PRELIMINARY GEOTHERMAL ASSESSMENT OF THE BIG SANDY VALLEY, MOHAVE COUNTY, ARIZONA

by
Alice Campbell and Nile O. Jones

Bureau of Geology and Mineral Technology
Geological Survey Branch
Geothermal Group

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

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I. INTRODUCTORY MATERIAL

A. Location and Access

The Big Sandy Valley is a north-trending valley located south and east of Kingman, Mohave County, Arizona (Figure I-1). Interstate 93 between Phoenix and Kingman travels along the axis of the Big Sandy Valley. This road provides major access to several small communities located in and adjacent to the valley. Well maintained dirt roads also lead to many of the ranches and mines in the area.

B. Local Support

Water acquisition is a prime concern for the owners of ranches and mines that are not near the Big Sandy River. Nearly all of the inhabidents of the area expressed a desire to aid in this geothermal energy study, but very few of their wells were acceptable for this study. The bulk of the data for this report was acquired through the geverosity of the Cypress-Bagdad Copper Company and the helpful staff at the Agricultural Extension Service in Kingman.

II. SUMMARY AND RECOMMENDATIONS

A. Water Resources

The water balance of the Big Sandy Valley can be determined by estimating the water in storage and the potential for recharge. Annual precipitation is approximately 11 inches (28 cm) per year. About 12% of the rainfall goes to groundwater recharge.

Reservoir estimates were based on storage values for the various rock types found within the basin and their estimated volumes. The study area has approximately 85,500 hm^3 of water in storage. Net recoverable water is approximately 42,800 hm^3.

Quality of the groundwater is generally good. Most wells contain less than 1,000 mg/l total dissolved solids (TDS). Slightly higher values are found in the southern portion of the valley. Most of the water can be classified as calcium-magnesium bicarbonate with local additions of sodium, chloride and sulfate. Fluoride content is generally greater than 1.0 mg/l, but often less than 2.0 mg/l.

B. Hydrothermal Resources

Three springs have temperatures in excess of 30^oC and most wells have simple temperature gradients in excess of 30^oC/km. Higher gradients are found along the coarse of the Big Sandy River as well as in the southern portion of the valley. Current data indicate reservoir temperatures in excess of 150^oC may be achieved at depths in excess of 3 kilometers. Desalting operations are unlikely in most of the valley. The best area for such use lies in the southern portion of the area. Direct use applications appear to be more likely.

III. LAND STATUS

The Big Sandy Valley has a watershead area of about 1145 km^2 (Map III-1). The Big Sandy Valley has a surface area of about 850 km^2. The general land status of the area by major controlling group is given in Table III-1.

There are five geothermal lease applications within the study area. The five applications total 10,773 acres (Figure III-1). Environmental assessment for the lease area is being done by the Bureau of Land Management, Phoenix District Office.

TABLE III-1. Land Status for the Big Sandy Valley and adjacent Watershead, Mohave County, Arizona.

Owner of Trust Group	Area (mi^2)	Area (km^2)
Private Ownership	441.5	1143.5
State of Arizona Trust	198.1	513.1
BLM Resource Lands	404.9	1048.6
TOTAL	1044.5	2705.2

Approximately 42% of the land is under BLM jurisdiction, 19% is State Trust and 39% is privately owned. The study area does not encompass military or Forest land.

