Geothermal Resources in the Black Rock Desert, Utah: MT and Gravity Surveys

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Keywords

Geothermal, exploration, geophysics, gravity, magnetotellurics, Pavant Butte, Sevier Desert, Black Rock Desert, Sevier Thermal Anomaly, heat flow

ABSTRACT

Recent geothermal studies on sedimentary basins in Western Utah suggest the possibility of significant geothermal reservoirs at depths of 3 to 5 km. Pavant Butte, a volcanic vent in the Black Rock Desert of Utah, is centered in such a basin. Previous geophysical work in the Pavant Butte area includes aeromagnetic, dipole-dipole resistivity and limited gravity surveys. Since 2010, we have added 73 magnetotelluric (MT) stations and 168 new gravity stations. Two-dimensional MT modeling shows a deep, broad corridor of low resistivities (< 10 ohm·m) 10 to 16 km wide at the base and centered in the basin. The complete Bouguer anomaly map indicates a 12 to 20 km wide gravity low of 30 mGal amplitude extending north-south through the entire basin. Results of 2D gravity modeling provide a maximum depth-to-basement estimate of 3 km and reveal an area over 15 km wide with more than 2 km of sediments overlying basement rock. Modeling results of MT and gravity data are consistent and only differ at the deepest portion of the basins where resistivities show no indication of the sediment-basement interface. However, we believe that this difference is due to the presence of hot, saline fluids contained in the pore space of the basement rock. An extended MT survey and drilling program, scheduled for summer 2012, will assist in determining the southern extent of this potential resource.

Introduction

The Black Rock Desert of west-central Utah and the adjacent Sevier Desert to the north are located on the eastern margin of the Basin and Range Province of western North America (Figure 1). The Black Rock Desert lies within the boundaries of the Sevier thermal area, which contains most of Utah's high and moderate temperature geothermal systems (Blackett, 2007). The Black Rock Desert has experienced extensive volcanism ranging in age from greater than 9 Ma to as recent as 600 years ago (Hintz, 2008). Heat flow values in the Pavant Butte area are 100-105 mW/m^2, 10-15 mW/m^2 higher than the typical 90 mW/m^2 of the northern Basin and Range. Allis et al. (2011) suggest that stratigraphically hosted geothermal reservoirs likely exist in the deep basins of the Basin and Range having heat flow values of 80-100 mW/m^2 with thick

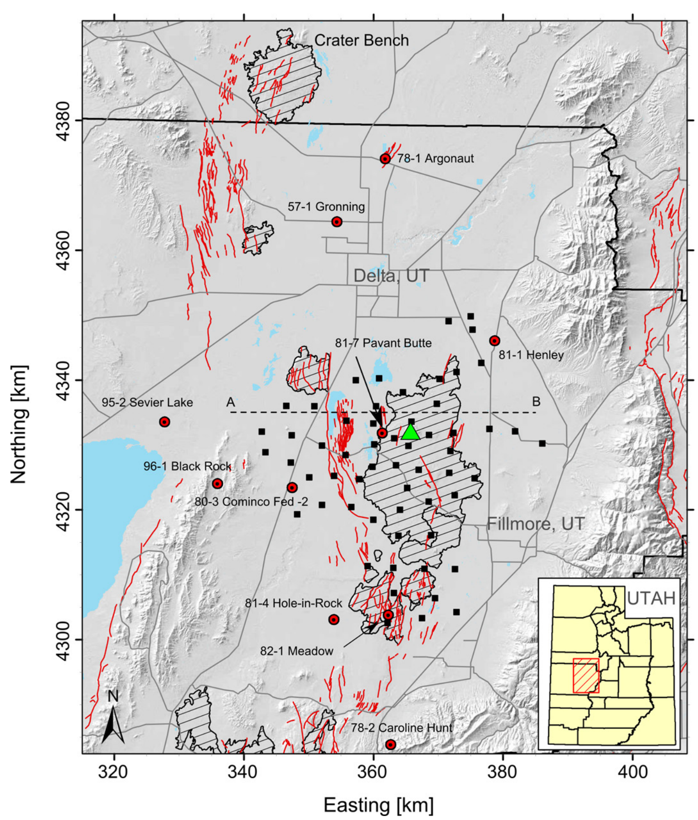

Figure 1. Map of Black Rock Desert showing survey area around Pavant Butte (green triangle). Red circles with black center are deep exploration wells from Hintze and Davis (2003), black hatched areas are volcanic flows, red lines denote Quaternary faults and black squares are MT stations. Black dashed line indicates gravity model transect AB.

