Evolution of Shallow Temperature Surveys

Maxwell Wilmarth[1] and Drew Siler[2]

[1]Baseload Power U.S., [2]Geologica Geothermal Group

email: maxwell.wilmarth@baseloadpower.us

Keywords

Shallow temperature survey, 2m probe, Puchuldiza

ABSTRACT

Exploration drilling for geothermal resources is expensive and the risk of not discovering an economic resource with exploration drilling is high. Lower cost, shallower direct measurements of the subsurface have therefore been conducted as part of early-stage geothermal exploration since at least the late 1970s. These surveys prioritize low cost and rapid data gathering over a wide field area. Since the mid-2000s the technique has been further developed and data corrections have become more sophisticated. This paper compares three shallow temperature (2 m probe) systems used by public and private groups. Additionally, findings are described from a shallow temperature survey conducted in 2010 at Puchuldiza, Chile. The results indicate that shallow temperature surveys are an effective method for discovering and characterizing geothermal resources.

1. Introduction

Exploration drilling for geothermal resources is expensive with high risk of not discovering an economic resource with exploration drilling. A variety of geological, geochemical, and geophysical surveys are typically conducted to lower the risk of failure. One of these techniques is shallow temperature surveys, which have been conducted in the Basin and Range province of the United States since at least the 1970s. The goal of a shallow temperature survey is to locate a thermal anomaly quickly and at low cost so that further exploration surveys can focus on an area of interest.

2. Shallow vs deep drilling

Deep drilling (>1000 m) costing on the order of \$1MM to \$10MM is required to discover a geothermal resource (**Figure 1**). Consequently, explorationists trade lower cost for shallower and less representative information about temperature distribution. Slim wells to ~1000 m at a cost of ~\$1MM are sometimes cost-effective, and handfuls of temperature gradient holes drilled from ~50 m to 150 m for \$10k to \$50k each are commonly used as well (e.g., Basin and Range, Salton Sea). Pushing this cost/depth relationship to its limit leads to shallow temperature surveys at depths of

~0.5 m to 2 m for a cost of <$500 per hole. A nominal depth of 2 m has become the standard in the industry for these types of surveys. A large number of these holes can be drilled for the same cost as a single temperature gradient (TG) hole and provide a much higher spatial density than a TG program. However, these shallow holes carry a higher risk of being impacted by surface effects and meteoric water than deeper TG holes.

Figure 1. Hole cost vs depth relationship

The goal of a shallow temperature survey is to identify anomalously high shallow temperatures that may be associated with a geothermal reservoir at depth. Shallow temperatures on the order of 1 m depth are affected by many non-geothermal surface processes which can cause variations in temperature equal to or greater than the magnitude of the thermal anomaly above the background temperature. Wet or damp soil and shallow cold aquifers can mask a geothermal reservoir and so the method has only been used in arid regions like the Basin and Range. The diurnal temperature cycle is dampened sufficiently at depths as shallow as 0.5 m. The seasonal cycle is significant to a depth of 10 m or more, but changes slowly enough that it can be ignored during a short survey or compensated for with seasonal monitoring.

Since the temperature signal measured at 2 m from a geothermal reservoir can be <5°C above background, various corrections to the 2 m temperature data are usually required, including corrections for elevation, albedo, and slope aspect. These are discussed further below.

TG hole programs investigate even deeper. A shallow temperature survey does not replace a TG hole program. Rather it provides a low-cost data set on temperature distribution for the development of a conceptual model early in the exploration phase of a geothermal prospect. Together with other low-impact exploration techniques like fluid geochemistry, structural mapping, and geophysical surveys such as MT and gravity, it can help target a TG hole program while environmental studies and drilling permits are obtained.