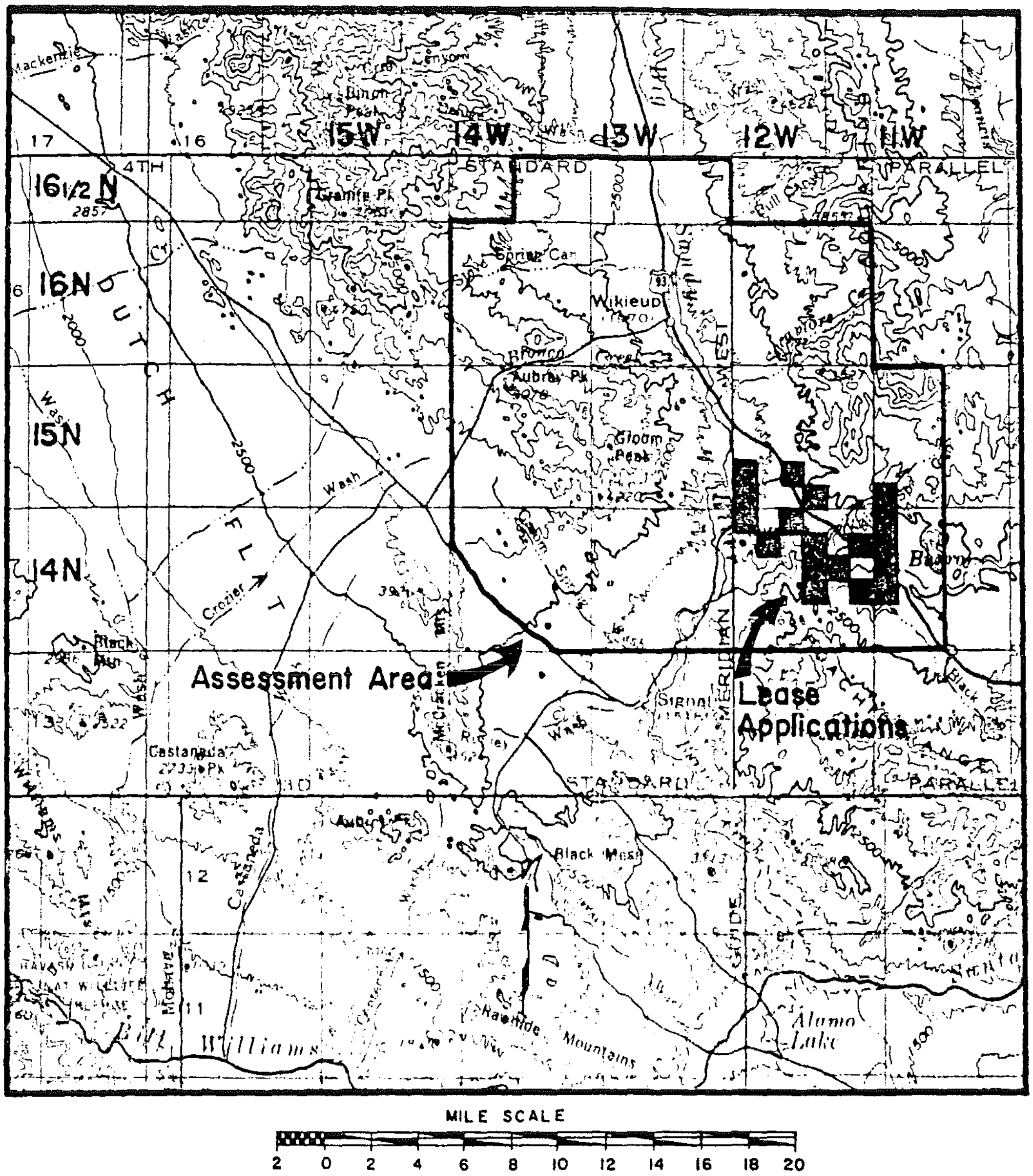

Figure III-3: Location of geothermal lease applications in the Big Sandy Valley, Arizona

IV. RESOURCE EVALUATION

A. Introduction

The Big Sandy Valley lies within the Basin and Range physiographic province, and is immediately adjacent to the Colorado Plateau province. This setting accounts for the presence of low-to-moderate temperature geothermal resource in the area. The valley occupies a structural depression caused by faulting. The groundwater basin within the valley is bounded on the east and west sides by major faults parallel to the valley and is floored by igneous and metamorphic rocks similar to those exposed in the adjacent mountain ranges. The groundwater basin is filled with continental sediments including lacustrine, fluviatile, aeolian and alluvial-fan deposits. Intercalated with these deposits are basalt flows and rhyolitic volcanic rocks. The continental sediments filling the basin have been broken by faulting at least as recently as Pleistocene time, and some faulting may be even younger.

B. Geology

The oldest rocks in the Big Sandy area consist of granitic gneiss of Precambrian age (Map IV-1). These rocks underwent some heating and metasomatism during the Laramide orogeny that affected nearly all of Arizona. Mineral deposits including gold and copper are found in the pre-Tertiary rocks near the present day valley. This mineralization may have contributed a major portion of the chloride and sulfate found in the valley sediments derived in part from the country rock.

