Effectiveness of 2-Meter and Geoprobe Shallow Temperature Surveys in Early Stage Geothermal Exploration

Richard E. Zehner[1], Kenneth N. Tullar[2], and Edward Rutledge[3]

[1]Geothermal Development Associates, Reno, Nevada U.S.A
[2]Nevada Exploration Inc., Sparks, Nevada U.S.A.
[3]Route-Ledger GIS, Payson, Utah U.S.A.

Keywords

Exploration, shallow temperature, 2-meter, Geoprobe, McGee Mountain, Hot Pot, Teels

ABSTRACT

Cost-effective geothermal exploration involves a stepwise approach wherein the least expensive tools that can advance (or reject) a property should be considered prior to more expensive techniques. Coolbaugh et al. (2007) demonstrated that shallow (2-meter) surveys were a cost-effective "direct push" tool that can identify and delineate geothermal outflow zones, prior to more expensive temperature gradient drilling. This paper evaluates the Geoprobe as another early-stage, direct push exploration tool that can collect water samples and temperature data at depths intermediate between 2 meters and typical temperature gradient drilling. In addition, the temperature relationship between surface anomalies identified by 2-meter surveys and the deeper thermal regime is explored.

To do this, 2-meter and Geoprobe surveys were conducted at three representative locations in Nevada: McGee Mountain in northern Humboldt County, the Hot Pot, in eastern Humboldt County, and Teels Marsh, in Mineral County. Geoprobe temperature measurements at 8-30 meter depths largely confirmed those from the shallow 2-meter measurements. At Teels Marsh, two surface thermal anomalies were found to have temperatures of 78°C and 97°C at shallow depth. In addition, water samples from the Geoprobe at these anomalies displayed encouraging geothermometry, enhancing the property's appeal. Thus, Geoprobe sampling should be considered as a potential next-step tool after 2-meter surveys, in appropriate geological environments.

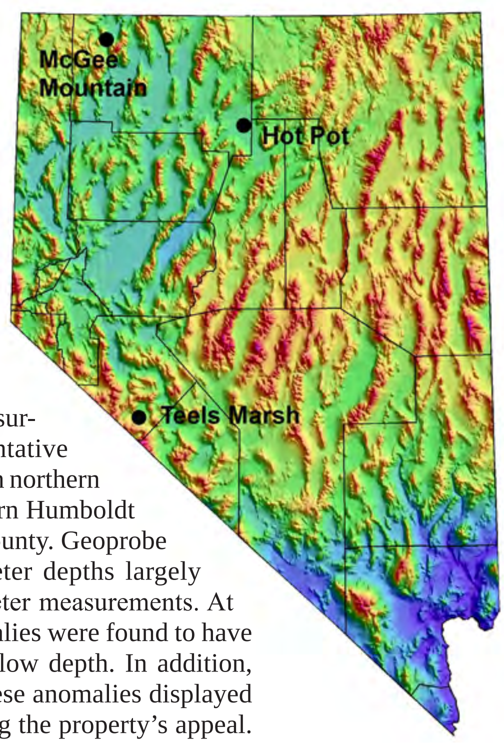

Figure 1. Location of properties discussed in this paper.

Introduction

Early stage geothermal exploration in the Great Basin often consists of identifying geothermal manifestations within an outflow zone, then tracking this outflow zone up the hydrologic gradient to the zone of upwelling. These manifestations typically include evidence such as thermal springs and wells, fumaroles, and surface sinter or travertine. Once identified, more expensive subsurface techniques, such as geophysics and temperature gradient drilling, are employed to pinpoint the high temperature (> 150°C) reservoir suitable for electric power production. Since geothermal exploration costs increase exponentially with each successive stage, it makes economic sense to perform as much low-cost, early stage work as possible.

Shallow (1-3 meter) temperature surveys have long been used to identify and delineate geothermal outflow zones (Olmstead, 1977; Trexler et al., 1982). Recent innovations of this technique by Coolbaugh et al. (2007) have led to the discovery of several blind geothermal systems in Nevada, including Teels Marsh (Kratt et al., 2008), Rhodes Marsh (Kratt et al., 2008), East Hawthorne (Kratt et al., 2010), and Emerson Pass (Kratt et al., 2010). However, data relating the 2-meter temperature anomalies to the actual underlying aquifer temperature remains sparse. In addition, a technology gap remains between this shallow 2-meter temperature sampling and the deeper, more expensive results of temperature gradient drilling.

