A PRELIMINARY REPORT ON THE GEOTHERMAL ENERGY POTENTIAL OF THE SAFFORD BASIN, SOUTHEASTERN ARIZONA

by

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INTRODUCTION

Hot (>30°C) water has been reported from the Safford area for at least seventy years. The most notable hot water occurrence, Indian Hot Springs, is located northwest of Safford near Fort Thomas. Indian Hot Springs, a health resort at the present time, includes several hot springs and an artesian well about 182 meters deep (Knechtel, 1938). Collective discharge of the springs and well is 320 gallons per minute (gpm) and the highest published discharge temperature is recorded at 48.3°C (Knechtel, 1938).

Nearly all wells deeper than 244 meters in the Safford area discharge artesian water. The deepest of these wells, the Mary Mack, was drilled in the NW¼, NE¼, Sec. 13, T6S, R.24E during 1929 and was completed to a depth of 1148 meters (Knechtel, 1938). The well encountered water flows at 495, 524, 676, 707, 978, and 1079 meters (Knechtel, 1938). In 1933, the well discharged 2500 gpm of 58.9°C sodium chloride water containing 3251 parts per million (ppm) total dissolved solids (TDS) and 4.9 ppm fluorine (Knechtel, 1938). Present status of the well is not known because a field check of the described well location failed to find the well; but the well has probably been plugged and covered.

Several hot wells (> 30°C) have been drilled near Buena Vista northeast of Safford, and one of these is known to have artesian flow. That well, located in NW¼, NW¼, NW¼, NW¼, Sec. 11, T.7S, R.27E, flows at about 800 gpm. The 49.5°C water discharges from around the base of a pump installed over a 24 inch surface casing.

An artesian well in the NW¼, SW¼, Sec. 36, T.6S, R25E northwest of Safford and north of Thatcher flows an estimated 500 gpm at 43.5°C from an 18 inch open surface casing. In the past this well supplied water to the Mount Graham Mineral Bath. During the flood in December 1978 the Gila River changed course and washed away the bath house. At the present time, the well discharges water containing 8292 milligrams per liter (mg/l) TDS into the Gila River (Swanberg, et al., 1977).

The Cactus Flat Artesia area just south of Safford has the largest concentration of hot artesian wells (>30°C). These wells are used for irrigation, health spas and for water supplies to Dankworth Lake, Roper Lake, and several ponds.

Rising costs and supply problems for hydrocarbon fuels have intensified the search for alternative energy sources. The hot wells and springs in the Safford area show that a geothermal resource is present. Developing the geothermal resource around Safford could bring such benefits as reduced energy costs, a constant, assured energy supply, and generating new agricultural-related businesses. This area warrants a detailed geological evaluation of the geothermal resource potential.

GEOLOGY

Geothermal fluids may evolve through three geological processes or mechanisms: (1) intrusion and cooling of magmas in the water bearing shallow crust, (2) deep circulation of meteoric water in areas with high or normal heat flow, (3) and high heat flow in areas with confined aquifers capped by a heat-insulating blanket of low heat-conductive rock. The youngest volcanism in the region consists of basalt eruptions. Basalt may not indicate a large quantity of heat because basalt (mafic) intrusions are usually tabular or pipe-like; basalt is very fluid and flows into fractures, bedding planes, and faults very quickly exposing a large cooling surface compared to their volume causing them to cool in a very short time. On the other hand, granitic (silicic) intrusions provide the best heat source because they are viscous and generally intrude as large bulbous masses that take a hundred thousand to a million years or more to cool. However, the last silicic intrusions of magma in the Safford area probably occurred around 26 million years ago in association with the eruption of silicic lavas that are exposed in the Gila Mountains where basaltic andesite dated at 26.9 $\pm$ .5 mybp overlie silicic ash flow tuffs at Bryce Mountain (Strangway, et al., 1976). The interval of 26 million years is more than enough time for these magmas to have cooled to the ambient temperature of the intruded country rock. Therefore, magma intrusion and cooling may not be an important heating mechanism in the Safford area.

The heating mechanism for the hot wells in the Safford area is probably deep circulation of water and/or high heat flow into confined aquifers capped by an insulating blanket of overlying sediment. The Gila River valley - San Simon valley at Safford form a sediment filled basin probably bounded by unexposed normal faults along the valley margins. Rocks forming the basement of the sediment filled Safford basin are probably similar to exposed rocks in the surrounding mountains. An interpretation of Safford area gravity data suggests that up to 6,000 feet (1.8 km) of sediment may overlie the basement rocks in the deepest parts of the Safford basin (Muller, et al., 1973) (Aiken, C.L.V. and Sumner, J.S., 1974). Probable graben structure and thick basin fill point towards deep circulation as the most likely heat source. Deep circulation usually results in temperatures less than 150^{o}C; but it doesn't preclude high temperature reservoirs (>150^{o}C). Heat is not the only requirement for a geothermal resource. Hot water must be stored in rock and must be easily extracted from that rock. In other words, the rock has to be porous and permeable. Some of the sediment fill of the Safford basin probably will meet these requirements.

Lithology, hydrologic character, and geometry of the basin fill sediments may be the most pertinent geological parameters controlling the geothermal reservoir(s) in the Safford basin. The basin fill sediment are deeply eroded along the trend of the Gila River and somewhat less eroded along the trend of the San Simon River. Post mid-Pleistocene erosion has carved three major terrace surfaces into the fill along the Gila River Valley (Harbour, 1966). A cobble to boulder conglomerate caps the terraces and basin fill sediments.

The inner valley or flood plain of the Gila River, San Simon River, Marijilda Wash and Stockton Wash contain up to 100 feet of predominately fluvial flood plain deposits overlying the incised basin fill sediments. The flood plain deposits are the most important agricultural aquifer, but have little or no geothermal potential. Basin fill will probably be the host to additional geothermal reservoirs. Harbour (1966) divides the basin fill into upper and lower units. Contact between them is believed to be the Pliocene-Pleistocene time-stratigraphic boundary as based on fossil and climatological evidence recorded in the sediment (Harbour, 1966). Upper basin fill consists of fluvial and minor lacustrine deposits. Local fanglomerates occur at the mouths of large canyons that drain the mountains. The fanglomerates are relatively small and do not extend very far into the basin. Wells drilled into the upper basin fill do not encounter hot water (30^{o}C).

Lower basin fill consists of three major facies (Harbour, 1966). The upper facies, green clay facies, is exposed in the lower terraces along the axis of the valley where downcutting has removed upper basin fill. The green clay facies, 400 to 800 feet thick, is mostly clay and siltstone with minor interbedded sands and gravel. Upstream drainage originating from the Duncan basin deposited a local deltaic sequence in the Sanchez area which is contemporaneous with green clay facies. The deltaic deposit consist of thick-bedded silt with channel conglomerates consisting of volcanic bounders (Harbour, 1966).

A clayey evaporite facies lies beneath the green clay facies and has been observed only in well cuttings (Harbour, 1966). The log of a Southern Pacific railroad well drilled in 1906 at Safford shows the evaporites facies to be 1100 feet thick (Knechtel, 1938). The evaporite facies appears to be confined to the basin axis and indicates former internal (closed) drainage.