The granitic rocks are overlain by volcanic and sedimentary rocks locally 150 to 300 m thick. These younger rocks are exposed principally in the Aquarius Mountains, although some flows are interbedded in the sediments filling the valley. The volčanic rocks range in age from Oligocene to Pliocene. Some cider cones just south of the Big Sandy Valley are probably of Recent age (less than 11,900 years). On the whole, these volcanic rocks are too old to contribute heat to a present day geothermal resource.

A sequence of old arkosic gravel and conglomerate forms the lowest sedimentary unit in the valley. Where exposed, the conglomerate appears to be older, highly cemented, and overlain by the less well-cemented gravel. The conglomerate resembles a talus breccia composed of rock types found nearby. It probably accumulated at the base of fault scarps that were formed when the valley began to subside. The thickness of the conglomerate is unknown; however, if it does represent a fault-scarp breccia, it could be a few thousand feet thick. This excessive thickness would be immediately adjacent to the main boundary faults and would extend no more than half a mile into the valley. In the central part of the valley the conglomerate is expected to interfinger with the gravel unit. The gravel unit could be anywhere from 300 to 1,000 m thick, but no wells have penetrated more then a hundred meters into it. According to Davidson (1973), this gravel unit appears sufficiently permeable to store and transmit substantial quantities of water. Where this unit is thick and buried beneath insulating fine-grained sediment, it probably forms the main geothermal reservoir in the valley.

The basal conglomerate and gravel is uncommformable (?) overlain by predominately fine-grained sand, silts, and clays. These sediments were deposited in and near a shallow lake, so this unit also includes lacustrine marls, silts and clays, fluvial and aeolain sands, and minor gravels. These sediments contain a moderate amount of clay and therefore are much less permeable than the underlying gravels. A few hundred to 1000 m of this unit is exposed in the basin and is referred to as 'Lower Basin Fill'. Sulfate and chloride concentrations in water derived from this unit tend to be high, suggesting the possibility of nearby evaporite beds.

On the eastern side of the valleyand in the vicinity of Tule wash, there lies a terrace gravel thought to be the same age as the lower basin fill. This unit has not been recognized elsewhere and may be the result of a local tectonic event such as an active fault.

The upper basin fill consists of about 50 to 100 m of silty gravel that grades to sandy silt, and appears to be the product of stream activity. This unit fills a trough carved into the lower basin fill. During its deposition the streams drained toward the Big Sandy River and then southward to the present outlet. The upper basin fill is presumably Pleistocene in age. This unit, as well as the overlying stream and floodplain alluvium, contain the highest-quality water in the basin, and are probably not a part of the geothermal reservoir.

The youngest unit in the area is the stream and flood-plain alluvium of Holocene age that underlies the Big Sandy River and its tributaries. The alluvium consists of uncemented layers and channel deposits of sand, gravel and silt. The alluvium varies from a feather-edge to as much as 15 m, although most often it is found to be about 10 m thick. Most of the wells in the valley draw from this unit or from the upper basin fill.

C. Structure

Geothermal reservoirs develop when favorable conditions of lithology, geometry and reservoir permeability are subjected to high heat flow. The geology of the Big Sandy area was described by Davidson (1973). Figure IV-1 shows a generalized section through the valley. The valley is typical of most in the Basin and Range tectonic province, although a few atypical features are found. The valley has dropped down along a series of steplike bounding faults. Displacement and the thickness of sediments should therefore be greatest in the central part of the valley. The available gravity data does, however conflict with this assumption. Map IV-2 shows the residual of Bouguer gravity map of the area (Aiken and others, 1979). Assuming the continental deposits in the valley are of lower density than the surrounding granitic rocks, then the configuration of sediments in the basis only approximates the model of a simple downdropped block. The gravity contours suggest two deep accumulations of sediment, one in the Round Valley area and one in the central part of the valley. If large amounts

