Geophysical Delineation of the Crater Bench, Utah, Geothermal System

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Keywords

Geothermal, exploration, geophysics, gravity, magnetotellurics, Crater Bench, Abraham Hot Springs, Baker Hot Springs, Crater Hot Springs, Fumarole Butte
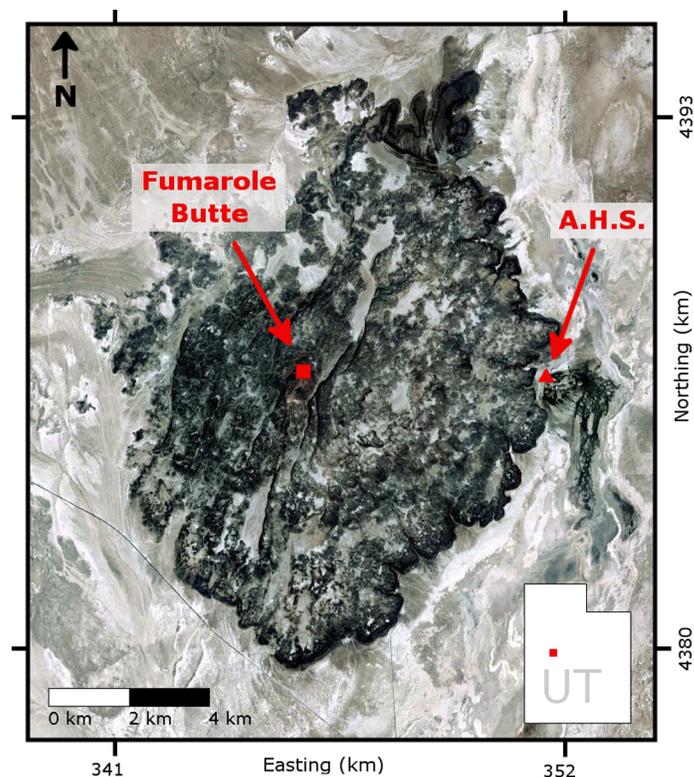
ABSTRACT

Crater Bench, the site of Utah's most active thermal spring system is situated in west-central Utah within the Basin and Range province of western North America. With flow estimates of 5400 and 8400 lpm and temperatures of up to 87 °C, minimum thermal output is estimated at 20 MW. However, the geothermal system is poorly understood with little constraint on subsurface extent and capacity. We report on geophysical surveys leading to a drilling program aimed at correcting these deficiencies. Previous work done in the area of Crater Bench includes aeromagnetic, dipole-dipole resistivity and limited gravity surveys. In the summer of 2010, we added 50 magnetotelluric (MT) stations and 88 new gravity stations. 2D MT modeling shows a lens-shaped conductor 300 to 500 m thick overlying an area of low resistivity (10 to 60 ohm·m) directly below the Crater Bench basalt flows as well as depth-to-basement estimates of 1.3 to 3.6 km. The complete Bouguer anomaly map indicates a 20 km by 10 km mass excess centered at Abraham Hot Springs (AHS) on the eastern margin of Crater Bench. Results of 2D gravity modeling provide depth-to-basement estimates of 1.5 km (above the gravity high) to 3.4 km (adjacent gravity-low areas). Modeling results of MT and gravity data correlate well and the prevalent deep structure is interpreted as a horst block, that may facilitate an upflow zone for the hot springs. A volcanic heat source is not indicated by MT modeling though it may still be a minor component in a deep-circulation geothermal system. Our predictions will be tested by drilling at the site in the summer of 2011. Geophysical surveys are an effective, practical and non-invasive approach to delineating subsurface controls and characterizing geothermal systems.

Introduction

Abraham Hot Springs (aka Baker or Crater Hot Springs) is located at the eastern margin of the Pleistocene age (0.9 Ma)

