PRELIMINARY GEOTHERMAL ASSESSMENT OF THE HARQUAHALA -TONOPAH AREA

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I. INTRODUCTORY MATERIAL

A. Location and Access

The Harquahala Plain and the Tonopah Desert are two distinct physiographic features which comprise the Harquahala - Tonopah study area in Yuma and Maricopa Counties, Arizona (Figure I-1). Interstate highway 10 crosses the area to connect Phoenix with the major cities in California. Numerous paved and good quality dirt roads provide access to the farming activity in both portions of the study area.

B. Local Support

Numerous contacts were established with the owners and operators of farms in the area. Ready access to wells and well records were provided by the ranch owners as well as the staff of the Roosevelt and Buckeye Irrigation Districts.

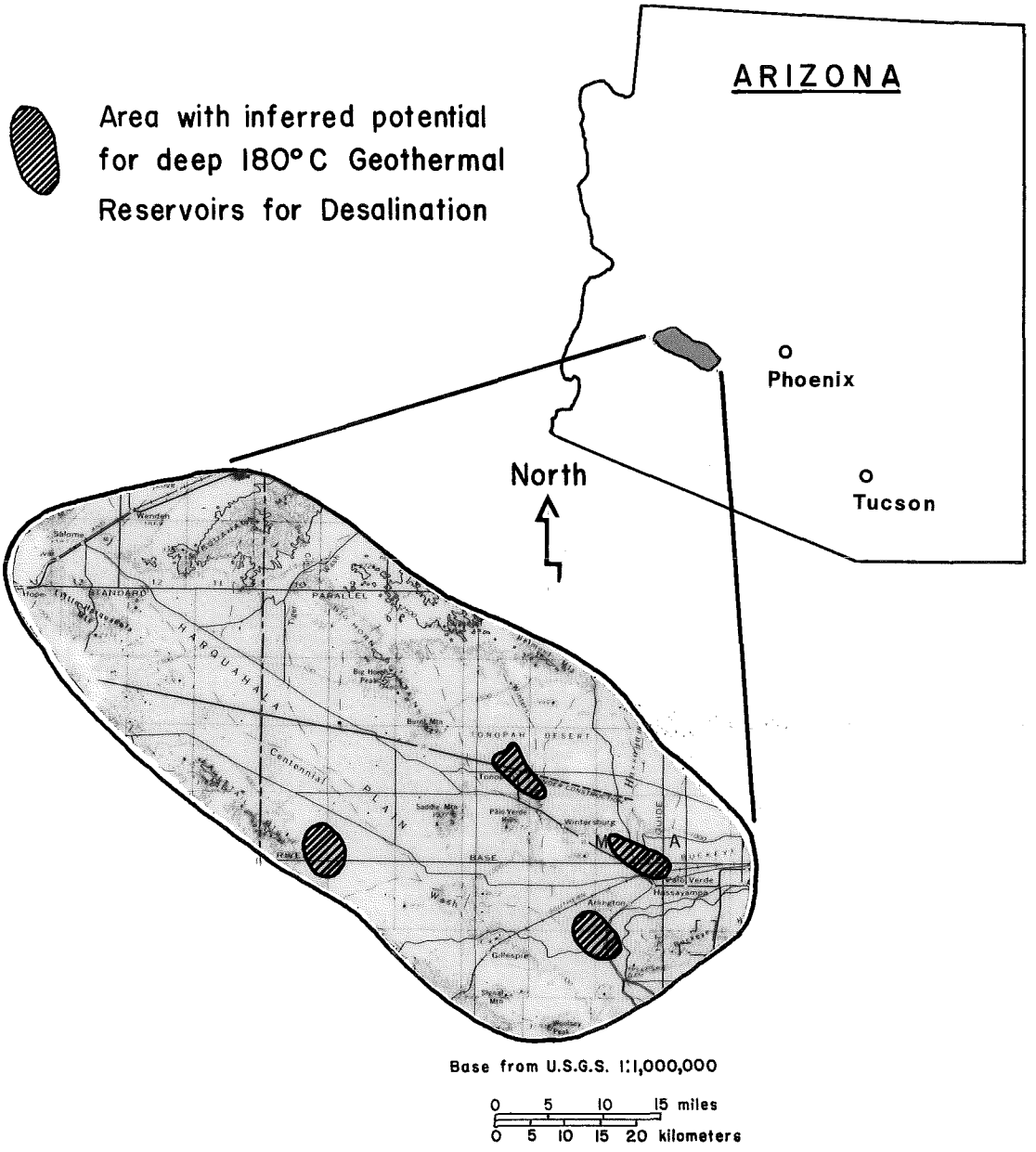

FIGURE I-1. Location map of the Harquahala-Tonopah Study Area, Arizona.

II. SUMMARY AND RECOMMENDATIONS

A. Development of Potential Resources

The water balance of the area was determined by estimating the water in storage and the potential for recharge. Annual precipitation is approximately 6.5 inches (16.5 cm) per year. Much of this water is returned to the atmosphere through evapotranspiration.

All reservoir estimates for water were based on storage values below 300 m. This is to elinimate those portions of the system that are currently being used by local agricultural interests. The Harquahala Plain has 149,800 hm^3 in storage and the Tonopah Desert has 45,000 hm^3. Recoverable water below 300 m is estimated to be 74,900 hm^3 for Harquahala and 17,500 hm^3 for Tonopah.

Water from existing wells generally contains less than 5,000 mg/l dissolved solids. Most wells contain in excess of 2 mg/l fluoride. Over 20% of the wells have fluoride values in excess of 5 mg/l. No more than 20,000 mg/l dissolved solids should be expected from any hydrothermal reservoir within this study area.

Abnormal temperature gradients occur near the town of Tonopah and in the southern portion of the Harquahala Plain. A reservoir temperature of 150°C should be achieved at depths of between 3 and 4 kilometers in either area. Discharge temperatures at Tonopah from wells of less than 100 m deep exceed 40°C.

III. LAND STATUS

The Harquahala Plain and Tonopah Desert have a watershed of about 3,800 km^2 (Map III-1). The Harquahala basin has a surface area of about 565 km^2 while the Tonopah basin area is about 220 km^2. Table III-1 shows the general land status of the study area by major controlling group.

Table III-1 Land Status of the Harquahala Plain and Tonopah Desert

Owner or Trust Group	Area (mi^2)	Area (km^2)
Private Ownership	418.6	1,083.7
State of Arizona Trust	148.4	384.2
BLM Resource Lands	900.3	2,330.8
Military Reservation	2.1	5.4
TOTAL	1,469.4	3,804.1

Approximately 61% of the land is under BLM jurisdiction, 10% is State land and 28% private. Less than 1% of the land is held by the military.

IV. RESOURCE EVALUATION

A. Introduction

A collection of published and unpublished geologic and hydrologic data from the Harquahala-Tonopah area was undertaken as a first step in assessing geothermal potential. Additional field work provided data to augment that which was already obtained. Compilation of all temperature and water chemistry information documents numerous areas where temperatures in excess of 40°C have or should be found. Energy-producing temperatures may be available at depths of 3,000 meters or less if many of the observed thermal gradients persist at depth.

B. Previous Work

Reconnaissance geology of the area was done by Wilson and others (1957) and Cooley (1971). Fugro Inc. (1974) updated the mapping information as part of work on the Palo Verde Nuclear Generating Station situated in the central portion of the study area. A general discussion of Maricopa County geology is found in Wilson (1962).

Detailed gravity work was done by Peterson (1968), Sumner (1974) and Cloran (1977). A regional Bouguer gravity map of Arizona was published by West and Sumner (1973). The residual aeromagnetic map of Arizona was published by Sauck and Sumner in 1970. Ground magnetic studies in the Tonopah area were conducted by Cloran (1977) as part of a hydrology and geothermal potential study. Stulik (1974) also discussed the hydrology and ground water conditions in the Lower Hassayampa area.

