PRELIMINARY ASSESSMENT OF THE GEOTHERMAL POTENTIAL

CITY OF SCOTTSDALE

PARADISE VALLEY, MARICOPA COUNTY, ARIZONA

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Introduction

Geothermal resources in the western United States are frequently associated with the deep fault-bounded and sediment-filled basins that characterize the Basin and Range physiographic province. The City of Scottsdale lies within the Paradise Valley, which is part of the southern Basin and Range province and thus constitutes a viable target for geothermal exploration (Fig. 1).

Warm wells have been reported in the Scottsdale area and are an indication that geothermal fluids may exist at depth. The purpose of this preliminary study was to determine whether potential geothermal resources occur in the Scottsdale area. Assessment methods included a literature review, review of local geology and geophysics, and collection and evaluation of available water chemistry and well temperature data. In addition we collected water samples for chemical analyses from 13 wells belonging to the City of Scottsdale (see Appendix A) and measured temperature gradients in six City wells that were not in service (see appendix B).

The Paradise Valley basin is bounded principally by the McDowell Mountains and Sawik Mountains on the east and northeast, and by the Phoenix Mountains on the west and southwest (Fig. 1). Maximum elevation is 1,230 m in the McDowell Mountains. Elevation at the northern end of the basin is about 670 m. Basin elevation decreases to the south, to about 358 m at the Salt River.

Climate in the Paradise Valley is semiarid. Maximum temperatures range up to 46°C (115°F). Mean annual air temperature is 20.3°C (68.5°F). Average precipitation at Scottsdale is eight inches a year, with extremes ranging from 2.63 to 18.1 inches.

For this report, Paradise Valley was arbitrarily divided into a northern half (from the south edge of T. 3 N.) and a southern half (everything south

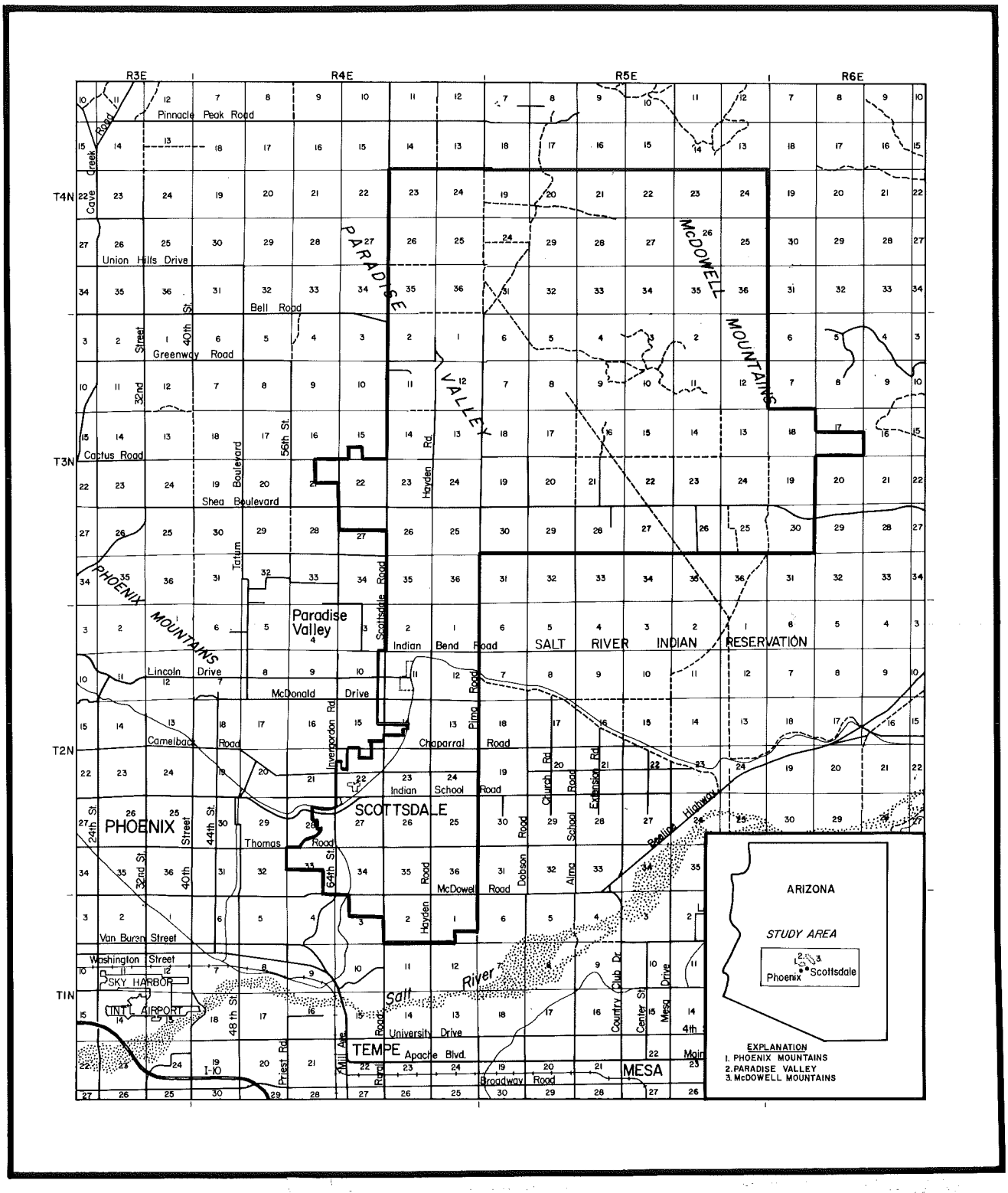

FIGURE 1. Location map of study area. Outline shows Scottsdale City limits.

of that township).

General Geology

The City of Scottsdale is located east of Phoenix in the Paradise Valley. The valley trends approximately northwest and has maximum dimensions of 17.6 km wide and 38.4 km long. Geology and ground-water conditions of the Paradise Valley have been described by numerous workers: Meinzer and Ellis, 1915; McDonald, Walcott, and Bluhm, 1947; Halpenny, Harshbarger, and Green, 1967; Arteaga, White, Cooley, and Sutheimer, 1968; Wilson, Moore, and Cooper, 1969; Shank, 1973; and Christenson, Welch, and Péwé, 1979.

The Paradise Valley is in the southern Basin and Range province, which is characterized in southern Arizona by northwest-trending, fault-bounded mountain ranges, separated by deep sediment-filled basins. The McDowell and Phoenix Mountains are composed largely of Precambrian igneous and metamorphic rocks: schist, granite, quartzite, gneiss, and slate. Cretaceous to Tertiary volcanic rocks, principally rhyolite, dacite, andesite, diabase, and basalt are present in lesser amounts (Fig. 2). The valley is underlain by a deep sediment-filled basin created by high-angle normal faulting of a brittle crust during a period of active tectonism called the Basin and Range disturbance (Shafiqullah and others, 1980); Scarborough and Peirce, 1978). Such tectonic basins typically underlie valleys in the southern Basin and Range province; the bounding faults have been shown in some instances to provide conduits for warm water rising to the surface (Chapman, Kilty, and Mase, 1978; Garside and Schilling, 1979).

A large part of Paradise Valley is underlain by more than 450 m of water-yielding alluvial deposits (Arteaga and others, 1968). The alluvium was informally divided into the lower alluvium, the middle alluvium, and the upper alluvium by these authors. In parts of the valley the lower alluvium overlies

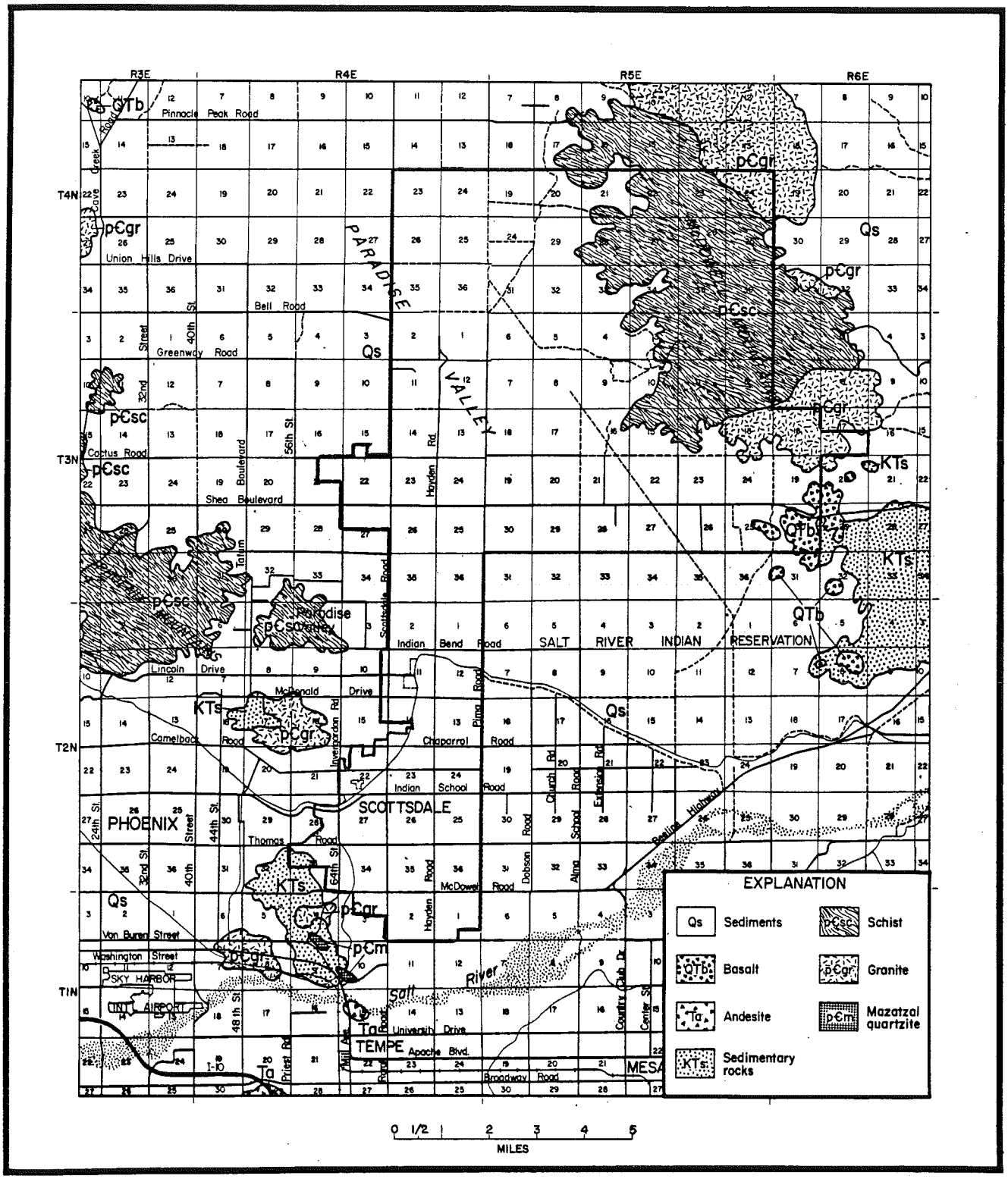

FIGURE 2. General geology of Paradise Valley and surrounding mountains (from Wilson, Moore, and Cooper, 1969)

a red unit, the Papago Park deposits of Pewe (Lausten, 1974), which is composed mainly of siltstone and silty sandstone (Arteaga and others, 1968). The red unit and the alluvial deposits form a single hydrologic aquifer.

Streams draining Paradise Valley are ephemeral. All streams flow southward to southwestward into the Salt River.

Gravity

A gravity survey of the Paradise Valley was completed by Lausten (1974) who showed that the underlying basin is a 5- to 6-km-wide graben that trends approximately N. 40° W., south of 33° 40' N, and nearly north-south, north of that latitude.