The Mary Mack well bottomed in coarse fluvial sediments that are called the basal conglomerate facies by Harbour (1966). Little is known about this facies, in particular, whether or not it may be hydrologically connected to the fluvial sediment and local fanglomerates adjacent to the mountain block. Water in these topographically higher sediments may give the basal conglomerate the artesian pressure observed in the Mary Mack well.

Hot artesian wells (>30°C) are also reported from the green clay facies near the basin margins at the Cactus Flat-Artesia area south of Safford. Artesian flows originate from channels of fluvial sand and gravel interbedded with the fine grained green clay facies and may be hydrologically connected to the topographically higher sand and gravels adjacent to the Pinaleno Mountains.

TEMPERATURE AND DEPTH DATA OF WELLS

A literature search revealed 36 wells in the Safford 15 minute and the Artesia 7.5 minute quadrangles which yield hot water (>30°C). Except for two wells in the Buena Vista area, all are flowing at the surface. An additional hot well (49.5°C) at Buena Vista was visited which was previously unreported. The well has considerable flow from around the base of an installed pump. All hot wells from these areas are tabulated in Table 1.

Using 18°C as the mean annual air temperature, temperature gradients were calculated by subtracting the observed surface temperature from the mean annual air temperature. The difference was divided by the depth; then the quotient was multiplied by 1000 to give the gradient. The gradient will be in units of °C/km if degrees celsius and meters are used for the temperature and depth.

Calculated gradients range from 216°C/km to 43°C/km. The highest calculated gradient is from a 90 meter well at

TABLE 1

WELLS IN THE SAFFORD AREA WITH TEMPERATURES GREATER 30°C

Number	Location	Temperature °C	Depth Meters	Map Quadrangle	Reference
1	T8S, R26E, 7AC	35.0	329.2	Safford	1 (See 33)
2	T8S, R26E, 7CA	33.0	243.8	Safford	1
3	T8S, R26E, 7BA	36.0	344.4	Safford	1 (See 27)
4	T8S, R26E, 7CD	34.0	289.6	Artesia	1
5	T8S, R26E, 7BD	35.0	365.8	Safford	1
6	T8S, R26E, 7BB	33.0	262.1	Safford	1 (See 35)
7	T8S, R26E, 7BD	34.0	396.2	Safford	1
8	T8S, R26E, 7BB	35.8	320	Safford	1
9	T8S, R25E, 12AA	30.6	304.8	Safford	1
10	T8S, R26E, 7AD	30.6	244.3	Safford	1
11	T8S, R26E, 18AC	34.0	244.3	Artesia	1
12	T8S, R26E, 32DA	33.0	121.9	Artesia	1
13	T8S, R26E, 32CB	33.0	109.7	Artesia	1
14	T8S, R26E, 33AC	33.0	225.6	Artesia	1
15	T8S, R26E, 33CA	33.0	121.9	Artesia	1
16	T8S, R26E, 33CA	33.0	121.9	Artesia	1
17	T8S, R26E, 33CA	33.3	152.4	Artesia	1
18	T8S, R26E, 32DC	33.0	121.9	Artesia	1
19	T8S, R25E, 12AA	36.7	320	Safford	2,4,6 (See 32)
20	T8S, R25E, 12AD	34.5	244.3	Safford	1,2
21	T8S, R25E, 1DD	35.6	213.4	Safford	1,2
22	T7S, R27E, 2CC	35.6	91.5	Safford	4
23	T8S, R25E, 12AC	34.4	320	Safford	4
24	T6S, R25E, 36CBB	46.5	659	Safford	4,5,6

TABLE 1 (CONTINUED)

WELLS IN THE SAFFORD AREA WITH TEMPERATURES
GREATER 30°C

Number	Location	Temperature °C	Depth Meters	Map Quadrangle	Reference
25	T7S, R27E, 2ADD	41.0		Safford	5
26	T8S, R26E, 7DD	42.0		Artesia	6
27	T8S, R26E, 7BA	41.5	344.4?	Safford	6 (See 3)
28	T7S, R27E, 11BBB	43.5		Safford	6
29	T7S, R27E, 2ACA	37.5		Safford	6
*30	T8S, R26E, 20DBC	44.0	395	Artesia	6 (Fig. 2)
31	T8S, R26E, &DAB	41.5		Safford	6
32	T8S, R25E, 12AAA	39.0	320	Safford	6 (See 19)
33	T8S, R26E, 7ACC	37.0	329.2?	Safford	6 (See 1)
34	T8S, R26E, 7AB	34.5		Safford	6
35	T8S, R26E, 7BB	33.5	262.1?	Safford	6 (See 6)
*36	T8S, R26E, 8BDC	39.4	195	Safford	6 (Fig. 3)
37	T7S, R27E, 11BBB	49.5		Safford	7

*Temperature Log

References

1 - Knechtel, 1938
2 - Hem, 1950
3 - Haigler, 1969
4 - Giardina, 1978
5 - U.S.G.S., WATSTORE File
6 - Swanberg, 1977
7 - This report

Buena Vista that has a 35.6°C surface temperature. The lowest calculated gradient is from the Mount Graham Mineral Bath well which is 659 meters deep and 46.5°C. The intermediate calculated gradients are from wells in the Cactus Flat-Artesia area.

Temperature and depth data for 44 artesian wells in the Cactus Flat-Artesia area are in Table 2 (Knechtel, 1938). The temperature gradients were then calculated for these wells. Well depths ranged from 79m to 400m with temperatures ranging from 20°C to 35.8°C. The range of calculated gradients was 29.7°C/km to 138°C/km. Figure 1 shows histograms of gradient variations from four 100 meter intervals. Shallow wells, 0 to 200 meters, exhibit three apparent gradient distributions. The two higher gradients in the shallow wells are thought to be the result of deeper hot-artesian aquifers leaking or flowing upward into the shallower aquifers. The majority of wells in the Cactus Flat-Artesia area have gradients around 50-60°C/km.

In order to delineate aquifers or zones of aquifers within the wells, drillers' comments reported by Knechtel (1938) were reviewed, and the reported water flows and depths noted. These data are tabulated in Table 3. All wells with reported aquifers below 140 meters have similar gradients, although the wells are of different depth and temperatures. These data suggest that the temperatures of the lower aquifers increase with depth systematically.

TABLE 2

TEMPERATURE
GRADIENT DATA(1)
FOR
CACTUS FLAT - ARTESIA AREA

Temperature and Depth Data From (Knechtel, 1938)

18°C Is The Mean Annual Air Temperature Used In Gradient Calculations.