Direct push technology ("DPT") Geoprobes were developed by the environmental industry to collect water, gas and soil samples from contaminated sites at shallow depths (10-40 meters), with a minimum of environmental disturbance. Nevada Exploration Inc. modified the Geoprobe and tooling for the specialized collection of water samples for mineral exploration in Nevada. The Geoprobe tooling was further modified for this study to take temperature as well as water samples at three geothermal sites in Nevada, where 2-meter surveys had been conducted. These sites include 1) McGee Mountain, in northern Humboldt County, 2) the Hot Pot, in eastern Humboldt County, and 3) Teels Marsh, in Mineral County (Figure 1).

This paper analyzes the advantages and limitations of these shallow 2-meter and Geoprobe techniques in early stage geothermal exploration in arid environments such as Nevada. Measured temperatures from the same site and at different depths are compared. The cost of running these surveys is calculated so that their cost effectiveness relative to other exploration techniques can be ascertained. A schema for low cost grass roots geothermal exploration is proposed.

Description of Shallow Survey Techniques

Two-Meter Survey

Detailed descriptions of the 2-meter survey method and equipment design can be found in Coolbaugh et al. (2007) and Sladek et al. (2007), and are summarized here. The survey method was devised to measure temperature as far below the zone of solar influence as possible, have minimal equilibration time, and yet be portable enough to fit on the back of an all-terrain vehicle (ATV); Figure 2). This method utilizes a direct push technology (DPT) technique where 2.3 m long, 0.54″ outer diameter hollow steel rods are pounded into the ground using a demolition hammer. Resistance temperature devices (RTD) are then inserted into the rods at 2-meter depths, and allowed to equilibrate for one hour. The temperatures are then recorded, the rods pulled out of the ground, and re-used at future sites. Usually multiple rods are planted over the course of an hour, and then the sampler returns back to the first station, measures the temperatures, pulls the rods, and so on, to eliminate waiting time. The equipment easily fits into the rear bed of a 2-3 person ATV, making the equipment extremely portable.

The technique does have drawbacks. Being direct push, the rods cannot penetrate hard substrates such as tufa, caliche horizons, large cobbles, or bedrock. In areas of hard substrates, rods tend to get stuck, causing delays and reducing the number of rods that can be planted and harvested per day.

In addition, the effects of solar heating can be large, and depends on such factors as albedo, slope, aspect, and elevation (Coolbaugh et al., 2010, discuss these effects and their mitigation). Although the daily effects of solar heating are minimized at this depth, seasonal changes approach 10ºC and temperature corrections must be made when performing return surveys at the same location, using long-term base station data. Sometimes, when measured temperatures are near the high end of background values, the source (solar or geothermal) of subtle temperature anomalies is difficult to resolve. Thermal anomalies that turn out to be associated with a geothermal system are distinct (i.e., spatially contourable), clearly above background temperatures, but remain qualitative in nature.

Geoprobe

The Geoprobe also uses DPT to push tools and sensors into the ground without the use of drilling to remove soil to make a path for the tool string, which in this case was 1.5 inch outside diameter with a 5/8 inch inside diameter. This study employed a Geoprobe brand 6600 series, mounted on a Ford F-550, powered by the vehicle engine, which relies on vehicle weight (~9 tonnes) combined with percussion for advancement of the string (Figure 3). The percussive force is supplied by a hammer operating at 32 Hz (1,920 cycles per minute) to provide a downward force of 32,000 lbs. The retraction force is 42,000 lbs. This allows the Geoprobe with 1.5 inch tool string to reach depths of more than 60m.

Typical Geoprobe methodology involves driving the string down until it can’t go any further “rejection”, then pulling back 1.5 meters or so to create a “cellar” or void space at the bottom of the hole (Figure 3, inset). After cleaning the inside diameter with water, a plastic tube is inserted down the string to just above the cellar, and a water sample is extracted (if the cellar is below the water table). During this study, after the water sample was

Figure 2. A 2-meter hollow rod is being inserted into the ground using a demolition hammer powered by an electric generator in the back of the ATV.

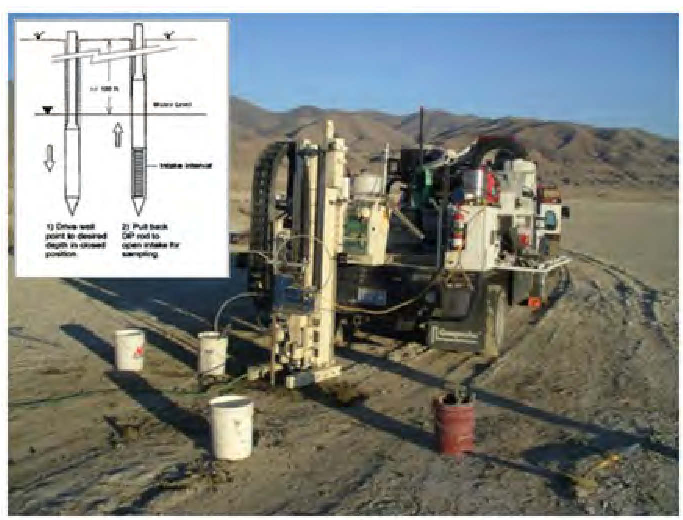

Figure 3. Geoprobe F550 mounted in water sampling configuration. Inset: Graphic shows how tool string is pounded into ground (left), then pulled out to create the “cellar” where water and temperature samples are collected.