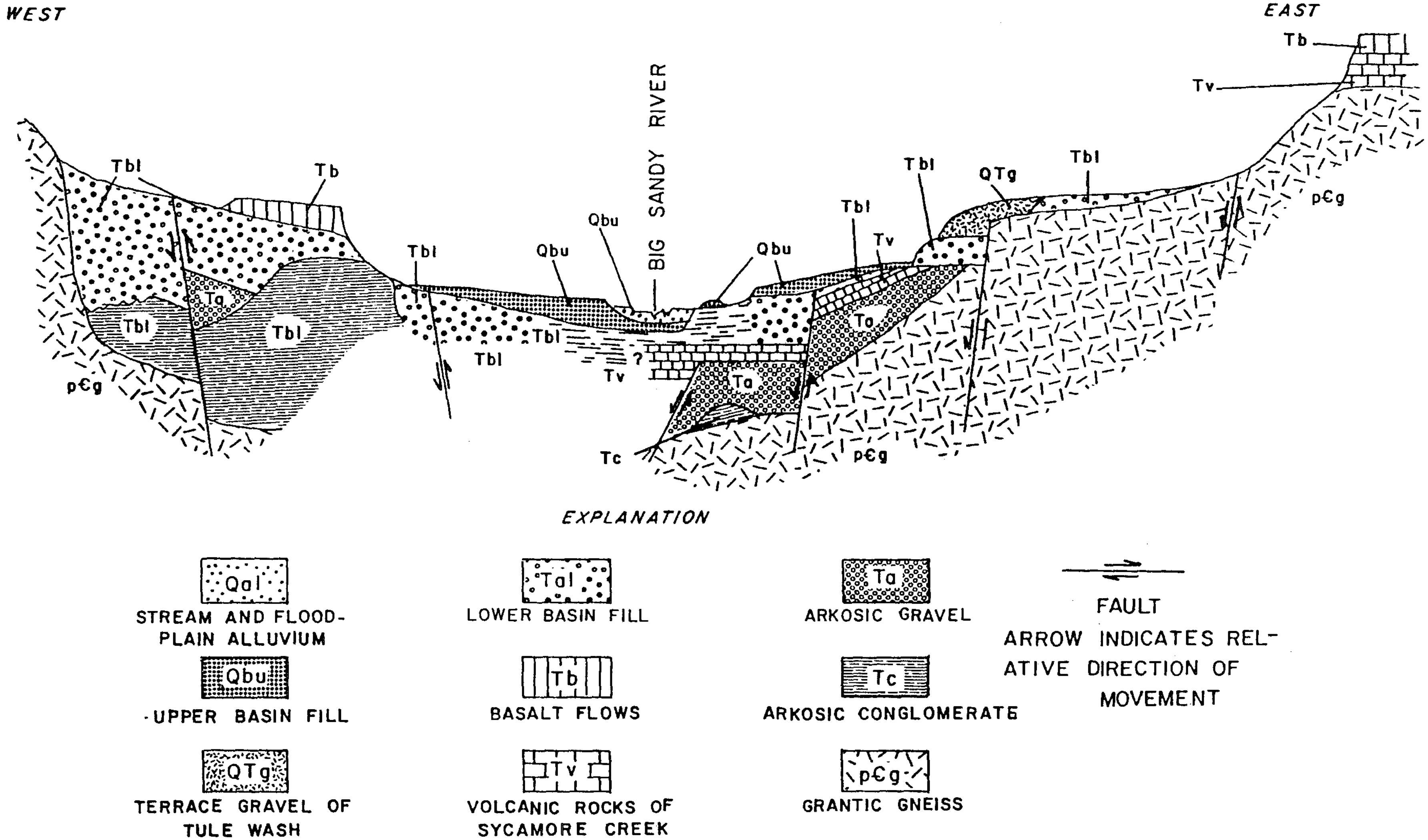

FIGURE IV-1: Diagrammatic section of the Big Sandy area.

of volcanic rocks are present in the subsurface, as is possible along the eastern and southern part of the valley adjacent to the Aquarius Mountains, then the valley could be deeper than the gravity contours suggest.

Evidence of subsurface rock types can be provided by residual aeromagnetic intensity maps. Map IV-3 shows aeromagnetic residuals for the area. In general the magnetic intensities are greater over the mountain areas and reflect the increase in magnetic minerals contained within the igneous rocks that comprise these ranges. The lower magnetic values over the valley are probably due to the lesser amounts of magnetite found in the sedimentary rocks. The slight magnetic high near Cane Springs corresponds to a slight gravity high in the same area and could indicate that volcanic or igneous rocks are present in the subsurface. Without more data it is difficult to tell whether this area is underlain by shallow bedrock or thick volcanic flows interfingered with sedimentary rocks. Magnetic lows can also be produced by evaporites, synclines and molten rock. Any conclusions solely based on geophysics meet be considered tentative a best.

