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ABSTRACT

The U.S. Air Force is facing a number of challenges as it moves into the future, one of the biggest being how to provide safe and secure energy to support base operations. A team of scientists and engineers met at Mountain Home Air Force Base near Boise, Idaho, to discuss the possibility of exploring for geothermal resources under the base. The team identified that there was a reasonable potential for geothermal resources based on data from an existing well. In addition, a regional gravity map helped identify several possible locations for drilling a new well. The team identified several possible sources of funding for this well—the most logical being to use U.S. Department of Energy funds to drill the upper half of the well and U.S. Air Force funds to drill the bottom half of the well. The well was designed as a slimhole well in accordance with State of Idaho Department of Water Resources rules and regulations. Drilling operations commenced at the Mountain Home site in July of 2011 and were completed in January of 2012. Temperatures increased gradually, especially below a depth of 2000 ft. Temperatures increased more rapidly below a depth of 5500 ft. The bottom of the well is at 5976 ft, where a temperature of about 140°C was recorded. The well flowed artesian from a depth below 5600 ft, until it was plugged off with drilling mud. Core samples were collected from the well and are being analyzed to help understand permeability at depth. Additional tests using a televiewer system will be run to evaluate orientation and directions at fractures, especially in the production zone. A final report on the well exploitation will be forthcoming later this year. The Air Force will use it to evaluate the geothermal resource potential for future private development options at Mountain Home AFB.

Introduction

The Snake River volcanic province overlies a thermal anomaly that extends deep into the mantle and represents one of the highest heat flow provinces in North America (Blackwell and Richards, 2004). This makes the Snake River Plain (SRP) one of the most under-developed and potentially highest producing geothermal districts in the United States. Elevated heat flow is typically highest along the margins of the topographic SRP and lowest along the axis of the plain, where thermal gradients are suppressed by the Snake River aquifer. Beneath this aquifer, however, thermal gradients rise again and may tap even higher heat flows associated with the intrusion of mafic magmas into the mid-crustal sill complex (e.g., Blackwell, 1989).

Geothermal power has long been used in southern Idaho, but it has been confined almost exclusively to direct use applications such as space heating and aquaculture (e.g., Mitchell et al., 1980; Neely, 1996). There is only one site where geothermal resources are used for power generation, the Raft River Valley site (Peterson et al., 2004; Neely and Galinato, 2007). Nonetheless, the potential for power generation is significant, especially using binary generation systems that can exploit lower temperature resources (Sanyal and Butler, 2005; Neely and Galinato, 2007).