T8S R25E

Number	Section/Quarter Section		Depth Meters	Observed Surface Temperature	Calculated Gradient °C/KM
1	1	DD	213.4	30.0	60.9
2	12	AA	182.9	21.1	22.4
3	12	AA	304.8	30.6	44.6
4	12	AA	304.8	29.4	40.7
5	12	AD	244.3	32.2	62.2
6	12	AD	243.8	32.2	62.3
7	12	AD	243.8	30.0	53.3
8	12	AC	400.2	28.9	29.7

T8S R26E

Number	Section/Quarter Section		Depth Meters	Observed Surface Temperature	Calculated Gradient °C/KM
*9	6	B	518.2?	28.3?	22.9?
10	7	AB	252.9	30.0	51.4
11	7	AB	76.2	25.0	104.9
12	7	AB	76.2	26.7	127.3
13	7	AB	91.4	26.7	106.1
14	7	AB	213.4	28.9	55.8
15	7	AC	152.4	25.6	56.4
16	7	AC	213.4	30.0	60.9
17	7	AC	213.4	28.9	55.8
18	7	AC	121.9	24.4	63.2
19	7	AC	329.2	35.0	54.7
20	7	AC	82.3	24.4	89.9

(1) Only flowing wells are tabulated.

* Lower sections of the well may have caved before measurements were made.

TABLE 2 (CONTINUED)

TEMPERATURE GRADIENT DATA(1) FOR CACTUS FLAT - ARTESIA AREA

Temperature and Depth Data From Knechtel, 1938

$18^{o}C$ Is The Mean Annual Air Temperature Used In Gradient Calculations.

T8S R26E (Continued)

Number	Section/Quarter Section		Depth Meters	Observed Surface Temperature	Calculated Gradient $^{o}C/KM$
21	7	AC	91.4	25.0	87.1
22	7	AC	106.7	23.9	62.8
23	7	AC	231.7	28.3	48.7
24	7	AD	251.5	29.9	51.3
25	7	AD	244.3	30.6	55.7
26	7	AD	152.4	25.0	52.5
27	7	DA	79.2	24.4	90.9
28	7	CA	243.8	32.8	64.8
29	7	CD	289.6	33.9	58.4
30	7	BA	244.3	29.4	50.8
31	7	BA	344.4	35.6	54.0
32	7	BD	365.8	35.0	49.2
33	7	BD	396.2	33.9	42.6
34	7	BB	262.1	32.8	60.3
35	7	BB	320.0	35.8	58.8
36	8	DA	121.9	25.0	65.6
37	8	BC	243.8	29.4	50.9
38	8	BC	243.8	28.9	48.8
39	8	BC	137.2	25.0	58.3
40	9	D	188.9	27.8	57.2
41	16	BC	115.8	26.1	78.6
42	16	BC	146.3	25.6	58.8
43	16	BC	182.9	27.2	55.8
44	18	AC	244.3	33.9	69.1
45	20	DA	126.5	24.4	58.5

(1) Only flowing wells are tabulated.

* Lower sections of the well may have caved before measurements were made.

TABLE 2 (CONTINUED)

TEMPERATURE
GRADIENT DATA(1)
FOR
CACTUS FLAT - ARTESIA AREA

Temperature and Depth Data
From Knechtel, 1938

18°C Is The Mean Annual Air Temperature Used In Gradient Calculations.

T8S R26E (Continued)

Number	Section/Quarter Section		Depth Meters	Observed Surface Temperature	Calculated Gradient °C/KM
46	20	DA	30.5	21.7	154.1
47	20	AC	91.4	25.6	94.1
48	20	AB	213.4	30.6	63.7
*49	21	BB	243.8?	20.0?	12.3?
50	28	CC	152.4	28.3	74.2
51	32	AD	228.6	25.0	34.9
52	32	DB	121.9	32.2	124.7
53	32	DC	103.6	29.4	119.7
54	32	DC	121.9	32.8	129.6
55	32	CA	152.4	27.8	70.9
56	32	CB	109.7	32.2	138.6
57	33	AC	225.6	32.8	70.0
58	33	CA	121.9	32.8	129.6
59	33	CA	121.9	32.8	129.6
60	33	CA	152.4	33.3	106.9

(1) Only flowing wells are tabulated.

* Lower sections of the well may have caved before measurements were made.

TABLE 3

AQUIFERS OR ZONES OF WATER FLOW FROM
FLOWING WELLS IN THE CACTUS FLAT - ARTESIA AREA[1]
IN 1938

Depth Meters	Well Numbers[2] From Table 2	Range of Observed Surface Temperature	Range of Gradient Values $^{o}C/KM$	Zone Number
24-30	26, 47, 46	21.7	154.1	1
76-91	11, 19, 27, 47	24.4-25.6	89.9-94.1	2
137-152	6, 7, 39	25.0	58.3	3
182-213	6, 7, 10, 14, 16, 17, 19, 32	28.9-30.0	55.8-60.9	4
244-267	6, 7, 10, 19, 25, 28, 32, 37	29.4-32.8	50.9-64.8	5
315-338	19, 31, 32, 35	35.6-35.8	54.0-58.8	6

(1) Data are from drillers' comments in the remarks column of tables in Knechtel, 1938.

(2) Well numbers which are underlined, 26, have only one flow from the zone or depth interval in which they are reported.

Conductive heat flow probably creates these temperature gradients. The upper flows, however, calculate to much higher gradients which probably result from convection or upward leakage of hot water from the lower aquifers. The 50-60°C/km gradients of the lower aquifers are high and may continue with depth. The deepest well in the basin, the Mary Mack well, which lies 15 air miles northwest of the Cactus Flat-Artesia, has a calculated gradient of 36°C/km. The 36°C/km gradient is slightly above normal.