3. History of the technique

Shallow temperature surveys for geothermal exploration are first represented in the literature starting in the late 1970s and early 1980s. They were first used at depths of 1-2 m to investigate many known geothermal systems in the Basin and Range. The equipment used in these surveys is unknown but assumed to be a truck-mounted drill rig. A summary of the history of these studies is provided in Kraal et al (2024)

In the mid-2000s, the survey technique was revived by the Great Basin Center for Geothermal Energy (GBCGE) at the University of Nevada, Reno (UNR) to map a large number of greenfield geothermal projects and especially blind systems. GBCGE discovered at least seven previously unknown thermal anomalies in Nevada: Southern Gabbs Valley, Teels Marsh, Rhodes Marsh, Columbus Marsh, East Hawthorne, Emerson Pass, and Petrified Springs (Kraal et al, 2024). The GCBGE system utilized a side-by-side Utility Task Vehicle (UTV) with a hand-held electric hammer which pounds closed-bottom steel pipe (the probes) into the ground (**Figure 2**). This method of inserting the probes works well in soft sediment but is difficult or impossible in rocky soil. GBCGE has also used a 2-stroke gasoline rock drill with mixed success. This system is still in use at the time of this writing by GBCGE and graduate students at UNR.

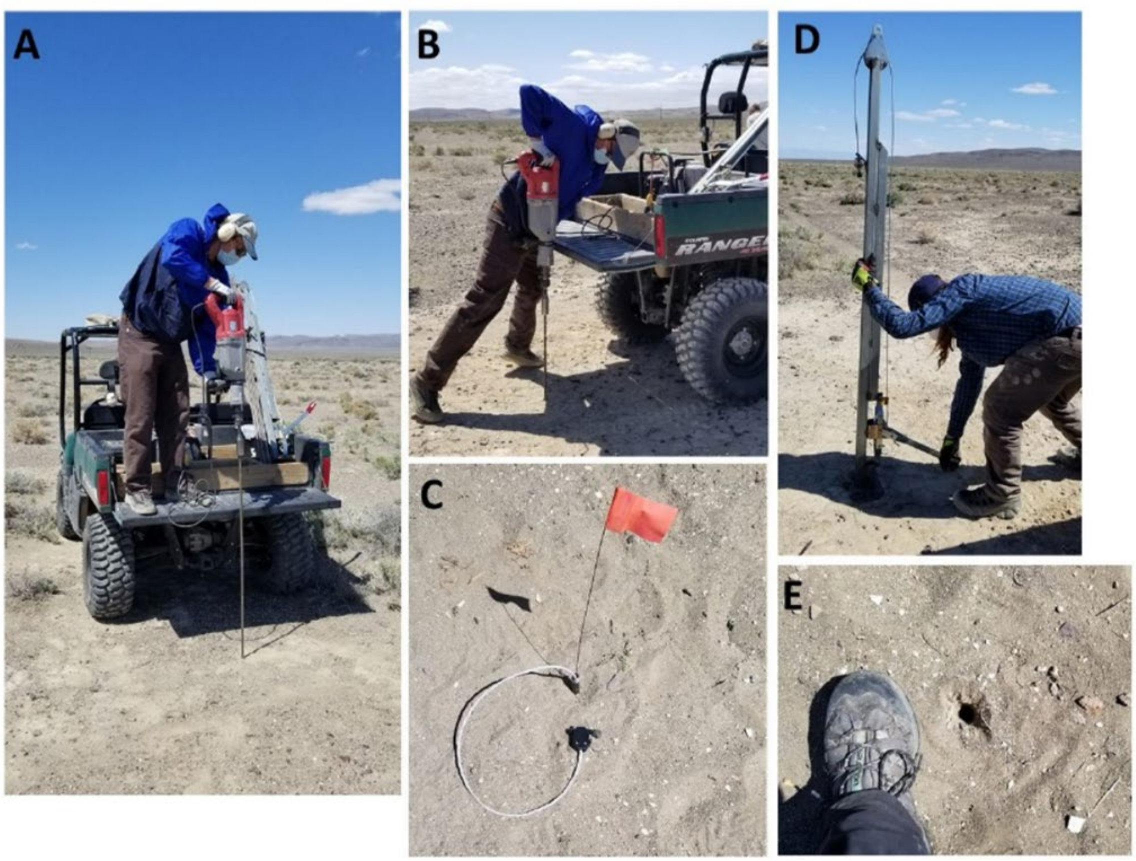

Figure 2. The GBCGE 2 m probe rig as described in Kraal et al (2024).