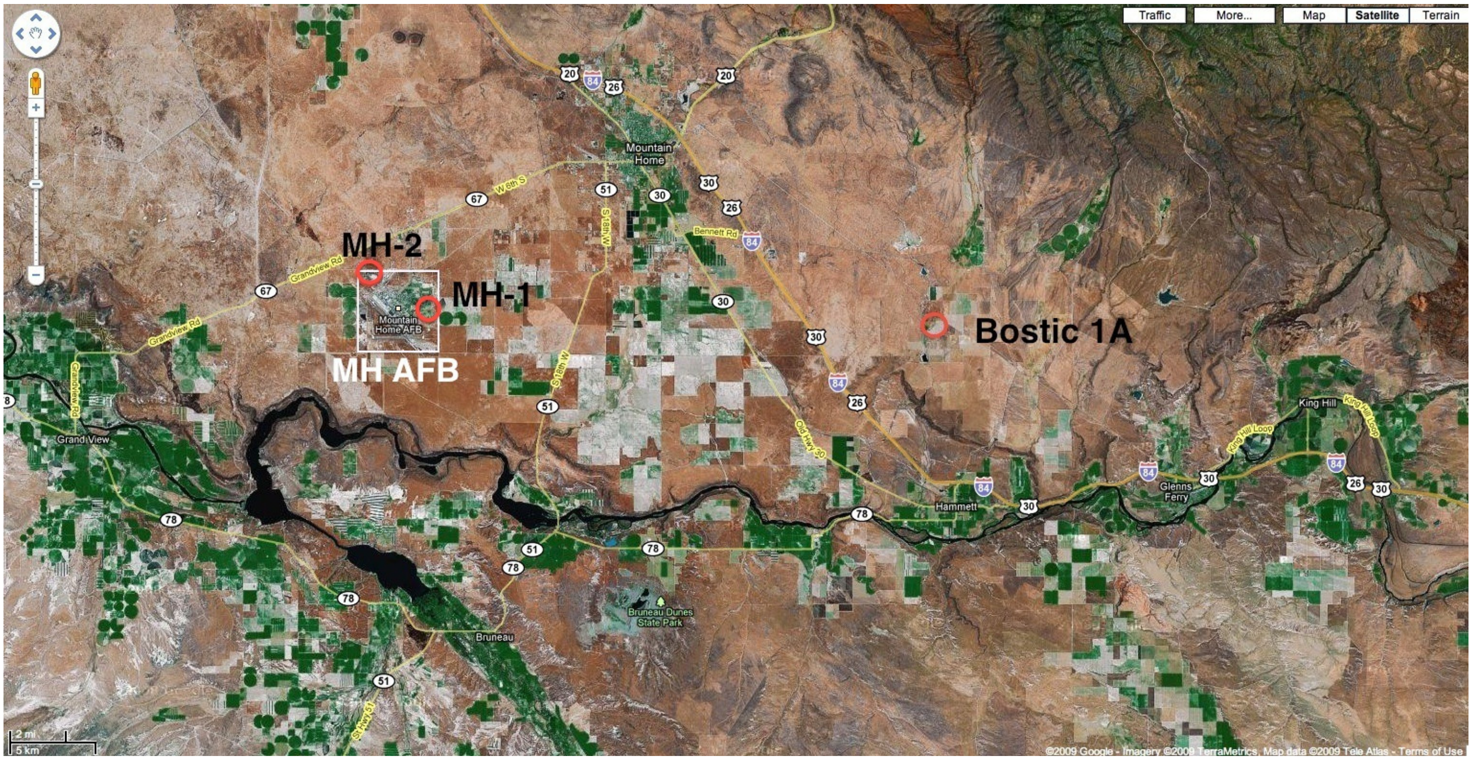

Figure 1. Map showing the location of Mountain Home AFB, Idaho, as well as the 1986 geothermal exploration well MH-1, the new geothermal exploration well MH-2, and the Bostic 1A well. City of Mountain Home lies at the intersection of HW-20, HW-30, HW-51, and HW-67; the Snake River and C.J. Strike Reservoir cross lower half of map.

The geothermal potential of deep drill holes in the western Snake River Plain was first suggested by the Bostic 1A well, a wildcat oil well drilled to a depth of 9676 feet in 1973, and subsequently acquired by Gulf Resources as a geothermal prospect (Arney et al., 1984). This well, located 12 miles southeast of Mountain Home, Idaho (see Figure 1), had a BHT of 175ºC at 2949 m. Union Oil acquired the well a few years later and was the focus of a Hot Dry Rock investigation by researchers from Los Alamos National Laboratory (Arney, 1982; Arney et al., 1982; 1984).

The high geothermal gradient in Bostic 1A (59ºC/km) stimulated an interest in geothermal power potential on Mountain Home AFB. In 1986, a 4404-foot deep test well (MH-1) was drilled at Mountain Home Air Force Base (MHAFB) to test for geothermal resources (Lewis and Stone, 1988). This well documented a temperature of 93ºC at 4000 feet depth (69ºC/km thermal gradient), which was too low for use with existing technology. Advances in geothermal technology since then suggest that temperatures high enough to produce power using binary cycle technology may exist at depths of 5000–6000 feet under the base. The MH-1 geothermal test well was plugged and abandoned shortly after drilling, so it is no longer available for further testing.

Idaho National Laboratory (INL) teamed with Utah State University and the Air Force at Mountain Home to drill a new geothermal gradient test well located on Mountain Home AFB to further investigate fluid flux, temperature gradients, and the potential for geothermal energy development. The goal of this project was to drill a temperature gradient well to a depth of over 5000 feet, with the final actual depth dependent on drilling conditions, rate of progress, and financial constraints. This drill hole was planned as an extension of the shallow test well drilled as part of Hotspot: the Snake River Geothermal Drilling Project, at a site located in the NW corner of Mountain Home AFB. Project Hotspot is an effort that is supported by a U.S. Department of Energy (DOE) contract (DE-EE-0002848) to drill three different wells across the snake river plain to evaluate the potential for geothermal energy resources (Shervais et al., 2011). The well at MHAFB is the third and final well drilled for Project Hotspot. As part of Phase 1 drilling at MHAFB, Project Hotspot produced a 2748 feet deep core hole that extended through the Pliocene lake deposits into basalt. Project Hotspot also produced detailed seismic, magnetic, and gravity profiles across the proposed drill site to aid in interpretation.

