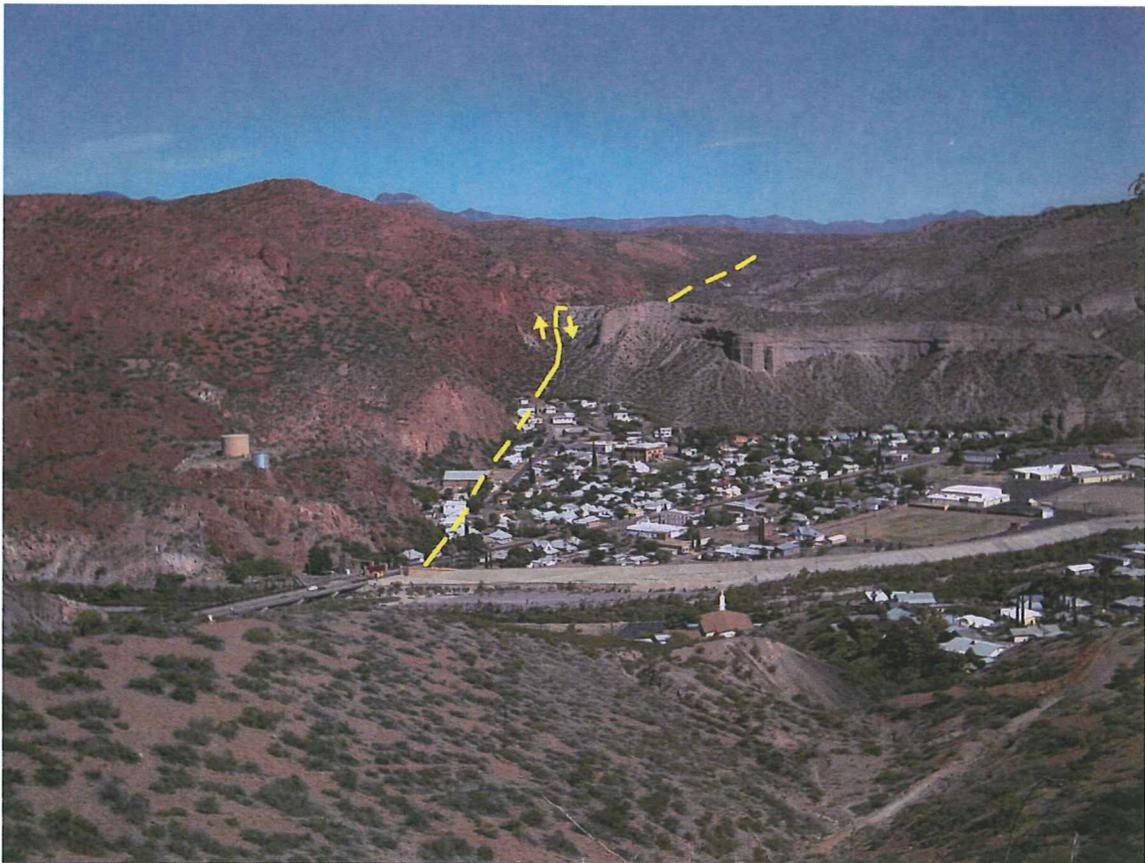


Arizona Geological Survey  
Contributed Report (CR-07-A)

Clifton Hot Springs, Arizona: GRED III -- Final Report  
David E. Brown



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## EXECUTIVE SUMMARY

This report details geothermal resource exploration done for Arizona Public Service and the U.S. Department of Energy. Arizona Public Services (APS) of Phoenix, Arizona, retained David Brown & Associates (DBA) in 2005 to evaluate the geothermal resources of the Clifton Hot Springs area in Greenlee County, eastern Arizona for electric power production. Project Management was provided by T<sup>2</sup> & Associates of Sacramento, California. The intent of the evaluation was to determine the local geologic controls of the geothermal system and, using publicly available data and original mapping performed for this project, to recommend locations for Controlled Source Audiomagnetotelluric (CSAMT) cross sections. The results of the geophysics were then combined with the geologic mapping to site three gradient holes, two of which were drilled to depths of 635 feet and 1,000 feet, respectively. This work was done with funding from the US Department of Energy under their Geothermal Resource Exploration and Development III (GRED III) program and co-funding from APS. Grant number was DE-FC36-04GO14346.

The geology of the Clifton area can be described as being very complex. Rocks of widely disparate ages have been juxtaposed by intense and pervasive faulting in the area. The structure of the area is dominated by major faults striking to the northwest and to the northeast. Regionally, these faults form a large V-shape, with the Laramide Orogeny intrusives that formed the nearby Morenci copper deposits located just above the apex of the V. All faulting in the area appears to be normal, with some left-lateral oblique slip noted during recent mapping. The basement rocks exposed in the study area are Pre-Cambrian granites and granodiorites. These rocks are then overlain by a number of Paleozoic limestones, quartzites, and shales. Several layers of Tertiary volcanic units and Tertiary-Quaternary sedimentary units overlie these rocks in the study area. The entire pile of rocks older than the Laramide Orogeny (about 40 to 80 million years before present) has been intruded by a series of crystalline units in plugs, domes, dikes, lappoliths, and laccoliths of Laramide age. Drilling and mapping indicate that, in all likelihood, the reservoir rock will be the Paleozoic and older rocks, with intrusives of Laramide crystalline rocks and Tertiary mafic lavas. The youngest volcanic rocks mapped in the area are undifferentiated andesite to rhyodacite flows of about 25 to 30 million years in age. A thick sequence of 250,000 to 2-million year-old continental sediments (the Gila Group) is found blanketing all of the older rock units in very small to very large patches, and filling the Duncan Basin to the south of the project area to a depth of several thousand feet.

All of the rocks in the area have been hydrothermally altered to varying degrees, with the younger volcanic and sedimentary rocks showing a young, condensate alteration with significant quartz and clay alteration, especially in areas of faulting and in volcanic units with significant incipient permeability. Some condensate hydrothermal alteration was

recognized in the young, terraced alluvium deposits. This indicates there may have been a much larger active hydrothermal system in the area at some time in the fairly recent geologic past. Clifton Hot Springs is a typical fault-controlled, sodium chloride-dominated system. The hot springs emerge from the bottom and edges of the San Francisco River, where the river has eroded down to intercept hot fluids ascending through fault zones. The predicted geothermal reservoir temperatures, using industry-accepted geothermic calculations of pre-existing data, range from about 130°C (266°F), to as high as 180°C (356°F). At the time of our investigation, the hot springs had been obliterated by a large flood during February of 2005, and could not be sampled for further analyses. Work performed in the 1950s and 1970s indicates the total thermal flow into the San Francisco River could be over a thousand gallons per minute.

CSAMT cross-sections were performed by Zonge Engineering of Tucson, Arizona. The results of their work confirmed the presence of a major, previously unmapped fault on the east side of the San Francisco Canyon, in the area of the Clifton Hot Springs orifices and other thermal features; and a number of other smaller paralleling faults, both synthetic and antithetic to the major fault. The structural interpretations from the geophysics by the Zonge team confirmed the detailed outcrop mapping by the DBA team. It appears this fault has formed a keystone graben under the San Francisco River, and appears to be controlling the local geothermal system.

Three gradient holes were located, based on the results of the geologic mapping and the geophysical survey. The first two were drilled to 635 feet and 1,000 feet respectively. The third was permitted, but suspended due to dramatic increases in drilling costs during the project. TG-1, located on the east side of the San Francisco River, just uphill from the county road on Potter Ranch property was planned to 800 feet, but carried only to 635 feet, due to very poor drilling conditions. Lithology to total depth was entirely Pre-Cambrian granites and granodiorites. Maximum temperature in the hole was 65.1°C (149.2°F) during a logging event in October of 2005. The gradient in TG-1 was convective and highly disturbed, due to upward borehole water movement. The final gradient measured in January of 2006, after the hole was completed, yielded a maximum fairly shallow temperature of only 56.3°C (133.3°F). This was due to washing out of the gradient from a highly productive, cool, artesian aquifer encountered near the bottom of the hole.

TG-2, located up a canyon on the west side of the San Francisco River, was carried to a depth of 1,000 feet. The hole was collared in the base of the Paleozoic section (Ordovician Longfellow Limestone), and bottomed in the Pre-Cambrian granites and granodiorites. The gradient measured in January, after drilling was completed, was a conductive gradient of 100°C/km, with a bottom hole temperature of 53.8°C (128.8°F).

# 1.0 PROJECT SCOPE AND LIMITATIONS

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## 1.1 PROJECT SCOPE

David Brown & Associates (DBA) was retained by Arizona Public Services (APS) of Phoenix, Arizona in 2005 to evaluate a geothermal resource area for electric power generation. T<sup>2</sup> & Associates provided general project management. The geothermal area is located on the San Francisco River, just north of the town of Clifton, in Greenlee County (Appendix I, Figure 1). The hot springs in the area are presently known as the Clifton Hot Springs, but have also been known in the past as the Aztec Hot Springs<sup>1</sup>. The scope of the project was to review all available literature on the geology, hydrogeology, and geothermal geology of the area; prepare a detailed geologic map; supervise a Controlled Source Audiomagnetotelluric (CSAMT) survey of selected areas (Appendix II); and drill several temperature gradient holes (Appendix I, Figure 5 and Figure 6). The project was funded under the US Department of Energy (USDOE) Geothermal Resource Exploration and Development III (GRED III) program DE-PS36-04GO94016. APS provided a 20% cost share.

Materials reviewed and compiled included all those documents developed by public agencies. A listing of these materials is presented in Section 7.0 References. No proprietary information was available for review. The interpretations from the available data were then used to serve as a baseline for detailed geologic mapping of the area of interest, locate the CSAMT cross-sections, and site potential temperature gradient hole locations. As a result of the mapping and geophysics, three temperature gradient holes were sited, and two ultimately were drilled. No sampling of the hot springs took place during this project due to their location in the bottom of the San Francisco River Canyon, where they were obliterated during flooding in February of 2005.

## 1.2 LIMITATIONS

The interpretations presented in this report are based on the assumption that the conditions found in any further exploration of the Clifton area do not vary dramatically from those described in the reviewed data and materials. If any variations are encountered during any further investigations for this project, DBA should be notified so that supplemental interpretations can be made. The interpretations of this report are intended only for the area described and should not be extended to adjacent areas. The findings and interpretations of this report are valid for the reporting date and under the conditions and project scope as described above. However, changes in the conditions of the leases, knowledge of the geology of the leases, or changes in applicable standards can occur with the passage of time, whether they result from natural processes, legislation, or the

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<sup>1</sup> Casius, Ernie, 2005, Personal Communication.

broadening of knowledge. Accordingly, the findings of this report may be invalidated by changes outside of our control.

It is understood that this report does not in any way guarantee the success of any drilling or development venture, even with further detailed exploration and evaluation. It is further understood that geothermal exploration is a speculative venture that may result in non-productive test wells, despite best exploration efforts.