Lausten (1974) showed that much of Paradise Valley is buried mountain pediment (0 to 600 m depth) that possibly extends as much as 6.4 km out into the basin from the present bedrock outcrops. The residual Bouguer gravity of this area (Lysonski, Aiken, and Sumner, 1981) shows nearly the same subsurface structure (Fig. 3). Such extensive pedimentation is not uncommon in southern Arizona. Menges and McFadden (1981) found that bedrock pediments flanking both the Sonoita Creek and Canada del Oro basins extend between 2 and 7 km basinward from present bedrock outcrops. The deepest point in the Paradise Valley basin occurs about T. 4 N., R. 4 E., NE corner sec. 29, approximately 1.4 mi north of Bell Road and 2.3 mi west of Scottsdale Road (latitude 33° 39.6' N; longitude 111° 57.8' W). This low point is located where the basin orientation changes to north-south. Lausten (1974) estimated that depth to basement in the deepest part of the basin varied from 2,750 to 6,100 m (9,000 to 20,000 ft), depending on the density contrast used in modeling the gravity (Table 1).

Oppenheimer and Sumner (1981) determined depth to bedrock in the Basin and Range province of Arizona, using a density contrast of -0.50 gm/cm. They

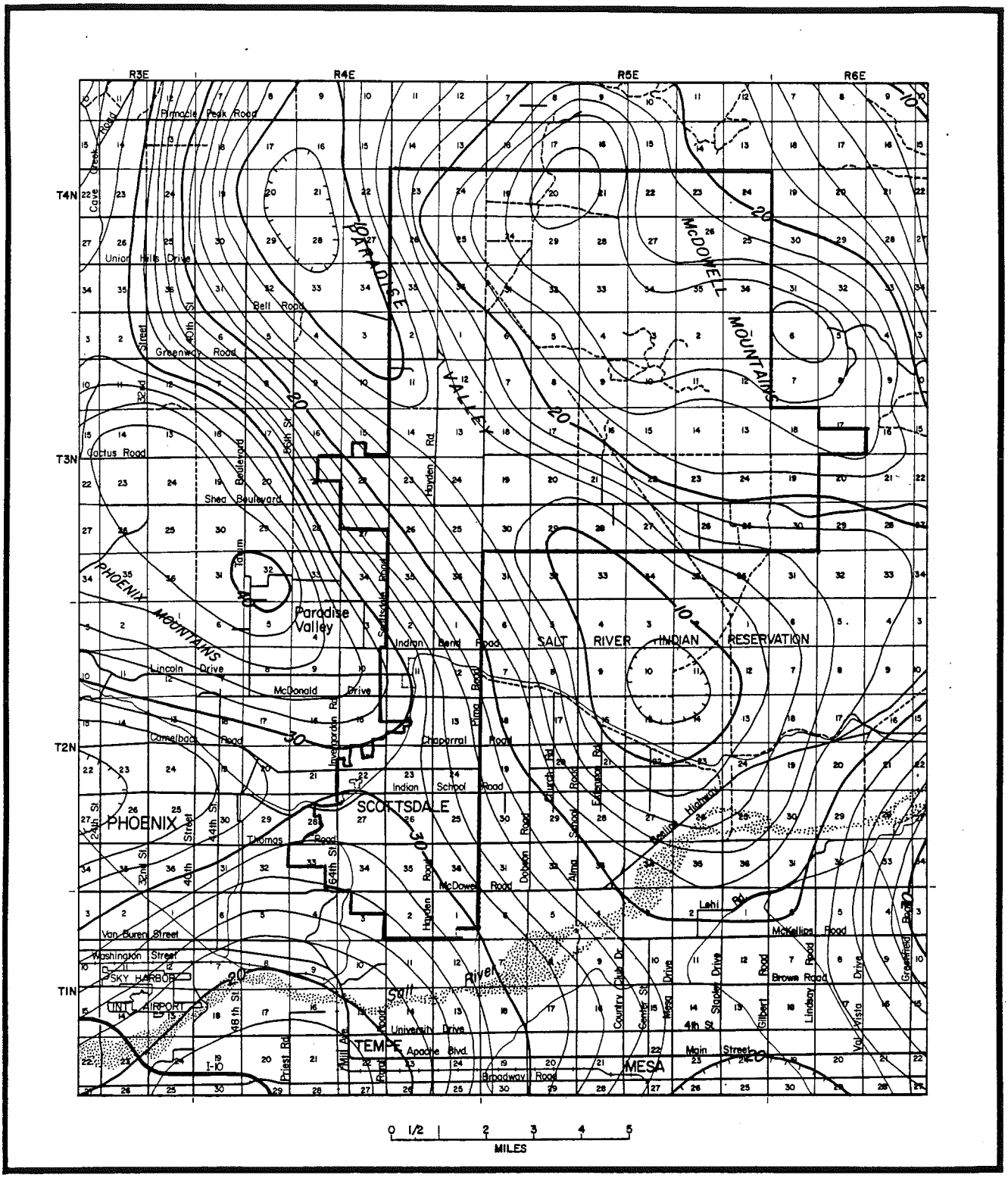

FIGURE 3. Residual Bouguer gravity of the Paradise Valley area, 2-milligal contour interval (from Lysonski, Aiken, and Sumner, 1981)

Table 1. Density contrasts and depths to bedrock (from Lausten, 1974)

Model	Density Contrast	Depth to Bedrock
1	-0.36 gm/cm^3	2,750 m
2	-0.31 gm/cm^3	Plate 8 missing
3	-0.26 gm/cm^3	5,500 m
4	variable	6,100 m

estimated depth to bedrock in the Paradise Valley to be between 915 and 2,900 m (3,000 and 9,600 ft).

Lausten (1974) postulated that the areas of steep gravity gradients are the major fault zones, a generally accepted hypothesis for the southern Basin and Range province. Figure 4 shows the fault zones outlined by Lausten (1974) superimposed on the fault zones we outlined on the basis of more recent and detailed residual Bouguer gravity work (see Fig. 3). There is little change in fault trends, but our western fault zone is wider than the zone estimated by Lausten.

Heat Flow

Average heat flow for the southern Basin and Range province is 2.1 HFU, about 0.5 HFU greater than the world average (Sass and others, 1980). This elevated heat flow in the Basin and Range province is generally attributed to the effects of thinner crust and to very deep basaltic intrusions into the base of the crust during the last 8 to 4 m.y. in the southwestern United States.

Heat flow measurements have not been made in the Paradise Valley. The nearest published values exist at Chandler (1.79 HFU) and south Phoenix (1.10 HFU), both of which are below the Basin-and-Range norm. These low values can easily be attributed to ground-water disturbance, and do not necessarily reflect areas of low crustal heat flux.

Geothermal Gradients

Thermal wells have been defined by the U.S. Geological Survey as those wells having minimum temperatures 10°C above the mean annual air temperature (MAT), which is 21°C in Scottsdale, and geothermal gradients exceeding the continental average of 30°C/km (Sammel, 1979). Geothermal gradients are calculated by subtracting the MAT from the maximum reported well temperatures

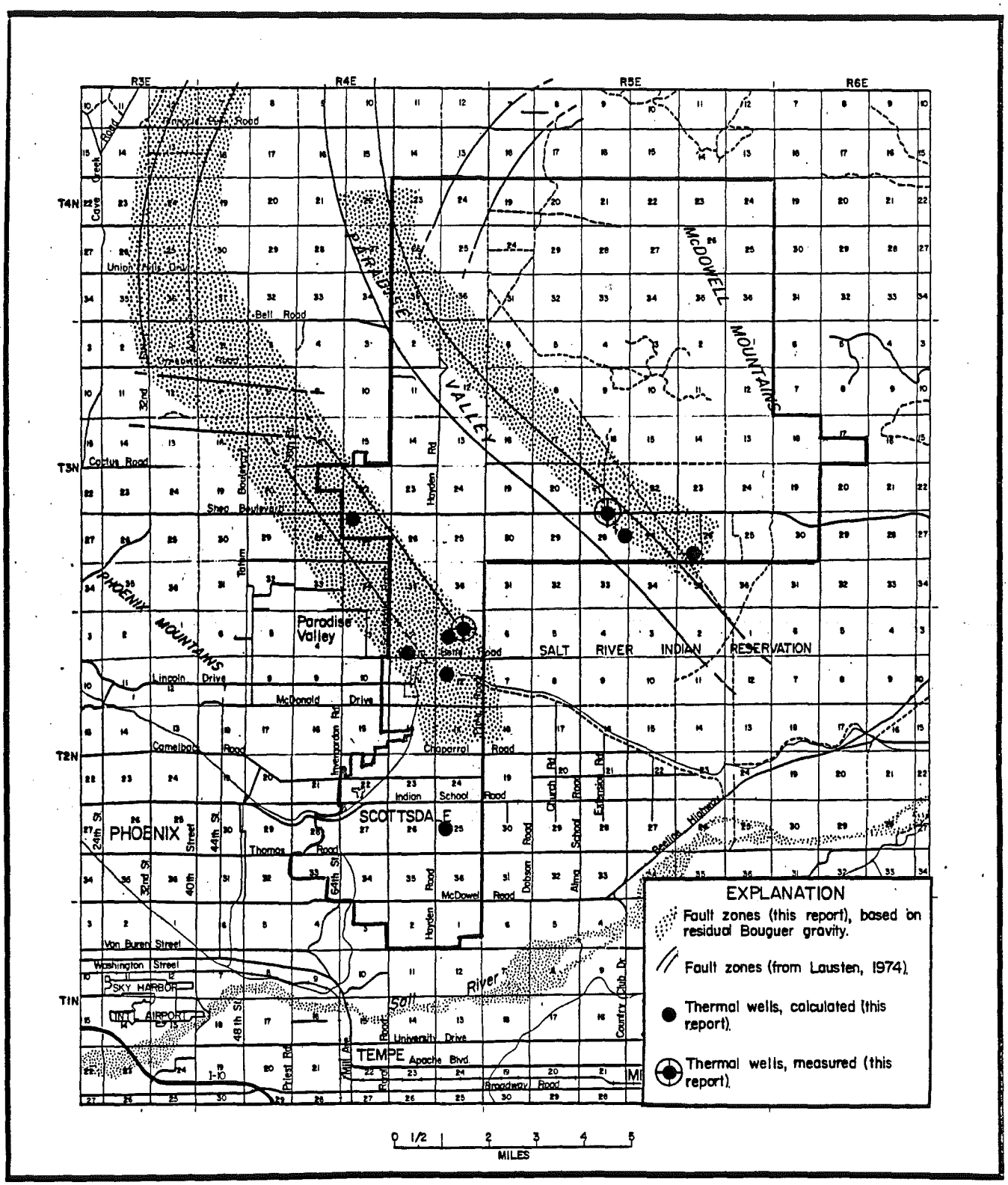

FIGURE 4. Fault zones, based on gravity, and thermal wells in the Scottsdale area

and dividing by total depths of the wells, times 1,000. The resulting gradients do not necessarily reflect actual depth of occurrence of thermal waters because subsurface conditions often distort an otherwise linear conductive thermal gradient. Convective flow of water in the wells or in surrounding formations, and changes in rock thermal conductivity associated with lithologic changes, are common conditions that disturb conductive gradients.

Because there is no method for determining accuracy of reported well temperatures and whether they represent minimum or maximum temperatures, we established slightly different criteria for defining thermal wells in the southern Basin and Range province. Our definition for thermal wells includes those wells having reported temperatures 12°C above the MAT and geothermal gradients exceeding 35°C/km. We calculated geothermal gradients for 38 wells that had reported or published well depths and temperatures, and evaluated their "thermal" character. Using our criteria, we determined that eight of the 38 wells are thermal (Table 2).