C. Geology

The Tonopah-Harquahala area is part of the Basin and Range Province of southern Arizona. The mountainous portion of the Province has proven to be the source material for much of the sediments now found in the adjacent basins. It is important, therefore, to recognize the diversity of rock types, structures and ages on the rocks exposed in the mountain blocks.

1. Surrounding Mountain Blocks. The Little Harquahala and Harquahala Mountains form the northern boundaries of the study area (Map IV-1). Mesozoic volcanic and volcaniclastic sequences, along with quartzose and feldspathic sandstones are intruded by younger granodiorite in the northern portion of the Little Harquahala Mountains. The Mesozoic rocks are in fault contact with older (Precambrian?) granite prophyry to the east. Folded and faulted Paleozoic sediments are found in the southern portion of the range. The Harquahala Mountains contain isolated remnants of folded and faulted Paleozoic and Mesozoic (?) sediments situated unconformably on Precambrian granite and schist. A Laramide intrusive is located in the north-central portion of the range. Further south are the northwest-trending Eagle Tail Mountains which occupy the western margin of the area. These mountains contain a thick sequence of Mid-Tertiary ash-flow tuff and lava. The volcanic rocks overlie Precambrian granites.

The Big Horn Mountains separate the northern portion of the Harquahala Valley from the Tonopah Valley. They are

similar to the Eagle Tail Mountains in that the Mid-Tertiary volcanic rocks overlie Precambrian basement rocks.

The southern boundary of the area is marked by the Gila Bend Mountains. Miocene volcanics overlie Precambrian granites and metamorphics. Late Miocene to early Pleistocene basalt flows are also found in this area.

North of Tonopah and forming the northern boundary of the study area are the Belmont Mountains. They are composed of Precambrian granite and metamorphic rocks, mid-Tertiary volcanics and numerous Tertiary dikes. The eastern margin of the area is defined by the White Tank Mountains. These are composed of Precambrian gneiss intruded by granite of probable Tertiary age, alaskite and pegmatite.

The Palo Verde Hills and Saddle Mountain are located in the central portion of the area. They are composed of mid-Tertiary volcanics ranging in composition from rhyolite to andesite.

Pre-Tertiary bedrock throughout the study area is uncomformably overlain by Miocene volcanic rocks which yield K-Ar ages of 14.6 to 20.3 m.y. (Table IV-1). The volcanics include flows and tuffs of basalt to rhyolite composition.

2. Basin Sediments. The sediments are subdivided into an older Unit I and younger Unit II as proposed by Eberly and Stanley (1978). The older Unit I has a basal Miocene fanglomerate, possibly a lahar, which contains rounded to angular clasts of andesite and basalt. The matrix is a well-cemented mixture of sand- and silt-sized particles.

TABLE IV-1. Radiometric age dates in the Harquahala, Tonopah and Buckeye area.

Location	Apparent age (m.y.)	Rock Type	Radiometric age method, mineral dated	Reference
33.386°N., 112.832°W.	20.3+0.7	olivine basalt	K-Ar., whole rock	Shoustra et al., (1976)
33.354°N., 112.851°W.	19.9+0.4	basaltic andesite	K-Ar., whole rock	Shoustra et al., (1976)
33.400°N., 112.928°W.	19.8+0.4	basaltic andesite	K-Ar., whole rock	Shoustra et al., (1976)
33.194°N., 112.804°W.	19.6+0.4	basaltic andesite	K-Ar., whole rock	Shoustra et al., (1976)
33.340°N., 112.794°W.	19.4+0.4	basaltic andesite	K-Ar., whole rock	Shoustra et al., (1976)
33.428°N., 112.875°W.	19.1+0.7	basaltic andesite	K-Ar., whole rock	Shoustra et al., (1976)
33.427°N., 112.960°W.	19.1+0.4	andesite	K-Ar., whole rock	Shoustra et al., (1976)
33.389°N., 112.830°W.	17.7+0.6	basaltic andesite	K-Ar., whole rock	Shoustra et al., (1976)
33.383°N., 112.835°W.	16.7+0.3	andesite	K-Ar., whole rock	Shoustra et al., (1976)
33.603°N., 112.878°W.	14.6+0.4	basalt	K-Ar., whole rock	Shoustra et al., (1976)
33.231°N., 112.774°W.	6+2.0	basalt	K-Ar., whole rock	Eberly and Stanley (1978)
33.328°N., 112.760°W.	3.19+0.19	basalt	K-Ar., whole rock	Shoustra et al., (1976)
33.236°N., 112.782°W.	2.62+0.45	basalt	K-Ar., whole rock	Shoustra et al., (1976)
33.347°N., 112.750°W.	2.25+0.36	basalt	K-Ar., whole rock	Shoustra et al., (1976)
33.351°N., 112.773°W.	2.20+0.20	basalt	K-Ar., whole rock	Shoustra et al., (1976)
33.329°N., 112.735°W.	2.10+0.23	basalt	K-Ar., whole rock	Shoustra et al., (1976)
33.349°N., 112.778°W.	1.96+0.12	olivine basalt	K-Ar., whole rock	Shoustra et al., (1976)
33.218°N., 112.214°W.	1.3+0.43	basalt	K-Ar., whole rock	Shoustra et al., (1976)
33.346°N., 112.769°W.	1.24+0.24	basalt	K-Ar., whole rock	Shoustra et al., (1976)
33.746°N., 113.674°W.	.69	granodiorite	K-Ar., biotite	Eberly and Stanley (1978)
33.750°N., 113.675°W.	65+5.5	granodiorite	K-Ar., biotite	Damon, et al., (1969)

Tuffaceous sand has also been recognized in the matrix of this unit. An intercalated basalt was dated by FUGRO Inc. (1974) at 16.7 m.y.

The younger Unit II contains a poorly cemented mixture of sand, silt and clay. A distinctive clay bed called the Palo Verde Clay (FUGRO, Inc., 1974; Scott and Moore, 1976) is persistent across much of study area. The clay was deposited in a lake environment. Paleomagnetic studies indicate deposition of the clay started about 3 million years ago and the lake environment continued to at least 2.4 million years ago (Fugro, 1974; Sheridan and Maisano, 1976). Overlying the Palo Verde Clay is a moderately to well-stratified sand and silt unit which is poorly consolidated. Local caliche beds are found near the surface while talus fans are located along the mountain fronts.

Figure IV-1 is a structural cross section of the study area. The cross section extends from the Harquahala Valley on the west to the Tonopah Desert on the east. Cloran (1977) constructed profiles across the Tonopah area and estimated the maximum thickness of the continental sediments to be in excess of 2,200 meters. The basin is shown as a graban bounded on the east and west by one of more high-angle normal faults.

3. Water Chemistry. Maps IV-2 and IV-3 show the distribution of fluoride and total dissolved solids, respectively, from irrigation wells in the study area. Most wells contain more than 2 mg/l fluoride. Over 20% of the wells for which