Phase 1 drilling by Project Hotspot employed slim-hole diamond core drilling to recover HQ-size core from the upper 2748 feet of the new test well. Phase 1 drilling was funded by the U.S. Department of Energy and the International Continental Drilling Program. This hole was logged to provide a complete record of lithology and physical properties, including fracture distribution, porosity, permeability, and density. Upon completion of Phase 1 drilling by Project Hotspot, the USAF assumed ownership and continued drilling as the Phase 2 Mountain Home Geothermal Drilling Project.

Purpose

Background

The Air Force is on target to generate 1 gigawatt of renewable energy by 2016. Mountain Home AFB is supporting this goal by investing in the collaborative effort to drill a new exploratory geothermal well. Currently, the base's maximum electrical power requirement is 14 megawatts. Idaho Power supplies electricity for the base and has been a reliable proponent and supporter of renewable energy projects throughout the State of Idaho and Mountain Home AFB. Grasmere Radar photovoltaic array site, in continuous operation since 1995, is a prime example of Idaho Power's commitment to renewable energy and continuous service. Elmore County also encourages the base's commitment to attracting new missions and private development. The vast amount of land surrounding the base provides potential for Air Force mission growth and commercial development.

The base is currently evaluating new missions as presented by HQ AF, which are favorable from multiple perspectives, both foreign and domestic. Geothermal power for the base can provide secure baseline power and support goals recently outlined by the Department of Defense Operational Energy Strategy. From a developer's standpoint, a geothermal power plant could provide renewable credits, a revenue stream from excess power, and a long-term, power purchase commitment. At this time, current power requirements will not change and steady growth in support of new missions is anticipated.

Site selection of the MH-2 drill hole was based on several lines of evidence that gave encouragement that a geothermal resource might be located in this area. A prominent regional Bouguer gravity anomaly that extends from the Boise area to the southeast has been shown to represent an uplifted horst block in the subsurface, especially near Boise itself (Wood, 1994). The extension of this same gravity high to the Mountain Home area is shown in Figure 2. The MH-1 drill site was located on the southern edge of the gravity high on the eastern edge of Mountain Home AFB. The MH-2 drill site was chosen in the NW corner of the base, near the contractor's entrance, but still on the southern flank of the prominent gravity high (see Figure 2).