collected, an RTD mounted in plastic tubing was then inserted into the cellar and allowed to equilibrate. Equilibration times are several hours in dry holes that have not penetrated to the water table, to several minutes in wet conditions. Thus, in addition to collecting uncontaminated water samples for geochemical analysis, the Geoprobe was made to perform as a sort of shallow temperature gradient well.

Like the 2-meter sampling technique, the Geoprobe also has its drawbacks. It has much greater "push" than the demolition hammer used in the 2-meter setup, but still cannot penetrate large amounts of the same obstacles, including bedrock. The heavy rig can engage most 4WD roads, but cannot be taken off road, thus limiting its range. Although permitting is much easier than conventional drill rigs (some BLM offices have declared it "casual use" and require only notification), minimal permitting is usually required. Hole abandonment is subject to state drill hole abandonment laws.

Field Work

Shallow 2-meter and Geoprobe surveys were conducted at three properties in Nevada, each having geology broadly similar to typical Basin and Range geothermal systems: McGee Mountain, the Hot Pot, and Teels Marsh.

McGee Mountain, Northern Humboldt County, Nevada

The McGee Mountain thermal area occurs along north-northeast trending range front faults on the east side of McGee Mountain, approximately 28 kilometers southwest of Denio. Early explorationists were attracted to the intense hydrothermal alteration, mercury mineralization, and an intermittent fumarole in Tertiary volcanic rocks along the range front structures (Hulen, 1979). Quartz and cation geothermometry taken from springs and wells several miles down gradient from the area arguably suggest reservoir temperatures in the 150°C to 180°C range. The property was evaluated in the 1970's by Phillips Petroleum, who drilled multiple temperature gradient holes, and by Earth Power Resources, who drilled two slim holes (1500-1 and 1500-2). The property was later acquired by Caldera Geothermal, Inc. (CGI), who performed 2-meter and Geoprobe surveys as part of a DOE Innovative Technology grant.

Temperatures at 2-meter depth were measured from 193 sites at McGee Mountain between November 2008 and March of 2009 (Figure 4A). Measured temperatures were adjusted for seasonal changes using repeated measurements at control stations where rods were left permanently in the ground. Anomalous (>18°C) temperatures were encountered along the range front in a narrow north-northeast striking zone approximately 2.3km long. The maximum temperature encountered at 2 meters was 70.6°C, southwest of the Painted Hills mercury mine, and close to the site of the intermittent fumarole and Hole 1500-1 (442m TD). Temperatures were variable over short distances and tapered off rapidly away from the range front. This thermal anomaly is interpreted as a steam-heated fault zone. Curiously, no discernable thermal outflow zone could be identified, although opalization in Tertiary sandstones form a sort of "fossil outflow zone" down the range front, away from the thermal anomaly area.

In addition, a Geoprobe survey was made at McGee Mountain in May 2010. 23 holes totalling 261m (857 feet) were completed on the property. The range front target was covered by coarse alluvium containing boulders, which reduced penetration depths. It was hoped that water samples within the thermal area would yield geothermometer temperatures equal to or better than those available from the cold springs and wells down gradient. However, the water table was not intersected in any Geoprobe hole, so no water samples could be collected. Still, bottom hole temperatures were measured. Sampling within the area of the range front thermal anomaly was hampered by low road density. Measured bottom hole temperatures corresponded well with those of adjacent 2-meter sample sites (Figure 4A).

Both DPT surveys yielded the temperatures one would expect on top of nearby slim holes (Figure 4B). The 2-meter survey measurement of 70.6°C was taken within 100m of Hole 1500-1, and compares well with the 87.5°C temperature measured in the first 50 feet of the well, given a typical high surface geothermal gradient. Similarly, the Geoprobe temperature of 15.5°C at 8 meter depth is in line with the 25°C temperature in the first 15m (50 feet) of Hole 1500-2. Still, the low 2-meter and Geoprobe temperatures in the vicinity of hole 1500-2 fell within the range of background values, such that the higher (probably conductive) geothermal gradient from Hole 1500-2 would go undetected in an exploration situation.