## 2.0

# PROJECT LOCATION, GEOGRAPHIC SETTING, AND PROPERTY OWNERSHIP

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### 2.1 PROJECT LOCATION

The Clifton Hot Springs are located along the lower San Francisco River in Greenlee County, Arizona (Appendix I, Figure 1), just north of the town of Clifton, the County Seat. Greenlee County is located on the border with New Mexico in east-central Arizona. The San Francisco River flows to the south through the hot springs area; *via* a narrow canyon cut several thousand feet into the local bedrock (Appendix IV). The San Francisco runs about ten miles further to the south, where it flows into the Gila River at Gillard Hot Springs. Just downstream of the junction of the two rivers is a canyon known as the Gila Box. At the southernmost extent of the area of interest is the town of Clifton, and at the upper end is the abandoned gold mining town of Oroville (Appendix I, Figure 1). Several miles to the west of the project area is the Morenci Mine, a major copper mine owned and operated by the Phelps Dodge Corporation since before 1900 (Appendix IV).

Access to the hot springs area is by gravel county roads, and 4-wheel drive tracks, some of which were used to access old precious metal mines and a now-abandoned large limestone quarry. Phelps Dodge, the major landholder in the area, controls road access to the eastern San Francisco River canyon rim. Phelps Dodge denied the Clifton geothermal team access across their lands or access to BLM or private lands *via* the roads they controlled. There are no roads accessing the larger portion of the western canyon rim. However, access for mapping was made by several, short, non-Phelps Dodge private and public roads, and *via* the banks of the San Francisco River.

Clifton Hot Springs is a group of warm to hot spring orifices located along the banks, and within the gravels of the main channel of the San Francisco River (Appendix I, Figure 1). The springs are distributed over several river miles, stretching from the town of Clifton on the south to the abandoned gold mining town of Oroville on the north. Temperature in these springs ranges from warm to about 75°C<sup>2</sup>. There are no known geothermal production wells in the area, with the exception of a shallow sump used at the Potter Ranch to heat small bathing tubs. The volume of water discharging into the San Francisco River has been estimated to be about 2.5 cubic feet per second<sup>3</sup>, which is equivalent to just over 1,000 gallons per minute. However, during this investigation the spring orifices could not be accessed, because they had been obliterated by severe flooding in early 2005.

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<sup>2</sup> **Witcher, J.C., 1981**, Geothermal Energy Potential of the Lower San Francisco River Region, Arizona: Arizona Geological Survey Open File Report 81-7, 134 p.

<sup>3</sup> **Hem, J.D., 1950**, Quality of Water of the Gila River Basin Above Coolidge Dam: US Geological Survey Water-Supply Paper 1104, 230 p.

## 2.2 GEOGRAPHY

The Clifton Hot Springs are located within the Transition Zone Geomorphic Province, between the geologically stable Colorado Plateau Geomorphic Province on the north, and the Arizona Basin and Range Geomorphic Province on the south (Appendix I, Figure 1, inset map). This location is important when considering the local geothermal resources and their geologic controls.

The Colorado Plateau is characterized by wide, flat areas, interrupted by occasional mesas, cliffs, chasms, and great canyons<sup>4</sup>. The Grand Canyon, Canyonlands, Glen Canyon, and Capitol Reef National Parks are all within this region. The Colorado Plateau extends from east central Utah and west central Colorado on the north, to the northeast half of Arizona on the south. Portions of the plateau also extend into northwestern New Mexico. This area is geologically relatively stable, though it does contain some active faulting and potentially active volcanic ranges. This area is primarily very old (2 billion years old) ocean bottom and island arc deposits that were uplifted during mountain building in the Mesozoic Era (100 to 225 million years before present).

The Basin and Range Province is a wide zone of crustal extension that extends from the Colorado Plateau and Rocky Mountain stable blocks on the east to the Sierran/Cascade Mountain front on the west. The northern end of the Basin and Range is a series of right-lateral wrench faults in Northern California, Oregon, and Idaho, and the southern end is a series of left-lateral wrench faults in southern California, Arizona, and Mexico.

The onset of the Basin and Range extension began between 15 and 25 million years before present. The actual cause is thought to be an upwelling plume within the earth's mantle, which in turn caused a thinning and pulling apart of the upper crust. This extension process created high mountain ranges of older rocks pulled out from beneath younger deposits *via* low angle detachment faults. The heavier rocks sank into wide flat basins that were then covered by playa and lake deposits. The lighter rocks rose up into narrow high mountain ranges *via* a process called *isostasy*<sup>5</sup>. Mount Graham; south of the project area, overlooking the town of Safford is an example of a detachment fault mountain range. Individual volcanic events then erupted throughout the region, brought on by the crustal thinning and intense faulting. This, in turn caused, local uplifting, faulting and folding. The entire Basin and Range Province is marked by areas of high heat flow.

The Transition Zone Province is an area of intense faulting and folding located between the stable Colorado Plateau and the tectonically active Basin and Range Provinces. This area has been subjected to periods of crustal extension and intense normal faulting,

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<sup>4</sup>Nations, D.J., Stump, E., 1996, Geology of Arizona: 2<sup>nd</sup> Edition: Kendall/Hunt Publishing Company, Dubuque, Iowa, 260 p.

<sup>5</sup> *Isostasy* is defined as the condition of equilibrium, comparable to floating, of the units of the lithosphere above the asthenosphere. American Institute of Geology, Glossary of Geology, 3<sup>rd</sup> edition, 1987.

followed by periods of crustal compression and reverse faulting. In the Paleogene (24 to 65 million years before present), this area was heavily intruded by crystalline rocks during the Laramide Orogeny<sup>6</sup>. The copper deposits at the Morenci Mine, just west of the Clifton area were created during this period of volcanic intrusion.

This pushing and pulling, intruding, and volcanic activity has created an area of intense faulting and folding. The tectonic activity has exposed and juxtaposed rocks of all ages. In the Clifton area itself, Pre-Cambrian rocks over 1.3 billion years old have been faulted up against rocks less than five hundred thousand years old. Mountain ranges built in the Transition Zone Province are much higher than the Basin and Range Province, and stand higher than the Colorado Plateau.

### 2.3 CLIMATE

As describe above, the State of Arizona is separated into three distinct geomorphic provinces (Appendix I, Figure 1). The northern part of the state is located within the Colorado Plateau. In the middle portion of the state, the Transition Zone runs approximately west-northwest. Clifton is located on the southern edge of the Transition boundary, near the Basin and Range. This zone generally consists of low-elevation desert, characterized by warm winters and scorching summers. Temperatures in the winter months average around 52°F and around 86°F in the summer, with highs reaching 120°F in the summer months. Annual rainfall is approximately 10 inches<sup>7</sup> in the Clifton area.

This high-elevation desert country is known as the Chihuahuan Desert, which extends from east-central Arizona south into Mexico. The Chihuahuan Desert, a subtropical desert, has a rainy season that begins in summer, around the month of July, and can last through September. Brief, intense monsoon storms originate in the Gulf of Mexico and arrive from the south, sweeping across the desert.

### 2.4 PROPERTY OWNERSHIP

A property ownership map was developed, and is presented in Appendix I as Figure 2. This shows the bulk of the property in the San Francisco River Canyon is owned by the Phelps Dodge Corporation, including almost the entire western rim of the San Francisco River canyon, back for several miles. There are only several small inliers of privately-held ground on the western banks of the river, located about a mile north of the Clifton City limits. It is also our understanding an imminent land exchange is turning some of the Phelps Dodge land back to the BLM in the near future<sup>8</sup>.

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<sup>6</sup> The *Laramide Orogeny* is defined as a time of intense deformation and mountain building in the Rocky Mountain region of the United States from the Late Cretaceous (80 million years ago) until the end of the Paleocene (40 million years ago).

<sup>7</sup> Sellers, W.D., and Hill, R.H. (editors), 1974, *Arizona Climate 1931-1972*, revised 2<sup>nd</sup> Edition, University of Arizona Press, 616 p.

<sup>8</sup> Thrasher, Larry, 2005, Safford BLM Geologist, Personal Communication.

The east canyon rim is owned by a combination of Phelps Dodge, the BLM, and several large private landholders. The Phelps Dodge land is primarily near the river, with the BLM land being further of the east. A large portion of the east rim, adjacent to the hot springs area is comprised of a number of patented mining claims controlled by the family that owns the Potter Ranch.

The BLM land on the east rim is controlled by Vulcan Power Company of Bend, Oregon through a series of BLM geothermal leases on the land.

### **3.1 INTRODUCTION**

Due to the presence of the world-class Morenci copper mine just west of the project area of interest; the areas immediately west of the Clifton Hot Springs have been included in geologic studies for many years by mining companies, graduate students, and public agencies. However, most of the mapping focused on the Morenci copper deposits, and not on the San Francisco River Canyon area. Even with all of the interest in the area, it was not until a compilation map was issued in 2000<sup>9</sup> that published modern mapping had completely replaced published work done at the turn of the 20<sup>th</sup> Century<sup>10</sup> by the USGS. The State of Arizona and Phelps Dodge, the owners of the Morenci Mine, did the work as a joint project. This mapping was the base for the detailed mapping performed for this project (Appendix I, Figure 7). A complete listing and annotation of previous geologic work in the area has not been included as a part of this project. However, a list of the references used to prepare the geologic map for this study are cited, as appropriate, and included in Section 7.0 References of this document. For a complete list of previous workers and their contributions to the geology of the Morenci and Clifton Hot Springs area, the reader is directed to the References portion of the 2000 AZGS publication<sup>11</sup>.

Mapping in the field for this project was done on black and white aerial photography provided by the environmental group at the Phelps Dodge Morenci Mine and digital topography obtained from the USGS. Near the close of the mapping phase, a new aerial photo survey was carried out by Cooper Aerial Services of Tucson, for Greenlee County. These newer photos were then combined with the Phelps Dodge photos to produce the detailed geologic map. These newer photos also formed the base for the graphics presented in this report.

Publicly-available, large-scale topographic maps were not available for the project area. Detailed digital topography of the area was obtained from the USGS database *via* a secondary Internet contractor located at [www.geocomm.com](http://www.geocomm.com). The digital topography was then combined with the aerial photos to produce the base maps used for this study.

Because of private road access issues, extremely hot weather, and the rugged local terrain, most of the mapping took place on foot, accessed from the County roads, the banks of the San Francisco River, and the few private access roads. Some areas could not

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<sup>9</sup> **Ferguson, C.A., and Enders, M.S., compilers, 2000**, Digital Geologic Map and Cross Sections of the Clifton-Morenci Area, Greenlee County, Arizona: Tucson, Arizona Geological Survey Digital Geological Map 1 (DGM-01), layout scale 1:24,000, 1 Adobe PDF file (3 plates), and other files.

<sup>10</sup> **Lindgren, W., 1905**, Description of the Clifton Quadrangle, Arizona: US Geological Survey Geological Atlas, Folio 129, 1:62,500.