In 2009, a purpose-built rig mounted on a side-by-side and utilizing a custom mast-mounted electric rotohammer and ¾" concrete drill bits was built by Geoglobal Energy (GGE) for use in the Altiplano of Chile, where arid conditions similar to the Great Basin predominate (**Figure 3**). Details of this system and the data collected at the Puchuldiza project in Chile are discussed below. The fate of this rig is unknown but it is assumed to still be warehouse in northern Chile.

In 2010, an upgraded version of the GGE rig was used by Nevada Geothermal Power at Blue Mountain, Nevada. This rig was parted out and sold sometime in 2011-2012.

Figure 3. The GGE rig in use at Puchildiza, Chile.

In the early 2020s, at least one company in Nevada utilized a direct-push type drilling rig commonly used in the environmental and geotechnical industries. This type of system can work well, but is limited to fine-grained sediment and roads traversable by trucks.

In early 2024, a new 2 m probe purpose-built rig designed and built for Baseload Power U.S. (BPUS) by Double R Drilling of Reno, Nevada for use in the Basin and Range. The innovations of this rig include a tiltable mast-mounted rotohammer and custom-made 2 m fully-fluted concrete bits (**Figure 4**). This system is discussed in detail below.

Figure 4. The 2 m prove rig designed and built for BPUS by Double R drilling.

4. Methodology

The methodology of inserting the temperature probes is similar for all three systems discussed in this paper: 1) a side-by-side UTV is used to carry personnel and equipment to the field, 2) 2 m long probes are inserted into the ground, 3) after thermal equilibration temperature measurements are made down the hollow probe with a resistive temperature device (RTD) on a wire, and 4) the probe is removed from the ground and re-used.

The GBCGE system has generally used a handheld electric hammer to pound hollow steel rods (probes) into sediment. This works well in fine-grained sediments and rocky soils with clast size up to ~2-4 cm. The disadvantages of this system are that the electric hammer is hand-held which fatigues the crew, it is difficult or impossible to penetrate rocky soil, and the probes must be laboriously jacked out of the ground by hand to remove them.

By contrast, the GGE system employed a hinged mast and track system with a winch to mount a rotohammer. The mast allowed for remote operation with a tether and was significantly less laborious to operate. The rotohammer could be used to either pound probes in the ground, similar to the GBCGE system, or to drill holes using ¾" concrete bits available off-the-shelf. The holes could be blown clean with an on-board air compressor and a long, thin, tube attachment. The bits were 2 m long but the flights only continued ~1 m. This required repeated hole cleaning after 1 m depth which significantly increased the total drilling time.

The newest system created by BPUS and Double R used a pivoting mast built from unistrut with a track that allows the rotohammer to move up and down. The mast can be tilted back onto the rig while driving and redeployed to the vertical position at the next location. The winch in the mast can also be used to pull rods after the measurements are complete. Two people can operate the rig (**Figure 4**) comfortably. Upon reaching the desired depth, the hole can be blown clean with air and a hollow steel rod is dropped into the hole. A tap on the rod with a sledge hammer ensures good contact with the formation. An RTD (**Figure 5a**), is threaded on a wire down the rod (**Figure 5b**).

A small amount of water can be poured into the pipe to ensure good conductive thermal contact with the RTD.

Although the RTD only needs seconds to minutes to thermally equilibrate, the steel rod requires up to an hour or more to equilibrate with the formation. We prefer to leave the rods in overnight before making a measurement. To make a measurement the RTD is plugged into an electronic meter and the temperature is read off the display (**Figure 5c**).

Figure 5. RTD and meter (a); Threading the RTD down the probe (b); and reading the temperature (c).

5. Corrections

Various corrections must be made to the raw temperature data in order to correctly map the shallow temperature distribution. These corrections have been detailed in Sladek et al (2009) and Kraal et al (2024). In the Puchuldiza and BPUS surveys, the most useful corrections were found to be 1) seasonal drift, 2) elevation, and 3) albedo, in that order. Other attempted corrections included slope aspect and total solar insolation, but were not found to be significant. Examples of the Puchuldiza survey seasonal trend (**Figure 6**), and negative correlations with shallow temperature for elevation (**Figure 7**) and albedo (**Figure 8**) are shown below.