Hot Pot Property, Humboldt County, Nevada

The Hot Pot property is located in the Kelly Creek Basin, just north of the Humboldt River, approximately 51km east of Winnemucca in Humboldt County, Nevada (Figure 1). The valley consists of Quaternary and Tertiary volcanic and sedimentary rocks resting unconformably on top of Paleozoic and Mesozoic basement rocks (Stewart, 1980). The Hot Pot is a low travertine hill sitting on top of Quaternary alluvium and dune sands. 58°C water used to flow from the springs, presumably until basin drawdown from the nearby Valmy power plant and Lone Tree mine eliminated surface flow. Trexler et al. (1982) sampled the spring and performed a reconnaissance 2-meter survey in the area, and Oski Energy (2011) completed detailed geophysics and some temperature gradient drilling on the property.

2-meter and Geoprobe sampling were conducted simultaneously at Hot Pot in April of 2012. Thirty-one 2-meter sites and twelve Geoprobe sites were sampled (Figure 5A). The ground at 2 meter depth was colder than at McGee Mountain; the cutoff between background and anomalous temperatures at 2 meter depth was ~11°C. The 2-meter sampling identified a thermal anomaly limited to a small area around the Hot Pot travertine terrace, which was confirmed by the deeper Geoprobe sampling (50.5°C).

However, the Geoprobe delineated additional thermal anomalies at sites a considerably further distance (up to 2km) away from the Hot Pot, along a NW-SE drainage that corresponds to a fault identified by Oski Energy (2011). At all five of the sites distal to Hot Pot where 2-meter and Geoprobe sampling occurred adjacent (i.e. within 100m) to each other, the Geoprobe identified +20°C temperatures at 18m-32m depths, where the 2-meter sampling indicated no anomaly. In addition, the Geoprobe encountered the water table at all sites along the drainage except the Hot Pot area, and was able to collect water

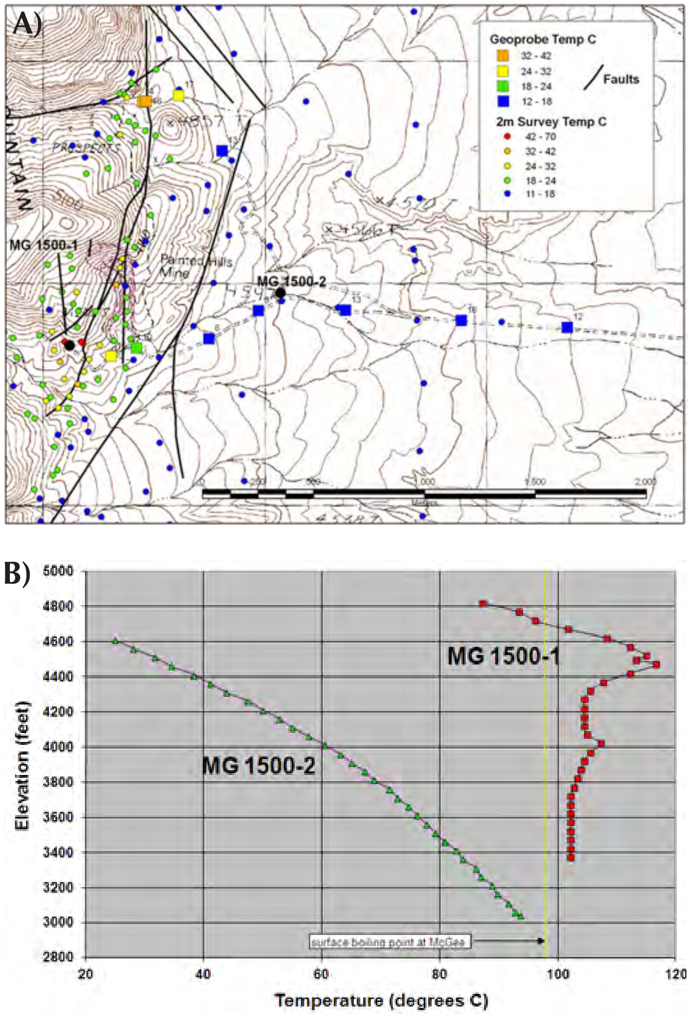

Figure 4. A) Map of McGee Mountain thermal area showing results of 2-meter and Geoprobe surveys. The depth in meters of Geoprobe temperature measurements are shown at upper right of each symbol. Temperatures from both 2-meter and Geoprobe surveys use the same color pattern; 2-meter temperatures have been seasonally corrected. B) Depth-temperature graph of holes MG 1500-1 and MG 1500-2 holes; note relationship of top hole temperature with those from nearby 2-meter and Geoprobe sites.

samples for geochemical analysis. Field conductivity measurements tended to confirm that a geothermal plume was centered on the Hot Pot (Figure 5B).