<sup>11</sup> **Ferguson, C.A., and Enders, M.S., compilers, 2000**, *Ibid.*

be reached on foot in a time-efficient manner, so aerial photo interpretation was used to determine lithology and structure.

Lithologic descriptions and unit breakouts are based on hand specimen and field descriptions only, and descriptions by previous investigators. No thin section or bulk rock chemical analyses were performed on any of the rock samples. Such detailed work was beyond the scope of this study.

## **3.2 STRATIGRAPHY**

### **3.2.1 GENERAL**

As previously described, the Clifton Hot Springs are located in the Transition Zone Geomorphic Province between the Colorado Plateau to the north and the Basin and Range Province to the south, with typically high density faulting, monocline development, and mineralized Laramide-age intrusions.

The oldest rocks have been altered by a pervasive potassic alteration, but it is, in all likelihood, not associated with the local geothermal system. It is more likely due to much older alteration events or incipient alteration associated with the placement of the local Laramide intrusives.

Old hot spring deposits were not identified in the area. However, a pervasive condensate alteration of all of the younger rocks was identified. It is characterized by fracture infilling with drusy and massive quartz and clay alteration in shattered fault zones, fractured areas, and zones of incipient permeability such as brecciated inter-flow zones (Appendix IV). This alteration was also identified in younger elevated terrace gravel deposits in the area near the Potter Ranch (Appendix I, Figure 2).

The geological units mapped in the Clifton Hot Springs area are described as follows, beginning with the oldest units first. The following geologic descriptions are modified from the AZGS mapping, and are used without specific citation throughout the entire section.

### **3.2.2 PRE-PALEOZOIC ROCKS**

#### **Proterozoic Granite (Map Unit XYg)**

The oldest rocks exposed in the project area are an undetermined thickness of brick red Proterozoic Granites (1.3 billion years old). This unit is distinguished by its bright red color, and is easily identified in outcrop and on aerial photos. This unit is seen at the surface throughout the Clifton area and will, in all likelihood, form the target geothermal reservoir rock for the Clifton area project. This rock is observed in outcrop to be highly fractured along several sets of joints at approximately 90° to each other. It was also

observed to have numerous intra-formational shear zones and faults that would provide additional fracture permeability.

Both drill holes encountered this unit. TG-1 collared in this unit and carried it to a total depth of 635 feet. TG-2 encountered this unit at a depth of 469 feet in Casius Canyon and carried it to the total depth of the hole at 1,000 feet. Intra-formational aplite dikes, cream to red in color were identified in the cores from TG-2. These dikes were also seen in outcrops on the area.

This unit is located in outcrop primarily on the east side of the San Francisco River Canyon, where it was exposed by a large fault zone in the river canyon, with an east side up sense of motion. The unit was not found in outcrop in the areas mapped on the west side of the river, except in low outcrops directly across from the Oroville town site.

### **Proterozoic Granodiorite (Map Unit XYgd)**

Also found in scattered outcrops on the east side of the river canyon were outcrops of a Proterozoic granodiorite. However, this unit is also highly fractured and would act as reservoir material similar to the red granite at depth. Though lithologically distinct from the granite, this unit shares the same potential reservoir rock characteristics.

During field mapping, outcrops of this unit appeared to be more pervasive than mapped by previous investigators. However, due to the difficulty in separating the two Pre-Cambrian units in the field, the outcrop patterns were adapted from previous investigators.

The lithology encountered in TG-1 at Potter Ranch alternated between this unit and unit XYg, with no apparent structures separating the rock types. This rock was not encountered in TG-2 in Casius Canyon.

## **3.2.3 PALEOZOIC ROCKS**

### **Coronado Quartzite (Map Unit Cc)**

The Coronado is a thin, Cambrian (570 to 500 million years old) unit of medium to thick bedded, brown to pink, quartzite with minor amounts of arkose sandstone. This unit nonconformably overlies the Pre-Cambrian units in outcrops east of the river in the blocks upthrown by a series of paralleling, synthetic faults. It was also identified in small outcrops in the area just east of Clifton Peak. While the unit is not significant from a geothermal resource perspective, drilling has shown it to occur in the geothermal reservoir, and it can be used as a distinctive stratigraphic marker unit.

This unit was encountered at a depth of 120 feet to 469 feet in TG-2.

### **Longfellow Formation (Map Unit O1)**

Directly overlying the Coronado Quartzite is the Ordovician (500 to 440 million years old) Longfellow Formation. The Longfellow is a 350-foot or more thick unit of brown to gray, medium- to thin-bedded limestone with occasional thin shaly beds. This unit has a characteristic “stack of flapjacks” outcrop nature that is easily identified in the field. This unit can be distinguished from the other limestone unit in the area by its distinct lack of macroscopic fossils.

On the north side of the Limestone Gulch area, this unit was shattered in an extensive, brecciated fault zone, with the individual breccia pieces completely rotated. The entire breccia zone and the country rock for a hundred feet or more back from the fault zone was flooded with silica. The age of this pervasive silicification is probably contemporaneous with the Laramide intrusives.

This unit forms high cliffs on the west side of the river canyon, and was identified in outcrops along the eastern shore of the river, indicating the presence of a fault along the eastern wall of the river canyon and a fault beneath the river channel itself. It was found in small outcrops north of Oroville, and as a rim rock on the hills east of the river where the unit has been upthrown over 1,000 feet. The unit was also identified in a small outcrop on the north side of Limestone Gulch, and in large outcrops overlying the Coronado Sandstone and underlying the Clifton Tuff.

While not expected to be found within the geothermal reservoir, the distinctive lithology is useful as a stratigraphic marker bed to determine the presence and relative movement of faulting in the area.

This unit was encountered in TG-2 at about 42 feet, where it had been intruded by the Laramide-age Quartz Diorite. The unit extended to a depth of about 120 feet.

### **Morenci Formation (Map Unit Dm)**

This unit is a very thin layer of Devonian (400 to 345 million years old) shale, found between the Longfellow limestone and the Modoc limestone. This unit is gray to reddish brown in color, very friable in nature, and can contain some argillaceous limestone. While the unit is not necessarily significant from a geothermal resource perspective, this very distinctive unit may occur in the geothermal reservoir, and can be used as a stratigraphic marker unit.

The unit was identified as a slope former in the high cliffs on the west side of the river and in a small outcrop on the east, upthrown block of the Corbell Canyon Fault, east of Clifton Peak. Detailed mapping will probably identify this unit in limited outcrops between the two limestone units.

### **Modoc Formation (Map Unit Mm)**

Overlying the Morenci Formation is a 150- to 300-foot thick unit of blue-green, fossiliferous Mississippian (340 to 320 million years old) massive limestone. This unit was mined by Phelps Dodge in a quarry just east of the Oroville town site area for use as a flux in their copper smelter. This unit is distinguished from the Longfellow Limestone by its finer grained nature and the presence of crinoids, coral and brachiopod macroscopic fossils.

As with the other thin Paleozoic units, this distinctive fossiliferous limestone acts as an excellent stratigraphic marker bed.

### **3.2.4 MESOZOIC ROCKS**

While there are some limited outcrops of Mesozoic rocks mapped in the Morenci Mine area, none were identified in the Clifton Hot Springs area during this field project.

### **3.2.5 TERTIARY ROCKS**

#### **Diorite Porphyry (Map Unit Tpd)**

This Paleocene (65 to 54.8 million years old) unit is exposed in outcrops on the west side of the San Francisco River, directly across from the Potter Ranch, extending from the mouth of the Casius Canyon, north to just across the river from Oroville. This outcrop is a large, heavily altered, sill-like structure that has intruded the Longfellow Limestone. The unit is found on the east side of the river in thick dikes that intrude the Pre-Cambrian, as well as the Paleozoic rocks.

An unaltered, moderate-sized outcrop was also identified on the north slope of Clifton Peak (Appendix I, Figure 7), where it was either faulted into contact with, or surrounded by flows of the Tertiary Andesite unit. This unit represents the Laramide intrusive in the San Francisco River Canyon area.

This unit is found throughout the Clifton-Morenci area intruding all older rocks. It can potentially be expected to be found in the geothermal reservoir. This unit occurs as dikes, sills, laccoliths, and lappoliths, intruding the older rocks. The diorite porphyry and similar units occur throughout the Morenci Mine area, and are responsible for the copper mineralization found there.

This unit was encountered in TG-2, intruding above and below the Longfellow Formation. In the drill hole, the matrix has altered to soft clay, with the euhedral quartz crystals and some of the potassium feldspars showing embayment, resorption, and other signs of alteration.

### **Clifton Tuff (Map Units Tc and Tcs)**

This Oligocene (33.7 to 23.8 million years old) ash-flow tuff is found in massive outcrops in the Clifton area, and in the Limestone Gulch area. It is also found as intra-canyon erosional remnants in several of the canyons on the west side of the river, in the area of the Casius Ranch.

The unit is a poorly lithified, crystalline ash flow tuff, with phenocrysts of plagioclase and biotite apparent under hand lens examination. The groundmass is made up of xenoliths and abundant, large, pinkish, compacted, juvenile pumice fragments.

This unit is difficult to distinguish in the field from the Bloodgood Canyon Tuff, based on hand specimen examination only. It is easiest to differentiate based on stratigraphic positioning.

Where the base is well exposed, as in the Limestone Canyon area, it can be underlain by a continental sedimentary unit (map unit Tcs) composed of a coarse, poorly lithified conglomerate with angular to sub-angular clasts of Paleozoic rock, primarily Modoc and Longfellow limestone. Parts of this sedimentary unit can be heavily altered and cemented with a condensate alteration and heavy deposition of massive and drusy quartz and a light green clay mineral.

While not likely to be encountered at depth in drill holes, this distinctive unit is extremely useful in determining surface structure and stratigraphic relationships.

### **Bloodgood Canyon Tuff (Map Unit Tbc)**

This Late Oligocene unit unconformably overlies the Clifton Tuff in upper Limestone Gulch, and is found intercalated within the Basaltic Andesite unit on the north rim of Chance Creek Canyon, and in the mid-sections of Limestone Gulch. It can be traced as a marker bed a mile or more north of Chance Creek. The unit ranges in thickness from a featheredge to 120 feet.

This unit is distinguished from the Clifton Tuff in hand specimen based on stratigraphic position and the presence of sparse sanidine crystals. Some of the isolated, remnant outcrops of highly altered tuff found in canyons on the west side of the San Francisco River Canyon could actually be Bloodgood Canyon Tuff.

### **Basaltic Andesite Undivided (Map Units Tb and Tbs)**

This Late Oligocene mafic volcanic unit overlies all older rocks throughout the eastern portion of the Clifton area and under much of the younger conglomerate units along the western San Francisco River Canyon rim. This unit ranges in thickness from 300 to 3,500 feet, with the thickest part seen in the Clifton Peak area.

Lithology of the unit ranges from a true basalt to as silicic as an andesite, trachyandesite, or dacite. Phenocrysts are rare in the flows of this unit. Also within this unit are flow breccias, mudflows, mafic lahars, and other near-vent features.