Temperatures were measured at 5-m intervals in six Scottsdale wells that are not in service (Fig. 5 and Appendix B). The depth intervals that we were able to measure in wells 42 and 61 are too short to be useful. The temperature profiles for the other four wells show considerable disturbance due to groundwater movement. The profiles show an influx of warm water at the deepest levels in the boreholes, and an exodus of water at shallower depths.

Geothermal gradients were determined for the above four wells having deep measurements, using the least squares method on straight segments of the profiles (Table 3). The gradients for wells 69 and 79 are normal for the Basin and Range province, but they extrapolate to mean annual air temperatures (MATs) that are too high for the Scottsdale area. Thus, the estimated temperatures at 1 km depth are too high also. More reasonable estimates, based on 21°C MAT, would

Table 2. List of wells having reported temperatures and depths. Asterisks indicate wells meeting the criteria for thermal (see text).

No.	Temp (°C)	Depth (m)	TG (°C/km)	Location
8	23.9	201	14.4	(A-2-4) 35DDC
9	31.0	300	33.3	35AAB
10	27.0	305	19.7	35ABB
18	28.0	366	19.1	25CDD
20	32.2	367	30.5	25DCA
21 *	36.7	395	39.7	25BCD1
22	32.8	366	32.3	25BCD2
24	32.0	404	27.2	25AAB
25	33.0	366	32.8	25ABB
26	32.0	366	30.1	25AAA
28	29.0	396	20.2	24BAD
30	31.1	381	26.5	24CAB
31	30.0	366	24.6	23DDD
40	30.0	310	29.0	13CAA
42	33.3	369	33.3	13ADD
43	35.6	427	34.2	12DDD
44 *	36.1	297	50.8	12BCA
51	31.1	280	35.7	11CBC
52	36.6	549	28.4	2ACD
53 *	33.3	340	36.2	2CDD
54	29.4	149	56.2	1DDD
55	29.4	152	55.1	1DAA
56 *	37.8	290	58.0	1CBA
57	29.0	152	52.6	(A-2-5) 6ACB
59 *	35.6	335	43.5	(A-3-4) 27BBA
62	26.9	526	11.2	21ADA
64	27.2	518	12.0	11CCC
65	37.8	590	28.5	11AAB
67	33.3	528	23.3	2BBC
68	35.6	530	27.5	2CAD
71 *	33.9	274	47.0	(A-3-5) 28ADD
72 *	33.3	244	50.4	26CDC
73	30.0	353	25.5	19ADB
74	35.6	488	29.9	19DAC
75	31.1	186	54.3	19ABB
76	31.1	353	28.6	19AA ctr
79	32.8	460	25.7	(A-4-4) 26A
+ 81 *	50.0	549	52.8	(A-2-4) 1ACC

+ Well 81 is thermal by both measured and calculated methods.

Table 3. Measured geothermal gradients, City of Scottsdale wells

Well No.	BH Temp (°C)	TD (m)	Depth Interval (m)	TG (°C/km)	Est. MAT (°C)	Est. Temp 1 km Depth
69	37.9	335	120-280	30.6	27.9	58.5
70*	49.5	470	170-350	71.1	23.4	94.5
			355-470	11.9	43.9	55.8
79	44.6	400	140-255	29.7	28.9	58.6
81*	36.8	465	210-240	54.1	20.0	74.1

* Indicates wells that are thermal. See Table 4 for well locations.

be temperatures of 52°C (69) and 51°C (79) at 1 km depth. Wells 70 (upper section) and 81 have reasonable MATs, high measured gradients, and high measured temperatures. These two wells meet the criteria for being thermal.

All of the thermal wells (measured and calculated) occur within the major fault zones of the Paradise Valley, in two discrete clusters (Fig. 4). We suggest that a northeast-trending fault zone might exist that intersects the two basin-bounding faults about where the two clusters of thermal wells occur. Where such faults intersect, fracture permeability in bedrock would be greatest. We suggest that in this region of Paradise Valley thermal fluids rise from depth along open bedrock fractures in the fault zones. At shallower depths in the basin the thermal waters most likely mix with cold ground water, resulting in the warm water that is encountered in local domestic and irrigation wells.

Temperature profiles of the kind shown in Figure 5 are indicative of hydrothermal convection systems, and suggest it is unlikely that higher temperature fluids will be found at moderately greater (economic) depths. Drilling to depths of 2 to 3 km might intersect the fault system in bedrock and intercept the thermal fluids before they mix with cold ground water.

Water Chemistry

Complete or partial chemical analyses are available for 80 wells in the Scottsdale area (Table 4). Most are domestic or irrigation wells.

Water quality for the southern Paradise Valley is generally lower than it is for the northern half. In the southern valley, dissolved solids content generally is in the range of 500 to 1,000 mg/l. Some wells yield waters that contain up to 2,400 mg/l dissolved solids. In the northern part of the valley dissolved-solids content of the water generally is low, between 200 and 500 mg/l.

Chemical Geothermometers

Experimental evidence has established that the silica concentration in

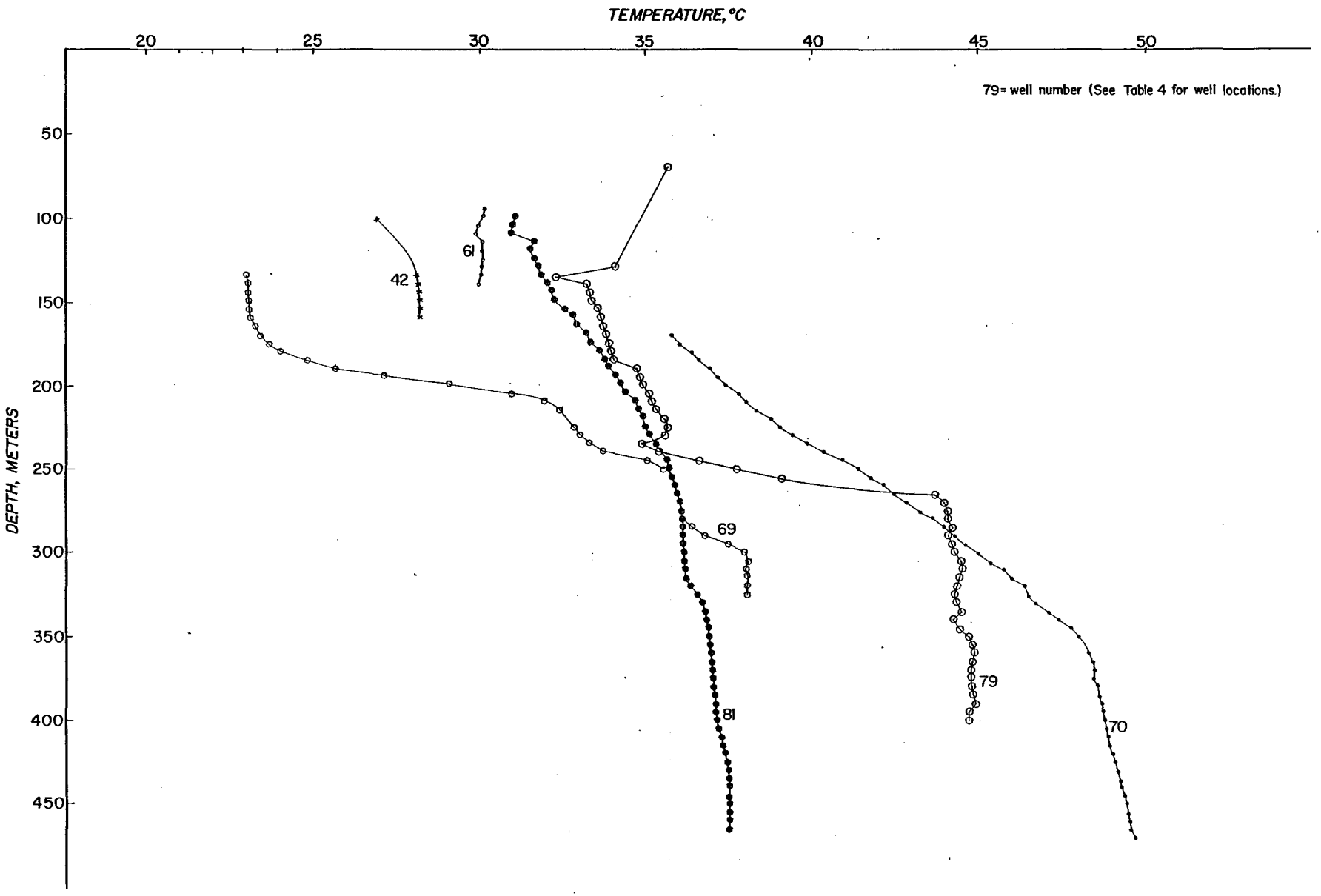

FIGURE 5. Temperature-depth profiles for wells measured in the Scottsdale area

Table 4. Locations, chemical analyses, and geothermometers for wells in the Scottsdale area

Data Sources:
1. USGS-WATSTORE
2. City of Scottsdale
3. Salt River Project
4. Paradise Valley Report
5. This Report

