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3D Magnetic Characterization of Hot Springs in a Hydrothermal System in the Alvord Basin, Oregon

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Keywords
Magnetics, 3D characterization, inversion, interpretation, hydrothermal, springs

ABSTRACT
Water is not magnetically susceptible. We utilize this knowledge to map the spring systems in the Borax Lake Hydrothermal System (BLHS). BLHS is an active group of hot springs located in the Alvord Basin. These springs are aligned linearly along a north-south trend. High resolution magnetic data were acquired over this area to map the near-surface magnetic variations. The total field magnetic data were inverted using a 3D inversion algorithm to produce 3D distribution of magnetic susceptibility. Although magnetic data has no depth resolution but imposing constraints during the inversion procedure gives us the flexibility to obtain geologically meaningful results. In particular, we apply depth weighting function in the 3D magnetic inversion (Li and Oldenburg, 1996) to counteract the decay of the magnetic response with depth. The regional magnetic fields that are associated with deeper structures are removed using a spectral basis function approach via linear inversion formalism. The residual data after regional removal are inverted using the 3D code. The 3D nature of the inverse problem is computationally challenging. The inverse problem is solved in the wavelet domain to reduce the computational costs. Interpretation of the 3D subsurface susceptibility distribution from the Alvord basin reveals conduit-like structures of low magnetic susceptibility that are possible channels of preferential fluid flow.

Introduction
As a part of multi-university biocomplexity project to study the connection between the hydrothermal systems and the geothermal microbial ecosystems, a wide range of geophysical data were acquired to characterize the system. In this paper we focus on the magnetic data acquired in the Alvord basin. The springs in Alvord basin are aligned linearly in the north-south direction (Hess et al., 2004; Fairley et al., 2003). The linear arrangements of the springs are offset laterally indicating the presence of faults. Bradford et al. (2004) showed via 2D seismic imaging the presence of mid-basin basement high at approximately 160m depth. The mid basement high is approximately aligned with the springs at the surface. In addition to 3D magnetic data, high-resolution 3D seismic reflection data were acquired to characterize the hot springs (Hess, 2006). The results from the 3D seismic reflection survey indicate faults that connect with the hot springs at the surface and we believe act as the conduits for up-flowing water (Hess et al., 2004; Hess, 2006).

Geology of the Study Area
The study region is located in the southeast corner of Oregon shown in Figure 1a. The basin is flanked by Steens...
mountain and Pueblo mountain to the west and by the Trout mountain towards the east shown in Figure 1b. It is a north trending graben typically seen in the northern Great Basin extensional area. Alluvial and lacustrine sediments from the late Miocene to Holocene are on top of Miocene volcanics including tuffs, basalts, and rhyolites. Bradford et al. (2004) showed that the most active fault system is near the center of the valley, which is also the location of the hot springs.

**Magnetic Data**

**Data Collection**

A high resolution magnetic data were acquired near the spring system. The area is approximately 1000 by 500 m shown in Figure 2a. The magnetic survey was collected using a Geometrics 858G cesium vapor magnetometer. Total field magnetic readings were acquired at 3425 stations with 30 m station spacing along the east-west direction and 10 m station spacing along the north-south direction. The raw total field data are shown in Figure 3a.

**Data Processing**

The first step in magnetic data processing is to remove the regional or the long wavelength components of the data. The long wavelength components are associated with deeper structures and are not of interest in the near-surface mapping of the spring systems. The removal of region can be approached in a variety of ways depending on the objective of the imaging. In this work we pose it as...
an inverse problem where the data are expressed as linear combination of spectral basis functions that are typically sine and cosine functions varying with spatial wave numbers. The data are projected onto these basis functions and the model parameters are the coefficients associated with these basis. The inverse problem determines these coefficients by progressively fitting the data with the spectral basis starting with lower wave numbers to higher wave numbers. The regional components of the data are then determined by the lower order spectral basis shown in Figure 3b.

The regional magnetic field is then removed from the raw data to produce the residual field shown in Figure 4a. Since the residual data lie on the surface they are upward continued using the spectral basis approach to generate the residual data. The residual data shown in Figure 4b indicates a good correlation with the locations of the hot springs. The upward continued data at 10m above the surface are input to the inversion algorithm. The upward continuation process also removes some of the high frequency noise associated with very near surface heterogeneities shown in Figure 4b.

**Data Inversion and Interpretation**

We developed a smooth model 3D inversion code with depth weighting similar to procedure outlined by Li and Oldenburg (1996). The algorithm can invert the magnetic residual data. The magnetic data from the Alvord basin was inverted to determine 3D magnetic susceptibility distribution. The noise in the data was assumed to be Gaussian with standard deviation of 3 nT. The predicted data from the model fit the observed data well (not shown). The model from the inversion of the magnetic data shows tubular structures that start at a depth of 170 m and continue to the surface. Although depth information is not directly available from magnetic data, however this value coincides with the depth of the mid-basement ~160m obtained from a 2D seismic line in the same area (Bradford et. al, 2004). These tubular structures are the low susceptibility zones that may represent the conduits for up-flowing geothermal water shown in Figure 5a,b. The blue region of low susceptibility shows good correlation with the location of the hot springs suggesting the validity of the magnetic inversion. The lower panel indicates the pipe like structure between the two susceptibility zones that is connected at depth. Our future goal is to combine the interpretation of the magnetic inversion with the structural information obtained from the seismic.

**Figure 4.** (a) The residual anomaly map and (b) the upward continued residual anomaly map. The blue stars indicate the location of the springs on the map.

**Figure 5.** (a) 3D distribution of magnetic susceptibility indicating low magnetic susceptibility which correlates well with the spring systems. (b) A cross-section view of the 3D image.
Conclusions

In this paper we present the imaging of spring systems using magnetic data. Assuming that water is not magnetically susceptible the total field magnetic data were inverted to determine the zones of the low magnetic susceptibility. These zones in the 3D volume show the inter-connection of the subsurface conduits and pathways of the water up to the surface. The 3D inversion was carried out by placing depth constraints in the objective function. Magnetic data are fairly inexpensive to acquire. With advanced processing and inversion valuable information can be obtained in a hydrothermal systems and its plumbing. In future we would like to further constrain the 3D magnetic inversion using the structures interpreted from the 3D seismic imaging. The goal would be to provide a better integrated model in this area.

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References


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