TEMPERATURE LOGS

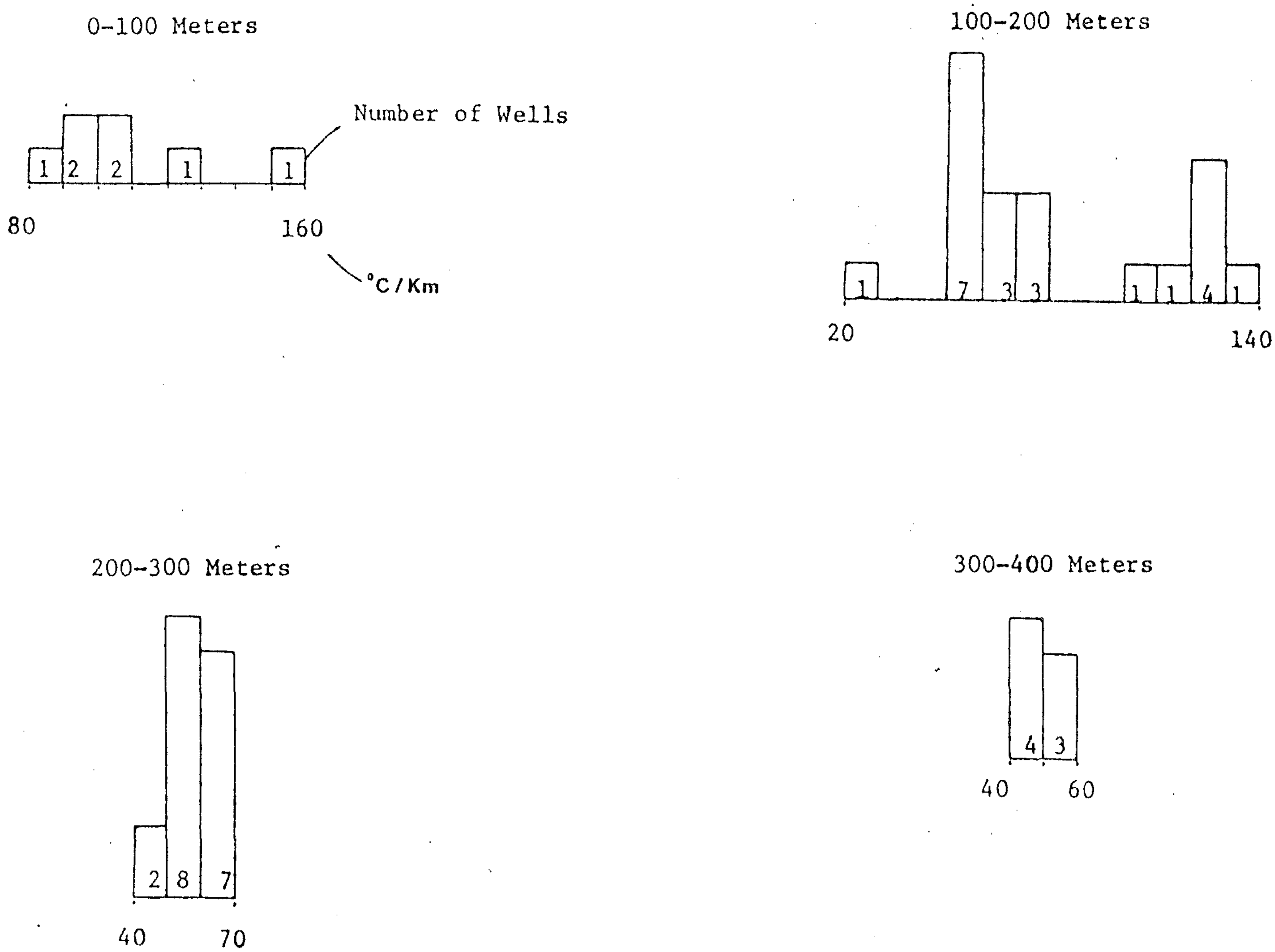
Two flowing wells, 6 inches in diameter, about 2.5 miles apart and approximately the same surface elevation were temperature logged. Temperature readings were taken at 5 meter intervals and recorded to the nearest hundredth of a degree celsius. Temperature logs of the wells are shown in Figures 2 and 3.

The well near Roper Lake is 195 meters deep and increased only 0.5°C from the surface to the bottom. Three zones of cold water mixing with upward flowing hot water were observed. The largest volume of cold water mixing with hot water is at 140 to 145 meters interval.

The well near Dankworth Lake is 390 meters deep; the surface temperature measured 44.61°C while the bottom temperature is 45.39°C. At 175 meters to 185 meters, upward flowing hot water appears to be flowing laterally out of the

FIGURE 1

HISTOGRAMS OF TEMPERATURE GRADIENTS
AT DIFFERENT DEPTHS FROM
WELLS IN THE CACTUS FLAT - ARTESIA AREA
IN 1938



Temperature and depth of flowing wells from Knechtel, 1938.

FIGURE 2

Temperature Log of Well Near Roper Lake

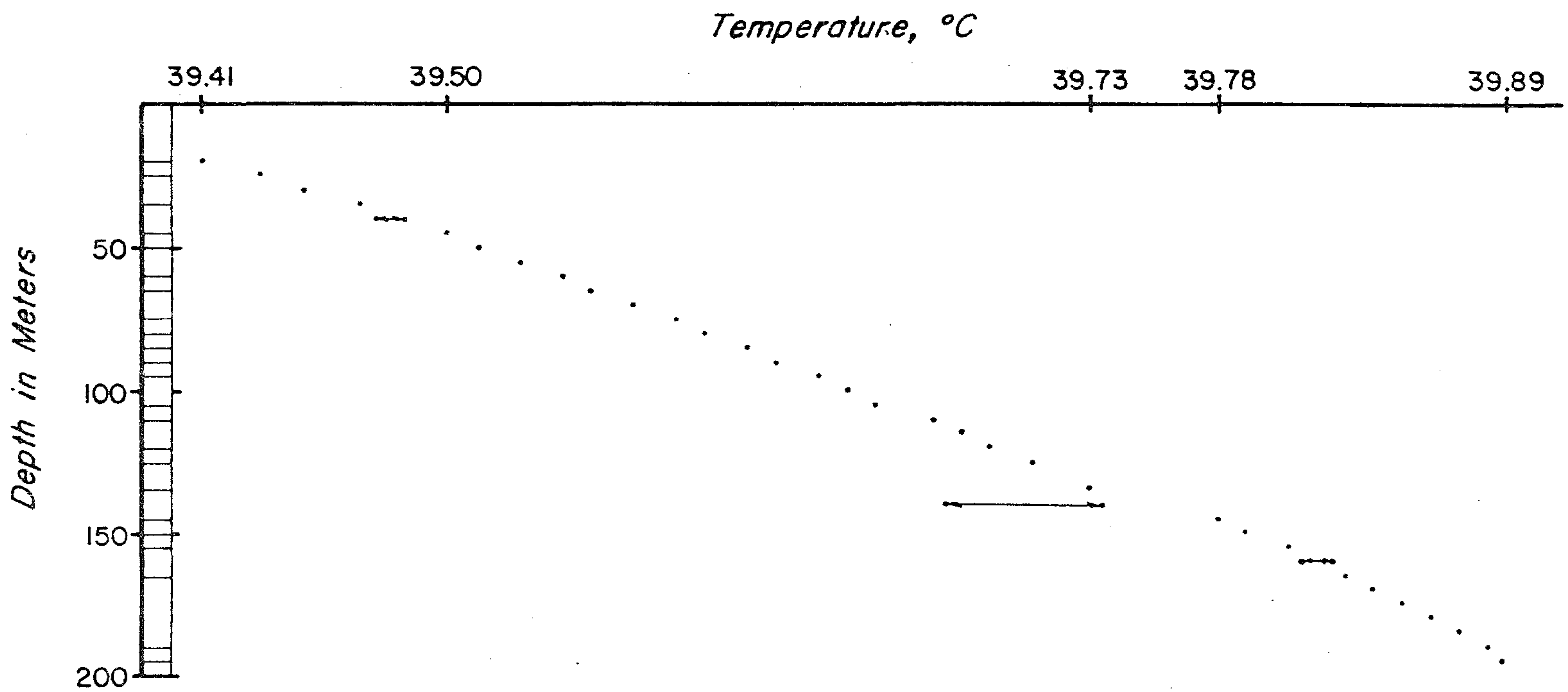
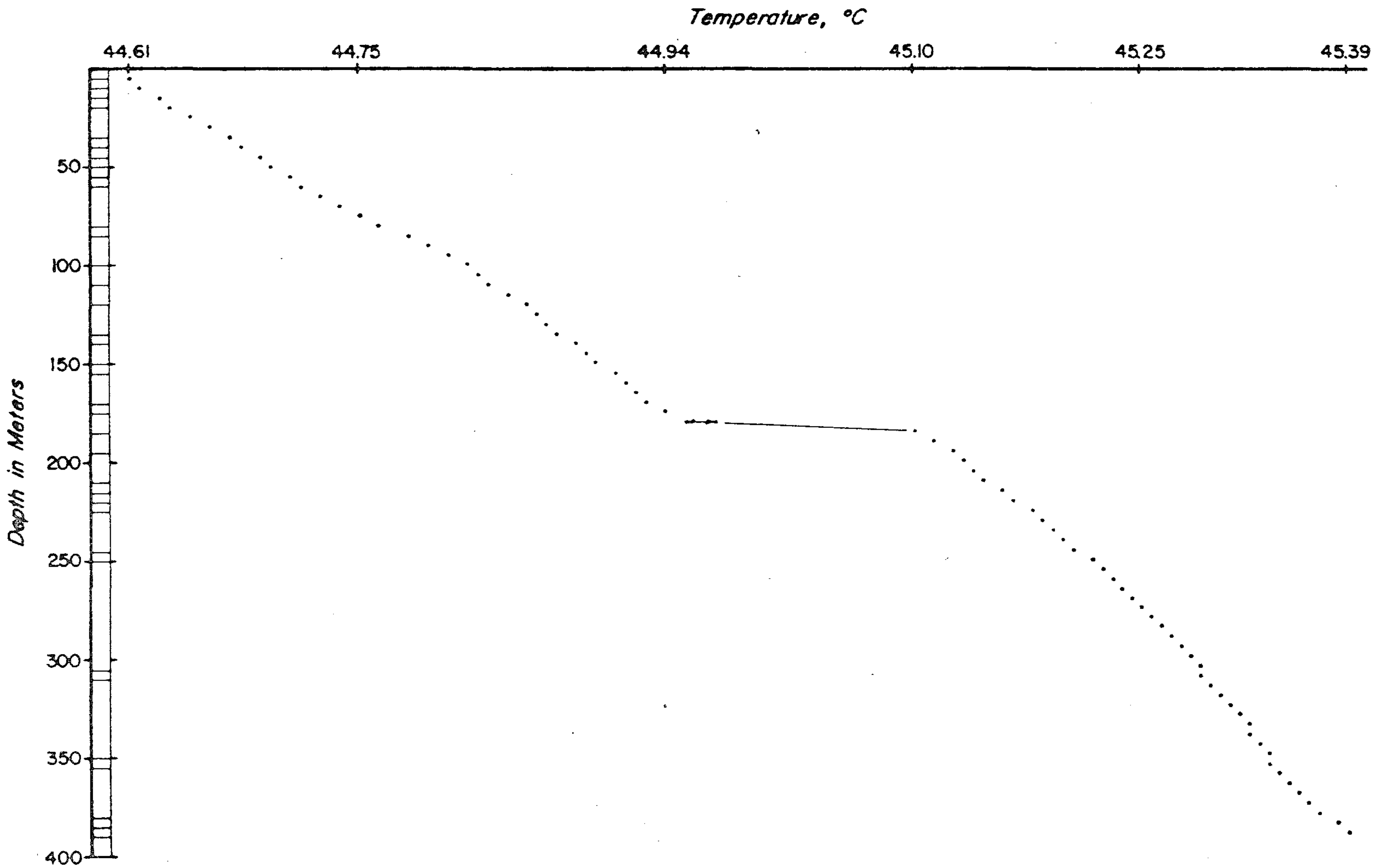