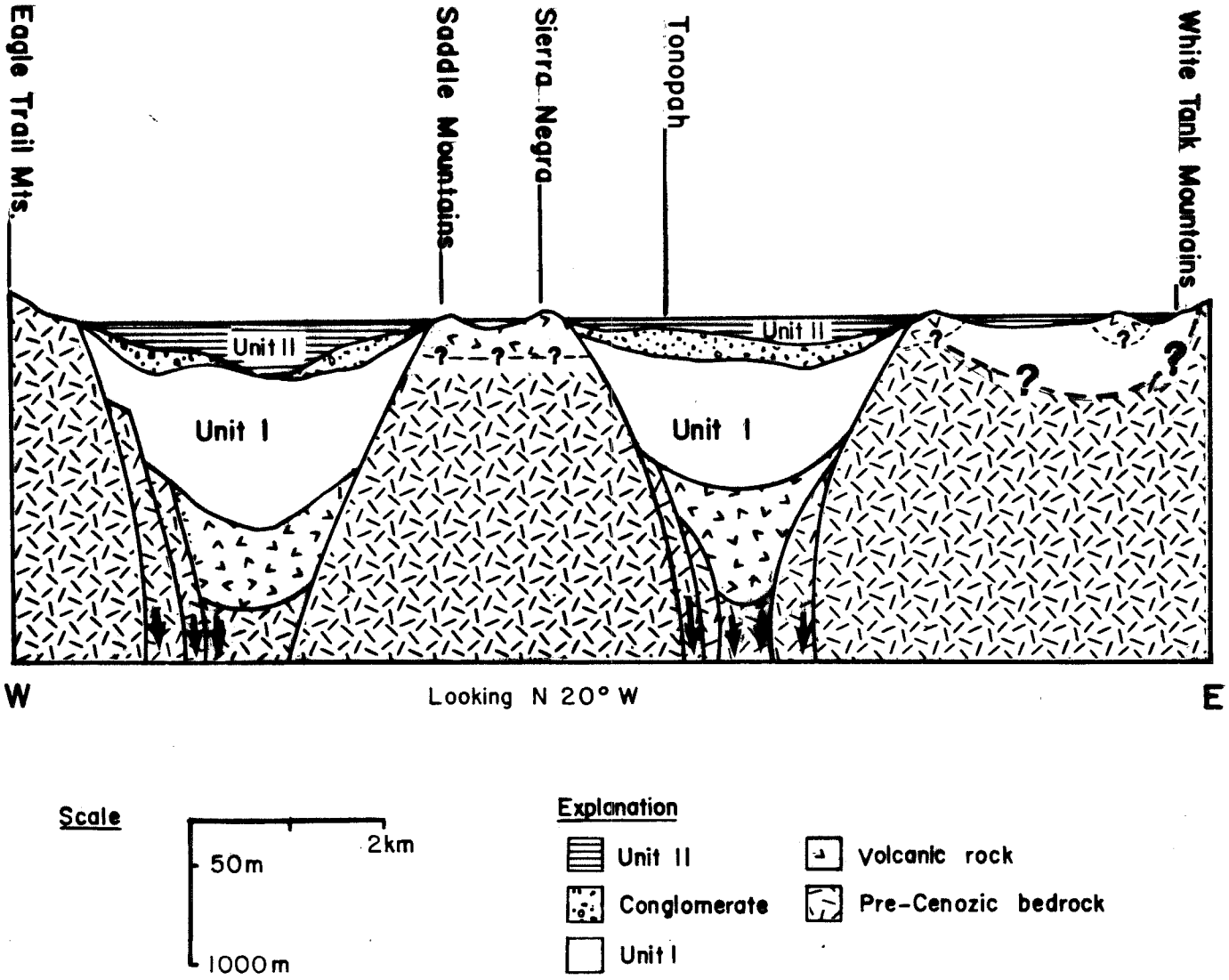

FIGURE IV-1: Cross section of the Harquahala-Tonopah Area, Arizona (After Chloran, 1979).

fluoride determinations were made contain more than 5 mg/l. The highest concentration of wells with values >5 mg/l occur in the Tonopah Desert along a line parallel to the Big Horn Mountains and the Palo Verde Hills. Several high values are also found in the southern portion of the Harquahala Plain, but insufficient data preclude definition of a trend. The Buckeye Valley has only one well containing more than 5 mg/l fluoride.

Most wells within the area contain between 500 and 5,000 mg/l dissolved solids. The wells which contain more than 1,000 mg/l are generally located along the Gila River, although a few are within the Tonopah Desert and the Harquahala Plain. Those wells with temperatures in excess of 40°C contain less than 1,000 mg/l. This is not an uncommon condition for moderate-to-high temperature, slightly alkaline waters (Swanberg, 1977).

Low calcium and magnesium values combined with higher sodium and chlorine values indicate the presence of halite within the basins. Sporadic sulfate values suggest minor amounts of gypsum are located in the Buckeye Valley and in the southern Harquahala Plain. Low values of bicarbonate and magnesium indicate the lack of significant concentrations of dolomite and calcite within the sedimentary sequence. This interpretation may be subject to revision when more is known about the quantity and distribution of the natural zeolites found within the area (Sheridan and Maisano, 1976).

Clays in general, and zeolites in particular, promote cation exchange reactions between the water and clay minerals (Hem, 1970). Several bodies of water in the Tonopah area show calcium and magnesium values that are somewhat low, while sodium values may be high. Table IV-2 compares the chemical composition of several wells with that of irrigation water from the Salt River.

4. Geophysics. Aeromagnetic and gravity maps for the state have been compiled by the College of Geosciences, University of Arizona (Sauck and Sumner, 1970; Aiken, 1975). Peterson (1968) compiled a regional Bouguer gravity map for parts of Maricopa, Pima, Pinal and Yuma Counties. This was later made part of a regional Bouguer gravity map by West and Sumner (1973). Additional gravity data were collected and interpreted by Sumner (1974) as part of the Palo Verde Nuclear Generation Station preliminary siting studies. Cloran (1977) expanded coverage of the area by conducting detailed gravity and ground magnetic surveys over the Tonopah Desert area.

Map IV-4 shows the residual aeromagnetic data of the area (after Sauck and Sumner, 1970). Contour intervals are 25 gammas. Map IV-5 is a preliminary residual Bouguer gravity map compiled by Sumner and Lysonski (1979) at 5 m/gal intervals.

In the Arizona Basin and Range Province, magnetic and gravity highs are often associated with areas of granitic

Table IV-2. Comparison of Water Analyses from Buckeye, Tonopah and Harquahala Irrigation Wells with Water Which Comes from the Salt River.

Location	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Cl mg/l	F mg/l	B mg/l	HCO_3 mg/l	SO_4 mg/l	SiO_2 mg/l	*TDS mg/l	pH
Salt River below Stewart Mt. Dam**	48	14	150	5.8	233	0.4	0.15	153	50	18	597	
(B-1-4)32bbb	3	1.6	110	1.6	64	4.9	3.89	68	55	24	303	8.5
(B-2-7)26abc	19	6.4	299	4.5	328	4.9	4.07	91	60	38	924	8.6
(B-2-6)36abb	27	7.5	331	4.0	503	4.3	4.63	59	67	31	1139	8.5
(B-2-7)28bbb	17	8.4	136	4.6	153	4.9	4.44	103	69	35	571	8.7
(B-2-6)19daa	20	2.0	150	5.3	182	5.3	4.25	110	65	26	803	8.6
(C-1-9)2dcc	7	18	290	5.6	264	4.1	4.25	180	100	26	1088	8.8

* Residue on evaporation.

**Hem, 1970, Table 17, No. 5.

intrusions. Further, the greater the magnitude of the anomaly, the closer the bedrock is to the surface. It follows that both gravity and magnetic lows reflect structural lows or corresponding depth to bedrock. Each of these observations appears to apply within the study area.

Gravity and magnetic highs are located over the Precambrian granites and granite gneisses in the Little Harquahala and Harquahala Mountains to the northwest, the Eagle Tail Mountains to the west, the Gila Bend Mountains to the south, the White Tail Mountains to the east, and the Belmont Mountains to the north. Magnetic and gravity lows occur over the basins in the Harquahala Plains and the Tonopah Desert. Magnetic and gravity profiles constructed across the Tonopah Desert anomalies indicate graben structures with faults on the east, south and west edges of the basin (Cloran, 1977). Similar graben structure with basin-bounding faults occur in the Harquahala Plain. The open gravity low between the Eagle Tail and Little Harquahala Mountains suggests structural communication between the northern Harquahala basin and the Ranegras Plain to the west.

The basin thickness is conservatively estimated at 2,200 meters for the Tonopah Desert and 3,000 meters for the Harquahala Plain (Cloran, 1977).

5. Water Temperatures and Gradients. Most of the wells in the study area are used for irrigation. Cotton is the most common crop, although some acreage is planted with citrus, dates, grapes, grain and alfalfa. Over 200 wells were

reviewed, either in person or through the literature search. The majority of these wells were completed to depth of 200 meters or more; however, a number of the historically significant wells were completed to depth of less than 100 meters. Table IV-3 lists 112 well sites where discharge temperatures exceeded 30°C. Eleven of the wells have temperatures of 40°C or more, and one well exceeded 50°C. Map IV-6 shows the known discharge temperatures of all wells identified to date.