Crater Bench basalt flows which overlay lacustrine and fluvial sediments of the Sevier Desert, 28 km northwest of Delta, Utah (Figure 1). Temperatures reach as high as 87°C and flow rates have been estimated at between 5400 and 8400 lpm (Rush, 1983). In regards to the summit of Fumarole Butte, the remnant volcanic vent, Gilbert (1890) noted that "about the outer edge of the summit there are 30 or 40 crevices from which warm, moist air gently flows," which "testifies to a residuum of volcanic heat in the old flue." Fluid analysis by Rush (1983) suggests that the hot spring water may be 50% mixed with non-thermal water and the hot water component could be 140 °C. The geological structure
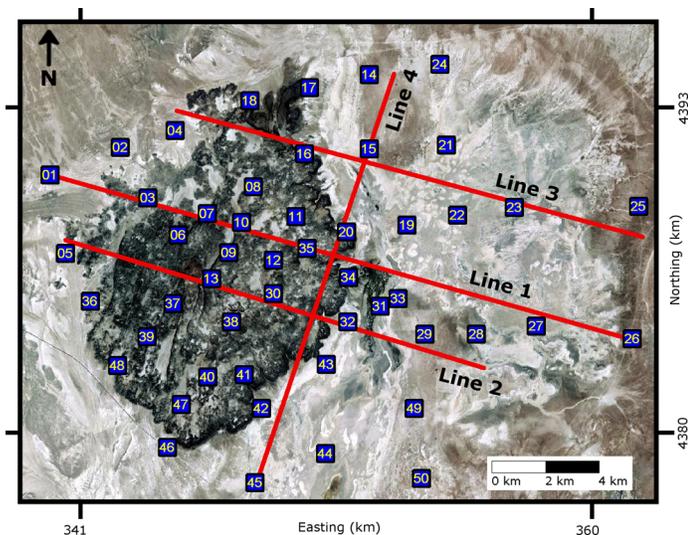

Figure 1. Crater Bench study area northwest of Delta, Utah. The extent of the basalt flow is readily visible. The volcanic vent (Fumarole Butte) and Abraham Hot Springs (A.H.S.) are shown.

controlling the hydrothermal system is unknown and the reservoir temperature is uncertain (Blackett, 2007). It has been hypothesized by Mundroff (1970) that water may have been heated by a high geothermal gradient or by contact with a cooling volcanic body and that conduits in the volcanic flow or concealed faults in the vicinity of the springs may furnish the avenues for deep circulation and emergence of water. We attempt to resolve some of these uncertainties in this study, primarily those attributed to structure.
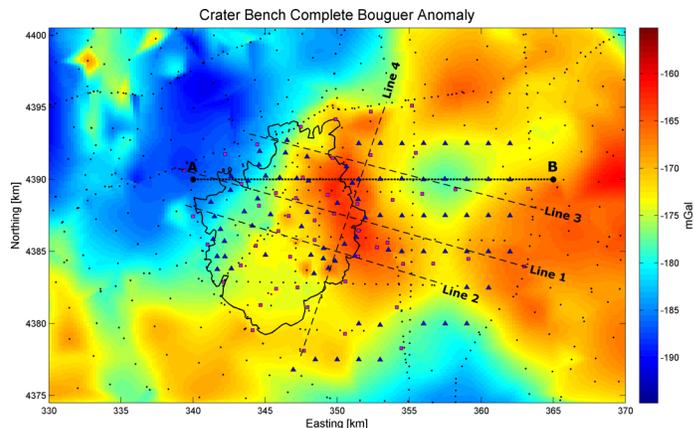
Methods

A total of 50 magnetotelluric (MT) soundings spread over an area of approximately 200 km^2, with an average station spacing of 2 to 3 km (Figure 2), were completed by Quantec Geoscience during the summer of 2010. Data quality is very good except for a few spurious points that were removed prior to the inversions. The MT modeling used 2D inversion codes (Wannamaker et al, 1987) that utilize the TM mode with tipper (a measure of the tipping of the magnetic field out of the horizontal plane). Since we observe 2D behavior in the data up to periods of 10 seconds followed by 3D behavior in the long-period data, we exclude the latter. The 2D domain is 129 x 49 nodes with a minimum discretization of 200 m in a multi-resolution grid. Azimuths of the MT inversion lines were determined by careful examination of polar diagrams which indicate the strike of the main geological structures in the study area. Three inversion lines are oriented at an azimuth of 110° intersected by a fourth at 20° shown in Figure 2.
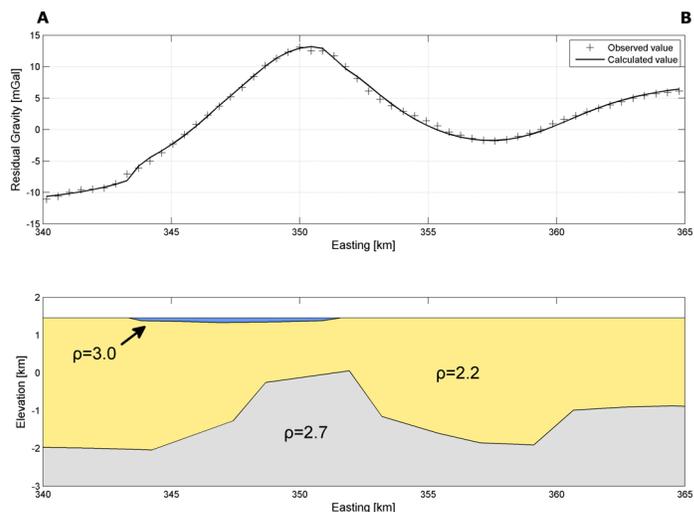

Figure 2. Crater Bench magnetotelluric station locations and inversion line positions. MT stations are blue squares labeled with station number and red lines are the 2D inversion model lines.