blankets of low thermal conductivity Oligocene to Pleistocene sediments. Similar areas of higher than normal heat flow, such as Pavant Butte, would result in still higher temperatures of the stratigraphic reservoirs at depth resulting in a more attractive exploration target. A multidisciplinary approach to obtain integrated solutions in Earth science problems, as discussed by Saltus and Blakely (2012), is practically a necessity in potential field studies in order to achieve effective results. Electrical surveys may be used to infer subsurface reservoir characteristics (Garg et al., 2007) and are useful in deep sedimentary basins as shown by Bujakowski et al. (2010). In this study, we use gravity and magnetotellurics combined with regional borehole information to resolve the structural geometry and provide evidence suggesting the presence of deep, hot saline fluids in this potential reservoir target.

Methods

A total of 168 gravity stations were measured in the summer of 2011 with a spacing of ~2 km in order to achieve better coverage adjacent to MT areas and spacing of ~1 km for profile modeling (Figure 2). Field measurements were made using two Scintrex CG-5 gravimeters following the methods of Gettings et al. (2008); we used a 6 minute time series and reoccupation of local bases only. Elevation control of better than 0.3m was achieved through post-processing of data collected by Trimble GeoXT GPS instrumentation, resulting in 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 and the formulas outlined by Hinze et al. (2005). A simple 2D gravity model of transect AB (Figure 3) was developed using the Semi-Automated Marquardt Inversion code (SAKI) (Webring, 1985). Two bodies were used in the model to represent the sedimentary fill and basement rock. Their respective densities of 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 and Davis, 2003). The Pavant Butte 81-7 exploration well (Figures 1 and 2) was used as a control point for sediment thickness and as a check of model densities. This well penetrates 9770 feet (2,978 m) of Oligocene and Plistocence sediments before reaching the Cambrian basement (Hintze and Davis, 2003).

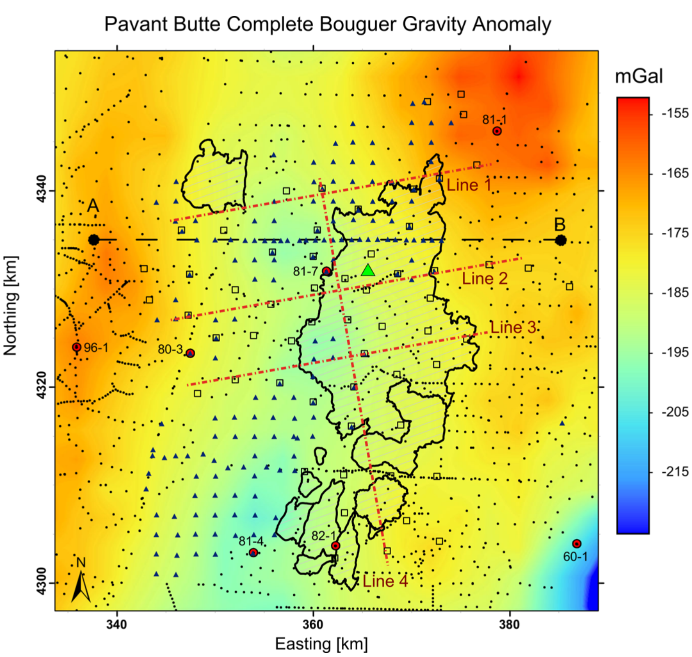

Figure 2. Complete Bouguer gravity anomaly map for study area. Black dots are historic gravity stations, blue triangles are new gravity stations, black dashed line AB is gravity model transect, black hatched areas outline volcanic flows, open black squares are MT stations, red dashed lines indicate MT model transects and red circles with black center are deep exploration wells identified by well number. Location of Pavant Butte is indicated by green triangle.