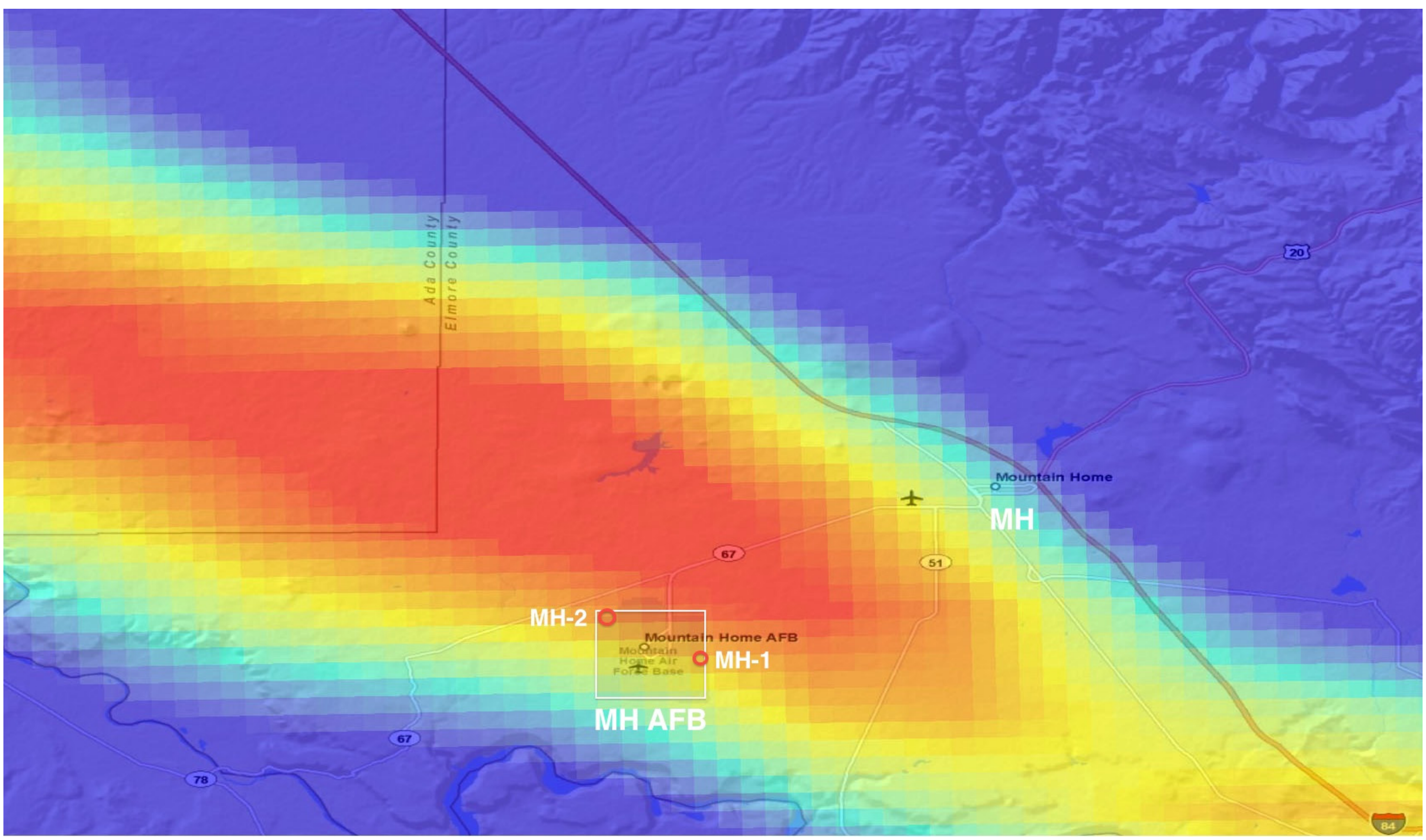

Figure 2. Regional Bouguer gravity anomaly near Mountain Home Air Force Base, Idaho.

Ground water temperature anomalies were also examined as a possible guide to warm water upflow, but the influence of cold waters from the Canyon Creek drainage west of MHAFB distorts water temperature contours and makes them unreliable indicators of deep thermal upflow.

Methods

Design and drilling of the MH-2 Test Hole was in accordance with the rules and regulations of the State of Idaho Department of Water Resources (IDWR). Additionally, well design had to account for the scientific needs of the Project Hotspot Team and the geothermal exploration interest of the U.S. Air Force. Drilling was carried out by DOSECC, Inc. (Drilling, Observation, and Sampling of Earth's Continental Crust). DOSECC used an Atlas-Copco CS4002 diamond-drilling rig. A geologist from Utah State University was also on site at the drill location 24 hours per day while the hole was advancing.

Drilling operations commenced at Mountain Home in July 2011 and were completed in January 2012. The well was constructed as follows: a 15-inch hole was drilled to 40 feet below surface (fbs); 10⅝-inch casing cemented from 0–40 fbs, air rotary drilling of an 8-inch hole from 40 fbs through the sequence of basalts to the top of a thick sequence of lakebed sediments estimated at 530 fbs; 6⅝-inch steel casing installed to 530 fbs and pressure grouted to land surface; coring of the lakebed sediments with 5½-inch PQ-core, which contained the sediment in a plastic tube. At this point, the drill rods became stuck at a depth of 1927 fbs and the hole was abandoned per IDWR requirements. The rig was moved over and drilling resumed again as follows: A 15-inch hole was drilled to 40 fbs; 10⅝-inch casing cemented from 0–40 fbs, air rotary drilling of an 8-inch hole from 40–710 fbs; 6⅝-inch steel casing installed from 0–710 fbs and pressure grouted to land surface; 5½-inch rotary drilling to 2030 fbs, 4½-inch temporary casing set to 2030 fbs, 3.830-inch HQ-core to 3753 feet, 3½-inch temporary casing set to 3753 fbs, 3.032-inch NQ Core to 5976 fbs and set 2⅜-inch casing 0–5976 fbs. The average coring rate was 100 ft per day and the average operating rate (inclusive of operating days) was 55 ft/day.