Well Number, This Report	Location	Analysis Year	Data Source	Number Assigned by Source	Temp. (°C)	Depth (m)	Thermal Gradient (°C/km)	pH	Na (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	Cl (mg/l)	F (mg/l)	HCO_3 (mg/l)	SO_4 (mg/l)	SiO_2 (mg/l)	TDS (mg/l)	T_{SiO_2} (Chalced)	T_{SiO_2} (Quartz)	$T_{Na-K-Ca}$	$T_{average}$	Cl/F	Ca/Mg	Na/Ca	Mg/Ca	Thermal Wells
1	(A-1-4) 2DCC	37	1	8234	22.8	-	-	7.4	350	1.0	113	47	411	-	445	-	-	-	-	-	14.2	-	-	1.46	2.70	0.69	-
2	(A-1-4) 2DDB	81	5,2	(25)	-	-	-	7.8	124	4.0	48	61	236	0.4	229	98	36	730	56	-	53.1	54.6	316	0.48	2.25	2.09	-
3	(A-1-4) 2CDD	74	3	22.5E 5N	-	-	-	-	155	-	103	19	285	-	213	84	-	764	-	-	-	-	-	3.29	1.31	0.30	-
4	(A-1-4) 1DDA	80	3	23.5E 5.3N	-	-	-	8.3	180	6.0	28	23	287	-	146	58	-	663	-	-	-	-	-	0.74	5.60	1.35	-
5	(A-2-4)36CDD	78	3	23.6E 6N	-	-	-	7.6	173	7.0	90	40	312	-	243	88	-	858	-	-	-	-	-	1.37	1.67	0.73	-
6	(A-2-4)35CDA	80	3	22.5E 6N	-	-	-	7.6	205	5.0	65	37	296	-	293	86	-	867	-	-	-	-	-	1.07	2.75	0.94	-
7	35DCC1	36	1	8287	22.8	-	-	7.6	423	-	116	48	429	-	451	-	-	-	-	-	-	-	-	1.47	3.18	0.68	-
8	35DCC2	66	1	8290	23.9	201	14.4	7.4	-150-		58	55	270	0.6	242	112	30	795	48	-	-	-	241	0.64	-	1.56	-
9	35AAB2	66	1	8336	31	300	33.3	7.7	-	-	86	30	225	0.3	166	114	-	-	-	-	-	-	402	1.74	-	0.57	-
10	35ABB	64	1	8337	27	305	19.7	7.9	-	-	56	46	170	0.3	150	82	-	748	-	-	-	-	304	0.74	-	1.35	-
11	(A-2-4)30CDD	54	1	8347	23.3	-	-	-	612	-	23	25	454	-	525	-	-	-	-	-	-	-	-	0.56	23.2	1.79	-
12	30DAA	36	1	8394	22.8	-	-	7.8	901	2.0	43	53	685	-	546	-	-	2870	-	-	54.3	-	-	0.49	18.3	2.03	-
13	30ACC	37	1	8412	24.4	-	-	8.1	543	2.0	48	55	294	-	381	-	-	1930	-	-	47.5	-	-	0.53	9.86	1.89	-
14	30ADA	37	1	8425	23.3	-	-	7.8	443	-	35	36	298	-	330	-	-	1490	-	-	-	-	-	0.59	11.0	1.70	-
15	(A-2-4)26CCD	80	3	22.3E 7N	-	-	-	8.1	158	3.0	70	40	228	-	262	132	-	779	-	-	-	-	-	1.06	1.97	0.94	-
16	25CDB	77	3	23.3E 7.3N	-	-	-	-	100	6.0	40	47	227	-	142	64	-	566	-	-	-	-	-	0.52	2.18	1.94	-
17	25BCD	74	3	23.3E 7.5N	-	-	-	7.9	94	-	41	38	193	-	157	46	-	497	-	-	-	-	-	0.65	2.00	1.53	-
18	25CDDA	66	1	8355	28	366	19.1	8.0	-	-	34	17	300	0.3	90	47	-	624	-	-	-	-	536	1.21	-	0.82	-
19	25CDB1	37	1	8360	24	-	-	7.7	269	1.0	54	22	287	-	336	-	-	956	-	-	23.3	-	-	1.49	4.34	0.67	-
20	25DCA	66	1	8363	32.2	367	30.5	7.9	-	-	38	16	170	0.2	168	29	-	443	-	-	-	-	455	1.44	-	0.69	-
21	25BCD	66	1	8419	36.7	395	39.7	8.2	-158-		50	32	295	0.6	148	60	34	703	54	-	-	-	263	0.95	-	1.05	*
22	25BCD	78	2	6	32.8	366	32.3	7.9	104	-	42	36	212	0.5	-	51	-	-	-	-	-	-	227	0.71	2.16	1.41	-
23	25BCD	81	5,2	(6)	-	-	-	7.8	130	4.0	41	40	246	0.5	151	64	30	610	48	-	56.7	52.4	264	0.62	2.76	1.61	-
24	25AAB	66	1	8436	32	404	27.2	8.0	-	-	35	20	185	0.3	170	29	-	425	-	-	-	-	330	1.06	-	0.94	-
25	25ABB	66	1	8437	33	366	32.8	8.0	-	-	24	19	95	0.3	198	16	-	317	-	-	-	-	170	0.77	-	1.30	-
26	25AAA	66	1	8440	32	366	30.1	7.9	-	-	28	15	215	0.3	132	32	-	482	-	-	-	-	384	1.13	-	0.88	-
27	(A-2-4)24BDA	81	3	23.5E 8.8N	-	-	-	8.0	150	5.0	34	25	260	-	117	43	-	595	-	-	-	-	-	0.83	3.84	1.21	-
28	24BAD	66	1	8506	29	396	20.2	7.5	-153-		29	26	260	0.7	130	37	23	593	37	-	-	-	199	0.68	-	1.48	-
29	24DBC	78	2	1	-	-	-	7.8	220	-	74	4	41	19.2	-	365	-	-	-	-	-	-	1.14	11.23	2.59	0.09	-
30	24CAB	78	2	2	31.1	381	26.5	8.2	151	-	25	14	234	0.8	-	36	-	-	-	-	-	-	157	1.08	5.26	0.92	-
31	(A-2-4)23DDD	66	1	8455	30	366	24.6	8.1	-	-	36	19	170	0.3	162	32	-	435	-	-	-	-	304	1.15	-	0.87	-
32	23BCC	80	3	22.1E 8.5N	-	-	-	7.6	86	2.0	23	17	122	-	139	38	-	369	-	-	-	-	-	0.82	3.26	1.22	-
33	(A-2-4)22DCC	75	3	21.5E 8N	-	192	-	7.5	155	-	154	116	314	-	222	484	-	1403	-	-	-	-	-	0.81	0.88	1.24	-
34	(A-2-4)19DDC	36	1	8456	22.2	-	-	7.7	283	3.0	80	36	238	-	308	-	-	1190	-	-	45.2	-	-	1.35	3.08	0.74	-
35	19CAA	54	1	8489	21.1	-	-	8.1	190	-	33	6	124	-	274	-	-	-	-	-	-	-	-	3.33	5.02	0.30	-
36	(A-2-4)14CDD	76	3	22.4E 9N	-	-	-	8.0	133	-	25	14	154	-	154	58	-	470	-	-	-	-	-	1.08	4.64	0.92	-
37	14BDD	36	1	8596	24	-	-	7.6	419	-	210	118	692	-	363	-	-	2450	-	-	-	-	-	1.08	1.74	0.93	-
38	14ABC	65	1	8605	31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
39	(A-2-4)13DBC	37	1	8573	22.8	-	-	7.6	297	-	77	40	312	-	430	-	-	1210	-	-	-	-	-	1.67	3.36	0.86	-
40	13CAA	66	1	8588	30	310	29.0	7.5	159	-	10	8.5	170	1.1	166	26	23	480	37	-	-	-	83	0.71	13.9	1.40	-
41	13CAA	75	3	23.5E 9.5N	-	-	-	8.4	154	2.0	11	4	153	-	160	25	-	429	-	-	-	-	-	1.67	12.2	0.60	-
42	13ADD	78	2	3	33.3	369	33.3	-	147	-	25	14	223	0.9	-	35	-	-	-	-	-	-	133	1.08	5.12	0.92	-
43	(A-2-4)12DDD	79	2	4	35.6	427	34.2	8.9	148	-	2.6	0.7	104	1.3	-	14	-	-	-	-	-	55.7	43	2.25	49.6	0.44	-
		81	5					8.4	109	0.6	1.7	0.5	42	1.4	220	14	31	270	49		62.4		16	2.06	55.9	0.48	
44	12BCA	78	2	5	36.1	297	50.8	8.8	146	-	5	2.0	86	1.4	-	27	-	-	-	-	-	-	33	1.52	25.4	0.66	*
45	12DAA1	37	1	8674	24	-	-	7.7	117	-	34	23	117	-	256	-	-	500	-	-	-	-	-	0.90	3.00	1.11	-
46	12BDD2	57	1	8721	33.3	-	-	8.2	107	-	14	12	72	-	213	-	-	-	-	-	-	-	-	0.71	6.66	1.41	-
47	(A-2-4)11DCC	75	3	22.5E 10N	-	-	-	7.0	35	3.0	24	21	24	-	214	12	-	234	-	-	-	-	-	0.69	1.27	1.44	-
48	11BBA	73	1	8752	29	-	-	8.2	71	4.3	9	5	14	0.7	213	-	15	-	20	52.7	41.2	47.0	10.7	1.11	6.87	0.92	-
49	11DCC2	66	1	8630	30	-	-	7.7	-	-	118	88	41	-	218	-	34	-	54	-	-	-	-	0.81	-	1.23	-
50	11ACC	36	1	8716	22.2	-	-	7.8	168	-	50	49	241	-	293	-	-	822	-	-	-	-	-	0.62	-	1.62	-
51	11CBC	66	1	8664	31	280	35.7	7.5	-20-		26	20	26	0.4	170	17	37	231	57	-	-	-	35	0.79	-	1.27	-
52	(A-2-4) 2ACD	78	2	12	36.6	549	28.4	8.1	38	-	24	22	19	0.4	-	9	-	-	-	-	-	-	25	0.66	1.38	1.51	-
53	2CDD	78	2	14	33.3	340	36.2	8.2	36	-	29	17	23	0.4	-	41	-	-	-	-	-	-	31	1.04	1.08	0.97	*
54	(A-2-4) 1DDD	78	2	9	29.4	149	56.2	8.6	190	-	10	3	202	0.4	-	68	-	-	-	-	-	-	271	2.02	16.6	0.49	-
55	1DAA	78	2	10	29.4	152	55.1	8.3	155	-	14	4	147	0.4	-	57	-	-	-	-	-	-	197	2.12	9.65	0.47	-
		81	5		-			7.4	161	1.2	5	2	136	0.5	146	40	25	420	40		63.6		146	1.52	28.1	0.66	
56	1CBA	78	2	11	37.8	290	58.0	8.1	59	-	23	15	32	0.5	-	9	-	-	-	-	-	-	34	0.93	2.24	1.07	*
57	(A-2-5) 6ACB	66	1	8793	29	152	52.6	8.1	-118-		7.2	3.2	76	0.8	188	23	24	-	38.7	-	-	-	51	1.37	-	0.73	-
58	(A-3-4)33ACC	73	1	8566	29	-	-	8.1	42	6.2	18	17	9	0.6	246	-	21	-	33	-	75.8	-	8	0.64	2.03	1.56	-
59	(A-3-4)27BBA	78	2	23	35.6	335	43.5	8.0	140	-	30	24	34	0.5	-	9	-	-	-	-	-	-	36	0.35	4.07	1.32	*
		81	5		-			7.8	40	2.5	16	28	36	0.5	227	15	50	240	72		48.5		39		2.18	2.88	
60	(A-3-4)25BBC	75	1	8887	42	-	-	8.2	94	2.7	3.5	0.4	24	0.8	199	-	20	-	31	63.4	93.4	78.4	16	5.31	23.4	0.19	-
61	(A-3-4)24CAA	78	2	17	-	-	-	8.3	53	-	16	13	11	1.2	-	12	-	-	-	-	-	-	5	0.75	2.89	1.34	-
62	(A-3-4)21ADA	80	2	32	26.9	526	11.2	7.8	37	-	19	28	34	0.5	-	8	-	-	-	-	-	57.4	36	0.41	1.70	2.42	-
		81	1		-			7.8	40	2.8	16	28	26	0.6	232	11	41	260	62		52.8		23	0.35	2.18	2.88	
63	(A-3-4)21BAA	58	1	8929	30	-	-	-	51	1.5	9.5	12	12	0.6	193	-	26	218	42	-	49.1	45.6	11	0.49	4.68	2.08	-
64	(A-3-4)11CCC	79	2	29	27.2	518	12.2	8.1	45	-	17	25	28	0.5	-	8	-	-	52	-	51.5	51.8	30	0.41	2.31	2.42	-
		81	5		-			8.0	45	2.3	15	23	32	0.6	227	14	33	220					29	0.40	2.61	2.52	
65	11AAB	79	2	7	37.8	590	28.5	7.9	47	-	41	18	32	0.4	-	10	-	-	-	-	-	-	43	1.38	1.00	0.72	-
66	(A-3-4) 5BCB	73	1	9018	28	-	-	8.1	44	3.8	12	11	12	0.4	185	-	11	-	9	42	70.1	-	16	0.67	3.19	1.51	-
67	(A-3-4) 2BBC	79	2	27	33.3	528	23.3	7.9	43	-	26	25	36	0.5	-	12	-	-	60	-	47.3	53.7	39	0.63	1.44	1.58	-
		81	5		-			7.5	44	2.7	23	24	52	0.5	220	17	39	280					56	0.58	1.67	1.72	
68	2CAD	79	2	28	35.6	530	27.5	7.8	46	-	26	26	32	0.4	-	12	-	-	-	-	-	-	43	0.61	1.54	1.65	-
69	2DAA	79	2	30	-	-	-	7.9	50	-	30	27	50	0.5	-	13	-	-	-	-	-	-	54	0.67	1.45	1.48	-
70	(A-3-5)28ABB	81	5	E-R1	-	-	-	8.2	86	3.4	12	10	44	1.7	210	20	38	300	59	-	73.7	-	14	0.73	6.24	1.37	
71	28ADD	78	2	20	33.9	274	47.0	7.9	77	-	34	16	66	0.5	-	21	-	-	66	-	55.7	60.9	71	1.29	1.97	0.77	*
		81	5		-			8.1	84	3.2	25	17	68	0.5	242	26	44	320					73	0.89	2.92	1.12	
72	(A-3-5)26CDC	78	2	19	33.3	244	50.4	7.8	59	-	51	10	52	1.1	-	22	-	-	-	-	-	-	25	3.09	1.01	0.32	*
		81	5		-			8.0	64	2.4	42	12	56	1.1	232	26	50	320	72		36		27	2.12	1.33	0.47	
73	(A-3-5)19ADB2	66	1	8916	30	353	25.5	7.5	-63-		28	18	48	0.9	242	12	39	328	60	-	-	-	29	0.94	-	1.06	-
74	19DAC	78	2	18	35.6	488	29.9	8.3	71	-	18	10	37	1.2	-	10	-	-	56	-	72.6	-	17	1.09	3.44	0.92	-
		81	5		-			7.6	75	3.8	14	13	42	1.0	225	13	36	270					23	0.65	4.67	1.53	
75	19ABB	78	2	21	31.1	186	54.3	8.0	44	-	35	17	25	0.8	-	9	-	-	-	-	-	-	17	1.25	1.10	0.80	-
76	19AA	78	2	22	31.1	353	28.6	8.0	47	-	38	17	38	0.8	-	10	-	-	60	-	50.0	55.0	25	1.36	1.08	0.74	-
		81	5		-			7.9	46	3.1	25	20	42	0.8	239	13	39	270					28	0.76	1.60	1.32	
77	(A-4-4)35BCB	78	2	31	-	-	-	7.7	110	-	54	48	230	0.8	-	81	-	-	-	-	-	-	154	0.68	1.77	1.46	-
78	(A-4-4)32BAD	53	1	9069	30.6	-	-	-	-	-	25	31	23	0.3	222	-	35	-	55	-	-	-	41	0.49	-	2.04	-
79	(A-4-4)26A?	80	2	33	32.8	460	25.7	7.8	57	-	41	24	70	0.8	-	16	-	-	-	-	-	-	47	1.04	1.21	0.96	-
80	(A-4-5)14DAC	76	1	9311	20	-	-	7.6	69	3.2	94	15	49	4.0	325	-	32	-	51	-	30.5	-	7	3.80	0.64	0.26	-
81	(A-2-4)1ACC	81	2	13	50.0	549	52.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*