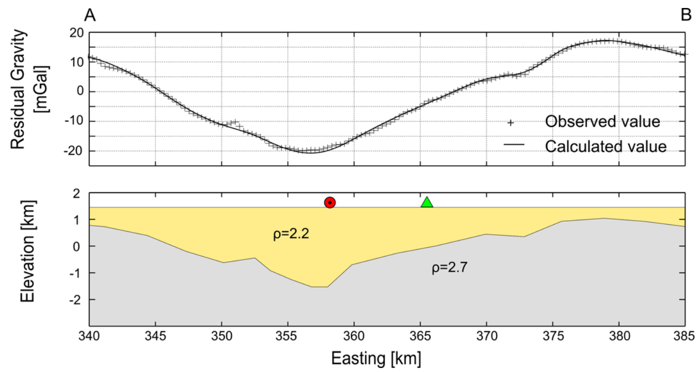

Figure 3. Residual gravity (top) and 2D gravity model (bottom). Light colored and dark colored bodies represent sedimentary fill and basement rock respectively with densities in g/cm^3 indicated. Pavant Butte indicated by green triangle and Pavant Butte well 81-7 indicated by red circle with black center.

A total of 73 MT soundings spread over an area of approximately 2000 km^2, with an average station spacing of 2 to 3 km (Figures 1 and 2), were completed by Quantec Geoscience during the summer of 2010 with station occupation times of 12 to 24 hours. Data quality is very good with the exception of a few spurious points that were removed prior to the inversions. The MT modeling used 2D inversion code (Wannamaker et al., 1987) that uses the transverse magnetic (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 that indicate the strike of the main geological structures in the study area (north-trending basin and bounding ranges). Three inversion lines are oriented at an azimuth of 80° intersected by a fourth at 350° shown in Figure 2.

Results

The complete Bouguer gravity anomaly (Figure 2) shows that the anomaly is symmetrical along the east-west direction. A prominent north-trending gravity low of -40 mGal approximately 20 km wide, is bounded by gravity highs to the east and west. The 2D gravity model of transect AB (Figures 2 and 3) fits a local signal of amplitude > 30 mGals with the lowest values east of center. The model shows a nearly symmetric, gently dipping basement interface with maximum depth found at approximately

357 km easting. The western interface is slightly steeper than the eastern interface.

The MT inversion lines with an east-west strike are all roughly symmetric and quite similar in appearance with a low resistivity body (< 10 ohm·m) centered deeply on each transect. The low resistivity zone broadens and thins to a 1 to 2 km thickness with decreasing depth (Figures 4a, 4b and 4c). High resistivity bodies are observed at depth near the edges of the models. Line 4 (Figure 4d) is also similar in appearance to the other lines with the exception that the northern end does not show a thinning of the conductive body. The MT inversion lines are presented in a 3-dimensional space in Figure 5 to help visualize the overall resistivity structure of the study area. The normalized RMS values of the 2D inversion models are between 1.0 and 2.0, which is quite good for field data.