Gravity and magnetic maps can also be used to infer geologic structure. Unexposed geologic features such as faults can form the boundaries of geothermal systems. Such structures can allow for entrance or exit of water from these systems. In general, high-angle faults produce steep linear gravity gradients, and the fault inference is further strengthened if the linear trend is also found in the magnetic contours. The coincidence of steep magnetic and gravity data indicate that major faults probably occur along the eastern margin of the basin between Cane Spring and the mouth of Sycamore Creek and southeastward from Cow Canyon to the Big Sandy River. The eastern basin-bounding fault is less distinct north of Cane Spring but probably follows the surface exposure of bedrock. The western fault boundary is much less apparent. The exception is on the northwest portion of the basin near the access road to Gold King Mine where the road follows a prominent subsurface linear trend. Bedrock outcrop to the east of this road has several faults that could be related to the gravity slides which are responsible for isolated blocks of bedrock such as the 40 acre outcrop near the Kabba Gold Mine. Another interpretation is that a large fractured pluton is present in the subsurface. This fault block is intriguing becuase neither the gravity or magnetic maps show any apparent 'roots' underneath the block.

The depth of the basin can be estimated from gravity data if the densities of the bedrock and continental sediments are known or can be estimated. Assuming the bedrock density of 2.67 gm/cm^3 and density for the sediments is 2.31 gm/cm^3 (Lausten, 1974), then the depth of the basin can be estimated by the formula:

$$\text{thickness} \times 1000 \text{ m} = \frac{g \text{ (mgal)}}{41.90 \times d}$$

(d = density contrast)

The maximum thickness of the sedimentary section in the southern part of the basin would then amount to about 1,340 m. The thickness of sediment in the northern part of the area comes to nearly 2,000 m. These calculations assume that the entire gravity low is due to the presence of a sedimentary sequence. If a smaller density contrast is chosen, then the computed thickness would be greater.

D. <u>Water Temperature and Chemistry</u>

Geothermal reservoirs often leave distinctive signatures on the groundwater in the area of the reservoir. Two common methods of detecting these systems include water temperature measurements and the water chemistry. Although water temperature and chemistry data are scarce for the valley, enough are available to indicate where potential geothermal waters may be found.

Measured water temperatures in wells and springs can be used to map regions of anomalous temperature or they may be converted to temperature gradients (in $^{O}C/km$) for wells where depth and temperature are both known. An anomalous temperature for this area is defined as the discharge temperature greater than $30^{O}C$. An anomalous gradient is one greater than about $30^{O}C$ (Muffler, 1979). Three springs in the area have measured temperatures in excess of $30^{O}C$: Cofer, Kaiser, and Big Pasture Springs. Most of the wells in the area have gradients over $30^{O}C/km$. The highest found was $240^{O}C/km$. Map IV-4 shows the spring temperatures and well gradients for the valley.

Temperatures and temperature gradients do not necessarily indicate the temperature or location of the subsurface reservoir. The map distribution of gradients shows, rather, the pattern of warm water circulation in the groundwater system. Very low gradients, such as the $27^{O}C/km$ near Round Valley, probably indicate a recharge area where cold water is percolating into the groundwater system. High gradients are generally found along the course of the Big Sandy River and imply that warm water is discharging from the reservoir. High gradients are also found in the southern part of the valley where groundwater may be rising in response to the constriction and shallowing of the groundwater basin. Relatively low gradients should be found immediately adjacent to the mountain ranges where runoff recharges the groundwater system. High gradients are also possible along faults that cut the sedimentary section and allow for upward movement of warm waters.

Water chemistry can also be used to define geothermal systems and, in some cases, geologic structure. For example, fluoride concentrations are often higher along faults. Most of the higher fluoride concentrations in the valley occur along the trend known faults and those predicted from the gravity and magnetic studies.

Temperature-dependent components of natural waters include silica and the relationships between sodium, potassium and calcium. Geothermometers based on these elements have been described by Fournier and Rowe (1966), and Fournier and Truesdell (1973). The assumptions used in these methods may be summarized as follows: 1) temperature-dependent reactions in the geothermal reservoir control water chemistry; 2) water-rock equilibrium must exist within the geothermal reservoir; 3) minerals supplying the constituents upon which the geothermometers are based must exist within the geothermal reservoir; 4) re-equilibration must not occur as the water migrates from the reservoir to the sampling point; and 5) there must be negligible mixing with near surface waters of different chemical composition (Fournier and others, 1974). Most of the chemical analyses available include silica, but very few contain potassium values. Therefore, the Na-K-Ca geothermometer was used on only a few waters. Table IV-1 shows the geothermometry of wells and springs in the area.