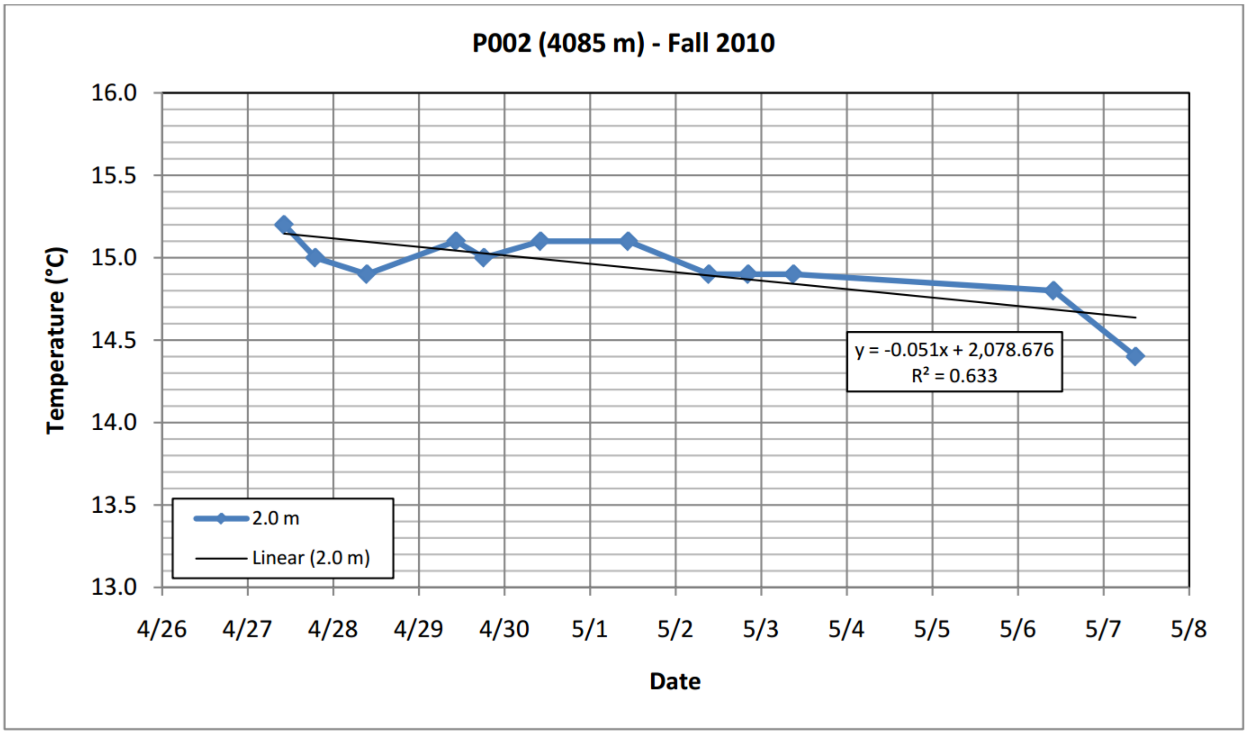

Figure 6. April/May monitoring of Puchuldiza base station P002. There was a small cooling trend at 2.0 m.