Teels Marsh, Mineral County Nevada

The thermal area is located on and adjacent to a Quaternary range front fault system along the west side of Teels Marsh, where the northwest striking Walker Lane structural zone makes a right step (Oldow et al., 1994). Triassic metavolcanics and Tertiary andesites are juxtaposed against Quaternary alluvium and playa deposits along the range front.

This blind target was discovered by the Great Basin Center for Geothermal Energy (GBCGE) during research into the relationship between geothermal systems and Quaternary borate deposits (Coolbaugh et al. 2006), followed by 2-meter surveys (Kratt et al., 2008). CGI performed additional 2-meter as well as Geoprobe sampling of the property. The soft alluvium and playa sediments

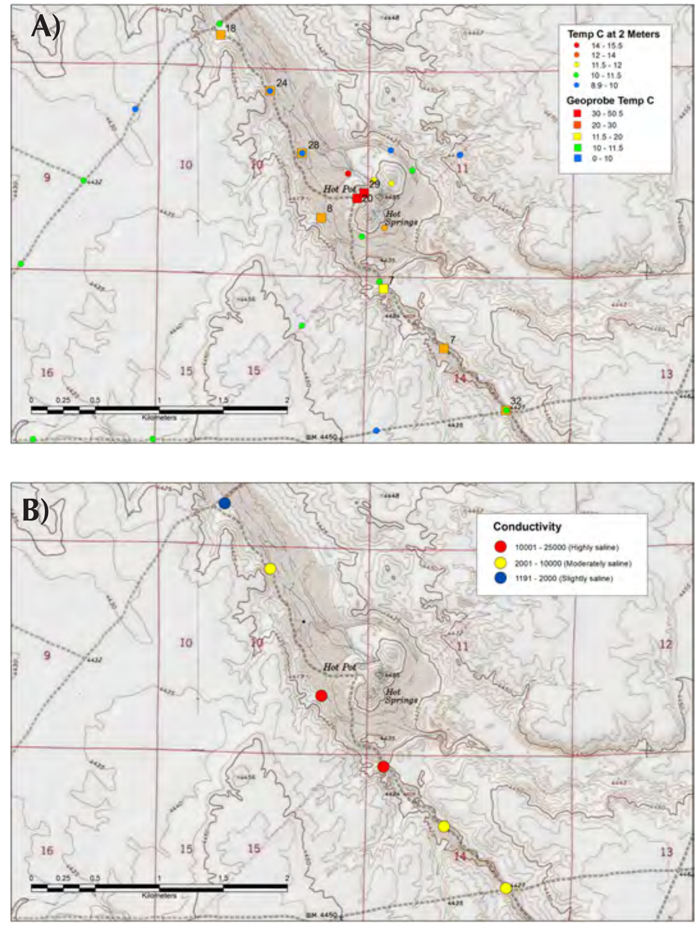

Figure 5. A. Map of the Hot Pot thermal area showing locations and measured temperatures from 2-meter and Geoprobe surveys. The depth of Geoprobe temperature measurements are shown in meters at upper right of each symbol. Temperatures from the 2-meter and Geoprobe surveys use a different color pattern above 12°C. B. Field conductivity measured from Geoprobe water samples shows spatial relationship with the Hot Pot.

comprising the substrate of the anomaly area provided an ideal sampling medium for both these DPT survey techniques.

The 2-meter sampling by GBCGE identified two distinct and robust thermal anomalies along the range front fault with temperatures reaching 35°C at 2 meter depth (Figure 6). The cutoff between anomalous and background temperatures was in the range of 16°C-18°C (Kratt et al., 2008). Additional deeper probing by Kratt et al. (2008) in the center of the southern anomaly found a temperature of 65°C at 9.5m depth. Later sampling by CGI discovered a third, weaker anomaly in the flats south of the marsh.

Geoprobe sampling during July of 2010 specifically targeted the 2-meter survey anomalies and consisted of 12 holes totaling 298m (976 ft.), with 3 holes reaching at least 30m depth. Measured temperatures confirmed those of the 2-meter survey and demonstrated increasing temperatures with depth within the anomaly areas. Sampling in the center of the southern thermal anomaly yielded a temperature of 78°C at 30m depth, confirming the 65°C probe measurement of Kratt et al. (2008). The measured temperature from the deepest (36.5m) hole, in the center of the northern thermal anomaly, was 97°C.