The results of the geothermometry indicate that few, if any of the springs or wells tap high temperature geothermal

TABLE IV-1

GEOTHERMOMETRY OF SELECTED WELLS AND SPRINGS

Name / Location/ Reference		T meas.	T chal.	Na-K-Ca B=4/3	Mg. corr.	T Na-K-Ca
Kaiser H. S.	(3)	37	110	100	-	100
Cofer H. S.	(4)	32	110	132	90	42
16-N-13W-3acc	(5)	21	49	59	-	-
16N-13W-3acd	(5)	21	54	70	-	-
16N-13W-10acc	(5)	21	50	68	-	-
16N-13W-15ccb	(5)	26	51	58	-	-
16N-13W-27	(2)	-	57	50	-	-
16N-13W-27cd	(2)	-	30	49	-	-
16N-13W-34bc	(2)	-	32	49	-	-
16N-13W-34bc	(1)	25	31	49	-	-
16½N-13W-22bcc	(5)	16	43	55	-	-
16½N-13W-27cbc	(5)	20	48	64	-	-
16½N-13W-27ccc	(5)	20	46	61	-	-
16½N-13W-27cdb	(5)	20	49	63	-	-
16½N-13W-34cba	(5)	18	45	52	-	-
17N-13W-10aaa	(1)	-	65	35	-	-
17N-13W-14baa	(5)	15	43	61	-	-
17N-13W-26aab	(5)	20	48	67	-	-
18N-13W-21cdb	(5)	27	34	33	-	-
18N-13W-28ab	(2)	-	32	42	-	-
18N-13W-28dc	(2)	-	28	41	-	-
18N-13W-34ccd	(5)	28	38	40	-	-
18N-13W-35aa	(2)	-	39	30	-	-
18N-13W-35aab	(1)	25	39	30	-	-
21N-11W-29creek	(1)	16	58	31	-	-

References:

1. Davidson, E. S., 1973
2. Dutt, G. R., and McCreary, 1970
3. Goff, R. E., 1979
4. Swanberg and others, 1977
5. This Report

systems. Kaiser Hot Spring, the hottest spring in the area, has a Na-K-Ca temperature of about 100°C and a silica (chalcedony) temperature of 110°C. Cofer Hot Spring has a Na-K-Ca temperature of 142°C and a silica temperature of 110°C. No wells for which potassium values were available yielded Na-K-Ca temperatures above about 70°C. Silica temperatures averaged about 60°C. Map IV-4 shows the locations of wells having silica geothermometers above 60°C. This map also indicates a high correlation between silica temperatures and high gradients. The mean silica concentration in all waters in the basin is 30 mg/l, which translates to a silica temperature of 52°C, even for young nonthermal river water.

The main conclusion that can be drawn from the geothermometry in this basin is that quantitative geothermometry is not very useful here. The most likely explanation is that the assumptions mentioned above are not all valid. The high background silica concentrations could be a result of rapid weathering of rocks in and around the valley. The silica concentration therefore might not represent equilibrium values. The Na-K-Ca geothermometer can also be disrupted by ion exchange processes in the clayey parts of the sedimentary fill (Hem, 1970). However, if allowance is made for these problems, there are still some very high silica concentrations that point to a geothermal reservoir in the temperature range of 60°C-90°C. The appearance of high silica concentrations in areas having high gradients substantiates the conclusion that warm waters are found within the basin.

E. Summary and Conclusions

The Big Sandy Valley has many characteristics indicating a low-to-moderate temperature geothermal resource in the subsurface. The valley is a structural depression filled with about 1,400 m of sediments. The upper part of the sedimentary section consists of silty and clayey lake beds, which could form an insulating blanket for a hydrothermal sustem. Evidence for a system of deep circulation of meteoric water includes: high silica concentrations, a pattern of temperature gradients suggestive of circulating groundwater and a few warm springs and numerous warm wells. Groundwater upwelling is likely to occur in the southern portion of the basin. Probable targets for drilling are the deepest parts of the basin, near Cow Canyon and Round Valley, along faults on the east margin of the valley, and along the inferred fault trending toward Cow Canyon.

