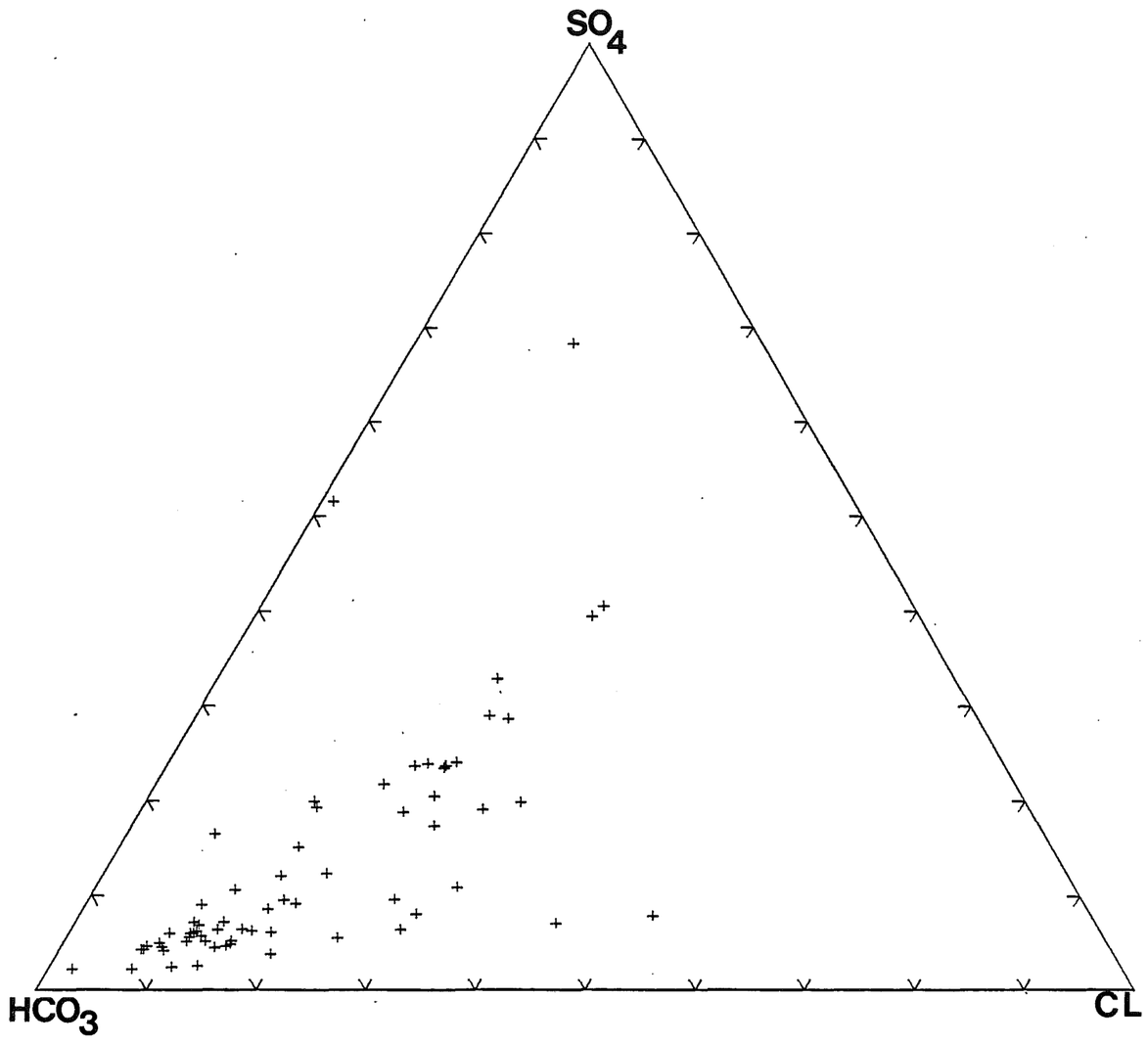


Figure 14. Computer plot of the major anions, Cl, HCO_3 and SO_4. Each apex equals 100%. The results indicate the water is primarily a bicarbonate (HCO_3) water low in Cl and SO_4.

CONCLUSIONS

In Avra Valley the surficial deposits of fine-grained sand and silt, thickly interbedded with coarse sand and gravel, attain a thickness in excess of 9 m. The coarse sands and gravels were deposited by laterally migrating stream channels and the fine-grained beds are sheet flood deposits. On the basis of pottery shards in a silt bed it was determined that upper 1.5 m of the surficial deposits had been deposited during the last 2000 years.

Two subsurface units beneath the surficial alluvium were defined by analysis of drill cuttings and borehole geophysical logs from a city of Tucson water exploration drilling program to a depth of 396 m. These two units are informally called the younger and older alluvium and are believed to be correlative with the Ft. Lowell Formation and the Upper Tinaja Beds, respectively.

The younger alluvium, for the most part uncemented, has an average thickness of 98 m. In the north and central parts of the valley the younger alluvium is characterized by interbedded coarse- and fine-grained sediments. In the southern part of the valley the younger alluvium consists almost entirely of sandy gravel and gravelly sand with a single, thick silt unit. The younger alluvium is interpreted as having the same depositional environment as the surficial deposits and conformably overlies the older alluvium.