thermal waters is largely a function of the temperature dependent solubility of the silica species being dissolved. Fournier and Row (1966) proposed a method of estimating subsurface temperatures in hot aquifers based on the concentration of silica in thermal water, assuming that there is equilibration of dissolved silica with quartz minerals in high-temperature aquifers and that this silica concentration is largely preserved as the thermal water flows to the surface. Their method appears to be the most accurate and useful for reservoir fluids in the temperature range of 150 to 225°C (Fournier, 1977). Arnorsson (1970, 1975) found that chalcedony rather than quartz generally controls the silica concentration in Iceland's thermal waters when reservoir temperatures are below 100-110°C. Between 110-150°C either species can be the controlling factor.

The sodium-potassium-calcium geochemical thermometer was devised by Fournier and Truesdell (1973) to estimate aquifer temperatures based on the molal concentrations of Na, K, and Ca in the thermal waters. Fournier and Potter (1978) devised a method to correct the Na-K-Ca temperature for the effects of magnesium.

Many basic assumptions are made in using the geochemical thermometers to estimate subsurface temperatures. These were discussed in detail by Fournier, White, and Truesdell (1974) who emphasized that it is unlikely that all assumptions will be fulfilled everywhere. The basic assumptions are: (1) the chemical reactions are temperature dependent; (2) there is an adequate supply of all reactants; (3) water-rock equilibrium occurs at the reservoir temperature; (4) hot water ascends rapidly to the surface so no re-equilibration of the "indicator" constituents occurs; and (5) thermal and nonthermal waters do not mix during flow to the surface or evaluation of such mixing is possible. These assumptions usually cannot be verified in the field so that geochemical thermom-

eters must be applied with caution and with a full understanding of the uncertainties involved.

Chemical geothermometers applied to low-temperature waters are generally less reliable than when applied to high-temperature waters. This is especially true for geochemical temperatures that are below 125°C, as well as those that differ between the two methods by more than about 20°C (Renner, White, and Williams, 1975). Some of the reasons for unreliable, low-temperature estimates include possible mixing of thermal and nonthermal water, non-equilibrium chemical reactions (Fournier, 1981; Sammel, 1979), and the possibility that silica concentrations are a function of high CO_2 concentrations, not high subsurface temperatures (Brooks and others, 1979).

Fournier (1981) pointed out that some low-temperature ground waters have equilibrated with chalcedony rather than quartz. We calculated chalcedony geothermometers for 28 wells for which a silica analysis was available, and Na-K-Ca geothermometers for 24 wells having an analysis for these three constituents (Table 5). Of these wells, only 19 had complete analyses that allowed calculation of both geothermometers. Ten of the 19 wells have geochemical temperatures that differ between the two methods by less than 15°C (Table 5). In all cases the chemical geothermometers indicate subsurface temperatures in the range of 45 to 60°C. The ten geotemperatures together have a mean value of 53.1 ± 4.4°C.

Qualitative geothermometers were also calculated and evaluated (Table 4). These methods include low ratios of magnesium to calcium (White, 1970) and high ratios of sodium to calcium and chloride to fluoride (Mahon, 1970). With few exceptions, these qualitative geothermometers are in the same range as values calculated for normal ground water in the southern Basin and Range province of Arizona and New Mexico.

Table 5. Measured and geochemical temperatures of wells in the Scottsdale area

Well No. This Report	Location	T_{SiO_2} (°C)	$T_{Na-K-Ca}$ (°C)	T_{ave} (°C)	T_{meas} (°C)
2	(A-1-4) 2DDB	56.0	53.1	54.6	-
23	(A-3-4) 25BCD	48.0	56.7	53.4	-
62	21ADA	62.0	52.8	54.7	26.9
63	21BAA	42.0	49.1	45.6	30.0
64	11CCC	52.0	51.5	51.8	27.2
71	(A-3-5) 28ADD	66.0	55.7	60.9	33.9
43	(A-2-4) 12DDD	49.0	62.4	55.7	35.6
76	19AA	60.0	50.0	55.0	31.1
48	11BBA	52.7[1]	41.2[2]	47.0	29.0
67	(A-3-4) 2BBC	60.0	47.3	53.7	33.3

[1]quartz geothermometer

[2]Mg correction applied

Conclusions and Recommendations

Warm-water wells that meet our criteria for being "thermal" exist in the Scottsdale area. Specifically, these wells occur within the major fault zones of Paradise Valley, which have been identified by gravity studies. It is our conclusion that the thermal fluids originate from deep circulation of ground water along Basin and Range faults. After heating, the fluids rise along permeable segments of the fracture zones. When the thermal fluids encounter cold ground water in the basin alluvium, mixing of the two fluids produces warm water with temperatures in the 45 to 60°C range. Hydrothermal convection systems are initiated and the mixed warm water is carried to shallower depths (the top of the convective cell) where it is intercepted by local domestic and irrigation wells.

Drilling to moderate depths of about 1 km (3200 ft) is not likely to encounter water with temperatures much greater than about 60°C. This is because temperatures at the bottom of a convection system are about the same as temperatures at the top. Furthermore, mixing is likely to occur at depths of 1 km or greater, so that the thermal fluids will already have been diluted. Drilling in the fault zones to depths of 2 or 3 km may penetrate fractured bedrock and intercept the geothermal fluids before they mix with cold ground water.

We recommend calculating geochemical mixing models to ascertain whether mixing is in fact occurring. Possible maximum temperatures of the geothermal fluid may be predicted by this method. In addition we recommend a detailed gravity survey of central Paradise Valley to precisely locate the fault zones and to ascertain whether a northeast-trending fault exists that intersects the two northwest-trending range-bounding faults. The intersection of two such faults would create greater fracture permeability that would allow migration of thermal fluids towards the surface.

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APPENDIX A

Chemical Analyses

City of Scottsdale Wells

Arizona Testing Laboratories

817 West Madison • Phoenix, Arizona 85007 • Telephone 254-6181

For: University of Arizona
Bureau of Geology & Mineral Technology
Geological Survey Branch
Geothermal Group
2045 North Forbes, Suite 106
Tucson, Arizona 85717
Attn: Ms. Claudia Stone

Date: July 23, 1981

Lab. No.: 2594

UofA Account No. 875198

Samples of Water received 7-20-81, submitted by City of Scottsdale, Mr. Jim Nelson

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REPORT OF WATER TESTS

	East Ranch #1	Well #32	Well #20	Well #18	Well #25
Total Dissolved Solids @180°C	300	260	320	270	730 mg/L
Potassium	3.4	2.8	3.2	3.8	4.0
Silica	38	41	44	36	36
Calcium	12	16	25	14	48
Magnesium	10	28	17	13	61
Sodium	86	40	84	75	124
Chloride	44	26	68	42	236
Bicarbonate	210	232	242	225	229
Sulphate	20	11	26	13	98
Fluoride	1.7	0.6	0.5	1.0	0.4
pH	8.2	7.8	8.1	7.6	7.8

Respectfully submitted,

ARIZONA TESTING LABORATORIES

Steven Hankins

Steven Hankins

Arizona Testing Laboratories

817 West Madison • Phoenix, Arizona 85007 • Telephone 254-6181

For: University of Arizona
Bureau of Geology & Mineral Technology
Geological Survey Branch
Geothermal Group
2045 North Forbes, Suite 106
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---

REPORT OF WATER TESTS

	Well #23	Well #19	Well #4	Well #27	Well #6
Total Dissolved Solids @180°C	240	320	270	280	610 mg/L
Potassium	2.5	2.4	0.6	2.7	4.0
Silica	50	50	31	39	30
Calcium	16	42	1.7	23	41
Magnesium	28	12	0.5	24	40
Sodium	40	64	109	44	130
Chloride	36	56	42	52	246
Bicarbonate	227	232	220	220	151
Sulphate	15	26	14	17	64
Fluoride	0.5	1.1	1.4	0.5	0.5
pH	7.8	8.0	8.4	7.5	7.8

Respectfully submitted,

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---

REPORT OF WATER TESTS

	Well #29	Well #22	Well #10
Total Dissolved Solids @180°C	220	270	420
Potassium	2.3	3.1	1.2
Silica	33	39	25
Calcium	15	25	5.0
Magnesium	23	20	2.0
Sodium	45	46	161
Chloride	32	42	136
Bicarbonate	227	239	146
Sulphate	14	13	40
Fluoride	0.5	0.8	0.5
pH	8.0	7.9	7.4