Temperature data was also collected with the DOSECC core barrel temperature tool at intervals, as discussed by Nielson et al. (2012). This allowed monitoring of temperature during drilling operations to avoid potential blow-out situations, and to assess thermal gradients while drilling. This tool was run to the bottom of the hole once each day (approximately every 100 ft depth) to monitor bottom hole temperatures. When the bottom hole temperature reached 100ºC (212ºF), drilling operations stopped and IDWR was notified. An annular blow-out prevention (BOP) device was installed before drilling resumed. This occurred at a depth of 4477 fbs.

At a depth of 5726 fbs, water began to flow from the well under artesian pressure. The flow was measured at 11 gpm with a temperature of 31.3°C at the surface. Water was allowed to flow for several hours before water samples were collected and sent to various laboratories for analysis.

Core of lake sediment from the upper part of the drill hole was recovered in standard IODP/GLAD butyrate core liners, following protocols established in the past decade for lacustrine drilling projects. Staff from LacCore, the National Lacustrine Core Facility at the University of Minnesota, supervised core handling and curation in the field. Meta-data on the core was entered into a mission-specific LacCore field database. The lake core was then packed into crates and shipped to the LacCore facility in Minneapolis for archiving.

Basalt core from the upper 700 ft and from below 2500 ft was extracted from the core barrel into plastic half-round core troughs where it was washed, dried, measured and described lithologically before transferring to core boxes. Each core box was photographed in the field using a copy stand with scales, grey scales, and color scales, then palletized for transport to the Utah State University Core Processing Laboratory for complete lithologic logging, high-resolution box photographs, and whole core 360º scanning. All logging data were entered into the ICDP Drilling Information System database; this data will be linked to the National Geothermal Database for distribution. Core processing both onsite and at Utah State University was carried by the Hotspot Science Crew.

In January 2012, a complete suite of geophysical well logs was obtained, including total natural gamma, temperature, pressure, and mud resistivity logs (through the drill string—entire hole), and spectral gamma, magnetic susceptibility, sonic, dual laterolog (resistivity), dip, caliper, orientation, and total magnetic field (open hole—from 3825 ft to TD at 5500 ft). The lithologic log is shown in Figure 3.

After logging, the temporary casing was reinstalled and the hole has been kept open for 3-4 months in order for temperatures to equilibrate to the normal thermal gradient. After all logging is complete the hole will be plugged and abandoned in accord with IDWR regulations.

Data

As described earlier, bottom hole temperatures were recorded during drilling using the DOSECC core barrel temperature tool. These temperatures are compared to the temperature log of the MH-1 corehole in Figure 4. As can be seen in this figure, the temperature's bottom hole