Simple temperature gradients were calculated by subtracting the mean annual air temperature from the observed discharge temperature, then dividing the result by the reported depth of the well. A mean annual air temperature of 21.1°C was selected from Druitt's (1976) map of mean annual air temperatures in Arizona. The metric system was used throughout, and the results are recorded in °C/km. Only those wells whose depths are in excess of 100 m were used. The well data are grouped according to gradient range to eliminate ambiguities. Map IV-7 is the product of this phase of the study. These values should be viewed as minimum temperature gradients as they assume 100% of the water being derived from the deepest penetration of the well. Mixing of waters from different aquifers and of different thermal character has been assumed to be negligible.

There are 133 wells in the area which meet the criteria outlined above. Approximately 75 wells were shallower than 100 m and/or did not have a known depth. Table IV-4 lists

Table IV-3. Wells and Springs in the Tonopah, Harquahala and Buckeye areas with Temperatures of 30°C or Greater

Location	Temperature °C	Depth Meters	Map Quadrangle	Reference
(B-1-4)30acb	40.0	607	White Tank Mts.	1
(B-1-4)32bbb	36.0	482	White Tank Mts.	1
(B-1-4)35aad	35.0	552	White Tank Mts.	2
(B-1-4)35acb	40.0	607	White Tank Mts.	3
(B-1-5)36aaa	32.0	350	White Tank Mts.	1
(B-1-6)8abb	31.0	245	Belmont Mts.	1,4,5
(B-1-6)10aab	30.5	515	Belmont Mts.	2,4
(B-1-6)27cbc	33.0		Arlington	4
(B-1-6)34acc	33.0		Arlington	4,6
(B-1-7)1bbb	30.0	268	Belmont Mts.	1,5
(B-1-8)6aaa	33.0	231	Cortez Peak	1,7
(B-1-8)6bb	32.0	183	Cortez Peak	3
(B-1-8)7cbb	40.5	244	Cortez Peak	3
(B-1-8)19abb	31.0	148	Cortez Peak	3
(B-1-8)19bc	30.0	214	Cortez Peak	3
(B-1-9)1bbb	33.5	468	Cortez Peak	3
(B-1-9)1ddc	37.0		Cortez Peak	6
(B-1-9)2abb	39.0	374	Cortez Peak	6
(B-1-9)2caa	35.0	488	Cortez Peak	6
(B-1-9)6ccc	34.5	433	Cortez Peak	3
(B-1-9)7ccc	35.0	519	Cortez Peak	3
(B-1-9)7dcc	34.0	279	Cortez Peak	3

Table IV-3. (Continued)

Location	Temperature °C	Depth Meters	Map Quadrangle	Reference
(B-1-9)11bbb	33.0	299	Cortez Peak	3
(B-1-9)12cbb	32.8	457	Cortez Peak	2
(B-1-9)12ccc	34.0		Cortez Peak	6
(B-1-9)13ab	31.0	342	Cortez Peak	3
(B-1-9)13abb	32.1	312	Cortez Peak	1
(B-1-9)14bbb	30.0	371	Cortez Peak	2
(B-1-9)15abc	35.6	522	Cortez Peak	2
(B-1-9)17cbb	36.0	456	Cortez Peak	3
(B-1-9)18bcc	35.0	457	Cortez Peak	2
(B-1-9)20bbb	32.0	275	Cortez Peak	3
(B-1-9)20ccc	34.4	457	Cortez Peak	2
(B-1-9)21bc	32.0	315	Cortez Peak	3
(B-1-9)28bcc	32.1	307	Cortez Peak	1
(B-1-9)28ccc	36.0	345	Cortez Peak	3
(B-1-9)32ccc	32.2	301	Cortez Peak	1,3
(B-1-10)1ccc	31.0	280	Cortez Peak	3
(B-1-10)1dcc	33.5	455	Cortez Peak	2
(B-1-10)1ddc	36.0	613	Cortez Peak	3
(B-2-6)6daa	34.0	305	Belmont Mts.	2,4,5
(B-2-6)31aaa	31.0	366	Arlington	1
(B-2-6)31daa	33.0		Arlington	4,5
(B-2-6)36abb	38.0		Arlington	1
(B-2-6)36bba	35.3		Arlington	1

Table IV-3. (Continued)

Location	Temperature °C	Depth Meters	Map Quadrangle	Reference
(B-2-7)14cbb	36.0	209	Belmont Mts.	1,3,4,5
(B-2-7)22bbb	31.0	244	Belmont Mts.	4
(B-2-7)22cbb	32.0	244	Belmont Mts.	4
(B-2-7)23cbb	34.0	183	Belmont Mts.	4,5
(B-2-7)25bca	42.0		Arlington	4
(B-2-7)26aaa	50.5	107	Arlington	1,3,4,5
(B-2-7)26aab	48.9	122	Arlington	2
(B-2-7)26abb	44.0	122	Arlington	1,4,5
(B-2-7)26abb?	34.0		Arlington	5
(B-2-7)26abc	36.0		Arlington	1
(B-2-7)26acb	36.5		Arlington	4,5
(B-2-7)26bab	35.5	137	Arlington	2
(B-2-7)26bda	49.4		Arlington	7
(B-2-7)27aaa	33.0		Arlington	5
(B-2-7)27aab	33.0	107	Arlington	6
(B-2-7)28bbb	32.5	319	Arlington	1,4,5
(B-2-7)28bdd	33.5	344	Arlington	4,5
(B-2-7)28cad	32.5	387	Arlington	5
(B-2-7)36abb	37.5	302	Arlington	4,5,6
(B-2-7)36bba	37.0	104	Arlington	6
(B-2-7)36cbb	33.9	296	Arlington	2,6
(B-2-8)17daa	32.0	156	Big Horn Mts.	3
(B-2-8)19cbb	35.0	329	Big Horn Mts.	6

Table IV-3. (Continued)

Location	Temperature °C	Depth Meters	Map Quadrangle	Reference
(B-2-8)19daa	35.0	363	Big Horn Mts.	3
(B-2-8)29bdd	38.0	506	Big Horn Mts.	6
(B-2-8)29cbb	34.0		Big Horn Mts.	6
(B-2-8)30aaa	35.0	360	Big Horn Mts.	6
(B-2-8)31aaa	34.0	371	Big Horn Mts.	3
(B-2-8)31baa	37.0	366	Big Horn Mts.	3
(B-2-8)32bba	35.0	525	Big Horn Mts.	3
(B-2-9)9abb	35.0	470	Big Horn Mts.	3
(B-2-9)9db	35.0	458	Big Horn Mts.	3
(B-2-9)10abb	35.0	458	Big Horn Mts.	3
(B-2-9)10bbb	35.0	397	Big Horn Mts.	3
(B-2-9)11bbb	35.0	458	Big Horn Mts.	3
(B-2-9)11cbb	35.0	459	Big Horn Mts.	3
(B-2-9)13baa	33.0	184	Big Horn Mts.	3
(B-2-9)14bbb	33.0	467	Big Horn Mts.	3
(B-2-9)26adc	38.0		Big Horn Mts.	6
(B-2-9)34bbd	40.0		Big Horn Mts.	7
(B-2-9)34dbb	37.0	579	Big Horn Mts.	6
(B-2-9)36bbb	33.0	335	Big Horn Mts.	6
(B-5-9)25dc	32.5	443	Big Horn Mts.	3
(C-1-4)5bab	30.6	485	Buckeye	3
(C-1-4)6bb	41.1	482	Buckeye	3
(C-1-5)28abb	34.4	182	Arlington	2

Table IV-3. (Continued)