Underlying the unit in the Limestone Gulch area, and directly across the river from the town of Clifton in the Chance Creek area, is a unit of continental sediments (Map Unit Tbs). This unit also includes base-surge deposits, ash deposits, and palagonite tuff, typical of a near-vent environment. The unit mapped by previous investigators on the side of Clifton Peak as unit Ts was inspected at the outcrop and seems to actually be a heavily altered interflow zone, not a sedimentary unit. This is also true for the Tbs unit identified previously on Mulligan Peak.

The unit Tbl<sup>12</sup>, mapped in the Limestone Gulch area as being hypabyssal bodies of the Tb unit were inspected, and found to be identical to other Tb flows in the area. Thus, it is not mapped separately.

### **Gila Group (Map Unit QTgs)**

These units are a collection of conglomerates of various lithologies that have been lumped into a loosely associated rock unit termed the Gila Group. They range in age from Pleistocene (0.10 million years old) to the Miocene-Pliocene time/stratigraphic boundary (5.3 million years before present). These units cap many of the hills and buttes in the Clifton area, and fill in the lower basins. They are seen as fairly thick units on the west side of the San Francisco River. Their presence and individual character are important geologically, and are important in determining fault location and relative offset. However, it is extremely unlikely that they would be encountered in any drill holes at depth.

These units have been mapped separately by other investigators as a number of distinctive facies. However, for this map, they have been lumped into one all-inclusive unit, QTgs.

### **Recent Deposits (Map Units Qt, Qac, Qa, Qap, Qao, Qtao)**

These units represent very recent deposits in the active San Francisco River Valley and on hillsides throughout the mapped area, including terrace, colluvium, alluvium, and pediment deposits.

## **3.3 STRUCTURAL SETTING**

Understanding the structural geology of a geothermal area is important. Most geothermal systems are controlled by faulting. The faults act as both subsurface barriers and subsurface pathways for fluid movement. Hot springs, geysers, rock alteration, and

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<sup>12</sup> Ferguson, C.A., and Enders, M.S., compilers, 2000, *Ibid.*

ancient hot spring deposits are usually found associated with faulting. The location of dikes, intrusives, shear zones and breccia zones are also important. These features tend to follow the local structural fabric and can intrude into existing fault zones and provide additional fluid pathways.

Concentrations of thermal features can commonly be found at the intersection of two or more of these types of features. Intersecting faults can create stress shadows resulting in open areas in fault zones, which can allow fluids to ascend to the surface, or ascend to an intervening shallow thermal aquifer where they can be intercepted by a drill hole. Therefore, understanding the structural geology, and locating the “thermal” faults in an area are of uppermost importance for successful geothermal exploitation.

### **3.3.1 REGIONAL SETTING**

The structure in the Clifton area is dominated by two regional, northwest-, and northeast-striking fault sets. These fault sets form a large, regional “V” shape, with the area just above the apex of the “V” occupied by the Laramide-Age crystalline intrusives that formed the Morenci copper deposits. All of the faulting seen in the area is primarily normal faulting, with only minor, left lateral oblique-slip faulting noted during recent field mapping. This indicates the dominant resultant stress field in the area is one of extension; in a general southeast-southwest direction; with a stable block in the area of Morenci mine and a slight sinistral rotation of individual fault blocks in the Clifton area<sup>13</sup>. Numerous dikes, intra-formational shear zones and breccia zones are found in the area. Most of these features follow the northwest-northeast structural fabric of the area.

### **3.3.2 CLIFTON HOT SPRINGS AREA**

The structure of the Clifton Hot Springs area is dominated by faulting. Isolated blocks of rocks of various ages have been juxtaposed against one another in a rather haphazard and complex fashion. Very little folding is seen in the area with the exception of drag folding next to the faults. In these areas, the rocks are generally shattered by brittle deformation, rather than folding. The one exception is on the west bank of the San Francisco River, across from Oroville, where a Laramide intrusive body has gently upfolded the Paleozoic section in an intrusive contact. It appears this folding occurred at depth, and under some pressure, to allow for the observed plastic deformation of the usually very brittle calcareous sediments.

The structure of the Clifton area is controlled by the San Francisco Fault. This normal fault strikes to the northeast, several miles west of the San Francisco River (Appendix I, Figure 7). The San Francisco Fault is a regional fault that can be traced tens of miles north to Alpine, Arizona, and south to the southern extent of the Morenci complex. At that point, the fault zone appears to hinge, or die out. A similar analogous fault, called

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<sup>13</sup> Walker, M.A., 1995, Structural Interpretation of the Morenci Mining District, Greenlee County: Unpublished MSc Thesis, New Mexico Institute of Mining and Technology, 130 p.

the Eagle Creek Fault, is found on the west side of the Morenci complex, striking off to the northwest. The San Francisco Fault actually only approaches the San Francisco River in the study area, just north of Oroville. Its trace does not even appear on the enclosed geologic map (Appendix I, Figure 7). This is due to the river eroding down and away from the fault trace, following the path of least resistance.

The sense of the San Francisco Fault is east side down, with the San Francisco River actually located within a narrow keystone graben, with a significant antithetic fault identified on the east side of the river during this field investigation (herein termed the Potter Ranch Fault). This fault was previously not known. The west rim of the canyon, west to the San Francisco Fault, is contained within a half-graben bounded on the east by a fault synthetic to the San Francisco Fault. The trace of this fault is located along the western shore of the river (herein termed the River Fault), and on the west by the San Francisco Fault itself. The trace of the River Fault was identified by outcrops in the area across the river from Oroville, and by previously unidentified offset units at the mouth of Casius Canyon.

Cross-cutting and offsetting the south end of the keystone graben the river is flowing out of is the Limestone Gulch Fault. This fault offsets lithologies of all ages and is synthetic and becomes sub-parallel to the San Francisco Fault. This fault is highly dilated near the mouth of the gulch, where the fault zone and the country rocks for several hundred feet away from the fault are flooded with silica. Individual pieces of breccia within the fault zone are completely rotated and highly silicified. It is suspected this fault is far more complex than mapped, but canyon fill prevents detailed mapping.

At the intersection of the Limestone Gulch Fault, the River Fault, and the Potter Ranch Fault all of the fault zones appear to have been dilated. This is seen in the field by wide breccia zones, common to all fault zones that have been flooded with silica. A large fault zone, seen in Corbel Canyon to the east of Clifton Peak has a similar brecciated, silica-flooded area at its intersection with the Limestone Gulch Fault.

Another fault zone, which appears to be the possible extension of the Potter Ranch Fault, south of Limestone Gulch, is similarly flooded with silica and highly shattered. The trace of this fault parallels the river on the east bank, just south of Limestone Gulch. The entire hillside is failing due to the brecciated nature of the fault zone in the Basaltic Andesite unit, and the intensive alteration and silica deposition (Appendix IV).

## **4.1 PREVIOUS FLUID GEOCHEMISTRY STUDIES**

### **4.1.1 GENERAL**

The geochemistry of the Clifton Hot Springs area has been included in a number of geothermal energy studies. The AZGS has performed most of this work; however, the area has also been included in several large compendiums of geothermal resources of the entire Western United States. No sampling of the hot springs took place during this study because the orifices were obliterated recent intense flooding

The area was first included in several compendiums assembled by the USGS<sup>14,15</sup> describing the local geothermal system and chemistry of the local geothermal fluids. James Witcher<sup>16</sup> and other investigators took a preliminary look at the area in several volumes, including some thermal water sampling and analysis. However, very little work was performed beyond the initial data collection and evaluation.

It is our understanding Phillips Geothermal may have owned the BLM geothermal leases at Clifton in the late 1970s through the end of the 1980s. However, the results of their work are not known.

In summary, some work has been done in the past studying the local geothermal fluids, but no sampling surveys were done on springs other than the hot springs, and no other wells were sampled or analyzed.

Study of hot springs and discharge temperatures is important as they represent the surface leakage of hot water from a subsurface geothermal reservoir. As the geothermal waters percolate to the surface, various forms of cooling, and precipitation of some minerals can occur. Thermal waters can cool by mixing with meteoric water near the surface, or by conductive or convective cooling methods. There are various geochemical methods that can be used to predict such things as: **1)** if mixing occurs, **2)** if and when the water re-equilibrates with quartz, or **3)** if there is any conductive cooling occurring. These geochemical models, when used in combination, can also be indicators of the geothermal water temperatures at depth.

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<sup>14</sup>**Mariner, R.H., and others, 1977**, Chemical, isotopic, and gas compositions of selected thermal springs in Arizona, New Mexico, and Utah: US Geological Survey Open-File report 77-654, 42 p.

<sup>15</sup>**Swanberg, C.A., 1977**, An appraisal study of the geothermal resources of Arizona and adjacent areas in New Mexico and Utah, and their value for desalinization and other uses: New Mexico Energy Institute report No 6, 76 p.

<sup>16</sup>**Witcher, J.C., 1981, *Ibid.***

#### 4.1.2 CLIFTON HOT SPRINGS

As previously described, Clifton Hot Springs is a collection of numerous warm to hot seeps and springs, located within the banks of the San Francisco River, stretching from Clifton on the south, to the Oroville town site some two miles north. The hottest of the springs is about 75°C, and occurs just north of the mouth of Limestone Gulch. Total discharge from the springs has been estimated at 2.5 cubic feet per second<sup>17</sup> (about 1,122 gallons per minute). Most of the discharge is found in the river gravels. Later authors then confirmed this large discharge<sup>18</sup>. Further work by the USGS indicated the mixed nature of the geothermal system<sup>19</sup>.

Inspection of analytical results from samples taken from the hot springs in various data sources from the 1950s through the 1970s indicates that the geothermal waters in the Clifton Hot Springs are dominated by the cations sodium and calcium, and the chloride anion (Appendix III). Having very high chloride content is usually a good indicator that there is a hot water resource. The wide range in chloride contents, along with the predicted high subsurface temperatures to be discussed in further detail later, suggest a fracture controlled and inhomogeneous geothermal reservoir<sup>20</sup>.

Chloride, lithium, and boron relationships can be very helpful in determining if mixing is occurring. This is due to the fact that these elements are the least likely to be involved in rock-water reactions as they have a high solubility, and their concentrations in hot waters are high relative to cold water<sup>21</sup>. If mixing is occurring, one should see a linear relationship with lithium and boron versus chloride. A culmination of the sampling data from all sources suggests that this is the case as plotting of lithium vs. boron, lithium vs. chloride, and the boron vs. chloride show a fairly strong linear relationship (Appendix III).

A plot consisting of chloride concentrations vs. measured temperatures showed no correlation (Appendix III). This could be an indication that conductive cooling is also taking place sometime after mixing occurs. The highest of the observed discharge temperatures was 75°C<sup>22</sup>. Because of this high discharge temperature, there is a possibility that the thermal waters are boiling in the subsurface.

The analytical results were used to predict subsurface temperatures using the various geothermometry calculations (Appendix III). The results vary from 130°C to 180°C, depending on the geothermometry used.