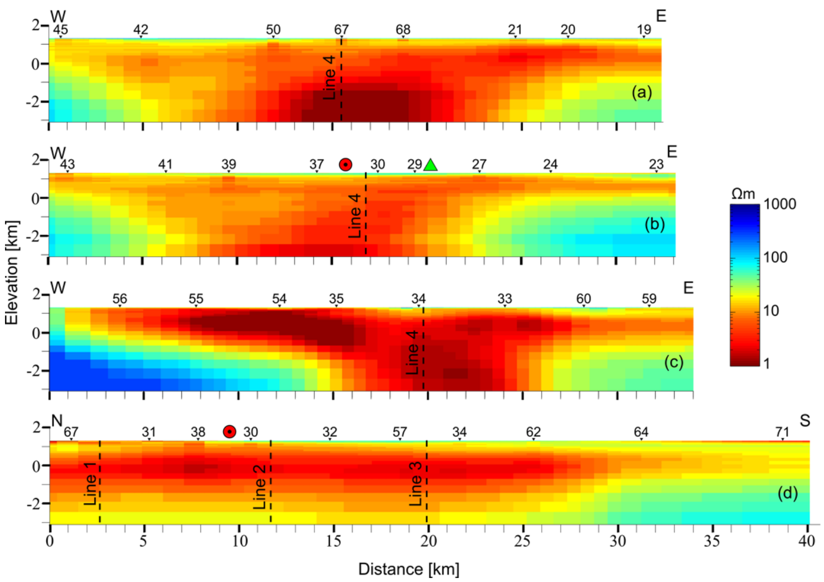

Figure 4. 2D MT models for lines 1 through 4 (a – d). MT stations indicated by black, upside down triangles and station number is shown. Dashed black lines are model line intersections, green triangle is Pavant Butte and red circle with black center is Pavant Butte well 81-7. Transect orientation indicated.

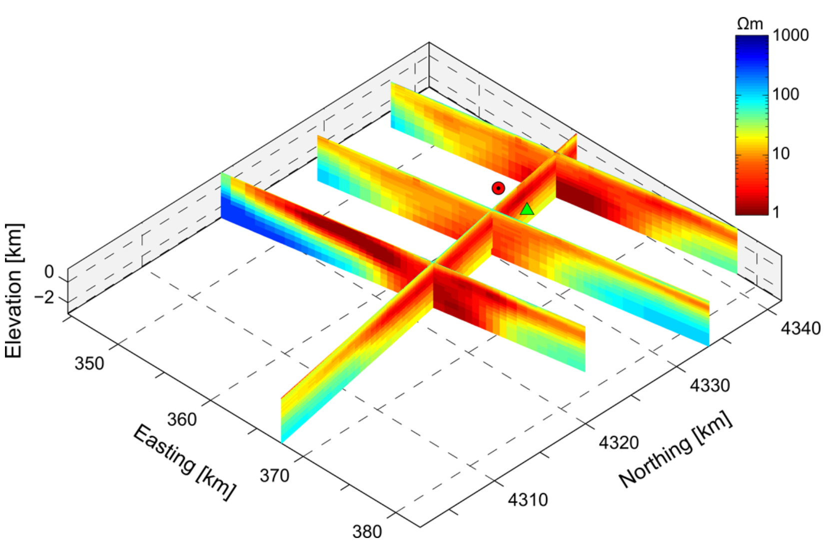

Figure 5. 2D MT models show in 3D space. Green triangle indicates Pavant Butte and red circle with black center is Pavant Butte well 81-7.

Discussion

The 2D gravity model (Figure 3) shows the maximum depth to the basement is approximately 3 km. The overall basin geometry suggested by the model is remarkably similar to the 2D MT models, differing primarily at the center of the modeled basin. The observed and modeled low resistivities can be explained by the presence of saline fluid in the pore space following Archie's Law (Archie, 1942) and thermal effects (Ussher et al, 2000; Kulenkampff et al. 2005; Milsch et al 2010), which both increase the bulk electrical conductivity of the host rock. Preliminary forward modeling of down hole resistivity logs from well 81-7 Pavant Butte (electrical resistivity monotonically decreasing with depth) agree with MT soundings recorded in the immediate vicinity. MT soundings recorded through the central part of the basin are also quite similar to those near well 81-7 Pavant Butte. Since the current data set does not reach the southern end of the basin completely, the southern extent of this interesting MT response in unknown. It appears that a 15 km wide area of the basin with sediment thickness > 2 km overlies the basement. These thick sediments constitute a thermal blanket that increases the temperature of the potential stratigraphic reservoir due to thermal conductivity effects (Allis et al. 2011 and 2012).

