

NOTICE CONCERNING COPYRIGHT RESTRICTIONS

This document may contain copyrighted materials. These materials have been made available for use in research, teaching, and private study, but may not be used for any commercial purpose. Users may not otherwise copy, reproduce, retransmit, distribute, publish, commercially exploit or otherwise transfer any material.

The copyright law of the United States (Title 17, United States Code) governs the making of photocopies or other reproductions of copyrighted material.

Under certain conditions specified in the law, libraries and archives are authorized to furnish a photocopy or other reproduction. One of these specific conditions is that the photocopy or reproduction is not to be "used for any purpose other than private study, scholarship, or research." If a user makes a request for, or later uses, a photocopy or reproduction for purposes in excess of "fair use," that user may be liable for copyright infringement.

This institution reserves the right to refuse to accept a copying order if, in its judgment, fulfillment of the order would involve violation of copyright law.

United States Department of the Navy Geothermal Exploration Leading to Shallow and Intermediate/Deep Drilling at Hawthorne Ammunition Depot, Hawthorne, NV

Michael Lazaro¹, Chris Page¹, Andy Tiedeman¹, Andrew Sabin¹, Steve Bjornstad¹,
Steve Alm¹, David Meade¹, Jeff Shoffner¹, Kevin Mitchell², Bob Crowder²,
Great Basin Center for Geothermal Energy³, and Greg Halsey⁴

¹ U.S. Navy Geothermal Program Office, China Lake, CA

² Southwest Geophysical, LLC

³ Great Basin Center for Geothermal Energy, University of Nevada, Reno, NV

⁴ Epsilon Support Systems, Inc.

Keywords

Geothermal exploration, Hawthorne Ammunition Depot (HAD), geothermal drilling, Nevada

ABSTRACT

Results of geological, geochemical, and geophysical studies performed by personnel from the Geothermal Program Office (GPO) strongly suggested that there is a geothermal resource beneath lands controlled by the Hawthorne Ammunition Depot. The geothermal fluid is thought to be convecting meteoric water that is derived from precipitation within the Wassuk Range and other nearby mountains. These waters percolate downward through open fractures in the mountain ranges to depths in excess of 7,000 feet. The fluids are then heated deep in the subsurface by the natural geothermal gradient of the area and flow back toward the surface using the Wassuk range-front and associated faults within the bedrock and the sedimentary cover in the southern Walker Lake Valley.

Two test holes were sited in 2008 and drilling was completed in March 2009 to depths of 4,000 (HAD -3) feet and 4,700 (HAD-2A) feet. While data from the holes are still being gathered and analyzed, preliminary results confirm the existence of a moderated temperature anomaly in excess of 217 °F at 1000 feet and 240°F at less than 2500 feet.

In addition to drilling, the Navy GPO has contracted the University of Nevada Reno Great Basin Center for Geothermal Research to conduct additional field exploration at HAD. The tasks required by the Navy range from field mapping and water sampling; detailed mapping, to low angle sun photo interpretations, trenching, to 3-D seismic interpretations and modeling.

The Navy recently completed a temperature gradient hole (TGH) drilling campaign. Results suggest multiple resources may exist on HAD lands. To further define the shallow resource, the Navy will drill one or two intermediate to deep geophysical test holes. The results of these shallow holes, synthesized with complimentary geophysical and geological data, will be used to

locate and drill one or two intermediate/deep geophysical test holes in late July or early August.

Introduction

Energy costs and availability fluctuations continue to impact the ability of military facilities to carry out their missions. The development of alternate energy resources on military lands can be a valuable component to reducing energy dependence and controlling energy costs for some facilities. One such facility is Hawthorne Ammunition Depot (HAD), located adjacent to the town of Hawthorne in western-central Nevada approximately 100 miles southeast of Reno, Nevada (Figure 1).

HAD is located in western Nevada within the Walker Lane tectonic belt – the ground between the stable North American continent and the Sierra Nevada micro plate which is roughly a 60-mile wide, north to northwest-trending region. Within this belt, northwest striking right-lateral (dextral) strike-slip faults can be traced northward from the San Andreas fault in Southern California through the central Mojave Desert and up along the eastern side of the Sierra Nevada range. A large number of geothermal energy prospects as well as some successful developments occur within this belt. Indications of the presence of a geothermal resource beneath HAD have been noted since the 1970s in the form of warm to hot water wells.