FIGURE 3

Temperature Log of Well Near Dankworth Lake



well and into a shallow aquifer.

The two logged wells are essentially isothermal, and the cooling that does occur is possibly due to adiabatic cooling. Conductive transfer of heat out the well into the country rock as the water flows upward to the surface is also a probable cooling mechanism. Interestingly, the two zones or aquifers that mix with the artesian flow are correlative to Zones 3 and 4 of Table 3. The Roper Lake well may derive its flow from Zone 4. If the aquifers are correlative with the 1938 data, then the aquifers have increased in temperature by several degrees celsius. Hot water losses to Zone 4 by the Dankworth well provides a possible mechanism for such a temperature increase.

GEOTHERMOMETRY

The silica concentration in hot water has been used to predict the base reservoir temperatures of geothermal systems (Fournier, 1977). Dissolution of silica from quartz, chalcedony, and opal is temperature dependent (Fournier and Rowe, 1966). The highest temperature waters will dissolve the most quartz, chalcedony, or opal. Silica geothermometry is therefore very useful in predicting minimum subsurface temperature when quartz and chalcedony equilibria controls the silica concentration in the reservoir, and when very little precipitation of silica occurs after the hot water leaves the reservoir (Fournier, White, and Truesdell, 1974). Silica geothermometry is most applicable where the hot water has not mixed with cold water. If mixing of hot and cold water is known to occur, additional techniques to include mixing model calculations may be used (Fournier and Truesdell, 1974).

Weathering and alteration of alumino-silicates (feldspars, kaolinite, zeolites) also contribute silica to natural waters (Garrels and MacKenzie, 1967). However, silica concentrations will tend to be controlled by quartz or chalcedony equilibrium since these reactions are reversible. Silica concentration with respect to quartz and chalcedony may be metastable at lower temperatures. Therefore, waters whose silica contents are mostly derived from the weathering or alteration of alumino-silicate rocks may have silica concentrations out of equilibrium with quartz or chalcedony. Silica introduced into water by dissolution of alumino-silicates at low temperatures will thus tend to cause anomalously high concentrations of silica with respect to theoretical quartz and chalcedony equilibrium concentrations. Silica geothermometry is used with the assumption that temperature dependent dissolution of quartz and chalcedony in the geothermal reservoir controls the silica concentration in these waters rather than any nonreversible reactions involving alumino-silicates after the water leaves the geothermal reservoir.

Silica concentrations of wells in the Safford area are plotted against temperature in Figure 4. The concentration of silica from the dissolution of quartz and chalcedony at increasing temperature are shown by the quartz geothermometer and the chalcedony geothermometer lines. Silica concentrations of wells in the Cactus Flat-Artesia area cluster around the chalcedony predicted temperature and indicates that these waters are probably in equilibrium with chalcedony. Observed surface temperatures are very close to the predicted silica temperatures. Therefore, the wells' observed temperatures are close to their bottom hole temperatures predicted by silica geothermometry. The two temperature logs agree with the geothermometry results.

The well at Mount Graham Mineral Bath and the wells at Buena Vista have much higher silica concentrations which may predict higher temperature reservoirs. Temperatures indicated by the chalcedony geothermometer for these wells is 85°C to 90°C. Bottom hole temperatures of these wells are not known. Since the wells have good artesian flow, large amounts of cold water are probably not mixing with these hot waters and cooling them as they flow to the surface, but rather the observed surface temperature is close to the bottom temperature of the well. The geothermometer temperatures are the temperatures of reservoirs at greater depth or nearby.

Ratios of sodium, potassium and calcium concentrations in geothermal waters have also been used to predict base temperatures of reservoirs (Fournier and Truesdell, 1973).

The Na-K-Ca geothermometer is less reliable in predicting reservoir temperatures than the silica geothermometer because the constituents used in the calculation may be involved in many non-temperature dependent reactions after leaving the reservoir.