Location	Temperature °C	Depth Meters	Map Quadrangle	Reference
(C-1-5)29adc	32.0		Arlington	4
(C-1-5)32baa	31.1	257	Arlington	2
(C-1-6)13cab	31.0		Arlington	4
(C-1-6)14dbb	30.0	340	Arlington	4
(C-1-6)17abb	31.1	372	Arlington	2
(C-1-6)18bbb	35.0	407	Arlington	3,4
(C-1-6)21cbb$_2$	33.0	124	Arlington	4
(C-1-6)26dad	32.2	346	Arlington	2,4
(C-1-8)4bb	33.9	61	Cortez Peak	3
(C-1-8)4bda	37.2	228	Cortez Peak	2
(C-1-8)8bcb	31.1	244	Cortez Peak	2,6
(C-1-8)9bbb	33.0	244	Cortez Peak	6
(C-1-9)1ccc	34.0	307	Cortez Peak	3
(C-1-9)2dcc	31.9	366	Cortez Peak	1
(C-1-9)5dcd	31.0	284	Cortez Peak	1,3
(C-1-9)6dcc	45.0	195	Cortez Peak	2,6
(C-1-9)7dcc	31.7	209	Cortez Peak	2
(C-1-9)11ccc	33.0	210	Cortez Peak	6
(C-2-5)5bcb	32.0	274	Arlington	4
(C-2-5)5ccb	30.0		Arlington	4
(C-2-5)9cbb	32.0	180	Arlington	4

Table IV-3. (Continued)

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1. This report.

2. State of Arizona, Land Department, Water Division Status Report (3-14-79).

3. Giardina and Conley (1978).

4. Stulik (1974).

5. Cloran (1977).

6. U.S. Geological Survey WATSTORE File (1979).

7. Swanberg and others (1977).

TABLE IV-4. Temperature Gradients for wells in the Tonopah, Harquahala and Buckeye areas.

Interval (Meters)	Number of Wells	Average Depth (meters)	Arithmetic Mean* Gradient ($^{o}C/km$)	Weighted Mean* Gradient ($^{o}C/km$)
0-100	11	64.6	76.1	68.9
100-200	27	141.7	85.7	81.9
200-400	75	299.8	34.6	33.7
> 400	31	488.5	28.0	27.6

* $\frac{\Sigma \text{ (Temperature Gradient)}}{\text{Number of Wells}}$

** $\frac{\Sigma \text{ (Temperature Gradient x depth of well)}}{\Sigma \text{ (Depth of Well)}}$

the arithmetic mean and weighted mean temperature gradients for all categories used in Map IV-6 as well as for those wells deeper than 100 m. With the exception of those wells less than 100 m in depth, the deeper the well category, the lower the mean average gradient. This reduction in gradient with depth is in response to the normal thermal behavior of sedimentary basins within the region as depicted in Figure IV-2. The low average for wells less than 100 m depth is probably due to the ground-water recharge masking the thermal waters. The results could also be influenced by the low number of wells represented in this suite.

Figure IV-3 is a frequency distribution plot in histogram form showing the simple temperature variations for the four selected well depth intervals. The bulk of the wells in (A) fall in the 20-50°C/km grouping. Spurious values continue up to 200+ ^{o}C/km without any orderly trends. Wells represented in (B) exhibit two gradient distributions along with four apparently spurious recordings. The bulk of these readings occur in the 30 to 80°C/km range. The second grouping is in the range of 90° to 120°C/km. Wells in intervals (C) and (D) show a progressive decrease in gradient without spurious values.

Map IV-7 shows the distribution of the simple temperature gradients. A high percentage of the more elevated gradient values occur around Tonopah. The southeastern portion of the Harquahala Plain also has a significant number of

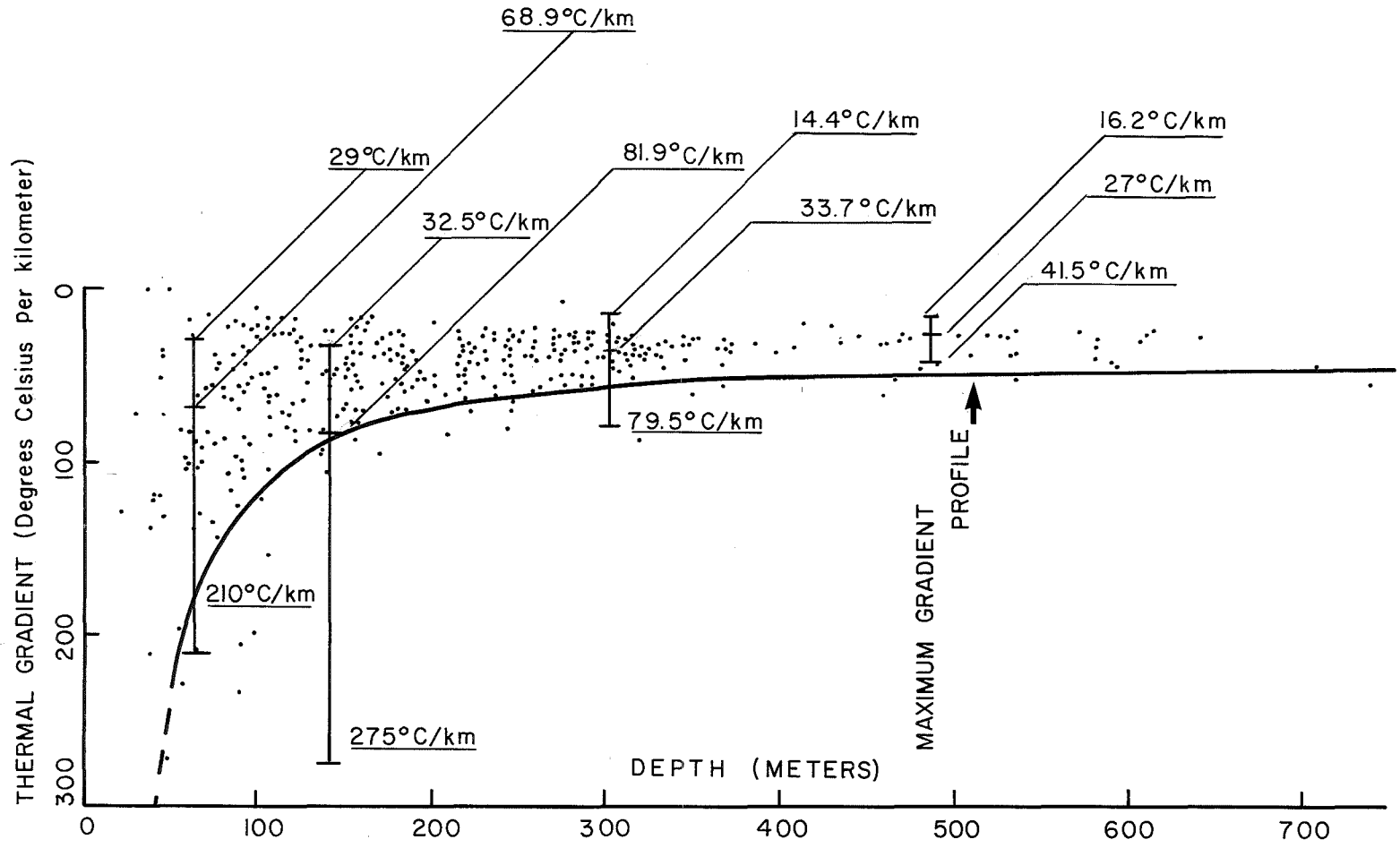
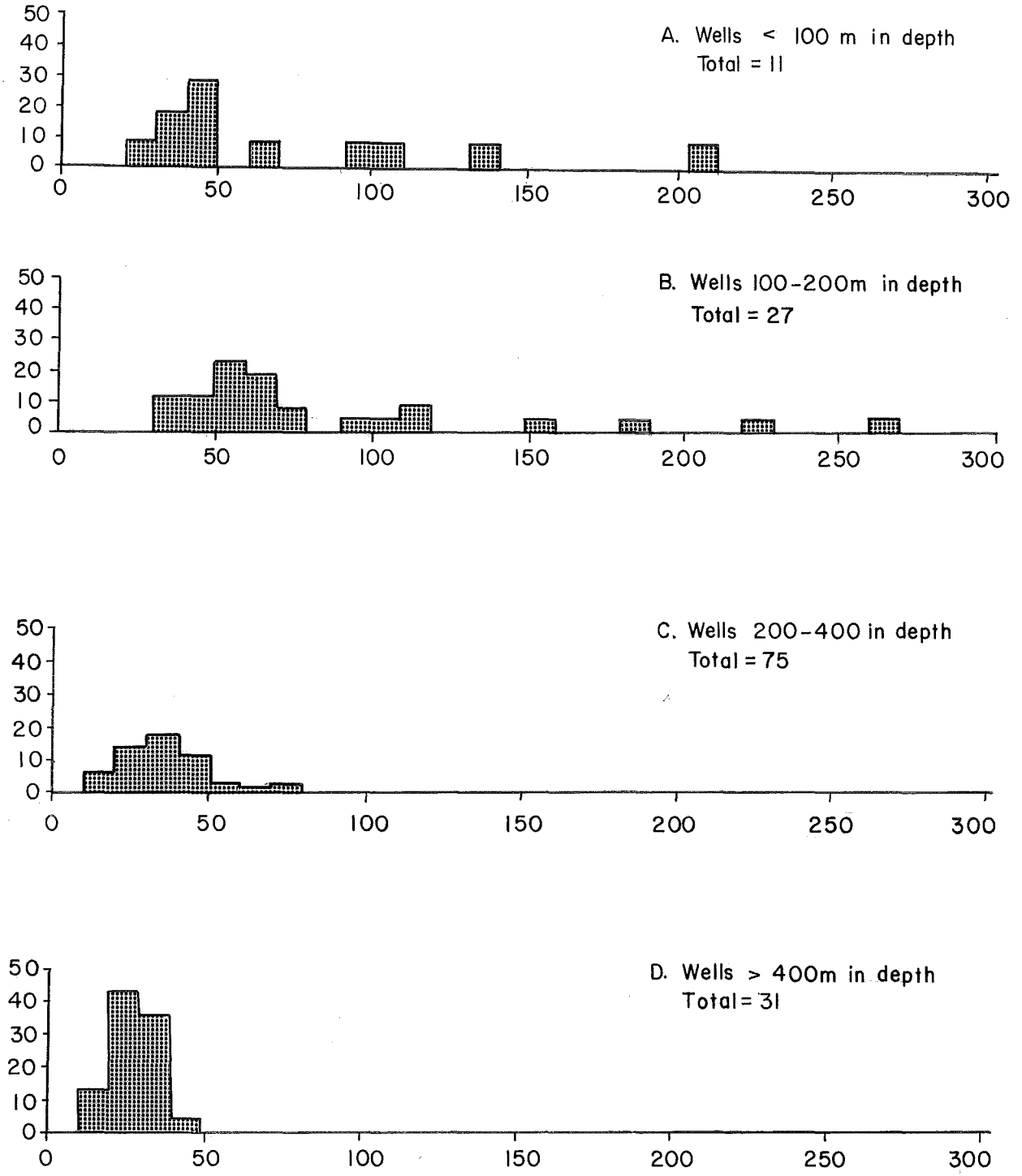