Several investigators have studied the geothermal resources in the Hawthorne region since that time including Bohm and Jacobson (1977), Robinson and Pugsley (1981) and Trexler et al., (1981). Bohm and Jacobson (1977) speculated that groundwater has “deep reaching circulation [with] considerably higher temperature, possibly above 212°F.” Robinson and Pugsley (1981) suggested that hot water may flow east from faults along the east slope of the Wassuk Range.

To complement these early exploration studies, Trexler et al., (1981) drilled two temperature gradient holes at HAD: HHT-1 and HHT-2 (Figure 1). These holes were drilled after the completion of numerous geochemical and geophysical surveys. Reported temperatures ranged from 93°F to 210°F at depths of 800' and

395', respectively. "Temperature profiles from these wells indicate relatively thick (~200') zones of hot fluids surrounded above and below by cool fluids," (Trexler, et al, 1981). Trexler speculates that fluids sampled from the hot (210°F) El Capitan well, located nearly one mile west-southwest of the town of Hawthorne, may represent a geothermal parent fluid.

The geothermal fluid is thought to be convecting meteoric water derived from precipitation within the Wassuk Range and other nearby mountains. The fluids are then heated deep in the subsurface by the natural geothermal gradient of the area and flow back toward the surface using the Wassuk range-front and associated faults within the bedrock and the sedimentary cover in the southern Walker Lake Valley.

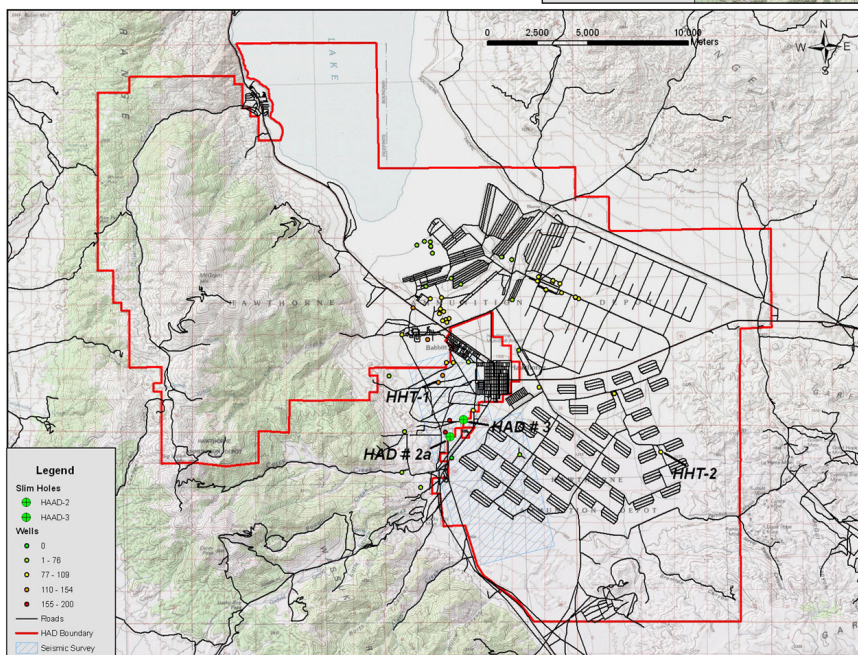


Figure 1. Map illustrating the boundary of HAD, locations of Temperature Gradient Holes (HHT-1 and HHT-2), known wells and corresponding temperatures, the area delineating the 3-D Seismic Survey, and the two slim holes drilled in '08-'09 (HAD-2A and HAD-3).

Results of recent geological, geochemical, and geophysical studies, including exploration drilling undertaken by the GPO, strongly suggest that there is a low- to moderate-temperature geothermal resource beneath HAD lands.

Previous Exploration Activities

Prior to GPO exploration at HAD, previous potential fields surveys dating back to the late 60s (aeromagnetic) through the early 80s (incomplete gravity) were the only geophysical data available to the GPO. Since then the GPO has conducted a number of geophysical and geological surveys at HAD where the culmination of this work led to exploratory drilling of two, slim holes in '08-'09.