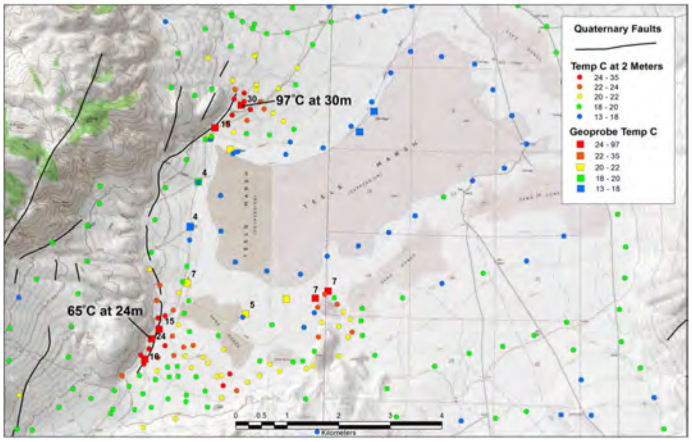

Figure 6. Map of Teels Marsh thermal area showing location and temperatures from 2-meter and Geoprobe surveys. The depth of Geoprobe temperature measurements are shown in meters at upper right of each symbol. Temperatures from both 2-meter and Geoprobe surveys use the same color pattern except for the warmest two (orange and red) interval. 2-meter temperatures have been seasonally corrected.

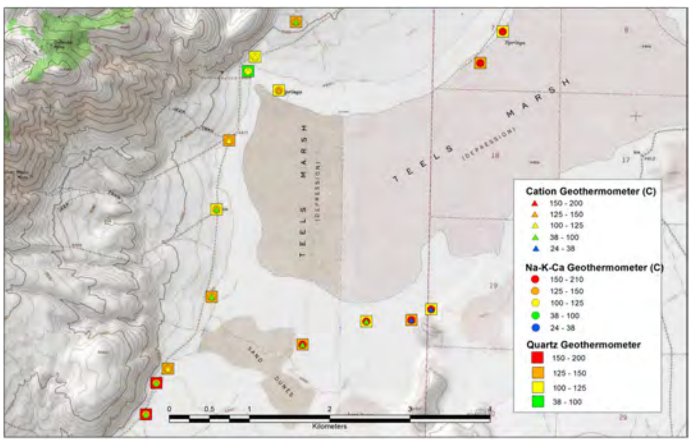

Figure 7. Estimated reservoir temperatures from quartz, Na-K-Ca, and cation (Na-K-Ca-Mg corrected) geothermometry from water samples collected from Geoprobe wells and springs at Teels Marsh. Water sampling from the Geoprobe wells allowed for geochemical assessment of the thermal waters of this blind system. The close sample spacing helps delineate possible spatial geochemical trends. For example, low cation geothermometer temperatures in some samples relative to Na-K-Ca geothermometer values (i.e. without the magnesium correction) may be due to local mixing with magnesium-rich playa waters especially prevalent at the south side of the marsh.

In addition, the Geoprobe was able to collect water samples in many of the holes that were analyzed for geochemistry and geothermometry (Figure 7). This was especially important at this "blind" target where no thermal spring or well was initially available for sampling (the cold springs on the northwest side of Teels Marsh had been sampled). The relatively high sample density furnished by the Geoprobe allowed for subtle geochemical trends to be identified across the thermal area.

Discussion

Performing 2-meter and Geoprobe DPT sampling at the three properties allowed for a critical assessment of these techniques under a variety of physical and geologic conditions.

At McGee Mountain, the 2-meter survey delineated a hot, narrow steam-heated fault zone with temperatures reaching 70°C. Measured temperatures within the anomaly varied over short distances, which seem more a function of the local geology than inconsistencies in the measuring technique. Geoprobe readings tended to confirm the results of the 2-meter survey but, being confined to roads, the Geoprobe couldn't reach most of the thermal anomaly area. Neither the 2-meter probes nor the Geoprobe identified the conductive thermal anomaly identified in hole 1500-2 as "anomalous". However, this lower-grade thermal anomaly might have actually been captured as part of the "background" temperature, but not identified, because the area covered by the DPT surveys was equal to or smaller than the area of the anomaly. Only deeper drilling would have unambiguously identified it.

Both DPT surveys at the Hot Pot property registered a thermal anomaly at the Hot Pot travertine hill, but only the deeper Geoprobe identified the 20°C-30°C temperatures at 18-32 meter depths along the sampled drainage. Field conductivity measurements from Geoprobe water samples also yielded real-time information confirming the location of the geothermal plume, as well as water samples for later geochemical analysis.

Both the 2-meter and Geoprobe methods worked best at Teels Marsh, largely because of the soft substrate conditions, shallow depth to the water table, and the presence of roads within the thermal anomaly to accommodate the Geoprobe. Utilizing these two methods, this blind geothermal target was upgraded to a strong candidate for future exploration, having high shallow temperatures and promising geothermometry.