A total of 88 gravity stations were measured using a Scintrex CG-5 gravimeter in order to achieve better coverage adjacent to MT areas (Figure 3). Elevation control of better than 0.3m was achieved through post-processing of data collected by Trimble GeoXT GPS instrumentation which allows for gravity accuracy of better than 0.1 mGal. The complete Bouguer gravity anomaly was computed using a reduction density of 2.67 g/cm^3. A simple 2D gravity model of transect AB (Figure 4) was accomplished

Figure 3. Crater Bench, Utah complete Bouguer gravity anomaly map. Transect AB and MT inversion lines indicated. Solid black trace outlines the surface extent of the Crater Bench basalt flows. New gravity stations marked by blue triangle, old gravity stations marked by black circles and MT sites marked by magenta squares.
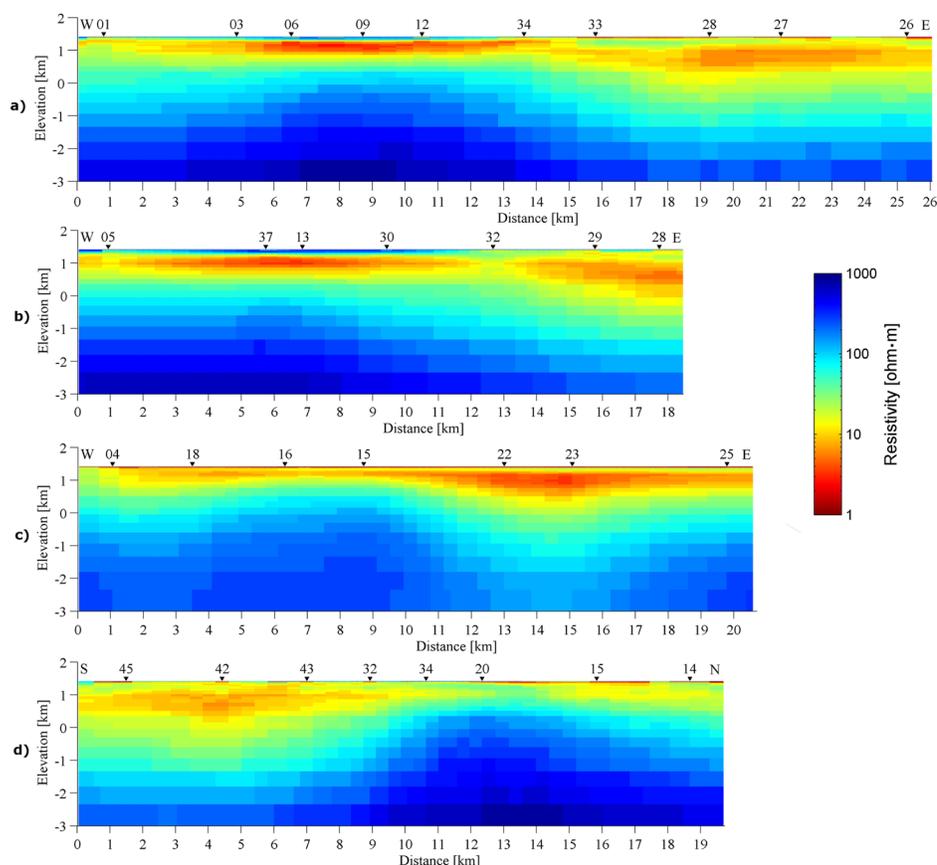

Figure 4. Crater Bench, Utah gravity profile and model of transect AB from Figure 3. The blue, yellow and gray colored bodies are the Crater Bench basalt flows, sedimentary fill and basement rock respectively. Body densities are given in units of g/cm^3.
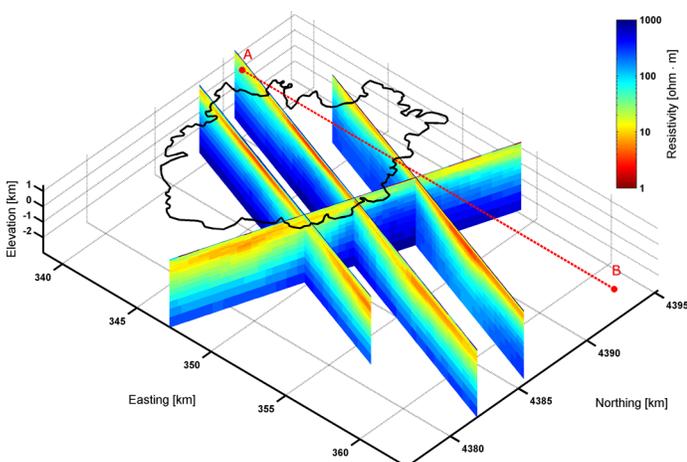
using the Semi-Automated Marquardt Inversion code (SAKI) (Webring, 1985) employing a starting model based on a 2D MT inversion line of a similar azimuth and location. Three bodies were used in the model to represent the basalt flows, sediment fill and basement rock. Their respective densities of 3.0, 2.2 and 2.7 g/cm^3 were held constant and based on average values for the appropriate lithology from regional geology reports and logs of nearby deep wells (Hintze, 2003). Since the actual thickness of the Crater Bench basalt flows is unknown, the modeled thickness is constrained between 60 to 100 m which is consistent with topographic relief at the surface.