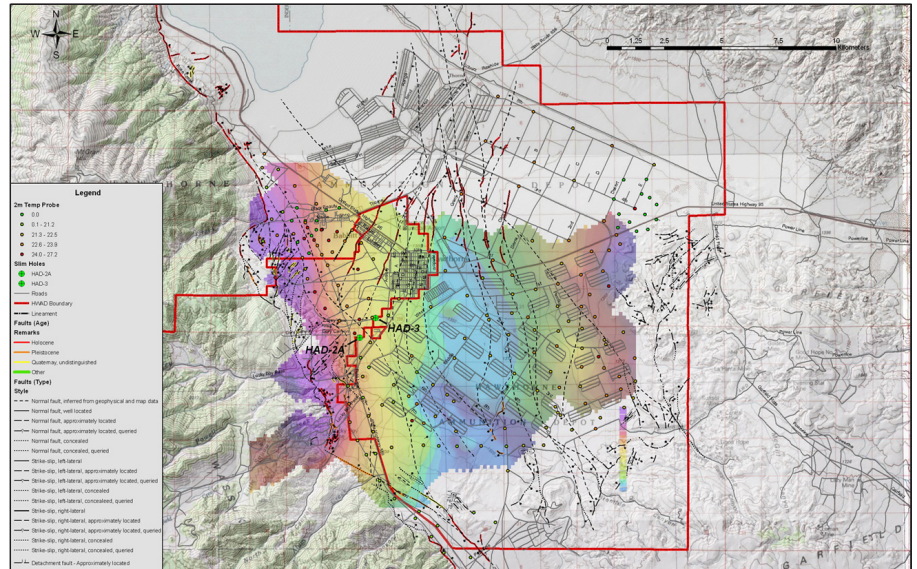


Figure 2. Map illustrating work undertaken by GPO; 2m probe locations and temperatures (°C), mapped faults, and Bouguer Gravity interpretation.

Magnetic surveys, both airborne (aeromagnetic) and ground based, delineate variations in the magnetic minerals of crustal rocks after the effects of the Earth's main magnetic field have been removed. Collectively magnetism and gravity data sets can be interpreted and integrated to provide an inexpensive overview of the structural setting and basement contours.

In the HAD area, the primary objective of our potential fields survey was to provide information on local and regional structural trends. A Complete Bouguer Gravity map of the HAD survey area is presented in Figure 2. These gravity data are displayed as colored levels contoured on an interval of 1 milligal (mgal; 1 mgal = 1×10^{-5} m/sec²). The Complete Bouguer Gravity map indicates that the gravity in the center of the southern Walker Lake Valley is characterized by a broad gravity low of less than -205 mgals. On the eastern and western flanks of the valley, gravity values increase to greater than -190 mgals. This increase in gravity indicates that the volcanic rocks cropping out in the Garfield Hills and granite of the Wassuk Range are denser than the unconsolidated sediments found in the valley. Additionally the gravity suggests a structural trend of the valley basement which may relate to active, potentially fluid-bearing structures.

The GPO conducted a 3-D seismic reflection survey in 2005 to try to image subsurface fault patterns in a volume beneath a 10 square mile area extending from Well HHT-1 to east of the Lucky Boy Mine (Figure 1). It was hoped that a better understand of fault geometries in and around a suspected geothermal upwelling zone near the El Capitan and Maples wells would be generated. The seismic data were re-interpreted by UNR-GBCGE staff in 2009 to characterize geothermal faults and reservoir properties.

Finally, surface mapping, along with 2m temperature probe surveys (see Figure 2), conducted by UNR-GBCGE and GPO personnel, are just a few examples of the work undertaken by the Navy to further understand the subsurface structure and the potential avenues for fluid flow within the surrounding mountain ranges.

2008/2009 Drilling Results

The GPO at China Lake, California contracted work to Thermasource Geothermal Consulting and Drilling, to drill two deep slim holes for the purpose to explore the potential geothermal resource at HAD. The two slim holes drilled were HAD-2a and HAD-3 (Figure 1). Drilling operations took place from October 2008 to March 2009.