This study also allowed for an examination of the temperature conditions at "depth" that cause true 2-meter thermal anomalies. Figure 8 compares the closest 2-meter site to a corresponding Geoprobe site, with a maximum radius of 100m. Two features of this graph are worthy of discussion. First, for the most part, anomalous and background temperatures identified by the 2-meter survey are more or less (see below) verified by the deeper Geoprobe temperatures. This lends credence to the technique as a "first pass filter" to sort areas for their geothermal potential using shallow thermal anomalies, as in grass-roots exploration settings. Second, the higher temperatures at depth as measured by the Geoprobe tend to correspond to higher temperatures at 2 meters, although the slightly different slopes of the lines indicate some variances in the thermal conductivity of soils. Still, hotter temperatures at 2 meters seems to indicate hotter temperatures at depth. It should be pointed out that although the lines connecting 2 meter temperatures to the adjacent Geoprobe readings are shown as straight, they probably follow a temperature gradient more similar to the line representing the measurements to 9.5 meter depth at Teels Marsh by Kratt et al. (2008) data (Figure 8).

Potential weaknesses in the 2-meter technique are indicated by arrows pointing to the 2m-Geoprobe lines in Figure 8. They point to situations where non-anomalous or background conditions as identified by the 2-meter survey are not corroborated by the Geoprobe: one from each property. In the instance from Teels Marsh (red line), the 2-meter site is 95m from its corresponding Geoprobe site, perhaps too far for a good comparison. At McGee Mountain (blue line), the 2-meter probe and Geoprobe sites are also close to the 100m limit of comparison. But here, the high variance of temperature with distance in this steam-heated fault zone probably also plays a role. At the Hot Pot property (green line), the 2-meter rod was planted right at (and measured just before) the location of the Geoprobe hole. As mentioned previously, anomalous 20°C to 30°C temperatures measured by the Geoprobe at several Hot Pot sites were not above background, according to the 2-meter technique. This seems to point to a minimum temperature at depth (approximately 30°C), below which a thermal anomaly cannot be detected by the 2-meter technique.

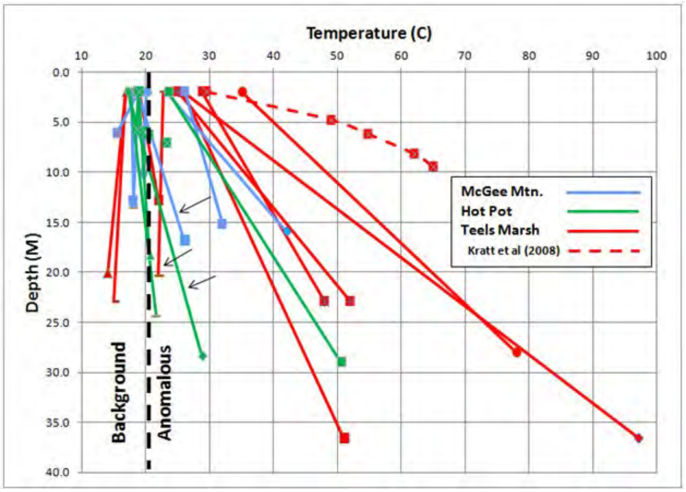

Figure 8. Depth temperature plot comparing results of 2-meter with Geoprobe surveys at the 3 properties. The lines pair the closest 2-meter probe to a Geoprobe hole, within a maximum distance of 100m. 2-meter temperatures have been corrected to the ~20°C Teels Marsh threshold between 'background' and 'anomalous' by adding the difference between this value and those of McGee Mountain (2.0°c) and Hot Pot (7.0°C). Arrows are discussed in the text.

Conclusions

2-meter surveys are a good technique to identify and delineate geothermal outflow zones prior to more expensive temperature gradient drilling (Coolbaugh et al., 2007). These surveys are quick, portable (with off-road potential), and inexpensive. We have found that Geoprobes, adapted to take bottom hole temperature measurements, are a cost-effective next step in geothermal exploration, particularly in situations where 2-meter sampling is effective. They provide a further aid in delineating geothermal outflow zones that should be considered in non-bedrock terrains before temperature gradient drilling takes place. The cost of a 2-meter and Geoprobe survey together are about the cost of one temperature gradient hole. In addition, Geoprobes can collect water samples for geochemical analysis without the contamination problems inherent in mud-based rotary temperature gradient drilling. The various strengths and limitations of these two techniques are summarized in Table 1.