Respectfully submitted,

ARIZONA TESTING LABORATORIES

Steven Hankins

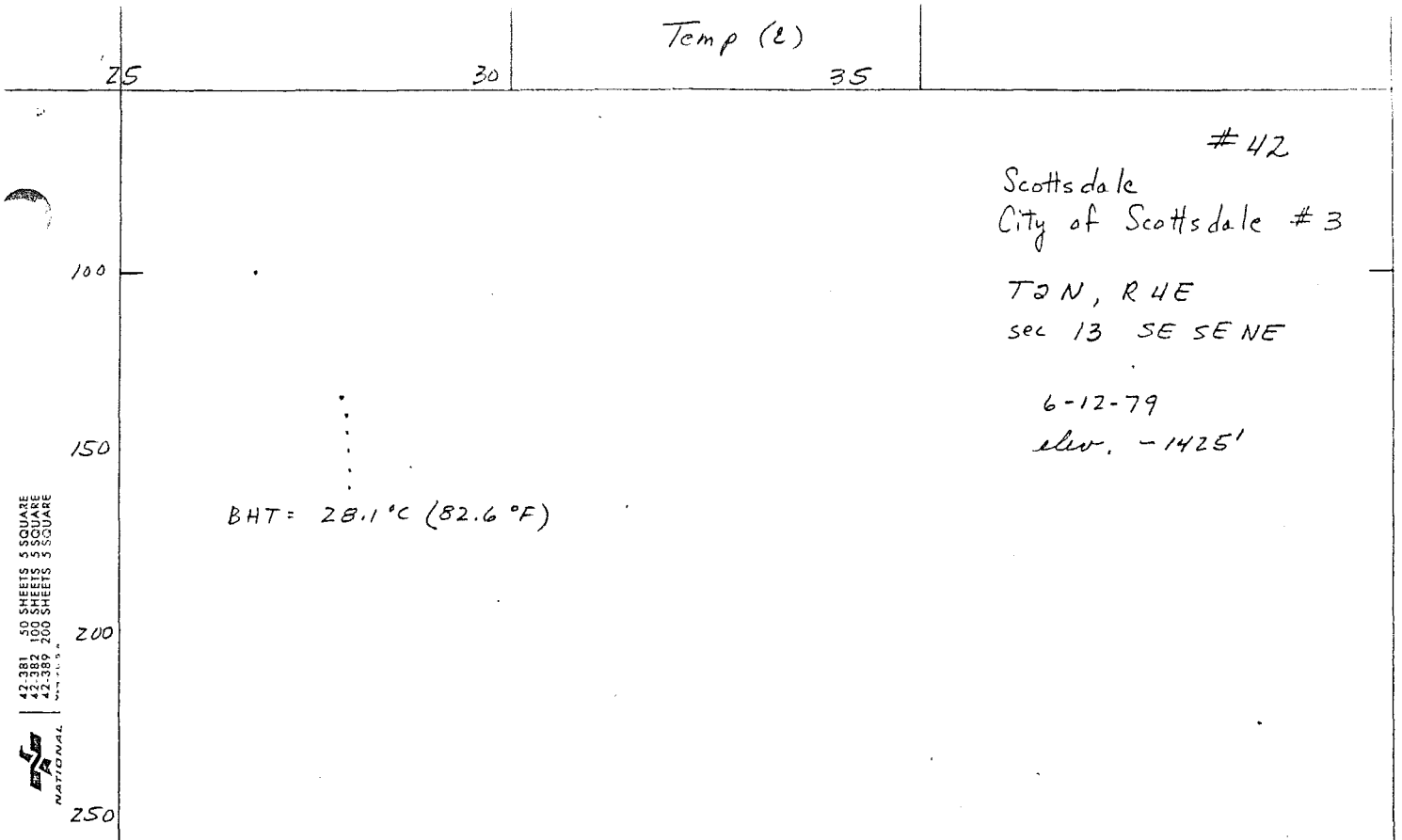
Steven Hankins

cc: City of Scottsdale
Mr. Jim Nelson
Water Utilities Dept.

APPENDIX B

Raw Well-Temperature Data

City of Scottsdale Wells


Temp (c)
25
30
35
100
150
200
250
BHT = 28.1 °C (82.6 °F)
#42
Scottsdale
City of Scottsdale #3
T2N, R4E
sec 13 SE SE NE
6-12-79
elev. -1425'

DATE: 6/12/79 HOLE NO.: #3 LOCATION: T2N, R 4E Sec 13 SE

40 m
2.67

DEPTH (METERS)	RESIST. (K-OHM)	TEMP. (°C)	GRADIENT (°C/KM)	DEPTH (METERS)	RESIST. (K-OHM)	TEMP. (°C)	GRADIENT (°C/KM)
R-Y 95 water	80.07 ↓ 79.99						
R 100	76.27	26.82					
① Y 105	76.04 75.84						
110	75.77 75.65						
115	75.25 75.10						
120	75.16 75.09						
① 125	74.56 73.99						
R 130	90 72.84						
② 135	72.79	28.07	35.7				
140	72.68	28.11	8.0				
eY 145	72.69	28.105	-1.0				
R 150	72.68	28.11	1.0		28.07°C	135 m	
Y 155	72.66	28.12	2.0		26.82	100 m	
160	72.66	28.12	0		1.25°C 35 m	35 m	
Y 165	72.65	28.12	0				
170							
③							

COMMENTS: Cable 1306

* well has cascading under because of Break in Casing

① Rapid Rise + Fall

② Very minor Rise + Fall in Readings

③ current too strong cable wrapping around (dare not weight down)

25 30 35 40

#61

Scottsdale
City of Scottsdale #17

T 3 N, R 4 E
sec 24 NE NE SW

7-16-81
elev ~ 1360'

100

150

B.H.T. = 30.0 °C (86.0 °F)

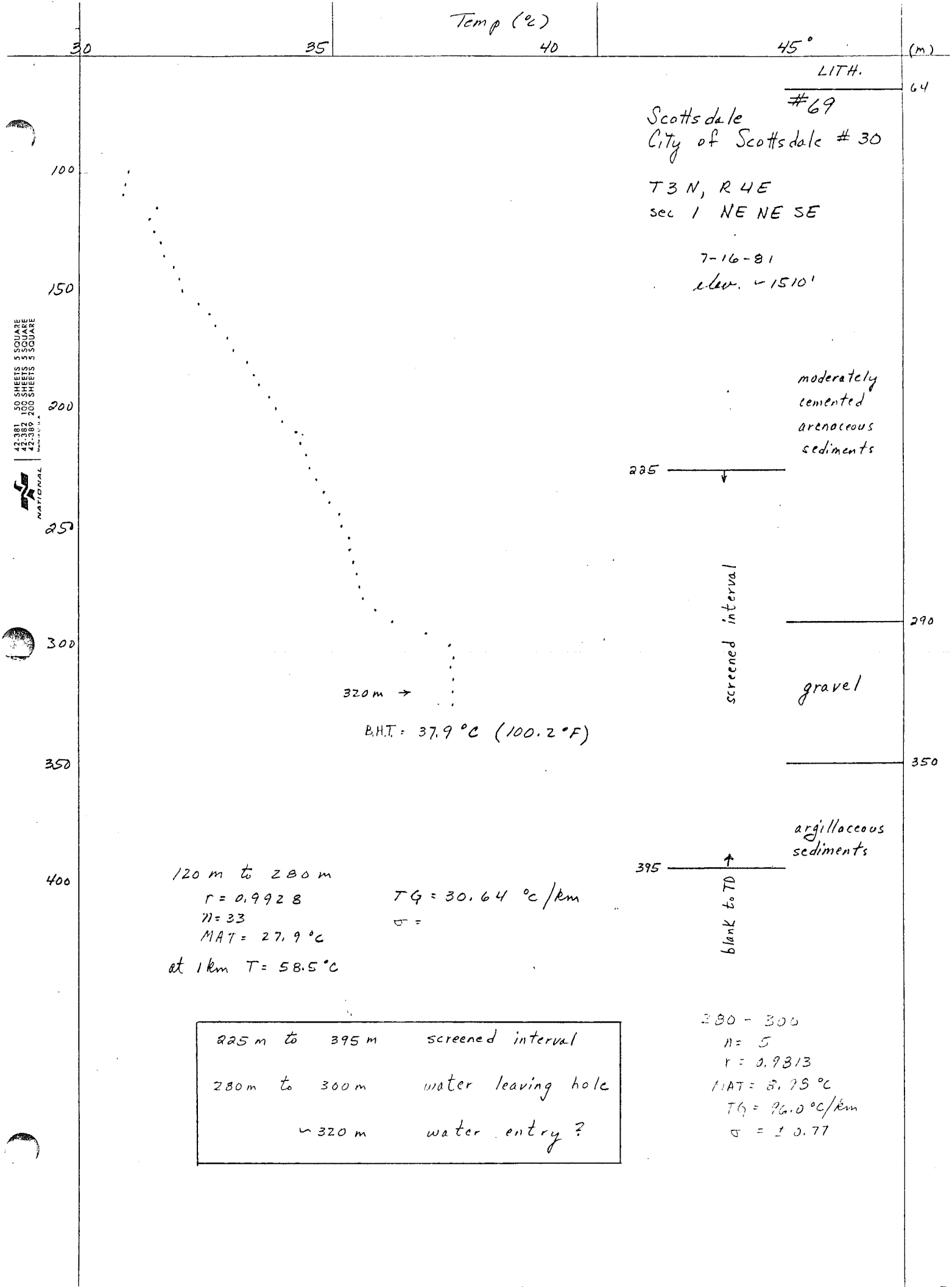
200

42-381 50 SHEETS 5 SQUARE
42-382 100 SHEETS 5 SQUARE
42-389 200 SHEETS 5 SQUARE
NATIONAL

DATE: 7-16-81 | HOLE NO.: Scottsdale #17 | LOCATION: T3N, R4E, sec 24

DEPTH (METERS)	RESIST. (K-OHM)	TEMP. (°C)	GRADIENT (°C/KM)	DEPTH (METERS)	RESIST. (K-OHM)	TEMP. (°C)	GRADIENT (°C/Km)
95	68.61	30.08					
100	68.64	30.07	-2.0				
105	68.84	29.99	-16.0				
110	68.91	29.96	-6.0				
115	68.53	30.11	30.0				
120	68.69	30.05	-12.0				
125	68.65	30.06	2.0				
130	68.72	30.04	-4.0				
135	68.73	30.03	-2.0				
140	68.85	29.98	-10.0				
145	68.85	Hung up					
95	71.12 and climbing						

COMMENTS: TD = 1280' (~390m)


Temp (°C)
30
35
40
45°
(m)
LITH.
64
#69
Scottsdale
City of Scottsdale # 30
T 3 N, R 4 E
sec 1 NE NE SE
7-16-81
elev. ~1510'
100
150
200
250
300
350
400
moderately cemented arenaceous sediments
225
screened interval
290
gravel
350
argillaceous sediments
395
blank to TD
320 m
B.H.T. = 37.9 °C (100.2 °F)
120 m to 280 m
r = 0.9928
n = 33
MAT = 27.9 °C
at 1 km T = 58.5 °C
TG = 30.64 °C/km
σ =
225 m to 395 m screened interval
280 m to 300 m water leaving hole
~320 m water entry ?
280 - 300
n = 5
r = 0.9813
MAT = 8.78 °C
TG = 96.0 °C/km
σ = ± 0.77

DATE: 7-16-81 | HOLE NO.: Scottsdale #30 | LOCATION: T3N, R4E NE NE SE sec 1 | PA 1

DEPTH (METERS)	RESIST. (K-OHM)	TEMP. (°C)	GRADIENT (°C/KM)	DEPTH (METERS)	RESIST. (K-OHM)	TEMP. (°C)	GRADIENT (°C/Km)
100 m	66.25 x	31.02		210	57.90	34.60	44.0
105	66.39 x	30.96	-12.0	215	57.76	34.66	12.0
110	66.55	30.90	-12.0	220	57.44	34.81	30.0
115	64.65	31.67	154.0	225	57.23	34.91	20.0
120	65.07	31.50	-34.0	230	56.86	35.08	34.0
125	64.78	31.62	24.0	235	56.62	35.19	22.0
130	64.43	31.76	28.0	(787') 240	56.33	35.32	26.0
135	64.15	31.88	24.0	245	55.86	35.55	46.0
140	63.75	32.04	32.0	250	55.76	35.59	8.0
145	63.55	32.13	18.0	255	55.45	35.74	30.0
150	63.30	32.23	20.0	260	55.42	35.75	2.0
155	62.62	32.52	58.0	265	55.18	35.87	24.0
160	62.04	32.77	50.0	270	55.10	35.91	8.0
165	61.73	32.90	26.0	275	54.97	35.97	12.0
170	61.07	33.19	58.0	280	54.85	36.03	12.0
175	60.85	33.28	18.0	285	54.53	36.18	30.0
180	60.25	33.54	52.0	290	53.52	36.67	98.0
185	59.83	33.73	38.0	295	52.06	37.40	146.0
190	59.49	33.88	30.0	300	51.24	37.82	84.0
195	59.12	34.05	34.0	305	51.05	37.92	20.0
200	58.73	34.22	34.0	310	51.08	37.90	-4.0
205	58.37	34.38	32.0	315	51.05	37.92	4.0