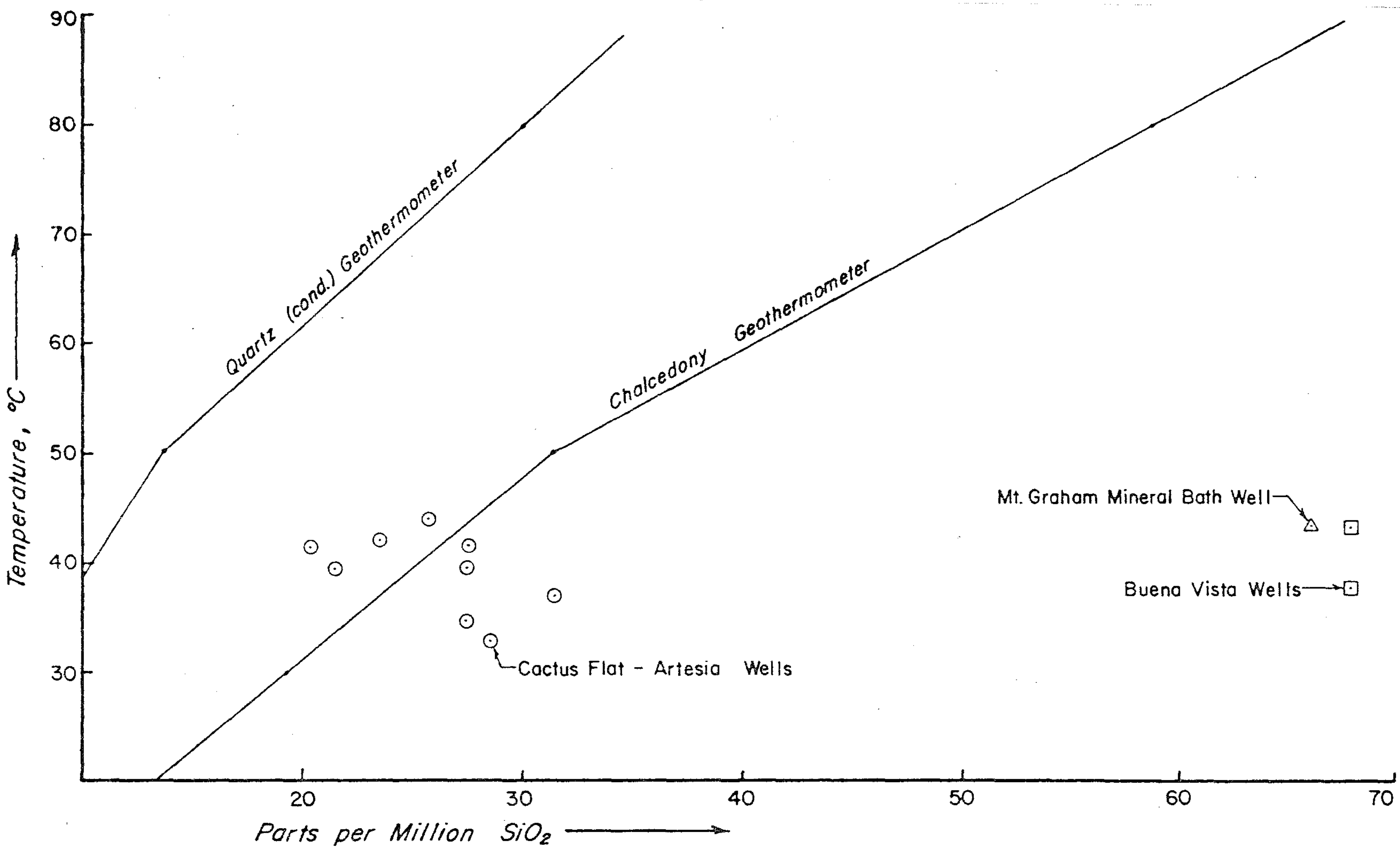
The Na-K-Ca temperature of the Mount Graham Mineral bath is around 70°C. The Na-K-Ca temperature is close to the chalcedony prediction, 85°C-90°C.

Buena Vista wells give Na-K-Ca temperature predictions of 115°C. 115°C is not in close agreement with the chalcedony prediction 85°C-90°C; however, the quartz geothermometer predicts 115°C for these wells. Therefore, these waters may be from a 115°C geothermal reservoir at depth or near Buena Vista.

Na-K-Ca temperatures of the Cactus Flat-Artesia area vary between 60°C and 90°C. These temperatures are suspect, but they may be indicative of higher temperature reservoirs since the quartz geothermometers of 75°C are in close agreement. It should be pointed out that these wells appear to be in equilibrium with chalcedony (see Figure 4), so that the quartz geothermometer is probably lower than the real temperature of the postulated reservoir.because some chalcedony precipitated from solution thereby decreasing the original silica concentration. If so, then the Na-K-Ca geothermometer prediction would be more realistic.