FIGURE IV-2: Maximum Gradient Profile of Maricopa County with gradient ranges for the Tonopah, Harquahala and Buckeye areas (After Giardina and Conley, 1978).



Horizontal scale: SIMPLE TEMPERATURE GRADIENT IN °C/km
Vertical scale: FREQUENCY PERCENT

FIGURE IV-3. Frequency distribution of simple temperature gradients for wells in the Harquahala Plain and Tonopah Desert.

above average gradients, but the distribution of wells is more widespread than around Tonopah. Several values of interest are also found in the Arlington Valley; however, no trends can be established with the available data.

The basin geometry (Cloran, 1977) suggests numerous basin-bounding normal faults generally paralleling the mountain fronts. Distribution of the higher temperature gradient measurements suggests leakage of warm waters upward along these faults.

Extensive well water sampling in the Tonopah Desert, Harquahala Plain, and Buckeye Valley was undertaken in May, 1979. The Na-K-Ca geothermometer of Fournier and Truesdall (1973) and the silica geothermometer of Fournier (1977) were applied to all samples. The selection of a silica geothermometer was done by plotting the observed well-head temperatures and silica concentrations in comparison with the quartz and chalcedony geothermometer lines. Since all measured values fall near or to the right of the chalcedony geothermometer line, the assumption is made that all waters sampled are in equilibrium with chalcedony (Fig. IV-4). Table IV-5 compares the measured temperature with the Na-K-Ca, SiO_2 (chalcedony) and SiO_2 (conductive) chemical geothermometers.

When the chalcedony geothermometer approximates the measured well temperature, or when the silica concentrations plot near the predicted temperature curve (Figure IV-4), then the water probably has achieved equilibrium with

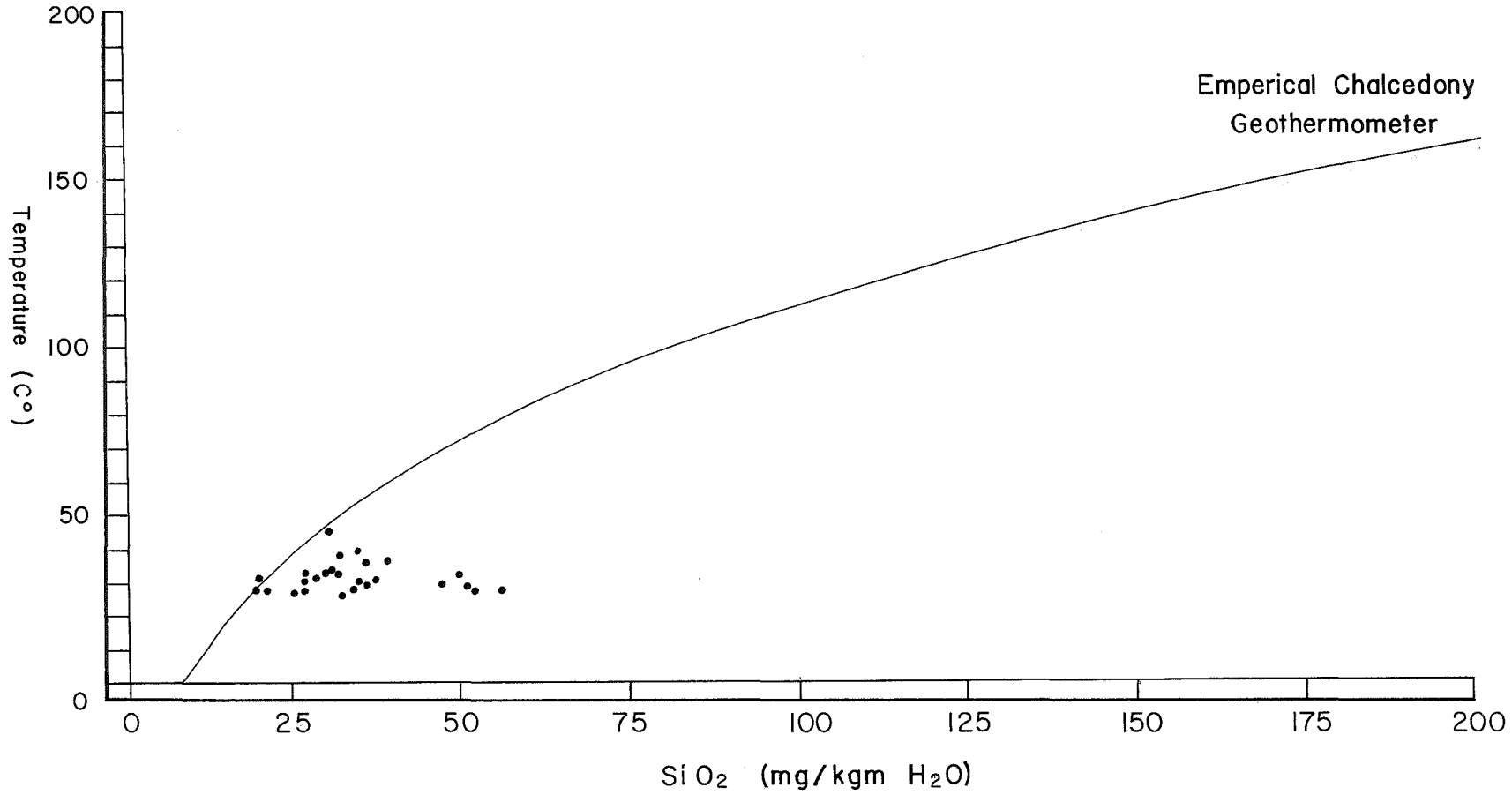


FIGURE IV-4. Chalcedony geothermometer with temperature - SiO_2 data from the Harquahala - Tonopah area.