Acknowledgements

Thanks to William Brandon for pointing out the potential benefits of using Geoprobes for geothermal exploration. Reviews by Mark Coolbaugh, Lisa Shevenell, and Martin Booth greatly benefitted the paper. Zack Simantel provided geotechnical support in the field. Both Caldera Geothermal, Inc. and Nevada Exploration Inc. generously provided data for this paper. Funding for this paper was provided in part by a DOE Geothermal Technologies Program, Recovery Act Grant (DE-FOA-0000109).

References

Coolbaugh, M.F., Kratt, C., Sladek, C., Zehner, R.E., and Shevenell, L., 2006, Quaternary borate deposits as a geothermal exploration tool in the Great Basin: Geothermal Resources Council Transactions, v. 30, p. 393-398.

Coolbaugh, M.F., Sladek, C., Faulds, J.E., Zehner, R.E., and Oppliger, G. L., 2007, Use of rapid temperature measurements at a 2 meter depth to augment deeper temperature gradient drilling: Thirty-Second Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California, January 22-24, SGP-TR-183.

Table 1. Comparison of shallow DPT techniques together with temperature gradient drilling.

Criterion	2-Meter Survey	Geoprobe	TG Drilling
Cost	Approximately $125/site, $18k/10 day survey*	Approximately $800/site, $40k/10 day survey	Depends on depth, but costs are ~$30k on up per hole**
Penetration Depth	2 meters	Up to 60 meters	Very deep (1000m?)
Portability	Off road capability	Requires road	Requires road and pad
Penetrability	Cannot penetrate hard substrates, such as bedrock.	Cannot penetrate hard substrates, such as bedrock.	Can penetrate all bedrock types
Permitting/ Permitting time	None to minor/ Up to several months	Minor/Up to several months	Moderate to extensive/ Months to Year
Reliability of temperature data	Subject to solar influences	Good, but usually limited to bottom hole	Temperatures can be measured at all depths
Water sampling	No	Yes, specifically limited to bottom hole interval.	Yes, but drilling with mud can contaminate water samples
Timing in an exploration program	Early stage/ reconnaissance	After 2-meter survey has delineated outflow zone	After both DPT surveys, or earlier if in hard substrate terrains

* Based on estimates from surveys performed by GBCGE and CGI
**Based on estimates from surveys performed by Nevada Exploration Inc.

Coolbaugh, M.F., Sladek, C., and Kratt, C., 2010, Compensation for Seasonal and Surface Effects of Shallow (Two-Meter) Temperature Measurements: Geothermal Resources Council Transactions, v. 34, p. 851-856.

Hulen, J.B., 1979, Geology and alteration of the Baltazor Hot Springs and Painted Hills thermal areas, Humboldt County, Nevada: report prepared for DOE Grant EG-78C-07-1701.

Kratt, C., Coolbaugh, M., Sladek, C., Zehner, R., Penfield, R., and Delwiche, B., 2008, A new gold pan for the west: discovering blind geothermal systems with shallow temperature surveys: Geothermal Resources Council Transactions, v. 32, p. 153-158.

Kratt, C., Sladek, C., and Coolbaugh, M.F., 2010, Boom and Bust with the Latest 2m Temperature Surveys: Dead Horse Wells, Hawthorne Army Depot, Terraced Hills, and Other Areas in Nevada: Geothermal Resources Council Transactions, v. 34, p. 567-574.

Oldow, J. S., Kohler, G., and Donelick, R. A., 1994. Late Cenozoic extensional transfer in the Walker Lane strike-slip belt, Nevada. Geology, v. 22, p. 637-640.

Olmsted, F.H. (1977), "Use of temperature surveys at a depth of 1 meter in geothermal exploration in Nevada," United States Geological Survey Professional Paper 1044-B, 25 p.

Oski Energy LLC, 2011, Advanced Seismic Data Analysis Program – The Hot Pot Project – DOE Award: DE-EE0002839, 2011 DOE Peer Review.

Sladek, C., Coolbaugh, M., and Zehner, R., 2007, Development of 2-meter soil temperature probes and results of survey conducted at Desert Peak, Nevada, USA, Geothermal Resources Council Transactions, v. 31, p. 363-368.

Stewart, J.H., 1980, Geology of Nevada: Nevada Bureau of Mines and Geology Special Pub. 4, 126 p.

Trexler, D.T., Koenig, B.A., Ghusn Jr., G., Flynn, T., and Bell, E.J., 1982, Low to moderate temperature geothermal resource assessment for Nevada: area specific studies, Pumpernickel Valley, Carlin and Moana, Final Report, June 1, 1981 – July 31, 1982. Work performed under U.S. Department of Energy Contract No. AC08-81NV10220, 177 p.