FIGURE 4

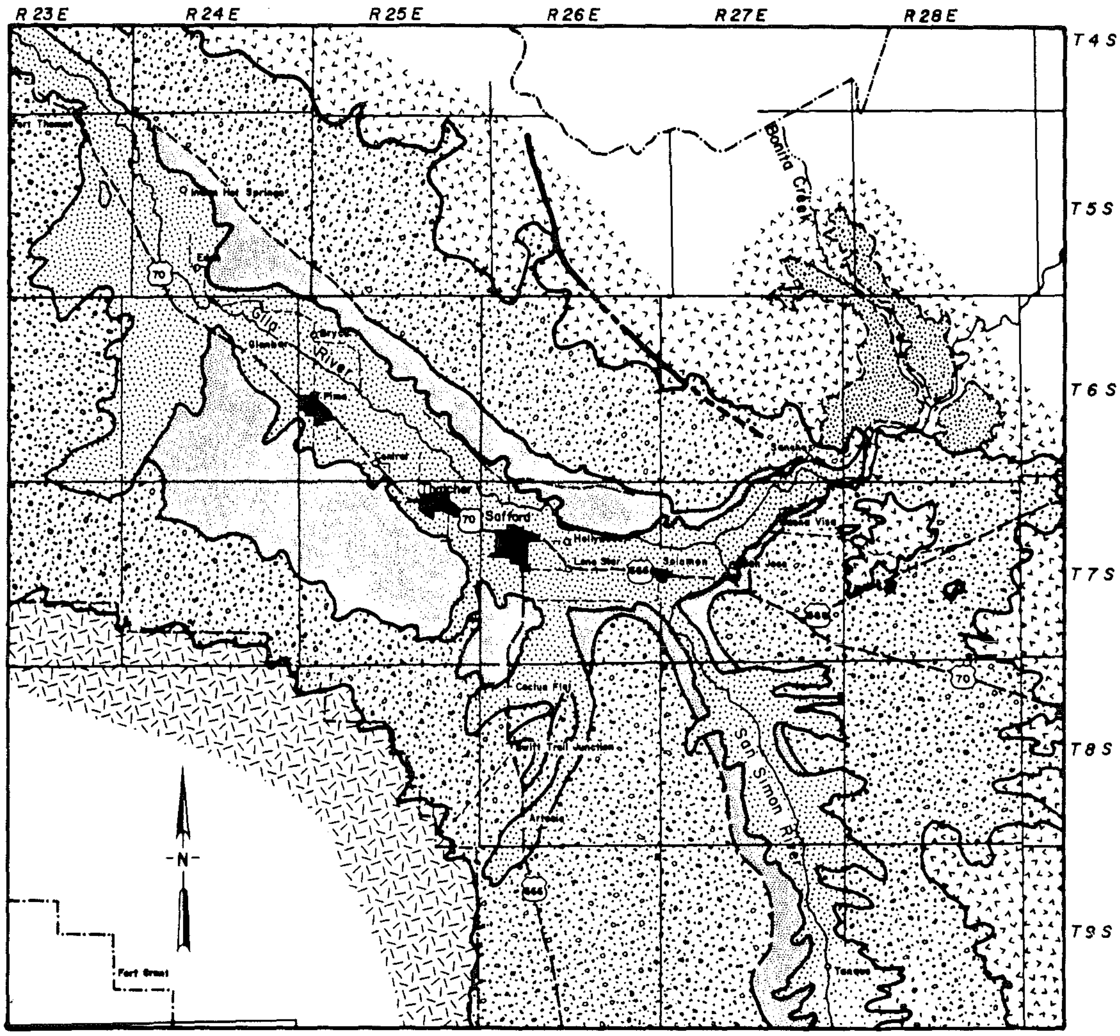
Temperature Vs Silica



Data for the geothermometry calculations are from Swanberg, et al., 1977, and from sampling by the Arizona Bureau of Geology and Mineral Technology Geothermal Group.

FIGURE 5

Generalized Geologic Map of Safford Area



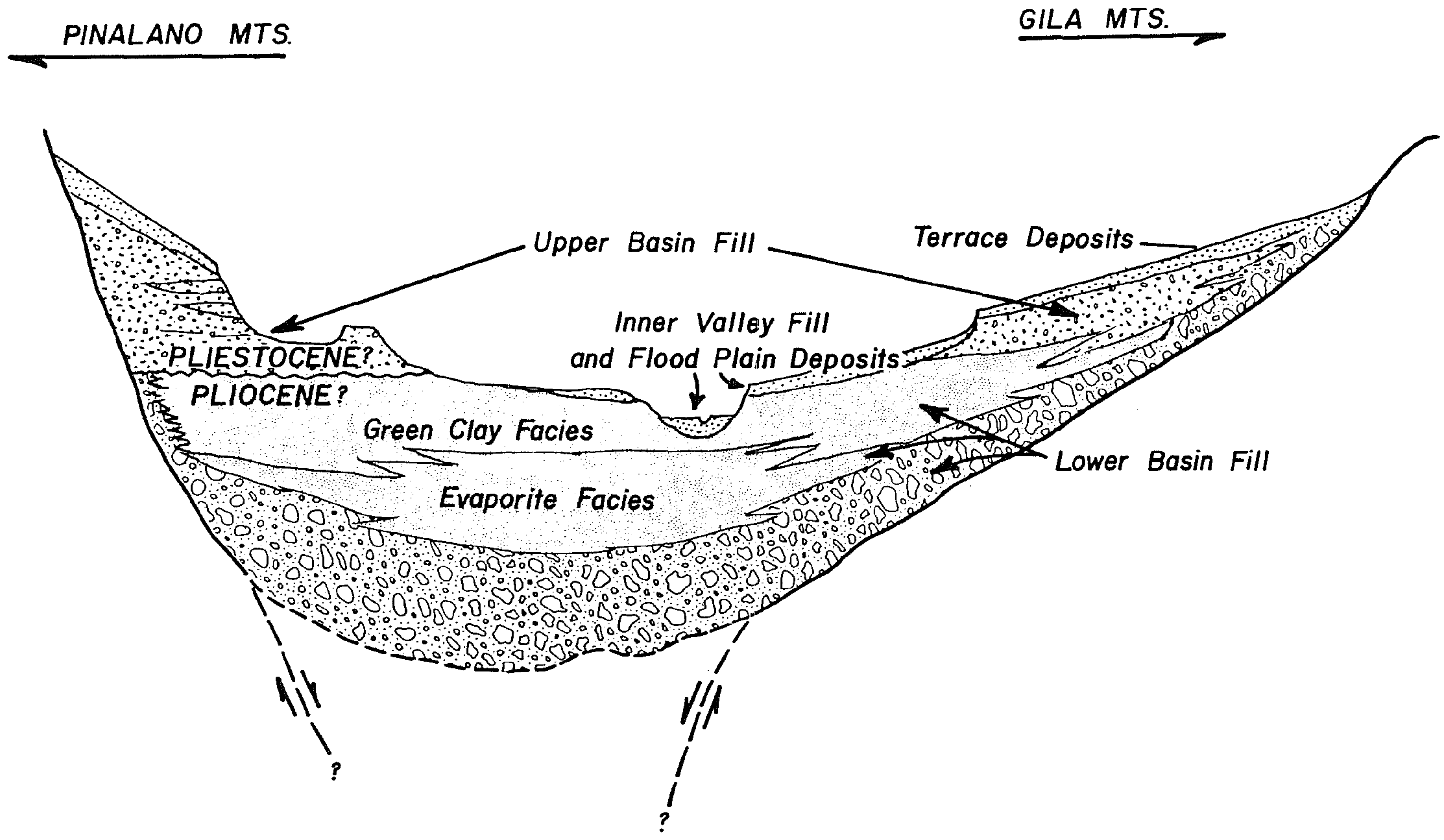
Geology From Harbour (1966)

- Terrace Deposits, Inner Valley Fill
- Upper Basin Fill
- Green-Clay Facies
- Evaporite Facies
- Basal Conglomerate
- Volcanic Rocks
- Plutonic and Metamorphic Rocks
- Fault

FIGURE 6

Generalized Sketch Showing Basin-Fill Relationships

Modified After Harbour, 1966



CONCLUSIONS

Preliminary study of the Safford area shows an excellent geothermal potential for low and intermediate temperature reservoirs. Available geothermometry and gradient data predict 50°C to 120°C geothermal water at reasonable depths (760m to 1200m). The basal conglomerate facies of the lower basin fill is the most likely reservoir and probably stores a large volume of hot water. Very good artesian flows are probable as was reported in 1938 at the Mary Mack well near Pima. Sodium chloride water with high fluoride content is likely. Total dissolved solids ranging from 1,000 mg/l to 10,000 mg/l or greater would be expected. Good geothermal reservoirs are also likely in alluvial channel deposits in the green clay facies along the basin margins. Further studies are needed to confirm these preliminary conclusions concerning the geothermal potential in the Safford basin. A high temperature resource (<150°C) is also possible, so additional studies are definitely warranted.

The most likely heating mechanism for the postulated geothermal resources is deep circulation of water in a normal or above normal heat flow regime. High heat flow through confined aquifers that are capped by low heat conductive rocks may be as important in this area. Land status of the Safford area appears to be favorable for geothermal exploration and development. The development of geothermal energy is favorably looked upon by the people living in the Safford area.

Geothermal uses in the Safford area include heat for new agricultural businesses and processes, space cooling and heating of large buildings and neighborhoods, desalination of brines (making more water available for domestic and agricultural use), hot fluids for economic in-place-leaching of low grade copper deposits and/or mine dumps, and possibly electrical power generation as new technology is invented that produces electricity with intermediate temperature geothermal resources (90°C to 150°C).