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<sup>17</sup> **Hem, J.D., 1950**, Quality of water of the Gila River Basin above Coolidge Dam: US Geological Survey Water-Supply Paper 1104, 230 p.

<sup>18</sup> **Swanberg, C.A., 1977**, *Ibid.*

<sup>19</sup> **Mariner, R.H., and others, 1977**, *Ibid.*

<sup>20</sup> **Witcher, J.C., 1979**, A Progress report of the geothermal investigations in the Clifton area: Arizona Geological Survey Open-File Report 79-2b, 16 p.

<sup>21</sup> **Witcher, J.C., 1981**, *Ibid.*

<sup>22</sup> **Witcher, J.C., 1981**, *Ibid.*

According to James Witcher, then of the Arizona Geological Survey, since boiling, cooling by mixing, and conduction all may occur, the quartz geothermometry temperatures may predict only the shallow reservoir temperatures since silica appears to have re-equilibrated with quartz in most springs<sup>23</sup>. This concurred with the silica geothermometers that were calculated. The best linear fit was obtained with the quartz geothermometer temperatures, using high concentration chloride springs. Those calculations showed that mixing more than likely does occur, and that it most likely occurs in an intermediate temperature reservoir. The temperatures in this reservoir model were predicted to range between 105°C and 150°C<sup>24</sup>.

In order to predict deeper subsurface temperatures, it is useful to use sodium-potassium-calcium geothermometers or chloride and enthalpy diagrams. Mixing models can also be a useful tool. However, in the case of Clifton, a mixing model proves not to be the best method to use. This may be because mixing models using silica and temperature work best when there is no conductive cooling occurring and the discharge rates of the springs are high. In Clifton this may not be true, as the highest discharge springs are in the river bottom and cannot be sampled. The Na-K-Ca geothermometer was calculated and predicted temperatures in the range of 159°C to 191°C, with the majority of the data falling within the 170°C to 180°C range.<sup>25</sup> Therefore, a shallow reservoir may exist with temperatures around 130°C, overlying a hotter, deeper reservoir.

## 4.2 PREVIOUS THERMAL REGIME STUDIES

Previous to this study, four heat flow measurements were available for evaluation in the Clifton area<sup>26</sup>. The AZGS took three of the heat flow measurements and one was taken in a regional study of heat flow<sup>27</sup>.

Results of the heat flow work show a range of between 0.4 Heat Flow Units (HFU) and 2.3 HFU<sup>28</sup>, with the higher number representing a relatively high background value for heat flow. The thermal gradients, which are more useful and applicable to geothermal exploration, ranged from about 1.5°F per one hundred feet to about 2.5°F per one hundred feet. Neither of these numbers was very high. However, none of the holes were drilled specifically for geothermal exploration. Two of the wells logged were wells of opportunity logged by the AZGS in order to determine the background heat flow regime. The two other holes were drilled specifically for the heat flow, but were drilled on the west side of the San Francisco River, one-half mile from the river bank, and what appears to be at a distance from the geothermal resource.

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<sup>23</sup> Witcher, J.C., 1981, *Ibid*

<sup>24</sup> Witcher, J.C., 1981, *Ibid*

<sup>25</sup> Witcher, J.C., 1981, *Ibid*

<sup>26</sup> Witcher, J.C., and Stone, C., 1980, Heat flow regime in the Clifton, Arizona area: Arizona Geological Survey Open File Report 80-1a, 29 p.

<sup>27</sup> Reiter, M, and Shearer, C., 1979, Terrestrial heat flow in eastern Arizona, a first report: Journal of Geophysical Research, Volume 84, Number B11, pp. 6115-6120.

<sup>28</sup> *One Heat Flow Unit* is defined as  $1 \times 10^{-6}$  cal/cm<sup>2</sup>.

As far as can be determined in this study, no deep drill holes or deep thermal gradient holes have been drilled previous to this project near Clifton Hot Springs.

### 4.3 PREVIOUS GEOPHYSICAL STUDIES

One geophysical study was reviewed for evaluation in this study. This is the only publicly available geophysical study done specifically for geothermal exploration<sup>29</sup>. This survey was part of an effort by the USGS to perform magnetotelluric and solid earth geophysics evaluations of all Know Geothermal Resource Areas throughout the western United States.

The results of the work indicate that the faulting seen at the surface appears to control the geothermal system. In the Clifton area, the conductive zone is narrow and seems to be associated only with the Potter Ranch Fault, north of its intersection and offset by the Limestone Gulch Fault. This is coincidentally the area of highest hot spring orifice temperature.

However, it should be pointed out that these studies are rather old (1980) MT studies that lacked in both sophistication and technology. With the new equipment and data reduction capabilities available now, 26 years later, the results could have been more detailed and helpful in understanding the fault system and siting gradient hole locations.

Reconnaissance gravity and aeromagnetic studies were also evaluated as part of the USGS study. However, the results of the solid earth geophysical studies merely confirmed the structural models seen in the geologic mapping of the area.

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<sup>29</sup> Klein, D., and others, 1980, Reconnaissance geophysics in the Clifton and Gillard geothermal areas, SE Arizona: US Geological Survey Open-File report 80-325, 19 p.

## **5.1 GENERAL**

This project consisted of three separate tasks.

- Produce a detailed geologic map of the Clifton Hot Springs, using the existing USGS and AZGS data as a base from which to start. The map produced is found in Appendix I as Figure 7, and geologic cross-sections are found in Appendix I, as Figure 8 and Figure 9.

The results of this work were integrated into the discussion of the geologic setting in Section 3.0 of this report.

- Perform a Controlled Source Audiomagnetotelluric (CSAMT) study of the area of interest to confirm the structural setting determined by the geologic mapping.

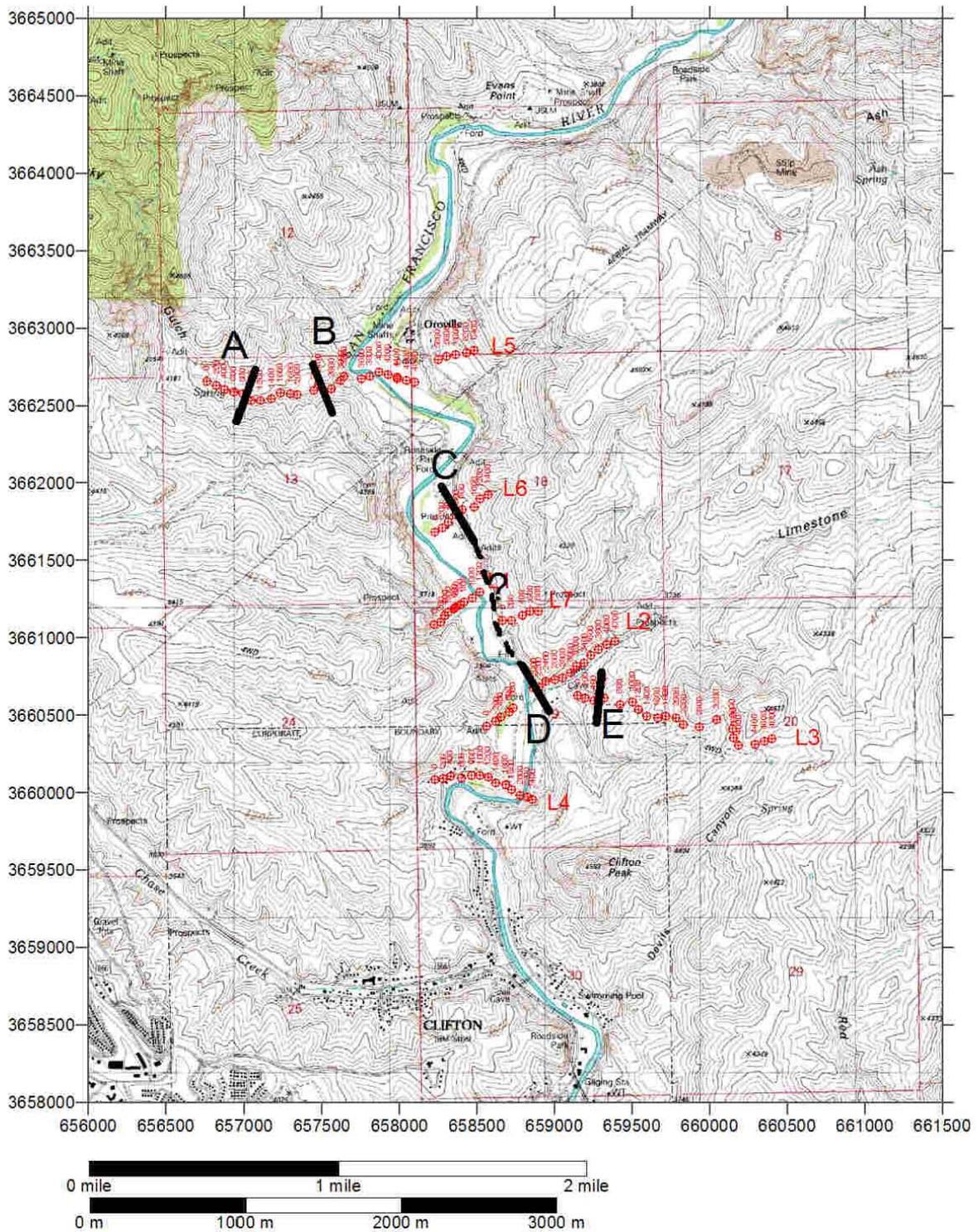
The results of this work are described later in this report in Section 5.2, and the entire report is included as Appendix II.

- Confirm the presence of a geothermal resource by drilling several slim diameter temperature gradient holes.

The results of the drilling, temperature logging, rock alteration logging, and secondary mineral identification and analysis are included in Section 5.3 of this report. Temperature and lithology logs are included in Appendix I as Figures 5 and 6, and in Appendix V.

## **5.2 GEOPHYSICS**

During May and June of 2005, a team of geophysicists from Zonge Engineering, of Tucson, Arizona, performed a CSAMT study of the Clifton Hot Springs geothermal area. In general, the geophysical survey confirmed the presence of a major fault along the east bank of the river, identified during the geologic mapping task by stratigraphic offsets, alterations zones, and geomorphological indicators. The geophysics also identified several other faults, including two faults on the western side of the river and several faults in the Limestone Gulch area. However, the strike of the faults in the Limestone Gulch area were not determined accurately by the geophysics, because they were intersected only on a single traverse line, and two intersections are needed to determine strike directions.