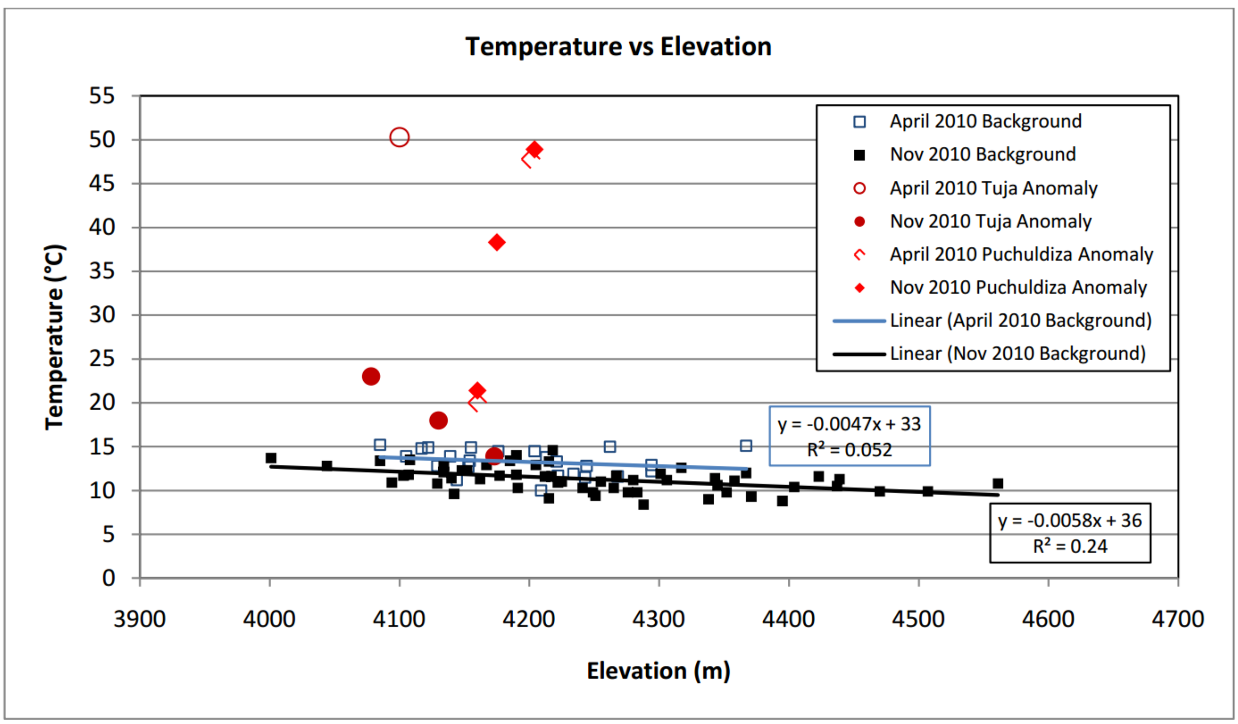

Figure 7. Puchuldiza uncorrected temperature vs elevation. There is a small negative correlation.