+2 ft.

x questionably

COMMENTS: Drilled 11/79 Cable resist .0710

TD = 1420' (35.5°C)

static w.l. = 346' At T > 96°F water contains

casing reduction at 735' high F, Cr, As

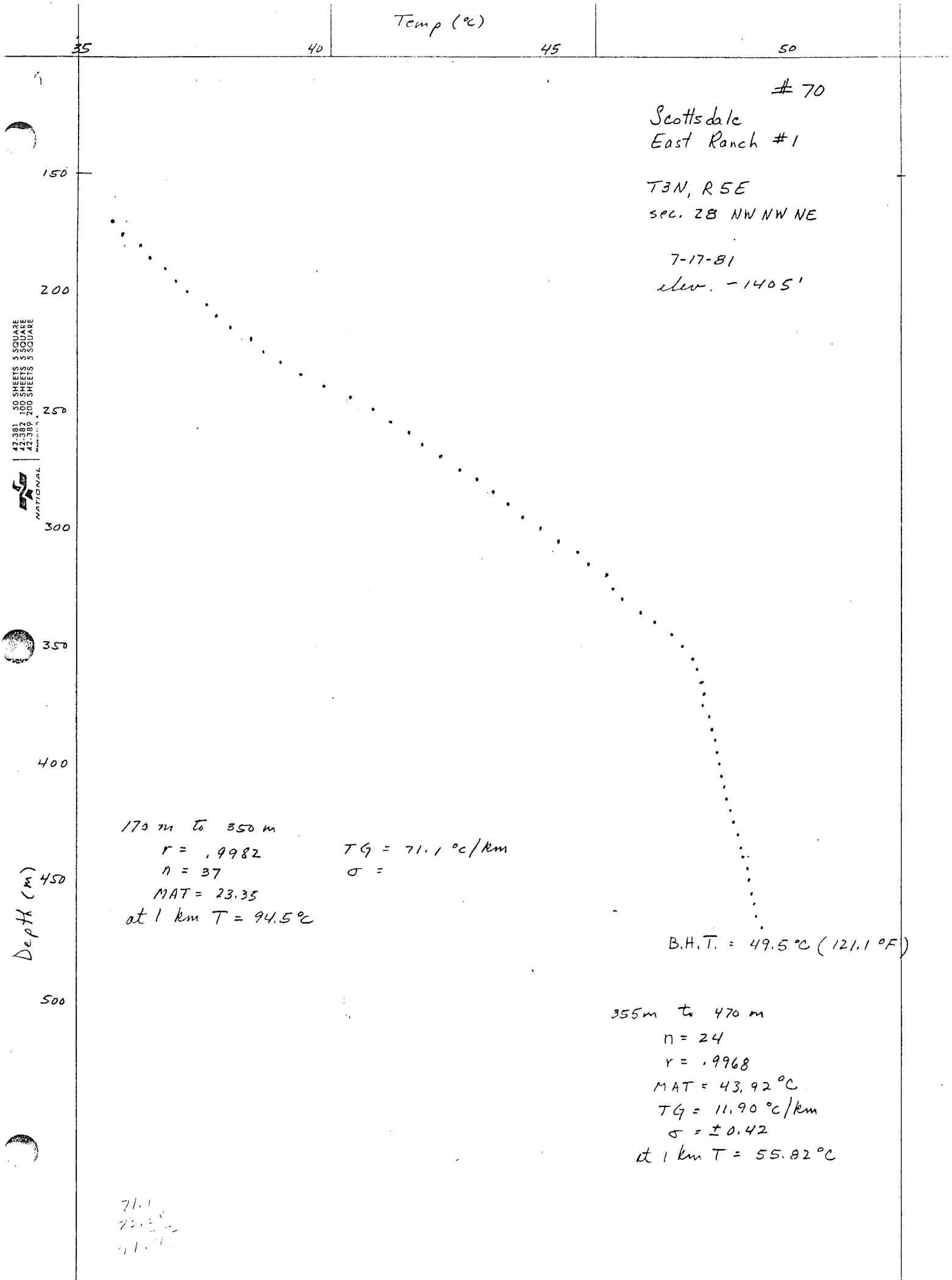
screened 735 to 1295'

blank casing to 1315' (400 m)

DATE: 7-16-81 | HOLE NO.: Scottsdale #30 | LOCATION: T3N, R4E SEC1 NE NE SE | PA 2

DEPTH (METERS)	RESIST. (K-OHM)	TEMP. (°C)	GRADIENT (°C/KM)	DEPTH (METERS)	RESIST. (K-OHM)	TEMP. (°C)	GRADIENT (°C/Km)
320	51.05	37.92	0				
325	51.05	37.92	0				
330	51.05	37.92	0				
335	51.05	37.92	0				

COMMENTS:


Temp (°c)
35
40
45
50
150
200
250
300
350
400
450
500
Depth (m)
70
Scottsdale
East Ranch #1
T3N, R5E
sec. 28 NW NW NE
7-17-81
elev. -1405'
170 m to 350 m
r = .9982
n = 37
MAT = 23.35
at 1 km T = 94.5°c
TG = 71.1 °c/km
σ =
B.H.T. = 49.5 °C (121.1 °F)
355m to 470 m
n = 24
r = .9968
MAT = 43.92 °C
TG = 11.90 °c/km
σ = ± 0.42
at 1 km T = 55.82 °C
71.1

DATE: 7-17-81 | HOLE NO.: #1 Cave Ranch 106th + Shea | LOCATION: Scottsdale | PR 1

DEPTH (METERS)	RESIST. (K-OHM)	TEMP. (°C)	GRADIENT (°C/KM)	DEPTH (METERS)	RESIST. (K-OHM)	TEMP. (°C)	GRADIENT (°C/Km)
170	55.40	35.76		270	42.43	42.76	64.0
175	54.92	35.99	46.0	275	41.82	43.14	76.0
180	54.24	36.32	66.0	280	41.26	43.50	72.0
185	53.74	36.57	50.0	285	40.73	43.83	66.0
190	53.12	36.87	60.0	290	40.19	44.18	70.0
195	52.60	37.13	52.0	295	39.70	44.50	64.0
200	52.05	37.41	56.0	300	39.00	44.97	94.0
205	51.33	37.77	72.0	305	38.58	45.25	56.0
210	50.96	37.96	38.0	310	38.09	45.59	68.0
215	50.36	38.27	62.0	315	37.69	45.87	56.0
220	49.56	38.69	84.0	320	37.29	46.14	54.0
225	49.02	38.98	58.0	325	36.91	46.41	54.0
230	48.38	39.33	70.0	330	36.56	46.66	50.0
235	47.58	39.76	86.0	335	36.10	47.00	68.0
240	~~47.19~~			340	35.71	47.28	56.0
245	46.68	40.26	100.0	345	35.26	47.61	66.0
250	45.66	40.84	116.0	350	34.96	47.84	46.0
255	44.91	41.28	88.0	355	34.62	48.09	50.0
260	44.30	41.63	70.0	360	34.50	48.19	20.0
265	43.53	42.09	92.0	365	34.37	48.29	20.0
~~270~~	42.96	42.44	70.0	370	34.23	48.39	20.0

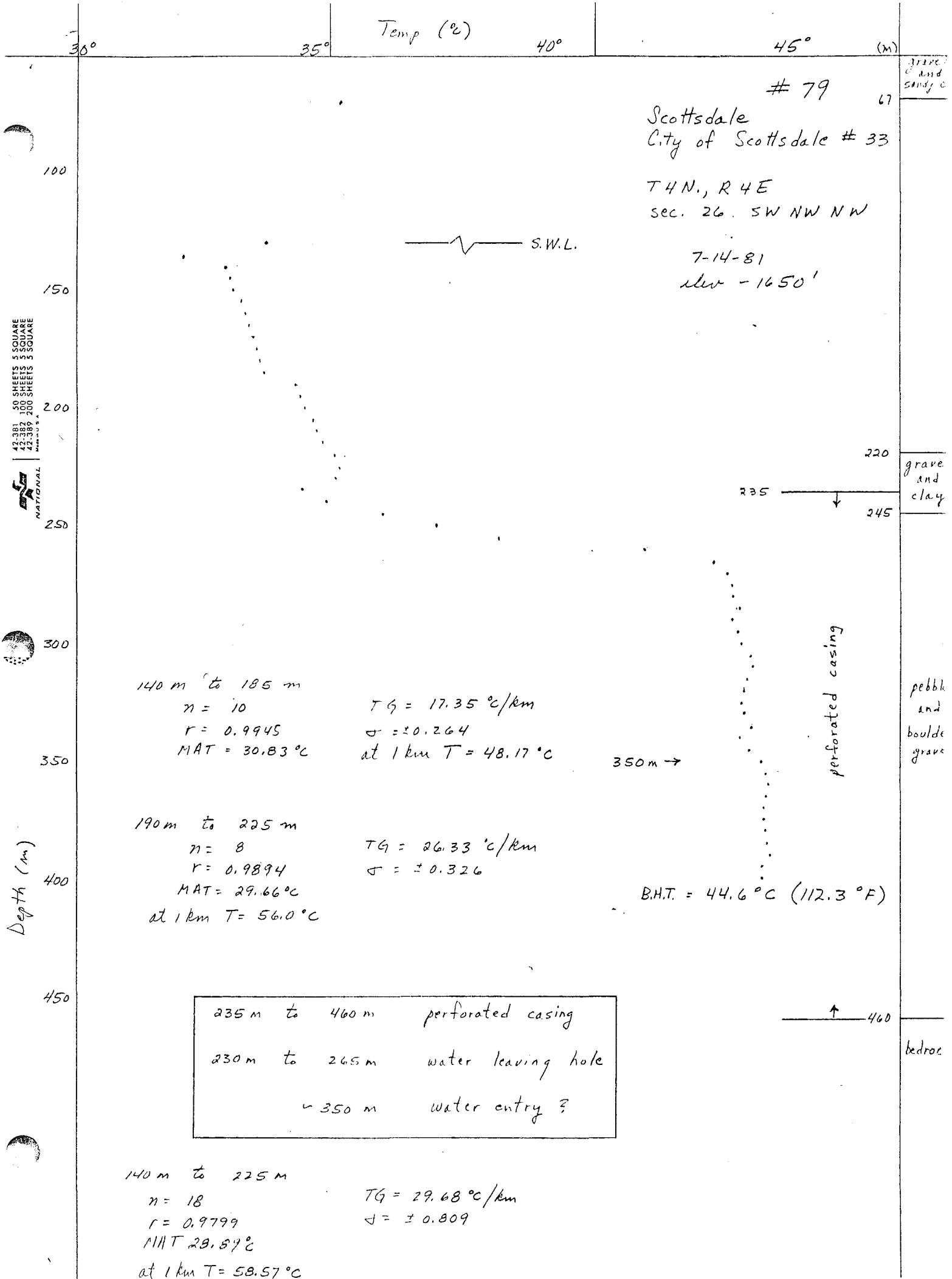
COMMENTS: ~180 m to water - 470 m TD

Cable resist .0741

DATE: 7-17-81 | HOLE NO.: East Ranch #1 106th & Shea | LOCATION: Scottsdale | PA 2