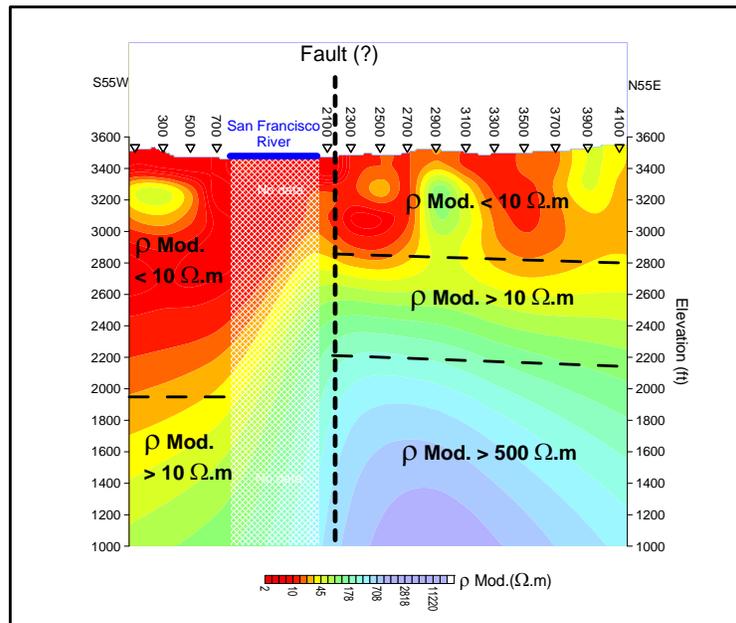
The following is adapted from the Zonge Executive Summary. The entire geophysical report is included as Appendix II of this report.

“...Natural Source and Controlled Source Audio-frequency Magnetotelluric investigations have been undertaken on seven lines across the Clifton geothermal area. The goal of this investigation was to characterize fault systems that may be high permeability zones which may be paths for geothermal fluids. Of particular interest are structures in the central portion of the survey area, along the San Francisco River.

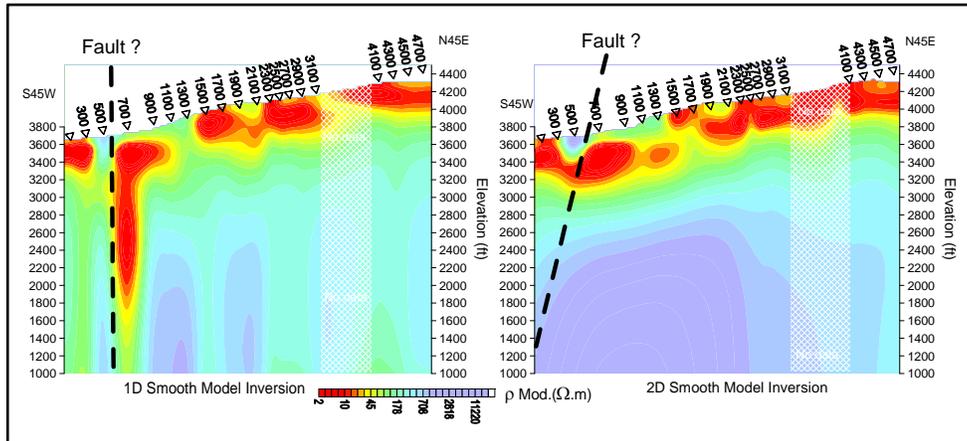
The electrical structure of the seven lines is similar, as would be expected given that the total width of the survey area is less than 3 miles. The general earth model is characterized by a low resistive surface zone with resistivities in range of 10 ohm-m, interbedded resistors might be present (L7, L6, L1) or not (L2, L3, L4, L5), overlying a moderate resistive layer, with resistivity greater than 10 Ohm-in. This resistor extends at depth until it grades into a more resistive body, having resistivity values higher than 100 Ohm-m. This generally layered earth model appears to be cut by near vertical features, thought to be related faulting in the area. This geophysical program identified five main high-angle contacts; with two located along the San Francisco River.

Determination of the dip angles of the different high angle structures is problematic in this area. The geophysical response is dominated by the changes in near-surface resistivity, which generates “static shifts”. The response of the deeper, larger, targets is buried in these near surface effect. Multidimensional modeling has significantly reduced this complication, but accurate determinations of the dip angles remains challenging...”

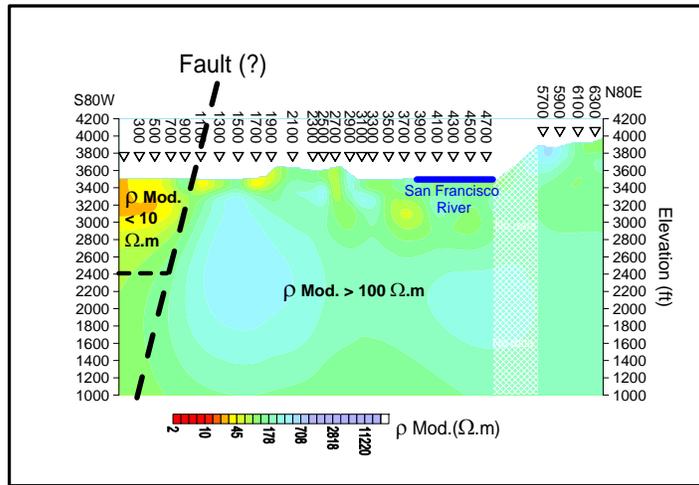
### Line 2



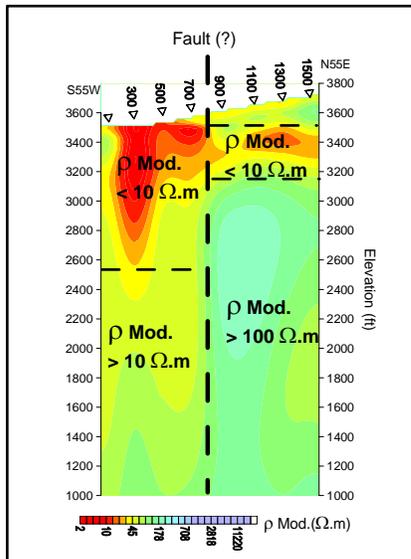
### Line 3



### Line 5



### Line 6



## 5.3 TEMPERATURE GRADIENT DRILLING

### 5.3.1 GENERAL

Three temperature gradient holes were located and permitted as a result of the geological, geochemical, and geophysical work. The following logic was applied to test the tentative geothermal model of thermal water upwelling along the fault zones in the San Francisco River Canyon.

A major fault zone paralleling the San Francisco River dominates the regional structural geology. This fault, termed the San Francisco Fault by previous workers, does not actually crop out in the immediate area of the project. It is found several miles to the west, where it truncates the major outcrops of Laramide intrusives in the Morenci mine in a down-dropped block. The fault forms a regional half-graben that runs for several tens of miles to the north-northeast. The eastern boundary of this half graben is a fault identified in this study along the west rim of the river canyon, termed the River Fault. The age of the San Francisco Fault has been determined by previous workers as being at the on-set of the Basin and Range (about 25 million years ago), and is the result of extensional forces in an easterly direction, up against the immobile block of the Laramide intrusive volcanic complex on the west.

A number of smaller faults parallel this regional structure, including the ones that appear to be controlling the local hot spring system. The fault system that appears to be controlling the local hot spring activity is found bounding a keystone graben centered on the San Francisco River Canyon.

The easternmost fault was not found in outcrop, but was identified in the area of the Potter Ranch by juxtaposed rock units and geophysics. It has been termed in this study as the Potter Ranch Fault. This fault was not identified by previous workers, as they did not recognize and map the juxtaposed rock units. This fault is antithetic to the San Francisco River Fault zone, with west side down.

The previous workers also placed the River Fault, which forms the western boundary fault of the keystone block, in the middle of the river. The actual trace was found to be along the western shore of the river. Relative motion on this fault is synthetic to the San Francisco Fault, with east side down.

Several crosscutting and offsetting faults, including an extensive silicified fault zone in the Limestone Gulch area, have intercepted and offset the San Francisco River Graben fault zone. These offsetting faults may have dilated the San Francisco River Graben, and are providing the fracture permeability necessary for ascending thermal fluids. The Limestone Gulch Fault Zone is seen to be dilated to hundreds of feet wide in places, especially at its mouth, and has been flooded with silica. The rocks involved in this fault

have been heavily altered near the fault zone, with the degree of alteration dropping off at a distance from its trace.

The Limestone Gulch Fault has a displacement of south side down, and appears to have offset the Potter Ranch Fault to the east several hundred feet. This offset fault, found in the canyon behind the Corbel Ranch has been named the Corbel Canyon Fault, and appears to be several hundred feet wide at its junction with the Limestone Gulch Fault, and, like the Limestone Gulch Fault, was flooded with silica. Displacement on the Corbel Fault is synthetic to the Potter Ranch Fault, with west side down. Displacement on the Potter Ranch and Corbel Canyon Faults is well in excess of 1,000 feet.

While previous investigators stated that all faulting in the area is normal in nature, this investigation found that a significant amount of the faulting is actually oblique in part, with a rake of 60° to 80° and a dominant left-lateral sense. This small amount of left-lateral sense of motion could explain the dilation and wide breccia zones found at the intersection of the Potter Ranch Fault, the Limestone Gulch Fault and the Corbel Canyon Fault.

### **Drilling Targets**

The intent of this drilling program was to define the thermal regime of the major faulting found in the area. The holes were drilled and completed as temperature gradient holes with 2-inch iron pipe tubing set to the bottom.

- Drill hole TG-1 was sited to determine the thermal nature of the footwall of the Potter Ranch Fault, in the area of the Potter Ranch. Anecdotal evidence indicates some of the gold prospect adits in the area had hot tunnels, including one driven just downhill from the drill hole location. Mrs. June Palmer, granddaughter of Mr. Potter, the original owner of the local gold mines and the Potter Ranch, stated that the tunnel near the drill site was too hot for her to enter when she was a child. This drill hole was programmed to a depth of at least 800 feet, but was only able to be completed to 635 feet. This hole was collared directly in the Pre-Cambrian crystalline unit.
- Drill hole TG-2 was drilled on the west side of the San Francisco River to test the thermal regime of the west side of the San Francisco River Graben. It was drilled up a short canyon from the Casius Ranch, away from potential floodwaters. Anecdotal evidence indicates water well drilling on the Casius Ranch encountered extremely hot water at a shallow depth. This hole was to explore if one of the Laramide Intrusive units was acting as a conduit for the thermal water. This drill hole was carried to a depth of 1,000 feet, and was collared near an outcropping of Laramide-age intrusive rock.
- Drill hole TG-3 was to be drilled at the intersection of the Corbel Canyon Fault and Limestone Gulch Fault zones. With the extensive nature of the rock

alteration and fault zone dilation in this area, and its association with local hot springs, it cannot be ignored as a potential geothermal model. This drill hole was to be carried to a depth of at least 800 feet and collared in either Paleozoic limestone or Tertiary mafic lavas. The general increases in drilling costs that occurred during 2005, however, precluded the drilling of this hole.

### **Drill Hole Design**

The temperature gradient holes drilled for this project were very simple designs. They were both begun using down-hole air hammers to maximize hole production for the remaining project budget. However, neither could be carried to total depth with air because of the high volumes of water being produced from each of the holes. Each was completed using HQ-size diamond core bits. Boart-Longyear was the drilling contractor for the job.