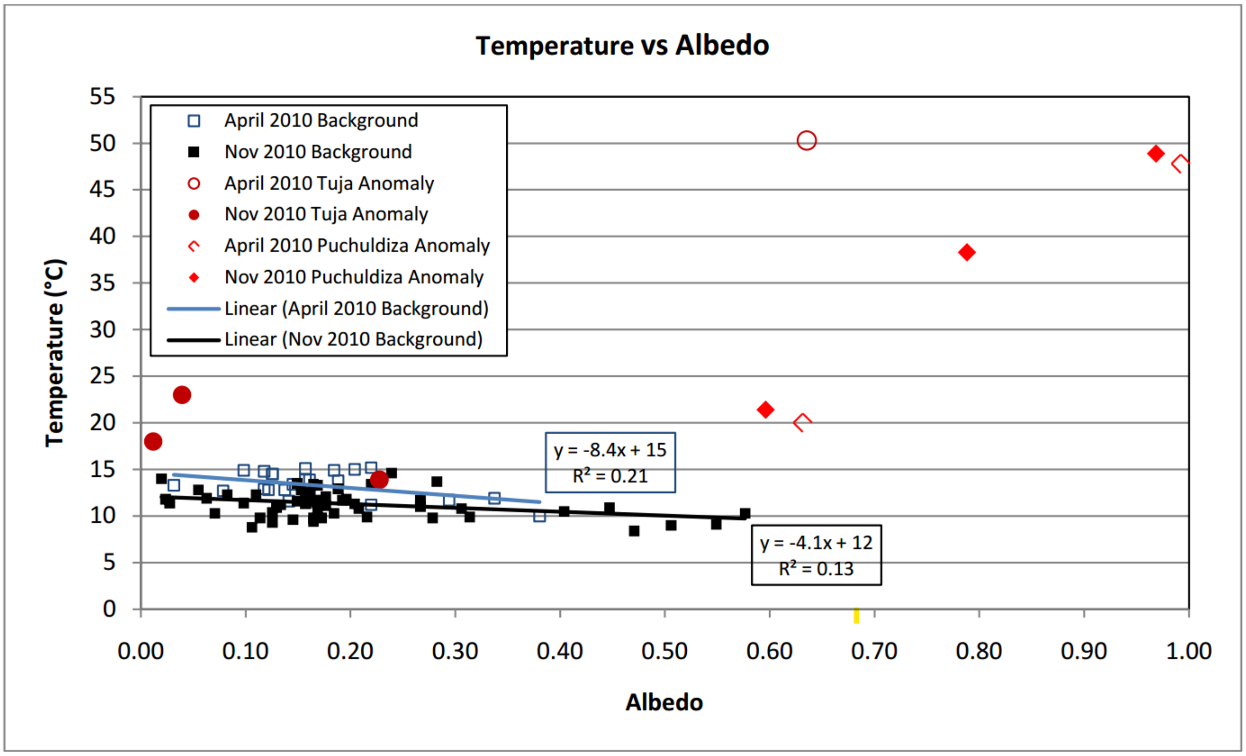

Figure 8. Puchuldiza uncorrected temperature vs albedo. There is a small negative correlation.

6. BPUS Standard Operating Procedures

The following Standard Operating Procedures have been developed by BPUS in concert with Geologica Geothermal Group. These SOPS build on the procedures used in the Puchuldiza surveys and borrow from the procedures of Kraal et al (2024).

6.1. Survey Operation

The essential aspects of 2 m surveying are 1) installing a 2-meter-long hollow rod (probe) into the ground, 2) waiting an appropriate period of time (typically at least two hours) for the probe to equilibrate with the ground temperatures, 4) recording the temperatures at 2 m depth, and 4) pulling the probe for later re-use.

6.2. Survey Design

The survey design consists of 1) at least two 'base stations' (label Base-1, Base-2, etc.) and 2) several dozen or more measurement locations (labelled 1, 2, etc.). It is critical that the field crew has a GPS-capable device (e.g. tablet or handheld GPS) that the survey design has been loaded onto prior to mobilization. This will ensure that data are collected in the correct locations.

6.3. Install Base Stations

On the first day of the survey, the first task is to install base stations. These probes are to remain in place for the entire duration of the survey. Locate each 'Base' location and install a probe.

Record the name of site (e.g., 'Base-1') and the time and date the probe was installed on the attached data sheet.

6.4. Installing Probes

To maximize time efficiency, it is recommended to install many (>10) probes, then return to measure the temperatures at each one and remove each one. The locations in the survey design are numbered (1, 2, 3…etc.), probes should be inserted in the same order as the numerical order of survey design. Locate and travel to location 1, install a probe. Record the name of site (e.g., '1'), the GPS coordinates, (Latitude and Longitude), and the time and date the probe was installed on the attached data sheet. Cap the probe with PVC cap (to keep out dust), and add flagging (so it can be easily found later, not accidental run over). Travel to 2 and repeat.

A typical survey might look like:

Day 1: Install two base stations
Install probes 1-15
Measure temperatures at both base stations
Measure temperatures and remove probes 1-15
Take a photo of data collection sheet and email it to office (if not using digital data input)

Day 2: Measure temperature at both base stations
Install probes 16-30
Measure temperatures and remove probes 16-30
Take a photo of data collection sheet and email it to office

Day 3: Measure temperature at both base stations
Install probes 31-50
Measure temperatures and remove probes 31-50
Measure temperature at both base stations, remove both base station probes
Take a photo of data collection sheet and email it to office

6.5. Making Temperature Measurements

Once many (>10) probes are installed, enough time (at least two hours) is likely to have elapsed, so the temperature of the probe is now in equilibrium with the temperature of the ground. Return to the first probe installed (e.g. 1). Insert the RTD, ensure that the RTD goes all the way to the bottom of the probe. Wait for the temperature readings to 'settle' on a single temperature. Typically, this takes less than 5 min. The RTD should be left at bottom for a minimum of 2 minutes. Record the time the measurement was taken, and the temperatures at 2m on the attached data sheet. Travel to the next probe, repeat.