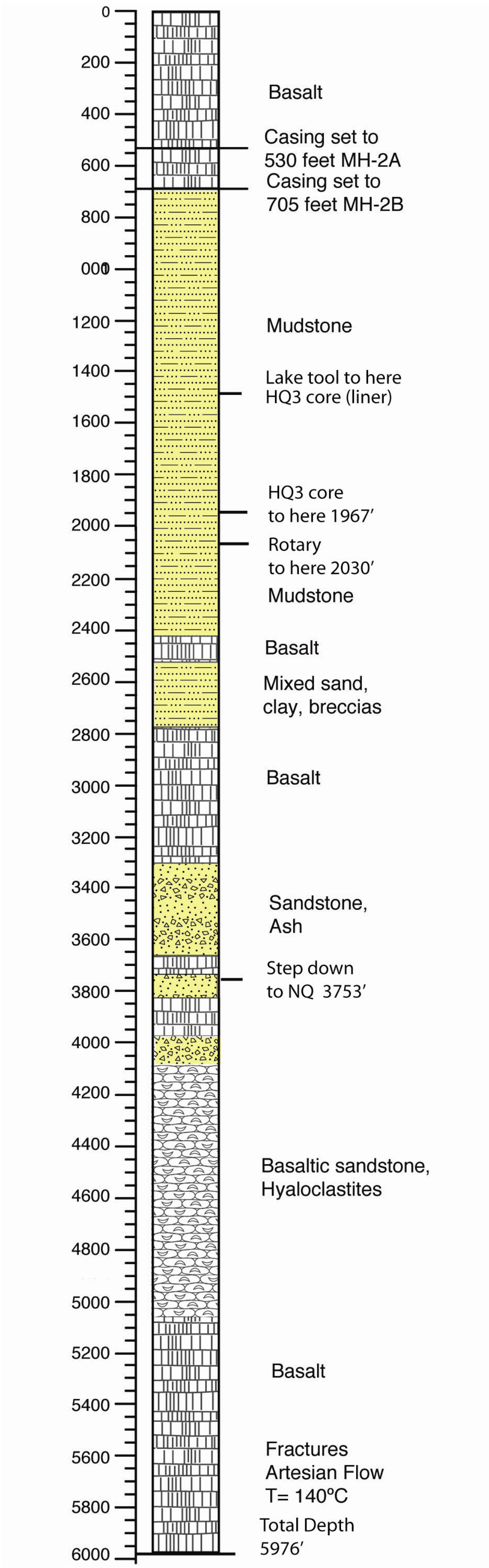

Figure 3. Lithologic log of MH-2 well at Mountain Home Air Force Base, Idaho.

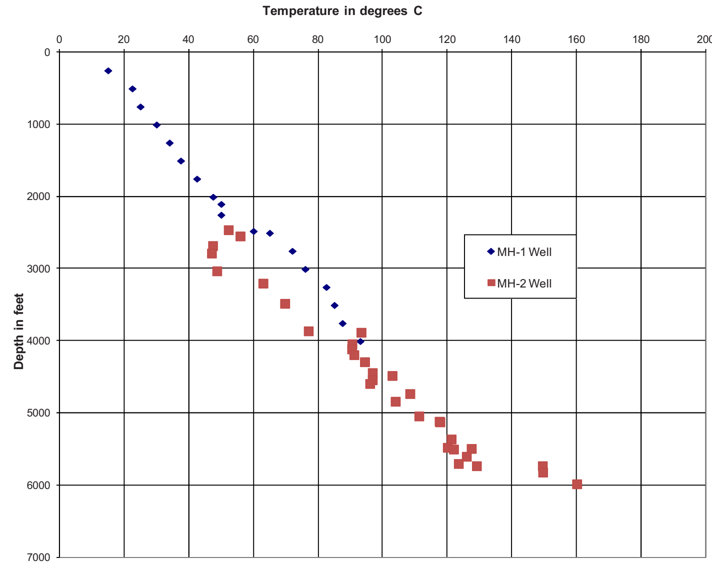

Figure 4. Temperature profile of 1986 Mountain Home AFB Geothermal Test Well (MH-1) as compared to 2011-2012 Geothermal Test Well (MH-2).

measurements of MH-2 decrease slightly below a depth of 2544 fbs, while temperatures in MH-1 increase at the same depth. This may be related to the invasion of cool drilling fluids into the fractured rock at this depth cooling the formation, as described by Nielson et al. (2012). At a depth of about 4000 fbs the MH-1 and MH-2 temperatures are similar. Below 4000 fbs the MH-2 the geothermal gradient is about 30°C/1000 ft (98°C/km). Below a depth of 5726 fbs, the MH-2 temperatures appears to increase rapidly; however, this may be attributed to drift in the electronics of the DOSECC core barrel temperature tool. See Nielson et al. (2012) for a discussion of this problem. The geothermal gradient is promising for further geothermal exploration.

Core processing on site included physical descriptions of mineralogy, including alteration minerals, fracture distribution, and core recovery. By monitoring factors such as alteration, secondary mineralization, fracture distributions, and core recovery during drilling operations, we were able to assess the impact of high geothermal gradients and the likelihood of intersecting a geothermal system. The formation of secondary minerals in particular allows us to assess whether the system has ever seen temperatures high enough to sustain power generation.