DEPTH (METERS)	RESIST. (K-OHM)	TEMP. (°C)	GRADIENT (°C/KM)		DEPTH (METERS)	RESIST. (K-OHM)	TEMP. (°C)	GRADIENT (°C/Km)
375	34.16	48.45	12.0					
380	34.11	48.47	8.0					
385	34.09	48.50	2.0					
390	34.04	48.54	8.0					
395	33.99	48.58	8.0					
400	33.88	48.66	16.0					
405	33.86	48.68	4.0					
410	33.74	48.77	18.0					
415	33.69	48.81	8.0					
420	33.59	48.89	16.0					
425	33.48	48.98	18.0					
430	33.38	49.05	14.0					
435	33.33	49.09	8.0					
440	33.23	49.17	16.0					
445	33.14	49.24	14.0					
450	33.09	49.28	8.0					
455	33.01	49.35	14.0					
460	32.95	49.40	10.0					
465	32.88	49.45	10.0					
470	32.80	49.52	14.0					

COMMENTS:



79

Scottsdale
City of Scottsdale # 33

T4N., R4E
sec. 26. SW NW NW

7-14-81
elev -1650'

DATE: 7-14-81 | HOLE NO.: Scottsdale #33 | LOCATION: T4N, R.4E, SWNWNW sec 26 | PAG 1

	DEPTH (METERS)	RESIST. (K-OHM)	TEMP. (°C)	GRADIENT (°C/KM)	DEPTH (METERS)	RESIST. (K-OHM)	TEMP. (°C)	GRADIENT (°C/Km)
air	70 m	55.75	35.60	-306.0	235	57.38	34.84	-136.0
?	130 m	59.07	34.07	-330.0	(787') 240	56.25	35.36	104.0
?	135	63.45	32.17	210.0	245	53.78	36.55	238.0
?	140	60.00	33.22	22.0	250	51.51	37.68	226.0
?	145	60.74	33.33	20.0	255	49.91	39.04	272.0
	150	60.51	33.43	24.0	260	43.40	42.17	626.0
water	155	60.24	33.55	22.0	265	41.25	43.58	242.0
	160	59.98	33.66	6.0	270	40.70	43.85	54.0
	165	59.92	33.69	16.0	275	40.50	43.98	26.0
	170	59.75	33.77	16.0	280	40.49	43.99	2.0
	175	59.55	33.85	22.0	285	40.29	44.12	26.0
	180	59.31	33.96	10.0	290	40.57	43.98	-28.0
	185	59.19	34.01	140.0	295 ~~300~~	40.32	44.10	24.0
✓	190	57.65	34.71	16.0	300 ~~305~~	40.18	44.19	18.0
✓	195	57.48	34.79	22.0	305 ~~310~~	39.81	44.43	48.0
	200	57.24	34.90	38.0	310 ~~315~~	39.75	44.47	8.0
	205	56.83	35.09	6.0	315 ~~320~~	39.87 ~~40.~~	44.39	-16.0
	210	56.76	35.12	34.0	320	39.89	44.38	-2.0
	215	56.40	35.29	48.0	325	~~39.~~ 40.14	44.22	-32.0
	220	55.90	35.53	12.0	330	39.99	44.31	18.0
	225	55.76	35.59	-14.0	335	39.78	44.45	28.0
	230	55.91	35.52	-136.0	340	40.26	44.14	-62.0

COMMENTS: Jim Nelson 956-4182 (home)

Probe 1 Spafford — Cable resist .0728

depth ≈1500' — Red + yellow first mark = 20 m

(≈ 470 m) — Most readings are rough as K ohm not

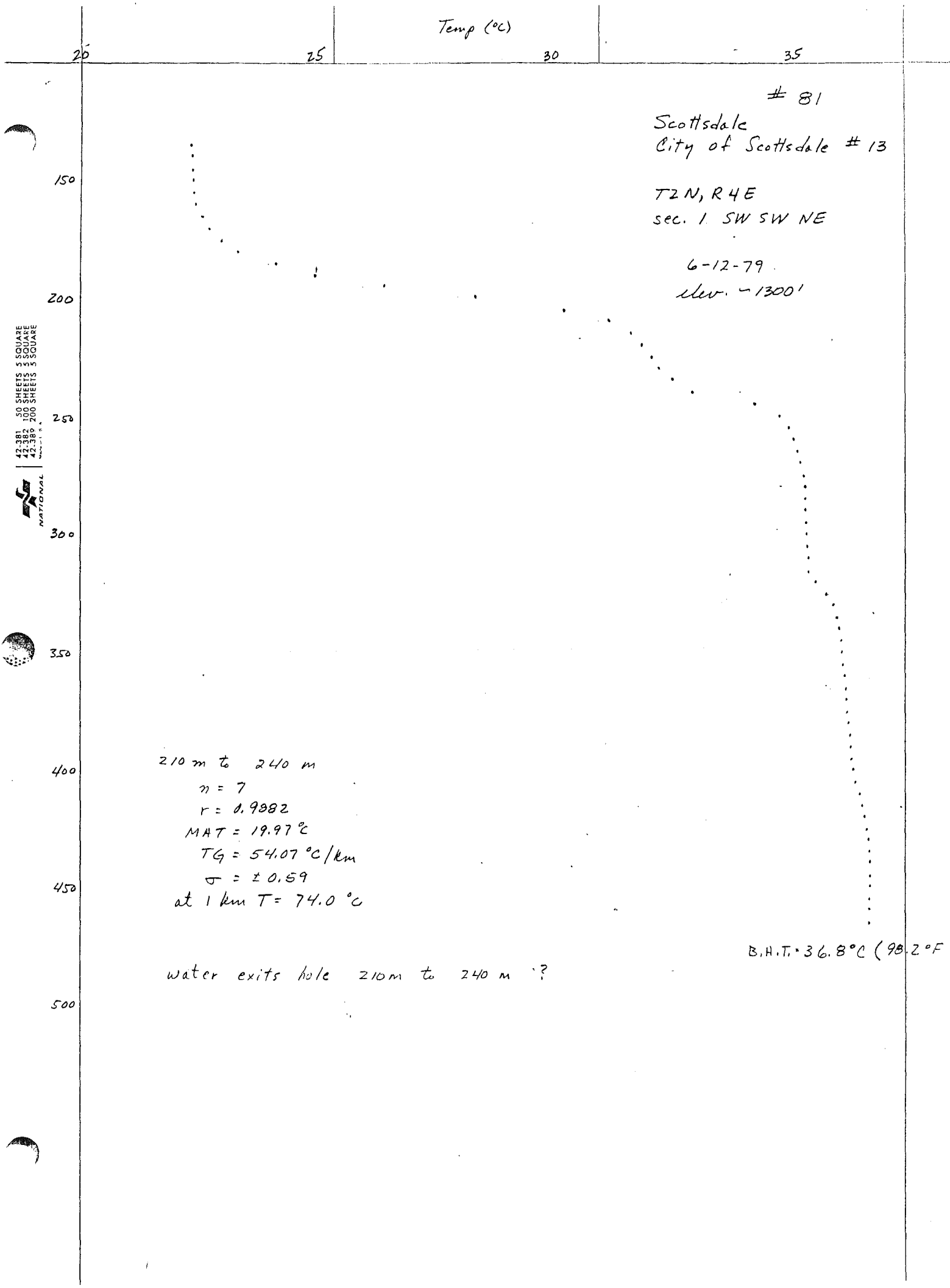
static W.L. = 300-400' — steady.

(≈ 100 m) — Knot in end of cable when brought to surface. About 5 m.

DATE: 7-14-81 | HOLE NO.: Scottsdale #33 | LOCATION: T4N, R.4E. SW NW NW sec 26

DEPTH (METERS)	RESIST. (K-OHM)	TEMP. (°C)	GRADIENT (°C/KM)		DEPTH (METERS)	RESIST. (K-OHM)	TEMP. (°C)	GRADIENT (°C/Km)
345	39.95	44.34	40.0					
350	39.64	44.54	40.0					
355	39.~~75~~ 50	44.64	20.0					
360	39.40	44.70	12.0					
365	39.44	44.68	-4.0					
370	39.52	44.62	-12.0					
375	39.51	44.63	2.0					
380	39.50	44.64	2.0					
385	39.41	44.70	12.0					
390	39.30	44.77	14.0					
395	39.60	44.57	-40.0					
400	39.60	44.57	-0-					

COMMENTS: 1500' 27.7°C


Temp (°C)
20
25
30
35
150
200
250
300
350
400
450
500
81
Scottsdale
City of Scottsdale # 13
T2N, R4E
sec. 1 SW SW NE
6-12-79
elev. ~1300'
210 m to 240 m
n = 7
r = 0.9882
MAT = 19.97 °C
TG = 54.07 °C/km
σ = ± 0.59
at 1 km T = 74.0 °C
B.H.T. = 36.8°C (98.2°F
water exits hole 210m to 240 m ?

DATE :

HOLE NO. : City of Scottsdale #13

LOCATION : Paradise Valley

PAG

DEPTH (METERS)	RESIST. (K-OHM)	TEMP. (°C)	GRADIENT (°C/KM)
125	83.55 ↓		
130	89.860		
135	89.92	22.37	
140	89.90	22.38	+ 2
145	89.88	22.38	0
150	89.89	22.40	+4
155	89.72	22.43	6
160	89.55	22.48	10
165	89.23	22.58	20
170	88.70	22.74	32
175	87.85	23.00	52
180	86.68	23.37	74
185	84.09 ↕	24.20	166
190	81.60	25.00	160
195	77.24	26.48	296
200	71.88	28.41	[illegible]
205	67.00	30.28	186
210	64.70	31.21	92
215	63.52	31.70	52
220	62.89	31.96	34
225	62.48	32.13	34
230	62.10	32.30	66

DEPTH (METERS)	RESIST. (K-OHM)	TEMP. (°C)	GRADIENT (°C/KM)
235	61.31	32.63	74
240	60.45	33.00	76
245	58.55	34.31	11
250	56.25	34.91	[illegible]
255	56.03	35.02	[illegible]
260	55.82	35.12	[illegible]
265	55.62	35.21	16
270	55.46	35.29	8
275	55.38	35.33	4
280	55.29	35.36	2
285	55.27	35.37	2
290	55.26	35.38	2
295	55.25	35.39	2
300	55.23	35.40	2
305	55.20	35.41	1
310	55.17	35.43	0
315	55.10	35.45	24
320	54.85	35.57	62
325	54.22	35.88	22
330	54.01	35.99	8
335	53.93	36.03	8
340	53.84	36.07	10

COMMENTS :

DATE : HOLE NO. : LOCATION :

DEPTH (METERS)	RESIST. (K-OHM)	TEMP. (°C)	GRADIENT (°C/Km)		DEPTH (METERS)	RESIST. (K-OHM)	TEMP. (°C)	GRADIENT (°C/Km)
345	53.73	36.12			455	52.42	36.78	0
350	53.70	36.14			460	52.41	36.78	0
355	53.64	36.17			465	52.41	36.78	0
360	53.60	36.19			①			
365	53.53	36.22						
370	53.49	36.24						
375	53.43	36.27						
380	53.38	36.30						
L-Y 385	53.30	36.34						
390	53.23	36.37	6					
395	53.17	36.40	8					
400	53.10	36.44	6					
405	53.04	36.47	8					
410	52.95	36.51	8					
415	52.87	36.55	14					
420	52.73	36.62	10					
425	52.64	36.67	10					
430	52.52	36.72	6					
L-Y 435	52.47	36.75	2					
440	52.46	36.76						
445	52.43	36.77						
450	52.42	36.78		1476'				

LR 33.8697 x2 4.7565

~~x̄ = .0065~~ or

r = .9910

COMMENTS :

① Probe hung up. Maybe casing reduction or obstruction.

50°C @ 1800'

[illegible] 548.8 [illegible] °C/Km

548.8 m [illegible]
450 m 36.78

98.8 13.2 °C
[illegible] = 133.8 °C/Km