The high-resistivity structure in the MT models is interpreted to be basement marbleized Cambrian limestone and dolomite yielding depth-to-basement estimates of 1 to 2 km near the western and eastern margins. At the center of the model lines there is no clear indication of basement which could be due to the truncation of MT data at 10 seconds with the intent to minimized 3D effects. Thin high-resistivity layers near the surface are interpreted as basalt flows and are consistent with surface observations and resisivity values of unweathered basalts (>1000 ohm·m) (Palacky, 1988). The low-resistivity bodies are interpreted to be basin sediments. These conductors appear to extend to at least basement depth (approximately 3 km) as revealed by oil and gas wells. The conductors are interpreted to be clays near the surface and hot, saline fluids or a combination thereof at depth. Since it is unlikely that there are extensive and thick clay layers in the basin (supported by well logs), we believe hot, saline fluids and temperature effects are producing the low-resistivity signal at depth.

Corrected temperatures encountered at the bottom of the Pavant Butte 81-7 well were in excess of 220°C (Figure 6). Temperatures logged in other deep wells in the Black Rock Desert appear to be significantly cooler (~100°C) at similar depths. For the southern wells 81-4 and 82-1 (Figures 1 and 2), their low temperatures can be explained by the documented loss of massive amounts of drilling fluid and mud to fracture zones during drilling. These losses likely led to greater than normal cooling of the well bore and surrounding rock and consequently, temperatures are probably under-corrected. For the remaining wells in the Black Rock Desert, the lower temperatures at depth are due primarily to thermal conductivity effects (see Allis et al. 2011 and 2012).

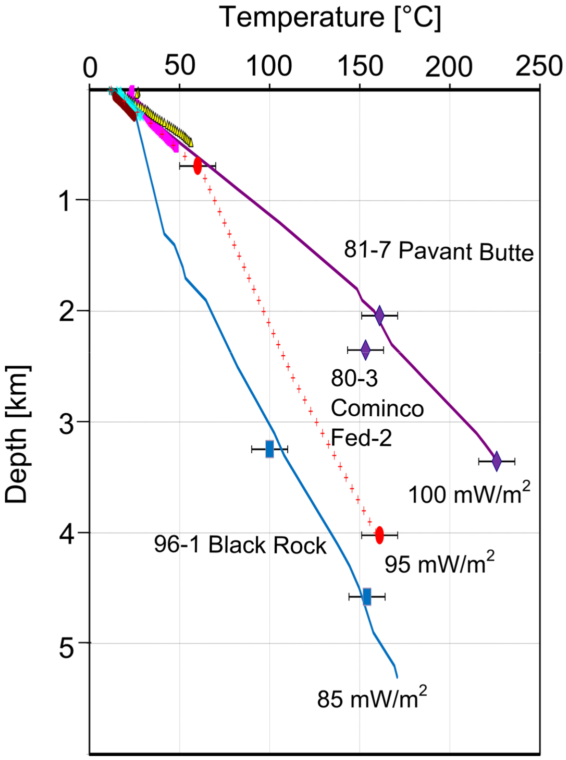

Figure 6. Temperature depth plot showing thermal gradients in Black Rock Desert for selected wells. Symbols show corrected bottom hole temperatures with error bars and heat flow values are indicated. Modified from Allis et al. (2012).

Conclusions

Preliminary models of the Black Rock Desert of western Utah show good agreement between both the MT and gravity data sets for the Pavant Butte study area. Thick sediments overlying the basement provide excellent conditions for the existence of stratigraphic reservoirs at depth. High temperatures and anomalous heat flow observed at Pavant Butte could be isolated from the rest of the basin and perhaps directly related to Quaternary faults to the east and west which could provide flow paths to the surface for hot fluids resulting in convective heat flow conditions rather than conductive. A drilling program for 5 to 7 shallow thermal gradient boreholes and an extended MT survey in the southern Black Rock Desert is scheduled to commence during the summer of 2012 to help resolve temperature record discrepancies and structure at depth.

Acknowledgements

We wish to thank Phil Wannamaker and Imam Raharjo for lending assistance in MT data processing and modeling, and Paul Gettings for lending assistance in gravity data processing and modeling. We also acknowledge the use of ARRA funds from the Utah State Energy Program and UGS funds supporting the data acquisition, compilation and the writing of this paper.

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