HAD #3

The first slim hole drilled was HAD #3, with crew and all necessary equipment arriving on site October 28, 2008, to completion on December 13, 2008. The total depth (TD) reached was 4016' but a 2.375" temperature tubing was only set to 3854' on top of the fill. Bottom hole temperature during downhole logging reached 192°F at 3838'.

HAD-2A

HAD-2A reached a bottom hole equilibrated temperature of 236°F. This hole is highly fractured and contains many shallow/intermediate fluid loss zones (Figure 3). Throughout the drilling campaign, MRT readings ranged from 220°F -244°F; similar temperatures were substantiated during post-drilling geophysical logging where temperatures at 1000' reached 217°F, and 236°F at 2500', respectively.

Lazaro, Page, Tiedeman, Sabin, Bjronstad, Alm, Meade, Shoffner, Mitchell, Crowder, UNR-GBCGE, Halsey

HAD-2A Rig Test

A rig test was conducted on March 31, 2009. The downhole pressure response during the flow test displays a 20-psi pressure drawdown in response to the startup of the downhole submersible pump. Over time, the pressure slowly increased due to the liquid column in the well becoming hotter and less dense. With the main production zone at 4,460' (inferred from TPS surveys run during the injection test conducted the following day), there was nearly 3,500' separating the main reservoir from the point of downhole pressure measurement (that is, the bottom of the bubbler tube above the pump). With this large of a separation, a small decrease in density resulting from a modest temperature increase would account for the gradual rise in the pressure at the bottom of the bubbler tube during pumped flow. After two hours of flow, both the downhole pressure and surface fluid temperatures stabilized.

The rig test conducted illustrated high permeability and transmissivity at relatively shallow depths. While the high productivity of well HWAAD-2A makes it difficult to calculate formation

properties precisely, the fact that the productivity was so high is a very encouraging result. At PIs near 10 gpm/psi, the production rate for most low- to moderate-temperature geothermal wells is limited by the flow capacity of the pump. To determine the production capacity of a full diameter well with productivity of the type demonstrated by HWAAD-2A, information on long-term pressure drawdown in the reservoir from a longer-term flow test or interference test would be needed (Geothermex Report 2009).

3.B Drilling Summary

Two holes drilled less than 1 mile apart have distinct temperature differences. HAD # 3 reached a maximum temperature of 181°F @ 4016', while HAD-2A reached a bottom hole equilibrated temperature of 236°F (see Figure 4). Throughout the drilling campaign, MRT readings ranged from 220°F -244°F; similar temperatures were substantiated during post-drilling geophysical logging where temperatures at 1000' reached 217°F, and 236°F at 2500', respectively.

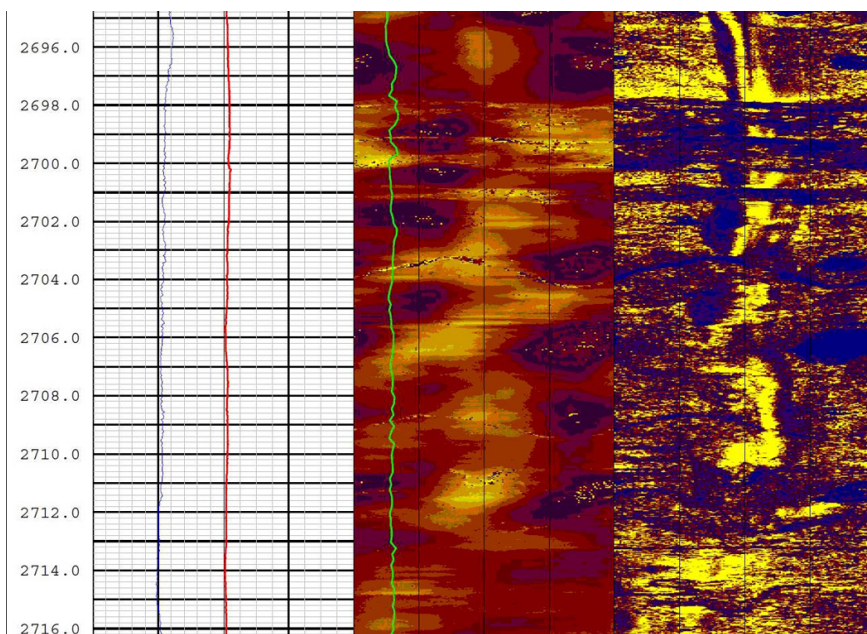


Figure 3. Acoustic Televiwer Image of HAD-2A illustrating fractures at various depths. Courtesy of Southwest Geophysical.