V. ENVIRONMENTAL IMPACTS

The investigation has not yet disturbed the environment of the Big Sandy Valley. Field work has been confined to sampling production wells held by the Cypress-Bagdad Copper Company. If further work is undertaken in the area it will probably produce minimal environmental impact. Procedures such as well sampling and geophysical surveys generally do not involve surface disturbance. Road access in the area is adequate for most sampling purposes. Environmental disturbance associated with drilling is confined to the immediate area around the site. Past drilling activity shows such disturbance to be neither extensive nor permanent.

The developer of a geothermal resource in the area should consider water quality problems associated with production of geothermal water, and engineering problems, such as subsidence, caused by groundwater pumpage in excess of recharge. The water chemistry problems of primary concern are boron, sodium and high total dissolved solids because these constituents, when excessive, are injurious to plants. The subsidence problem would occur only if very large volumes of water were withdrawn. The benefits of geothermal en ergy would have to be weighed against the cost of repair to structures if subsidence were to occur.

VI. BIG SANDY VALLEY GROUNDWATER RESERVOIR ESTIMATE

The Big Sandy River groundwater basin occupies a structural trough produced by faulting. The surface area of the groundwater basin in 850 km^2, and gravity data suggests it is about 1,350 m deep. No wells are known to have penetrated the full thickness of sediment in the basin, but the stratigraphy can be estimated from exposed sediment and by analogy with other nearby basins in the Basin and Range tectonic province. A small amount of water in the upper 100 m of the basin is used for local water supply and some is exported from the basin for use by the Cypress-Bagdad Copper Company.

The waterbearing materials in the basin consist of continental sediments ranging in age from early Tertiary to Holocene. The lower portion of the reservoir consists of arkosic conglomorate and gravel, volcanic rocks and the Lower Basin Fill. These units correspond to Lower Unit I, Middle Unit I, and Lower Unit II of Eberly and Stanley (1978). The Unit I sediments have been faulted, tilted, and are locally quite well cemented. This unit probably comprises most of the geothermal reservoir. Davidson (1973) estimates the specific yield to be 15% for the uppermost 15 m and 10% for the depth range of 15-213 m. For the purposes of this report, the specific yield of the lower sediments is taken as 5% and is based on the lower unit's deeper burial and cementation. The specific yield of the volcanic rocks is set at 1%. The total volume of waterbearing material below 213 m is 958,800 cubic hectometers (hm^3).

The total volume of water in storage in the basin below 213 m is 42,772 hm^3. Of this amount, about 1,300 hm^3 is in the volcanic rocks and about 41,500 hm^3 is in the lower sedimentary sequence. See Table VI-1 for a summary of the reservoir estimate.

Water in the deeper parts of the basin is probably under confined to semiconfined conditions. Withdrawal of

TABLE VI-1

BIG SANDY VALLEY GROUNDWATER BASIN

Sediment Type	Thickness	Area	Porosity	Specific Yield
Volcanic Rocks	152 m	850 km^2	2%	1%
Lower Basin Fill	976 m	850 km^2	10%	5%

Volume of lower basin fill	829,600 hm^3
Volume of volcanic rocks	129,200 hm^3
Water in storage in basin fill	82,960 hm^3
Water in storage in volcanics	2,584 hm^3
Net recoverable water in basin fill	41,480 hm^3
Net recoverable water in volcanics	1,292 hm^3

large volumes of water from confined aquifers could present problems similar to those encountered during withdrawal of large volumes of water for irrigation. For example, subsidence resulting from groundwater pumping has been well documented in parts of the Southwest, and has been linked to removal of large volumes of water from or beneath fine-grained, nonindurated sediments.

OFR 79-15

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Hem, J.D., 1970, Study and interpretation of the chemical characteristics of natural water, second ed., United States Geological Survey Water-Supply Paper 1473, 363 p.

Lausten, C.D., 1974, Gravity methods applied to the geology and hydrology of Paradise Valley, Maricopa County, Arizona: unpub. MSc thesis, Arizona State University, 137 p.

Muffler, L.J.P. (ed.), 1979, Assessment of geothermal resource of the United States, 1978: U.S. Geological Survey Circular 790, 163 p.

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.

West, F.G., and Laughlin, A.W., 1979, Aquarius Mountain area, Arizona: a possible HDR prospect: Los Alamos Scientific Laboratory Report LA-7804-MS, 16 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.