TABLE IV-5. Discharge temperatures of wells from the Harquahala Plain and Tonopah Desert along with the predicted Reservoir Temperatures from SiO_2 and Na-K-Ca geothermometry.

Location	Temperature °C	Na-K-Ca °C	SiO_2 (chalcedony) °C	SiO_2 (conductive) °C
(B-2-7) 26abb	44.5	90.9	45.1*	76.7
(B-2-7) 26abc	36.0	85.6	58.7	89.6
(B-2-7) 14cbb	38.5	73.8	53.6	84.8
(B-2-6) 36bba	35.3	75.3	54.9	86.0
(B-2-6) 36abb	38.0	75.1	49.5	80.9
(B-2-6) 31aaa	31.0	95.6	29.4*	61.7
(B-2-6) 32bab	27.3	93.2	25.2*	57.6
(B-2-6) 33dbb	26.5	72.7	31.4*	63.6
(B-1-6) 8abb	30.5	92.4	43.5	75.3
(B-1-7) 1bbb	29.9	98.8	56.2	87.2
(B-2-7) 28bbb	32.5	148.8	69.8	100.0
(B-2-6) 8aaa	29.7	80.0	54.9	86.0
(B-2-6) 5daa	29.7	84.7	53.6	84.8
(B-2-6) 4caa	28.8	85.2	54.9	86.0
(B-2-6) 9aba	26.2	90.0	50.9	82.2
(B-2-6) 9baa	27.8	83.3	52.2	83.5
(B-2-6) 19daa	27.5	82.8	42.0	73.8
(B-1-9) 13abb	32.1	148.3	70.9	101.0
(B-1-9) 24abb	29.0	122.9	67.8	98.1
(B-1-9) 24cdc	27.0	124.4	76.7	106.5
(B-1-9) 24bbb	28.0	131.8	71.9	102.0
(B-1-9) 28bcc	32.1	116.5	45.1	76.7
(B-1-9) 32ccc	32.2	113.6	46.6	78.2
(C-1-9) 5dcd	31.0	89.8	49.5	80.9
(C-1-9) 4dcc	26.8	98.4	38.7	70.6
(C-1-9) 3ccc	28.5	117.2	42.0	73.8
(C-1-9) 2dcc	31.9	119.8	42.0	73.8
(C-1-8) 5caa	27.5	92.0	72.9	102.9

* Equilibrium between the measured water temperature and the solubility of chalcedony.

chalcedony and the bottom hole temperature is therefore assumed to be the value predicted by the silica geothermometer.

The Na-K-Ca geothermometers, as well as the silica geothermometer, are used to predict the base reservoir temperature. Comparison of the conductive quartz and Na-K-Ca geothermometers (Figure IV-5) shows general agreement between the two methods for wells sampled in the Tonopah Desert. Reservoir temperatures should be between 75 and 100°C. The one exception, well (B-2-7) 28 bbb, lies nearest to the western boundary of the graben structure (Cloran, 1977) and may be receiving hotter waters coming up alongside this structure. There is no discernible variation in the water chemistry of this well and that from other wells.

Most of the wells in the Harquahala Plain fail to show agreement between any two of the temperature evaluation methods. Inspection of the water chemistry shows the Harquahala samples to be slightly calcium deficient relative to water samples from other portions of the study area. Thus the reservoir temperature is tentatively set at 75 to 110°C. No mixing models have been run on any of the water samples within the study area.

D. Conclusions

1. One hundred twelve wells within the study area have recorded temperatures in excess of 30°C. A complete inventory of all wells will no doubt provide additional occurrences.

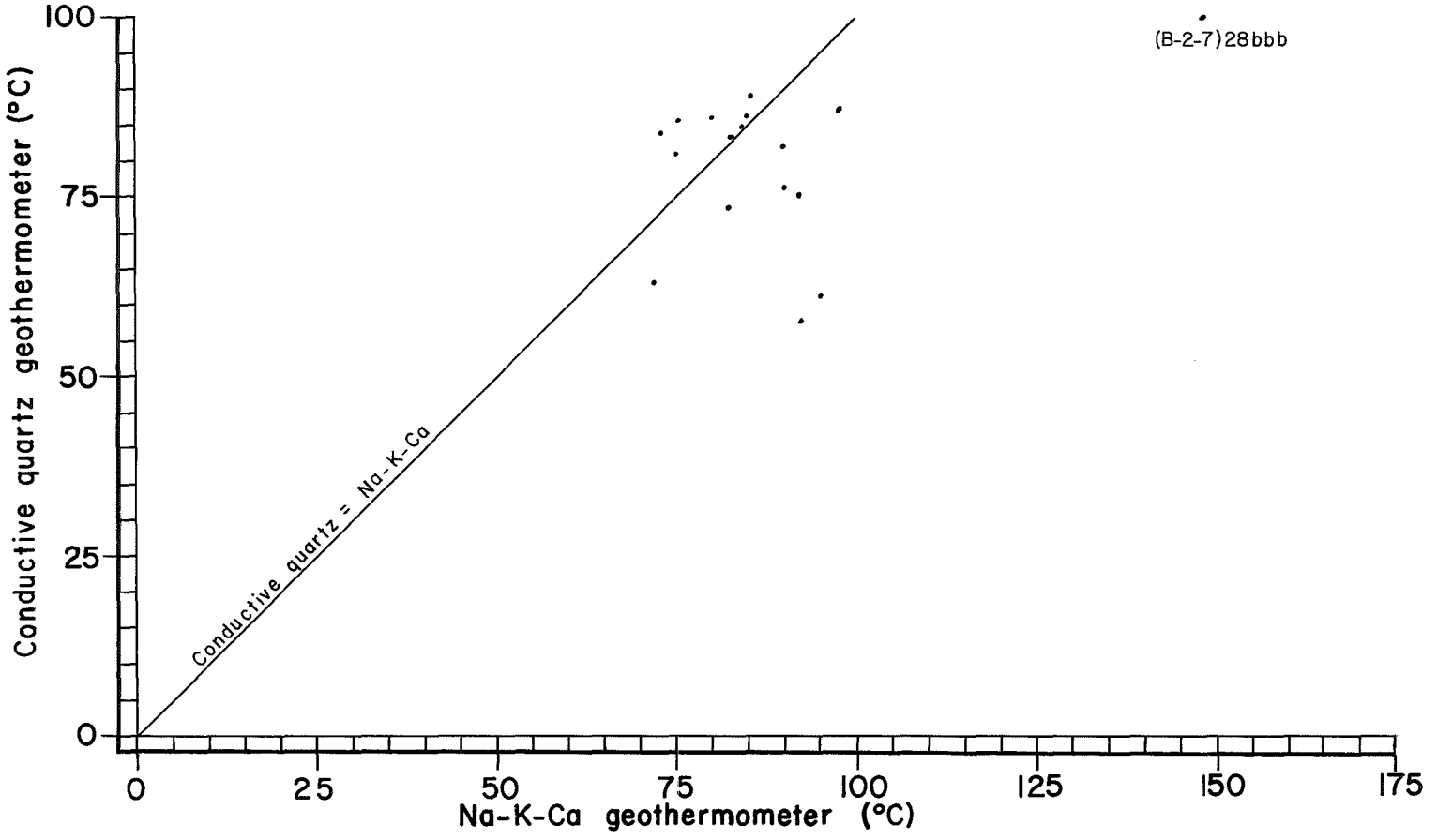


Figure IV-5. Conductive quartz and Na-K-Ca geothermometers for water samples from the Tonopah Desert, Arizona.