REFERENCES

Aiken, Carlos L. V., and Sumner, John S., 1974, A Geophysical and Geological Investigation of Potentially Favorable Areas for Petroleum Exploration in Southeastern Arizona, Arizona: Oil and Gas Conservation Commission Report of Investigation 3.

Arnorsson, Stefan, 1975, Application of the Silica Geothermometer in Low Temperature Hydrothermal Areas in Iceland: American Journal of Science, Vol. 275, pp. 763-784.

Berry, Robert C., 1976, Mid-Tertiary Volcanic History and Petrology of the White Mountain Volcanic Province, Southeastern Arizona: Unpub. PhD. Dissertation, Princeton University, 317 p.

Davidson, Edward S., 1960, Geology of the Eastern Part of the Safford Basin, Graham County, Arizona: Arizona Geological Society Digest, Volume III, pp. 123-126.

Davis, Stanley N., 1964, Silica in Streams and Ground Water: American Journal of Science, Vol. 262, pp. 870-891.

Dellechaie, Frank, 1976, A Hydrochemical Study of the South Santa Cruz Basin near Coolidge, Arizona, in Proceedings of the Second United Nations Symposium on the Development and Use of Geothermal Resources, Volume I, pp. 330-348.

Dunn, Peter G., 1978, Regional Structure of the Safford District, Arizona: Arizona Geological Society Digest, Volume XI, pp. 9-16.

Eaton, Gordon P., and Timmons, Clayton E., 1966, Principle Facts for Gravity Stations in the Saffod and San Simon Valleys, Arizona: U.S. Geological Survey Open File Report

Eberly, L. D., and Stanley, T. B., 1978, Cenozoic Stratigraphy and Geologic History of Southwestern Arizona: Geological Society of America Bulletin, Vol. 89, pp. 921-940.

Fair, Charles L., Nov. 1971, Geohydrology of the Safford Inner Valley: Arizona Geological Society Digest - Volume IV, pp. 125-130.

Feth, J. H., and Hem, J. D., 1963, Reconnaissance of Headwater Springs in the Gila River Drainage Basin, Arizona: U.S. Geological Survey Water-Supply Paper 1619H, 54 p.

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, Vol. 264, pp. 685-697.

Fournier, R. O., and Truesdell, A. H., 1973, An Empirical Na-K-Ca Geothermometer for Neutral Waters: Geochem et Cosmochim Acta, Vol. 37, pp. 1255-1275.

Fournier, R. O., and Truesdell, A. H., 1974, Geochemical Indicators of Subsurface Temperature - Part 2, Estimation of Temperature and Fraction of Hot Water Mixed with Cold Water: U.S. Geological Survey Journal of Research, Vol. 2, No. 3, pp. 263-270.

Fournier, R. O., White, D. E., and Truesdell, A. H., 1974, Geochemical Indicators of Subsurface Temperature - Part 1, Basic Assumptions: U.S. Geological Survey Journal of Research, Vol. 2, No. 3, pp. 259-262.

Fournier, R. O., 1977, Chemical Geothermometers and Mixing Models for Geothermal Systems: Pergamon Press, Geothermics, Vol. 5, pp. 41-50.

Garrels, Robert, M., and Mackenzie, Fred, T., 1967, Origin of the Chemical Compositions of Some Springs and Lakes, in Equilibrium Concepts in Natural Water Systems: American Chemical Society, Washington, D.C., pp. 222-242.

Giardina, S., and Conley, J. N., 1978, Thermal Gradient Anomalies: Arizona Oil and Gas Conservation Commission Report of Investigation 6.

Gerlach, T., Norton, D., DeCook, K. J., and Sumner, J. S., 1975, Geothermal Water Resources in Arizona: A Feasibility Study, Project Completion Report, U.S. Department of Interior, Office Water Resources Research Project A-054-ARIZ., Washington, D.C., 36 p.

Haigler, Leon B., 1969, Geothermal Resources, in Mineral and Water Resources of Arizona, Arizona Bureau of Mines Bulletin 180, pp. 575-580.

Halpenny, L. C., et Al., 1952, Groundwater in the Gila River Basin and Adjacent Areas, Arizona -- A Summary: U.S. Geological Survey, Open-File Report (Tucson, Arizona.)

Harbour, Jerry, 1960, Sedimentology and Stratigraphy of the Basin-Fill Sediments in the Safford Valley: Arizona Geological Society Digest, Volume III, pp. 131-132.

Harbour, Jerry, 1966, Stratigraphy and Sedimentology of the Upper Safford Basin Sediments: Unpub. PhD. Dissertation, University of Arizona, 242 p.

Heindl, L. A., 1960, Geology of the Lower Bonita Creek Area - A Preliminary Report: Arizona Geological Society Digest, Volume III, pp. 35-39.

Heir, John, D., 1950, Quality of Water of the Gila River Basin Above Coolidge Dam, Arizona: Geological Survey Water-Supply Paper 1104, 230 p.

Hollander, J. T., 1960, Geology and Aquifer Characteristics of the Inner-Valley Alluvium in the Safford Valley, Arizona: Arizona Geological Society Digest, Volume III, pp. 133-135.

Knechtel, Maxwell M., 1938, Geology and Ground Water Resources of the Valley of Gila River and San Simon Creek, Graham County, Arizona: U.S. Geological Survey Water-Supply Paper, 796-F, 222 p.

Marlowe, James I., 1960, Late Cenozoic Geology of the Lower Safford Valley -- A Preliminary Report: Arizona Geological Society Digest, Volume III, pp. 127-129.

Muller, A. B., et al., 1973, An Analysis of the Water Quality Problems of the Safford Valley, Arizona: Technical Report No. 15, Department of Hydrology and Water Resources, University of Arizona, 126 p.

Robinson, R. F., and Cook, Annan, 1966, The Safford Copper District, Lone Star Mining District, Graham County, Arizona, in Titley, S. R., and Hicks, C. L., eds., Geology of the Prophyry Copper Deposits, Southwestern North America: University of Arizona Press.

Scarborough, R. R., 1975, Chemistry of Late Cenozoic Airfall Ashes in Southeastern Arizona: Unpub. M.S. Thesis, University of Arizona, 107 p.

Strangway, D. W., Simpson, J., and York, D., 1976, Paleomagnetic Studies of Volcanic Rocks from the Mogollon Plateau Area of Arizona and New Mexico: New Mexico Geological Society, Special Pub. No. 5, pp. 119-124.

Swanberg, C. A., et al, 1977, An Appraisal Study of the Geothermal Resources of Arizona and Adjacent Areas in New Mexico and Utah and Their Value for Desalination and Other Uses: New Mexico Energy Institute Report No. 6, 76 p.

White, D. E., and Williams, D. L., 1975, Assessment of Geothermal Resources of the United States - 1975, U.S. Geological Survey Circular 726, 155 p.

Van Horn, W. L., 1962, Late Cenozoic Alluvial Deposits of the Upper Safford Valley, Graham County, Arizona: Arizona Geological Society Digest, Volume V, pp. 89-96.