The change downsection from clay to chlorite-bearing fracture fills, to calcite-silica filled vesicles/veins, and finally to the onset of quartz and laumontite formation as a fracture-filling minerals, all attested to the increase in temperature with depth to potential geothermal levels. In addition, the decrease in recovery in the lowermost sections of core (from near 100% to ≤ 50% recovering per run) indicated the onset of a fracture-rich environment with minimum aperture sizes of over 2 inches. The mineralogy of the vesicle and fracture-fill assemblage is consistent with high-temperature deposition that has cooled somewhat over time, but is still hot enough for power generation (Nielson et al., 2012).

Water samples were collected and sent to Thermochem, Laboratory & Consulting Services, Santa Rosa, CA. Thermochem performed a geothermal exploration package analysis on the water data. The geochemistry indicates that the water is highly evolved based on the deuterium and oxygen-18 concentrations. The water is sulfate-rich, Cl-poor, suggesting steam-heated volcanic waters; the low pH (~5.6–5.7) is typical of fluids equilibrated with altered basalt (Giggenbach and Gougel, 1989; Giggenbach and Glover, 1992). Equilibrium temperatures calculated from quartz, Na/K, K/Mg, and Na/K/Ca solubilities are ~130ºC to ~154ºC (Fournier, 1981; Fournier and Potter, 1982; Giggenbach, 1988; 1991; 1997). The are essentially the same as current formation temperatures as measured in the well (Lachmar et al., 2012; Nielson et al., 2012), and are in the range of geothermal fluid temperatures at Raft River.

Results

The occurrence of over 2000 feet of fine-grained lake sediments is likely a major factor preserving this geothermal system. The low conductivity of sedimentary rocks acts as an insulating blanket to maintain high temperatures in the reservoir, and the low permeability of the clay-rich lake sediments prevents upward migration of the thermal fluids, and downward migration of cold meteoric water that could degrade the resource. The effectiveness of this sedimentary seal is attested by the artesian flow of geothermal water to the surface from a depth of over one mile below the surface (5726 feet).

The high degree of alteration of the basalt host rock at depth also prevents migration of the geothermal waters, except along fracture systems. The occurrence of open fractures at depth is documented by many examples of open, crystal-lined cavities within the core, while the occurrence of older fractures is documented by mineralized fractures that are now completely sealed by calcite, quartz, and laumontite deposition. Laumontite is a common mineral in many geothermal systems and shows that the system has been at these high temperatures for some time.

Central to evaluation of this resource will be a full assessment of the fracture-dominated permeability. Because the producing geothermal zone was encountered by the NQ-size drill rod, the hole diameter is too small for an effective flow test. As an alternative, we plan to carry out a high-temperature televiewer survey of the open hole after the liner is pulled to image the fracture system, and to calculate the effective permeabilities. Because pulling the liner requires remobilizing the drill rig back to the site, we plan to schedule this survey to coincide with the plug-and-abandon process. Until then, we are keeping the hole open to allow for continued temperature surveys.

Considering that the thermal gradient of MH-1 and MH-2 are similar to a depth of 4000 fbs (see Figure 4) supports the notion that this geothermal system extents over at least the distance separating the two wells, which is 2.9 miles (4.7 Km). The temperatures measured and calculated by geothermometry are within the range necessary for a binary electrical plant. The unknown factor at this point is whether there is sufficient formation permeability and geothermal water to support electrical generation. At depth, fracture density and aperture is the dominant mechanism controlling permeability. Some physical evidence was observed in core that recent faulting may have occurred in this location. The presents of non-mineralized slickensides suggest relatively recent offset. Additional drilling is warranted to further evaluate the water yield and physical dimensions of the geothermal resource.

Summary

A 5976-foot deep corehole was drilled in the northwest corner of the Mountain Home Air Force Base in southeast Idaho. Beneath a 700 ft thick layer of basalt an approximately 1800 ft thick sequence of lake sediments were encountered. Beneath the lacustrine sediments was a sequence of basalts with minor sedimentary layers. Artesian flowing water was encountered at a depth of 5726 feet. The maximum downhole temperature is estimated to be approximately 140° C. This temperature is corroborated by geothermometry calculations of equilibrium temperatures. The extent of the geothermal resource is estimated to be at least three miles in horizontal extent. A final report on the collaborative drilling project will be available near the end of CY–2012 and identify potential for development of a geothermal resource at MHAFB.

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