Results

The MT inversion lines with a west to east strike display a high resistivity structure (> 100 ohm·m) rising gently from the west and dipping steeply to the east (Figures 5a, 5b and 5c). Intermediate

Figure 5. Crater Bench, Utah magnetotelluric 2D inversion line 1 (a), 2 (b), 3 (c), and 4(d) from Figure 2. Projections of MT stations used in each inversion are indicated by labeled triangles for each section.

Figure 6. Crater Bench, Utah magnetotelluric 2D inversion models represented in 3D space. Solid black trace outlines the surface extent of the Crater Bench basalt flows and dashed red line indicates gravity transect AB.

resistivity bodies of 10 to 100 ohm·m lay immediately above this deep structure and are covered by localized low-resistivity bodies of 5 to 10 ohm·m in certain areas. Very low resistivity lenticular bodies between 300 and 500 m thick are observed at the western ends of lines 1 and 2 covered by a thin, high-resistivity body near the surface (Figures 5a and 5b). MT inversion lines are pre-

sented in a 3-dimensional space in Figure 6 to lend assistance in visualizing the overall resistivity structure of the study area. The normalized RMS values of the 2D inversion models are between 0.7 and 1.0 which is quite good for real-world data.

The complete Bouguer gravity anomaly in Figure 3, shows a peculiar gravity high (mass excess) centered below AHS spanning 20 km north-south and 10 km east-west. A gravity low (mass deficiency) is present just east of the gravity high. The 2D gravity model of transect AB (Figure 4) displays a deep structure consisting of basement rock originating at the western end and gently climbing in the eastward direction until reaching a maximum elevation roughly co-incident with the location of AHS and the edge of the Crater Bench basalt flows. The continuing eastward basement body then dips steeply into a small basin. A small amplitude, higher spacial-frequency gravity signal is observed imprinted on the lower-frequency signal at 343 and 350 km eastings.

Discussion

The high-resistivity structure in the MT models is interpreted as basement rock (marbleized Cambrian limestone and dolomite) yielding depth-to-basement estimates ranging from 1.3 to 3.6 km. Intermediate-resistivity bodies are interpreted as sedimentary rocks and fill and low resistivity bodies are interpreted as clay-rich sediments. The thin high resistivity body at the surface is within unweathered-basalt resistivity values (> 1000 ohm·m) suggested by Palacky (1988) which correlates well with the observed surface geology. The underlying conductors may be clays generated by hydrothermal alteration, hot fluids, brines or a combination thereof. The region with resistivity values of 10 to 60 ohm·m may be the signature of a reservoir, making it an attractive geothermal target (Johnston et al., 1992).

The dominant structure in the 2D gravity model (Figure 4) is the basement. The shape of the modeled basement high bears great resemblance to an uplifted horst block. The high-frequency signal imprinted on the low-frequency signal at 343 and 350 km easting is interpreted as an effect of the Crater Bench edges. Depth-to-basement estimates based on this model range from 1.5 to 3.4 km and are quite similar to 2D MT model estimates of 1.3 to 3.6 km. Due to uncertainty inherent in gravity modeling, the basement depth may be less than what is indicated in the 2D gravity model. Fine tuning of model densities will improve the approximation, although deep geometry should not change drastically in this case since MT models are used as a guide.

Conclusions

Modeling of the deep structure interpreted as basement has good agreement between both the MT and gravity data sets for

the Crater Bench study area. A geothermal system with a major volcanic heat component does not appear to be represented by the MT modeling though it may still be a minor factor. The possibility that the horst block is a conduit for the flow of fluids from a much deeper, basin-centered geothermal system such as those suggested by Allis et al., (2011) should be explored further. Planned drill sites in the immediate vicinity of Crater Bench will provide detailed information on lithology and geothermal gradients. This will allow us not only to test our hypotheses, but also provide better constraints on future geophysical data modeling in this study area and other geothermal systems of a similar geologic setting.

Acknowledgements

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