- ❑ The holes were set with 6-inch surface casing cemented bottom to top. TG-1 had 80 feet of casing, and TG-2 had 120 feet of casing.
- ❑ The holes were initially advanced with as small an air-hammer bit as practicable to increase drilling speed and efficiency.
- ❑ Both holes were completed with a 2-inch steel tube run to the bottom and backfilled with water. This tubing was backfilled with soft grout as well as was possible. But, due to the high permeability, neither hole had a return to surface from the grouting.
- ❑ The holes were logged by a Registered Professional Geologist. The cuttings and cores will eventually be archived with the Arizona Geological Survey, in Tucson, Arizona.
- ❑ Bottom-hole temperatures were logged as often as was practical, before beginning a day's drilling, using a set of hand temperature gear supplied by David Brown & Associates. Completed hole logging was then done in January of 2006 after the gradient had reached a certain equilibrium.
- ❑ Another round of temperature logging needs to be accomplished sometime in 2006. If the Clifton project is to be pursued, we recommend the holes be left open as reservoir monitors.

### **5.3.2 DRILLING RESULTS**

#### **TG-1**

TG-1 was carried to a total depth of 635 feet. The hole was initially projected to go to 800 feet (Appendix I, Figure 5). The hole was suspended due to difficult drilling conditions that prevented advancing the hole using the HQ-size core bit.

## **Lithology**

The hole collared in a talus deposit overlying Pre-Cambrian granite and granodiorite, and carried that bedrock lithology to the bottom of the hole. The rock type varied, as the hole was advanced, between the two Pre-Cambrian units with the brick red-granite dominating. This relationship between the two rock types is seen in outcrop at the surface.

The granite was observed to be highly fractured, with unhealed fractures ranging from as close as less than an inch to more than a foot in separation. The hole produced significant water, with an air-lifted volume of upwards of 600 gallons per minute at a depth of only about 550 feet. The high water volume drowned out the air hammer bit, and required the hole be converted to HQ-size rock coring. The rock coring continued to 635 feet, where near-vertical unhealed fractures deviated the drill bit severely, and prevented further drilling. The rock core recovered reflected the intense fracturing of the rock (Appendix V).

The drillhole was sited where it would intercept the foot wall of the Potter Ranch Fault. The results of the drilling seem to indicate the fault zone has a number of paralleling faults, and the drill hole intercepted the fractures associated with the zone.

## **Temperature**

The temperature profiles in the hole over time and the blooie line temperatures reflected a changing hydrology in the hole.

### **Blooie Line and BHT Temperatures**

During drilling of the upper 550 feet, the blooie line temperatures increased at a steady rate, with a temperature of about 145°F (62.8°C) recorded at a depth of about 520 feet (Appendix I, Figure 5). A bottom hole temperature (BHT) taken with an electronic probe and backup maximum-reading-thermometer yielded a temperature of 160°F (71°C) inside the drill rods at a depth of 390 feet at the beginning of the drilling day on October 19, 2005.

As the hole advanced beyond 500 feet, the blooie line temperatures dropped. A blooie line temperature of only 125°F (51.7°C) was observed at 550 feet. From about 555 feet and beyond, there was no surface circulation, so no blooie line fluid temperatures could be taken.

### **Temperature Gradients**

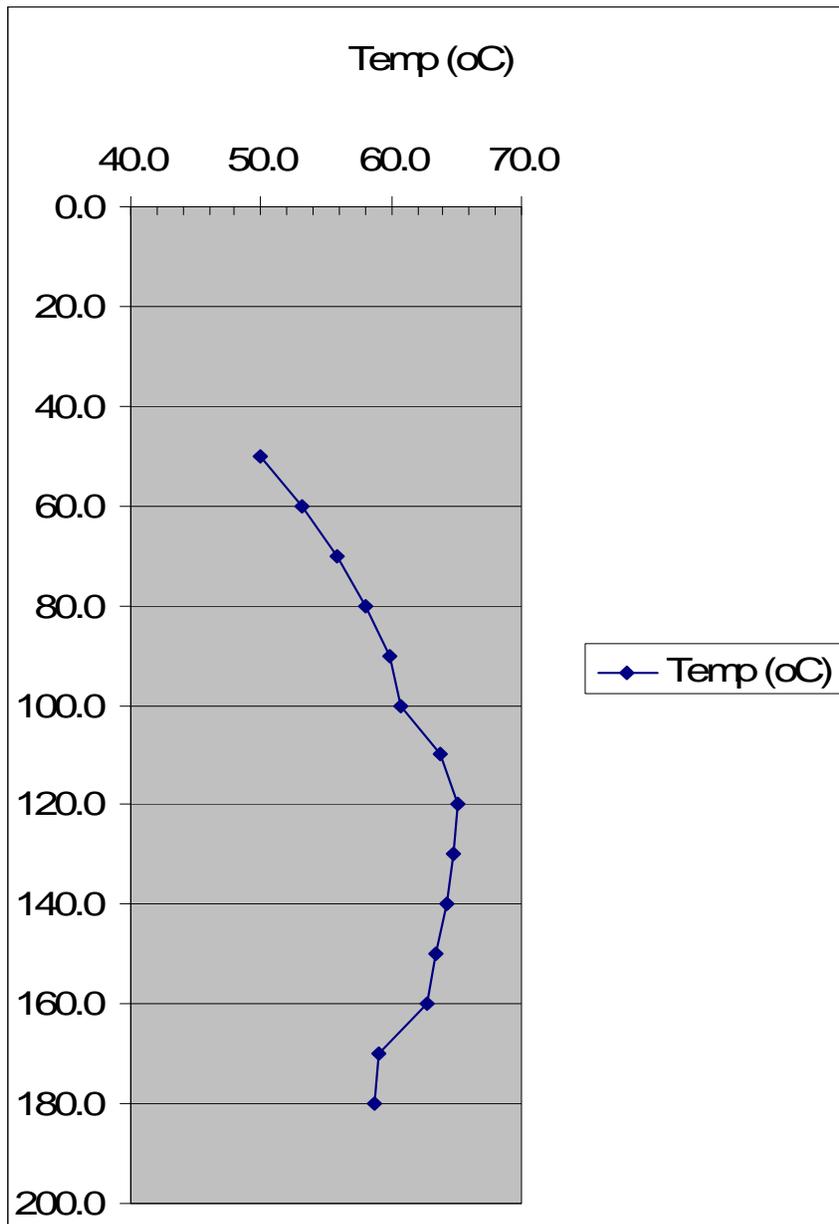
As presented on the next page, with depths shown in meters, a temperature profile taken through the drill rods when the hole reached a depth of 590 feet yielded a profile with a maximum temperature of 150°F (65.1°C) at a depth of 393 feet (Appendix I, Figure 5). The profile then reversed and cooled down to 137.7°F (58.7°C) at a depth of 590 feet.

In January of 2006, as shown on the following page, a temperature gradient was logged to the total depth of the hole at 623 feet (Appendix I, Figure 5). The temperature profile

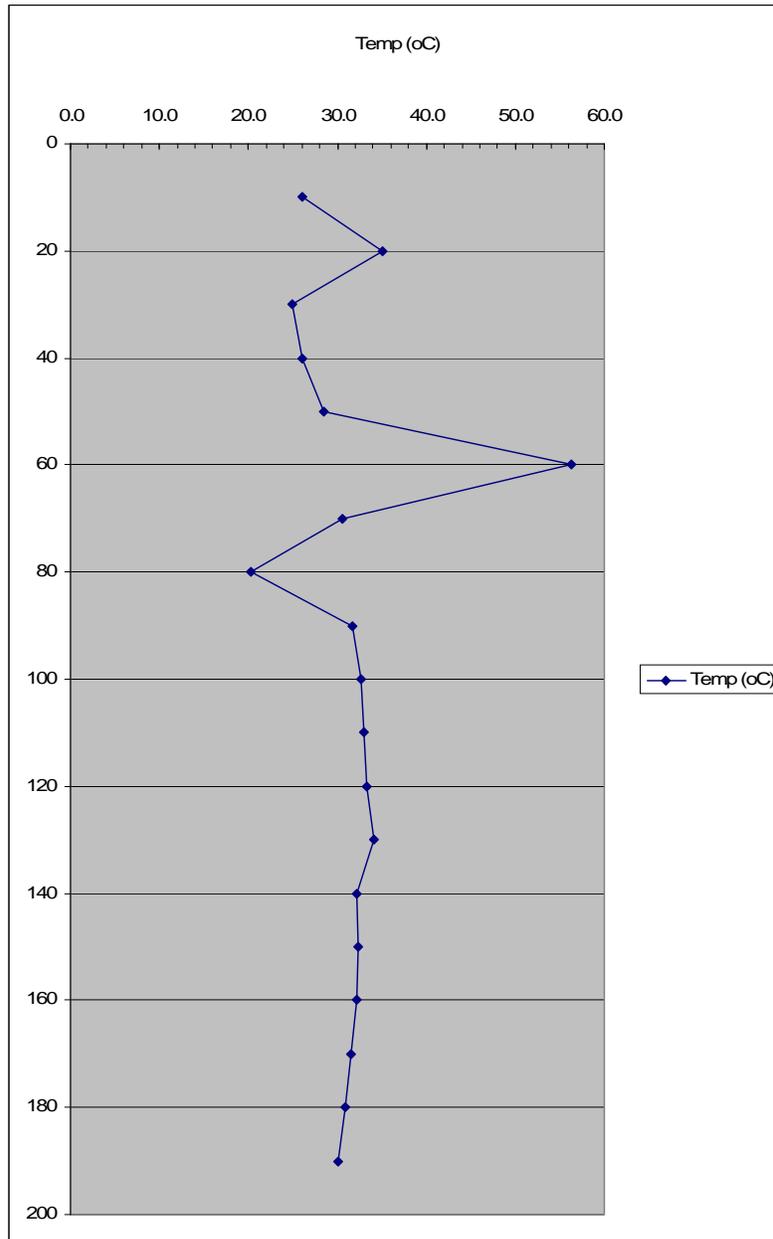
showed the hole had cooled down significantly, with a maximum temperature of only 93.1°F (34.1°C) at a depth of 427 feet. However, a single temperature spike anomaly of 133°F (56.3°C) was observed at about 197 feet. This anomalous temperature compared closely to 127.6°F (53.1°C) recorded during the earlier logging event performed during drilling.

The analysis of the drilling and gradient logging temperatures for this hole indicates there is a warm aquifer located in the upper part of the hole that was then overwhelmed by a upward-moving, highly productive cool aquifer at a depth of about 555 to 600 feet. This was reflected in the geology and circulation history of the hole.

**TG-1 Temperature Gradient (10/30/2005)**



### TG-1 Temperature Gradient (1/11/2006)



### TG-2

TG-2 was carried to a total depth of 1,000 feet. The hole was initially programmed to go to 1,200 feet. However, the hole was suspended at 1,000 feet due to drilling budget constraints.

### Lithology

The hole was collared in a deposit of canyon fill alluvium. The fill extended to a depth of about 26 feet, where the drill hole encountered the Ordovician calcareous arenite Longfellow Formation. This unit carried to about 50 feet where the Cambrian Coronado Quartzite was encountered.