Conclusion and Ongoing Efforts

Recent elevated temperatures encountered during shallow drilling on the East Flank of Hawthorne indicate potential multiple geothermal prospects may exist. Currently, the Navy has drilled thirteen -500' Temperature Gradient Holes (TGH) on Lazaro, Page, Tiedeman, Sabin, Bjronstad, Alm, Meade, Shoffner, Mitchell, Crowder, UNR-GBCGE, Halsey

Hawthorne Ammunition Depot (Figure 5). Preliminary results of the shallow drilling have encountered temperatures in excess of 180°F at depths less than 200' in proximity to the eastern boundary of HAD (Figure 6a). Additional TGH's drilled to west of the Excelsior Mountains, and to the west of the current operations, at the southeastern base of Mount Grant have encountered temperatures in excess of 150°F at depths less than 500'

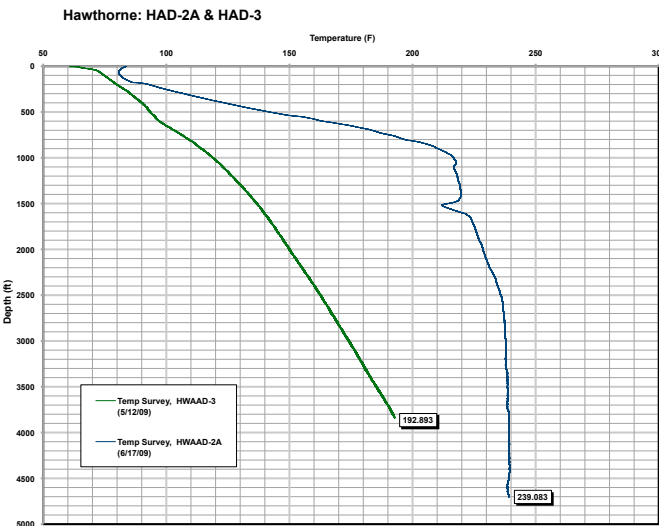


Figure 4. Equilibrated temperature logs of deep-slim holes: HAD-2A and HAD-3.

(Figure 6b). A shallow anomaly exists on the east flank of HAD just west of the eastern boundary on the north side of Route 95. TGH-14a (182.6°F) and TGH-12 (185.6 °F) are the hottest of the 13 shallow holes drilled to date.

Intermediate/deep drilling targets will be selected, based off of the equilibrated shallow temperature gradient drilling results. The intermediate/deep drilling will begin in late July or early August; some results from the shallow drilling will be included in this final report, with complete results of the intermediate/deep drilling being presented at GRC in October.

Pursuant to the recently signed MOA with the Army, the Navy GPO will continue to provide technical oversight regarding