6.6. Transmitting the Data

At the end of each day's data collection take a photograph of the day's data sheet and the base station data sheet and email it to the office. Depending on the day-to-day results, some adjustments to the survey design may be made. If adjustments are made, a new KMZ file will be emailed to the field crew. On the final day of the survey measure temperatures at the base stations, pull the base station probes and send a photograph of the final day's data sheet and the base station data sheet to the office.

7. Quick Reference Guide for Standard Operating Procedure (SOP) at each survey location

The following Table (**Figure 9**) details the order of events that should occur at each survey location, including base stations.

ALWAYS WEAR PROPER PPE (Minimum: SAFETY GLASSES & WORK GLOVES)
2m probe survey: Probe installation
1) Locate and drive to the planned survey location. a. It is acceptable to deviate by up to 50 feet from the planned location to avoid areas that have obstacles (e.g. fence, debris, culvert, steep drainage channel, animal burrows etc.) b. Do not install a probe if there is standing or running water on the surface, relocate to the nearest dry area. Avoid drainage channels, even dry channels may have ground water just below the surface. 2) Install the probe to 2 meters (6 ft, 3 and 1/3 inches). a. In the event of a failed installation (less than 2 meters), re-locate by several feet and try again. 3) Record the survey point name (e.g., 1) and GPS location (latitude and longitude) in decimal degrees format with 6 digits in the decimal (e.g. 38.828714, -117.579906) even if it is identical to the plan, on the attached data sheet. 4) Save the location in a GPS or tablet as a point. 5) Record the time that the probe was inserted on the attached data sheet. 6) Record any site-specific information (e.g., had to move because of fence) on the attached data sheet. 7) Cap the probe with PVC cap. 8) Mark the probe with flagging or cone so it can be re-located easily and to prevent others from driving over it. 9) Travel to the next location.
2m probe survey: Temperature measurement
1) Relocate to the probe location. 2) Confirm that >2 hrs have passed since the probe was inserted. 3) Remove the PVC cap and insert the RTD. 4) Make sure the RTD goes all the way to the bottom of the probe (2m). 5) Wait at least 2 minutes for the RTD to equilibrate. 6) Record the time of the temperature measurement on the attached data sheet. 7) Record temperatures at 2m on the attached data sheet. 8) Photograph location, include station number (written on small white board or notepad) and meter with screen showing 2m temperature reading. 9) Pull the probe and move to the next station.

Figure 9. SOP Quick Reference Guide.

Conclusion

Shallow temperature surveys have been conducted as part of early stage geothermal exploration since at least the late 1970s. These surveys prioritize low cost and rapid data gathering over a wide field area. Since the mid 2000s the technique has been further developed and data corrections have become more sophisticated. So too has the custom equipment used in these surveys become more sophisticated. The 2 m probe survey methodology developed by the GBCGE, and private companies such as GGE and BPUS can be applied to a large area of the Basin and Range to explore for new geothermal systems, especially blind systems.

Acknowledgement

This work relied heavily on assistance from many people. The Puchuldiza survey was greatly assisted by the work of GGE team members Pedro Muñoz, Jim Stimac, Silke Lohmar, Domingo Maldonado, Sergio Iriarte and Andrea Gonzalez. Data analysis and report preparation benefitted from special contributions by Anna Colvin and Esther Mandeno, and from review by Glenn Melosh, Jim Stimac and David Sussman. The BPUS survey was heavily dependent on Chris Reede from Double R Drilling who designed and built the rig from BPUS specifications, and led the testing and data collection. Geologica staff contributed to the BPUS system design and testing including Peter Drakos, Matthew Folsom, and Leland Davis.

REFERENCES

Coolbaugh, M.F., Sladek, C., and Kratt, C., 2010, Compensation for seasonal and surface affects of shallow (two-meter) temperature measurements, GRC Transactions, v. 34, p. 851-856.

Kraal, K., Lindsey, C., Zimmerman, J., Sladek, C., and Burgess, Q. 2024, Development of shallow (2-m) temperature survey standard operating procedures and interpretation workbook. PROCEEDINGS, 49th Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California, February 12-14, 2024. SGP-TR-227.

Sladek, C., Coolbaugh, M.F., and Kratt, C., 2009, Improvements in shallow (two-meter) temperature measurements and data interpretation, GRC Transactions, v. 33, p. 535-542.