The older alluvium has been divided into two facies,

fanglomerate and mudstone. The moderately- to well-cemented fanglomerate facies consists of sandy gravel and gravelly sand while the mudstone facies consists of silt and clay with little or no sand and gravel. The lower section of the mudstone is gypsiferous. The mudstone facies is found in the northern and north-eastern parts of the valley while the fanglomerate facies occupies the northwestern, central and southern parts of the valley where bedrock is at shallower depths. The aerial distribution of these facies is inferred to be fault controlled, as the depth-to-bedrock information indicates probably faults.

Continuous downwarping of the northern part of the basin, north of the Silver Bell-Bisbee discontinuity, apparently occurred after graben formation during the Basin and Range disturbance. This downwarping maintained a closed drainage system in which deposition of fine-grained sediments and evaporites occurred.

The geothermal resource in the Avra Valley is one of low temperature (<90°C) to possibly one of moderate temperature (<150°). South and southwest of the Silver Bell-Bisbee discontinuity 30°C water is fairly ubiquitous at depths of 305 m and 50°C water may be inferred to exist at depths of 1000 m, assuming a gradient of 30°C/km and a mean annual air temperature of 20°C.

North of the Silver Bell-Bisbee discontinuity the geo-

thermal resource is not well defined. The lower gradients and surface discharge temperatures indicate the possibility of recharge to the ground water system. In addition, the deep basin has a considerable thickness of Miocene and younger sediments insulating the near-surface ground water from the heat source in the basement of the basin. This heat source could be warm or hot water migrating upward along bounding faults or transverse structures and trapped beneath the sediments. It could also be the convective heat flow from the basement granite supplying essentially the same heat as in the southern half of the basin but the heat is spread through a greater volume of sediments and insulated from the near-surface ground water. Deep gradient or heat flow holes in excess of 900 m will be necessary to confirm a geothermal resource in the northern part of the valley. However, assuming a gradient of 30°C/km and a mean annual air temperature of 20°C, there is the potential for 110-120°C water at 3000 m.

While these temperatures and depths are not overly attractive today, anticipated advances in utilization technology will make these waters a viable resource in the near future.

Acknowledgements

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REFERENCES

Allen, Timothy, J., 1981, The subsurface stratigraphy of the northern Avra Valley, Pima County, Arizona: Kent State University, Unpub. M.S. thesis, 82 p.

Antevs, E., 1962, Late Quaternary climates in Arizona: Amer. Antiquity, v. 28, no. 2, p. 193-198.

Bikerman, M., 1967, Isotopic studies in the Roskruge Mountains, Pima County, Arizona: Geol. Soc. Am. Bull., v. 78, p. 1029-1036.

Davidson, E. S., 1973, Geohydrology and water resources of the Tucson Basin, Arizona: U. S. Geol. Survey Water Supply Paper 1939-E., 78 p.

Eberly, L. D. and Stanley, J. B., 1978, Cenozoic stratigraphy and geologic history of southwestern Arizona: Geol. Soc. Am. Bull., v. 89, p. 921-940.

Oppenheimer, Joan M., 1980, Gravity modeling of alluvial basins in southern Arizona: Univ. of Arizona, Unpub. M.S. thesis, 96 p.

Fenneman, N. M., 1931, Physiography of the western United States, McGraw-Hill Book Company, Inc., p. 326-395.

Fournier, R. O. and Truesdell, A. H., 1973, An empirical Na-K-Ca geothermometer for natural waters: Geochemica et Cosmochemica Acta, v. 37, p. 1255-1275.

Fournier, R. O. and Rowe, J. J., 1966, Estimation of underground temperatures from silica content of water from hot springs and wet steam wells: American Journal of Science, v. 264, p. 685-697.

Hahman, Sr., W. R., 1979, Geothermal energy in Arizona: Geothermal Energy, v. 7, no. 11, p. 7-18.

Lepley, L. K., 1977, Landsat lineament map of Arizona, scale 1:1,000,000; Bureau of Geology and Mineral Technology, open file.

Lysonski, J.C., Aiken, C.L.V. and Sumner, J.S., 1981, Complete residual Bouguer gravity anomaly map, Tucson; scale 1:250,000; Bureau of Geology and Mineral Technology; Tucson; open file.

Matlick, III, J. S., 1975, A new geothermal exploration

method using mercury: Unpub. M.S. thesis, Arizona State University, 83 p.

Matlock, W. G. and Marin, G. C. A., 1976, Ground water in Avra and Altar valleys, Arizona: College of Agriculture, University of Arizona, 59 p.

Rehrig, W. A. and Heidrick, T. L., 1976, Regional tectonic stress during Laramide and late Tertiary intrusive periods, Basin and Range province, Arizona: in Wilt, J. C. and Jenney, J. P., eds., Tectonic Digest, Arizona Geological Society Digest, v. X, p. 205-228.

Titley, S. R., 1976, Evidence for a Mesozoic linear tectonic pattern in southeastern Arizona: in Wilt, J. C. and Jenney, J. P., eds., Tectonic Digest, Arizona Geological Society Digest, v. X, p. 71-102.

WATSTORE, 1981, U. S. Geological Survey.

White, N. D., Matlock, W. G. and Schwalen, H. C., 1966, An appraisal of the ground-water resources of Avra and Altar valleys, Pima County, Arizona: Water-Resources Report no. 25, Arizona State Land Department, 66 p.

Wilson, E. D., Moore, R. T. and Cooper, J. R., 1969, Geologic map of Arizona; scale 1:500,000; Arizona Bureau of Mines and United States Geological Survey, Tucson.