2. Chemical geothermometry suggests reservoir temperatures in excess of 70°C. Temperatures of 100°C are likely in at least two areas (Tonopah and the southern Harquahala Plain). The northern Arlington Valley and the western Buckeye Valley may also possess moderate temperature (50-150°C) water.

3. Abnormal temperature gradients and chemical geothermometry tend to occur along the margins of gravity lows on the basin-side of inferred basin-bounding structures. In at least one case there appears to be direct access between the upper aquifers and a deeper heat source.

4. Development of the moderate temperature resources in the study area may lead to the discovery of high temperature resources in the deeper portions of the basins.

V. ENVIRONMENTAL ASPECTS

A. General

The investigation to date has not disturbed the environment in the Harquahala Plain, Tonopah Desert or Buckeye Valley. Field work was confined to locating and sampling existing irrigation wells.

Should additional work in these areas be required to substantiate the findings of this report, the nature of such work would probably not disturb the surface. Such work might include the sampling of wells not included in this survey, or close-spaced gravity survey in the south and central portions of the Harquahala Plain. Since road access is extensive throughout much of the area, one could drive to or walk to any measurement site.

If heat flow drilling is contemplated, the existing road access is such that drill sites can be located to minimize local impact. Much of the area is being or has been farmed. Chances are high that some of the drill sites may have to be located on cultivated land. Arrangements will have to be made with the owner to minimize inconvenience to the farmer.

Should an economic resource or resources be developed in the Harquahala Plain or Tonopah Desert region, appropriate care and concern will have to be taken in its development. Many of the problems associated with the development of such a resource are akin to those of the farmer who is trying to develop new ground-water irrigation systems. Brines and/or adverse concentrations of undesirable trace elements cause

concern in both cases. Removal and disposal of such irritants is dependent upon the concentration of the contaminants.

Withdrawal of ground water may also cause local subsidence, but this is true whether the waters are thermal or not. Thus it can be seen that the development of a geothermal resource is little different from developing irrigation wells of equal capacity. The main difference seems to be that geothermal systems are deeper.

VI. RESERVOIR ESTIMATE

A. Harquahala Basin Reservoir Estimate

Beneath the Harquahala plain lies a ground-water basin about 2400 m deep. The surface area of this broad valley is about 565 km^2. Very little subsurface data are available; however, the stratigraphy may be inferred by analogy to nearby basins. Since water in the upper part of the basin is extensively used for local agricultural supply, the upper 300 m of basin fill will be excluded from the reservoir volume estimate. Over 100 m of the upper basin fill has been dewatered by agriculture.

Based on the description of basin and range structure and stratigraphy presented in Eberly and Stanley (1978) and the gravity map of Peterson (1968), the basin probably contains about 1800 m of basin-fill sediments and 600 m or more of volcanic rocks. Based on lithologic logs of deep wells in nearby basins, the porosity of the basin fill probably averages 20% and the specific yield about 10%. For the volcanic rocks, the effective porosity is about 1% and the specific yield, 0.5%.

The total volume of water in storage in the basin, beneath the upper 300 m, amounts to 150,000 cubic hectometers (hm^3). Of this amount, about 2,000 hm^3 is within the volcanic rocks. Recoverable water is estimated to be 74,000 hm^3 within the basin fill, and 1,000 hm^3 from the volcanic rocks. See Table VI-1 for a summary of the reservoir estimates.

Table VI-1

Harquahala Basin

Sediment Type	Thickness	Area	Porosity	Specific Yield
Basin fill	1500 m	475 km^2	20%	10%
Volcanic Rocks	600 m	300 km^2	1%	.05%

Volume of basin fill	868	thousand hm^3
Volume of volcanics	185	thousand hm^3
Water in storage in basin fill	148	thousand hm^3
Water in storage in volcanics	1.8	thousand hm^3
Net recoverable water in basin fill	74	thousand hm^3
New recoverable water in volcanics	0.9	thousand hm^3

Water in the deeper parts of the basin is probably under confined to semi-confined conditions. Withdrawal of large volumes of water from basin-fill sediments could present problems similar to those experienced during withdrawal of large volumes of water for agriculture. For example, subsidence resulting from ground-water pumping has been well documented in parts of the southwest, and has been linked to withdrawal of water from or beneath fine-grained, nonindurated sediments. But, it appears, the volcanic rocks are not susceptible to subsidence. The extent and magnitude of any subsidence problem cannot be determined yet because of a lack of relevant data. Another problem involves protection of potable water supplies in shallow parts of the aquifer from saline geothermal waters. The potable waters can be adequately protected using reasonable care and current technology.

B. Tonopah Basin Reservoir Estimate

The Tonopah basin is a small but deep ground-water basin that is tributary to the Salt River. The basin's surface covers about 220 km^2, and gravity data suggest the basin to be at least 2100 m deep (Cloran, 1977). Although no wells have penetrated the full thickness of basin fill, the sequence of materials filling the basin and underlying the basin fill can be inferred by comparison with nearby basins and consideration of rock units in the surrounding outcrop areas. Water in the upper part of the basin is extensively used for agricultural supply, so the upper 300 m of basin

fill was excluded from the reservoir volume calculations.

Based on the description of basin and range structure and stratigraphy presented in Eberly and Stanley (1978) and the gravity map of Cloran (1977), the basin probably contains about 1200 m of basin fill sediments and 900 m of volcanic rocks. Based on lithologic logs of deep wells in nearby basins, the porosity of the basin fill probably averages 20%, and the specific yield about 10%. For the volcanic rocks, the effective porosity is probably about 1% and the specific yield about 0.5%.

The total volume of water in storage in the basin, using the porosity method, amounts to 44,000 cubic hectometers (hm^3). This estimate agrees with the 40,000 hm^3 calculated by using the gravity method (Cloran, 1977). Of this volume, about 1,000 hm^3 is contained within the volcanic rocks, and 11,000 hm^3 is contained within the upper 300 m of basin fill. Recoverable water is set at 16,000 hm^3 in the basin fill, and 500 hm^3 in the volcanic rocks. See Table VI-2 for a summary of the reservoir estimate.

Water in the deeper parts of the basin is probably under confined to semiconfined conditions. Withdrawal of large volumes of geothermal water from basin-fill sediments could present problems similar to problems experienced during withdrawal of large volumes of water for agriculture. For example, subsidence resulting from ground-water pumping has been well documented in many parts of the southwest and has been linked to withdrawal of water from or beneath fine-grained,

Table VI-2

Tonopah Basin

Sediment Type	Thickness	Area	Porosity	Specific Yield
Basin fill	1200 m	185 km^2	20%	10%
Volcanics	900 m	116 km^2	1%	0.5%

Volume of basin fill	220	thousand hm^3
Volume of volcanics	160	thousand hm^3
Water in storage in basin fill	44	thousand hm^3
Water in storage in volcanics	1	thousand hm^3
Fresh water in upper 300 m	5.5	thousand hm^3
Net recoverable water in basin fill	17	thousand hm^3
Recoverable water in volcanics	0.530	thousand hm^3

nonindurated sediments. However, the volcanic rocks would not be susceptible to subsidence. Because of a lack of deep basin drilling or first order level surveys, the historic extent of the subsidence problem cannot be determined. Another question involves protection of potable water in the shallow parts of the aquifer from saline geothermal waters. The potable water supplies can be adequately protected using reasonable care and currently available technology.

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