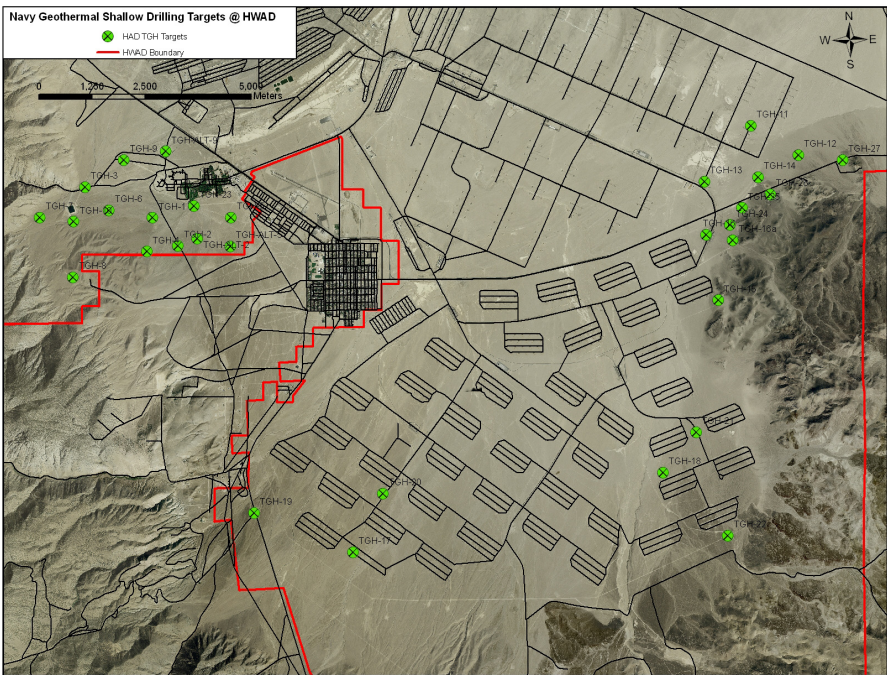


Figure 5. Locations of shallow temperature gradient holes drilled at HAD.

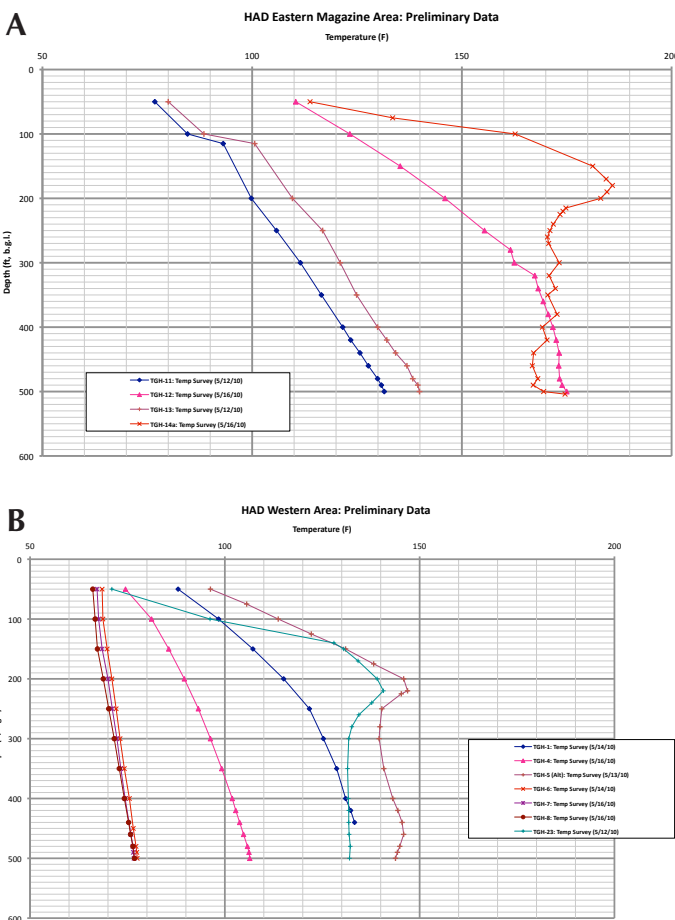


Figure 6a. Eastern HAD 500' Temperature Hole Temperatures as of 6/4/2010.
Figure 6b. Western HAD 500' Temperature Hole Temperatures as of 6/4/2010.

resource development and management of geothermal and geothermal-hybrid resource production at HAD.

References

Bohm, B.W., and R.L. Jacobson, 1977, *Preliminary Investigation of the Geothermal Resources near Hawthorne, Nevada*, Desert Research Institute, Project Report #50.

Geothermex Report, March 2009. Rig Test of Hawthorne Well HAD – 2A.

Robinson, Steve and Maggie Pugsley, 1981, *Geothermal Resource Area 8: Mineral and Esmeralda Counties Area Development Plan*, Nevada Department of Energy Contract # DE-Fco3-80RA50075

Trexler, D.T., et al, 1981, *Low-to-Moderate Temperature Geothermal Resource Assessment For Nevada, Area Specific Studies*, Nevada Bureau of Mines and Geology, UNR, Reno, NV, DOE/NV/10039-3, prepared for U.S. Department of Energy.