The Coronado was identified as a quartzite to arkose sandstone with highly lithified argillaceous layers. The unit showed high angle to near vertical fractures about 1 mm wide, filled with micro-quartz and hematite.

The Coronado was then underlain at about 469 feet by the Pre-Cambrian red granite. This granite then carried to the bottom of the hole, with the exception of a diabase dike or sill identified from 834 to 860 feet and then again from 887 to 883 feet. This diabase was very fine grained with no individual phenocrysts visible to the hand lens. Veins of fine calcite were observed to extend from the diabase, into the surrounding Pre-Cambrian country rock. This unit may be related to feeder dikes for the Tertiary Basaltic Andesite unit seen on the surface.

Unlike TG-1, the granite was not observed to be highly fractured, with the few fractures observed healed with quartz or calcite. However, there were signs of compressional fractures in the hole, with the core exhibiting small, high angle reverse fractures that were then filled and healed with calcite and quartz.

### **Temperature**

The temperature profiles in the hole over time and the blooie line temperatures reflected a consistent hydrology in the hole.

### **Blooie Line and BHT Temperatures**

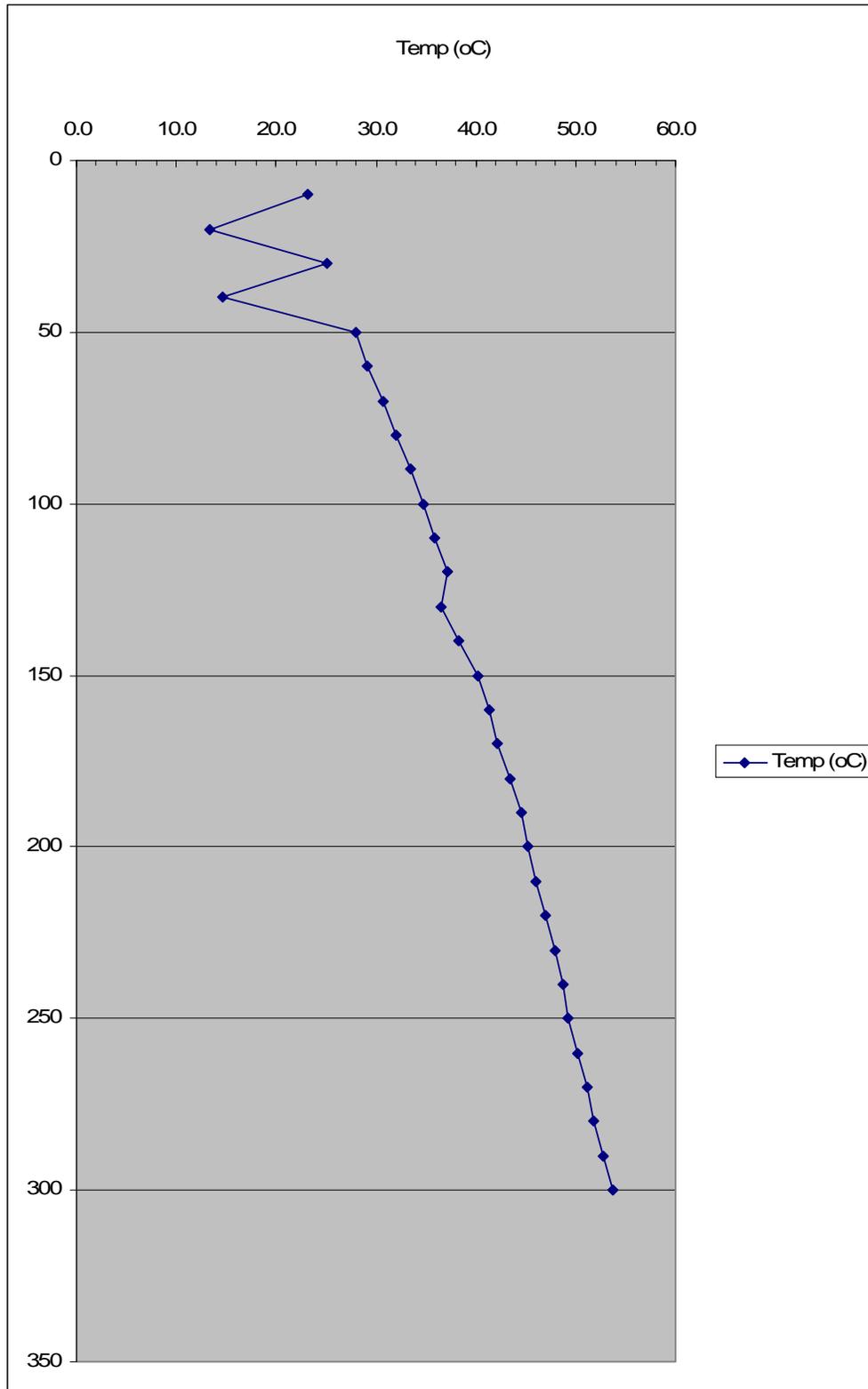
During drilling of the upper 325 feet, the blooie line temperatures increased at a steady rate, with a temperature of about 80°F (26.7°C) recorded at a depth of about 150 feet and a reading of about 90°F (32.2°C) at 280 feet. A bottom hole temperature (BHT) taken with an electronic probe and backup maximum-reading-thermometer yielded a temperature of 78.8°F (25.6°C) inside the drill rods at a depth of 120 feet at the beginning of the drilling day on October 29, 2005. At about 325 feet, the hole began producing too much water to advance with air. The drilling method was changed and the hole advanced to total depth using HQ-size coring. There was no drilling fluid return to the surface, so no blooie line temperatures could be taken.

### **Temperature Gradients**

In January of 2006, a temperature gradient was logged to the total depth of the hole at 1,000 feet (Appendix I, Figure 6). The temperature profile showed the hole with a maximum temperature of 129°F (53.8°C) at a depth of 1,000 feet. The gradient shows a distinctly straight-line curve, indicating a conductive thermal environment at a rate of increase of about 100°C per kilometer.

The analysis of the drilling and gradient logging temperatures for this hole indicates there is a much hotter geothermal source below the bottom of the hole. If the geothermal gradient holds to depth, then temperatures of over 100°C could be expected at a depth of about 3,000 feet.

### TG-2 Temperature Gradient (1/11/2006)



### 5.3.3 SECONDARY MINERALIZATION

Secondary minerals observed in the recovered core and cuttings from holes TG-1 and TG-2 show evidence for what is interpreted as one hydrothermal pulse, followed by cold to ambient groundwater events. Potential secondary minerals associated with the current geothermal activity in TG-1 were not identified, due to the lack of sample recovery in that portion of the hole where the temperature gradient profile showed hot water flow. Secondary minerals associated with the current geothermal system were not observed in core from TG-2. This is not unexpected, in that the temperature gradient profile for this hole shows a conductive thermal pattern. This indicates that the active geothermal system is at some depth below the 1,000-foot completion depth. This is consistent with the temperature profile in this hole.

The single significant hydrothermal event, observed in both holes, deposited minor microcrystalline silica and sulfides in narrow fractures. This may be minor, and a distal hydrothermal activity related to the main action that formed the nearby Morenci copper ore bodies.

The next event is the effect of cold water with a high Eh and low pH. The most probable source of this water is downward-moving meteoric water. The likely source for the oxygen is the atmosphere. The lower pH may be an artifact of oxidizing pyrite ( $\text{FeS}_2$ ) releasing sulfur into the water, forming a sulfuric acid solution. This alteration resulted in hydrous iron oxide minerals replacing mafic minerals in the host granite and leaving relict hydrous iron oxide minerals at former sulfide mineral sites. Related leaching of the host granite of sodium and other easily mobilized elements resulted in the “weathered” appearance of the rock. Locally, secondary kaolinite reflects the low pH of the water flowing through this rock.

Subsequent to the above two events, fluid with a high carbonate content flowed through the rock depositing microcrystalline white calcite ( $\text{CaCO}_2$ ) in narrow fractures. Additional alteration along the fracture faces produced thin coats of white to green to blue-green waxy clay-like material. The water associated with this event must have had limited oxygen content, in that it did not oxidize any of the iron oxide minerals from earlier alteration.

The most recent indication of fluid moving through the rock is the precipitation on fresh fracture faces of drusy calcite crystals, commonly 5 to 8 mm across. No co-genetic alteration or other precipitation minerals are observed associated with this late-stage calcite. The fractures hosting this drusy calcite are observed cutting earlier fractures and rock alteration.

## 6.0 INTERPRETATIONS AND RECOMMENDATIONS

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### 6.1 INTERPRETATIONS

Based on the geology, geophysics, geochemistry and limited test drilling, the following interpretations about the geothermal model at the Clifton study area have been made.

- ❑ The geothermal system appears to be the remnant of what may have been a very large system at one time, certainly larger than that seen today. Ubiquitous condensate rock alteration extending into the young, elevated gravel terrace deposits seems to indicate this larger system was active, as recently as 10,000 or less years ago.
- ❑ The system appears to be intimately associated with the faulting found on both the east and west sides of the San Francisco River. Crossing faults, such as the Limestone Gulch Fault or other cross-cutting structures seem to have localized the most recent rock alteration and the hottest spring orifices near these junctures. This could mean the cross-faulting is also localizing the thermal upwelling.
- ❑ Geothermometric analyses of hot spring water seem to indicate the presence of a geothermal reservoir of at least 130°C or more.
- ❑ The results of gradient drilling and temperature logging indicate the presence of a geothermal system at depth under the site with temperatures perhaps approaching or exceeding those predicted by geothermometry. The results of the drilling also confirm the intimate association of the upwelling plumes of thermal water with the faulting identified during field mapping.
- ❑ Accurate siting of geothermal test wells to intercept faults at depth in the San Francisco Canyon area may have a high degree of probability for success.

### 6.2 RECOMMENDATIONS

Based on the work done for this project, analysis of work done previously by others, and the interpretations presented above, the following recommendations have been developed.

- ❑ TG-2 should be re-entered, the 2-inch tube pulled, and the hole extended to a depth of at least 3,500 feet. We recommend the hole be cored to total depth using HQ-coring.

- We recommend the drill hole programmed for the Corbel Ranch area (TG-3) be completed to 2,500 feet using the same drilling technique.
- We recommend a third drill hole be advanced to 2,500 feet near the San Francisco River on the Casius Ranch property. This will test the thermal regime within the San Francisco River graben keystone block.
- As the geology of the area is extremely complex, we recommend that when the drilling is complete, and the structural and thermal regime are better understood, detailed geologic maps of each of the drill sites be completed and integrated with the work done for this stage of the project.
- The exploration program should also include budgeting for at least 15 or more geochemical analyses of collected waters. The hot springs could not be sampled during the year 2005 program, but potentially could be in the near future when they re-establish themselves in the river. Also, if thermal waters are encountered in the three drill holes, they should be sampled and analyzed.

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