Play Fairway Analysis for Geothermal Systems in the Great Basin Extensional Province Emphasizing Magnetotellurics, Structural Geology and Isotope Geochemistry

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SUMMARY

We combine magnetotellurics (MT), structural geology and isotope geochemistry (especially He) in the search for blind geothermal systems in the Great Basin extensional province, western USA. Known high temperature systems lie in 3D dilatent structural settings and typically exhibit ⁴He anomalies indicative of deep magmatic sources. They also usually show MT low-resistivity upwellings of crustal scale connecting deep crustal igneous activity to the near surface system. We utilize MT in an areal reconnaissance mode subject to 3D regularized inversion to locate low-resistivity upwellings not currently associated with a known system as a means of seeking hidden systems. Geothermal significance is tested through structural analysis to identify dilatency potential and through geochemical surveying for ³He anomalies to establish presence of deep heat sources. Several promising prospects for followup surveying and ultimately thermal gradient drilling are identified particularly in the active eastern Great Basin.

Keywords: magnetotellurics, inversion, finite elements, geothermal, case study

INTRODUCTION

Play Fairway Analysis (PFA) in the geothermal context combines regional geological/geophysical understanding with knowledge of prospect controls to produce an inventory of prospect leads (see Fraser, 2010, for an oil and gas analog). The potential for resources should be high where active magmatism creates a large heat endowment while active deformation within diverse structural trends may create reservoir space. Thus we have been drawn to examine the active eastern Great Basin of western Utah where, active N-S striking extension with high-temperature, bimodal volcanism cross-cuts E-W trending transverse structures of mid-Cenozoic age (Wannamaker et al., 2008; Bendersky et al., 2012) (Figure 1).

BACKGROUND AND ASSUMPTIONS

In extensional (rift) systems, exhumation of the crust elevates the geotherm and creates fracture permeability. A common model for geothermal systems here involves deep circulation of waters driven by topographic flow to depths potentially of 10 km near the brittle-ductile lithologic transition. However, other high temperature extensional systems clearly have magmatic affinities given nearby volcanism and other evidence such as He isotopes (e.g., Simmons et al., 2015). A pronounced N-S trend of Quaternary basaltic and bimodal volcanism cross-cuts E-W trending transverse structures of mid-Cenozoic age (Wannamaker et al., 2008; Bendersky et al., 2012) (Figure 1). The Snake River Plain of Idaho (Figure 1). Western Utah contains the most pronounced seismic tomography anomalies in its upper-most mantle of the entire U.S. apart possibly from the eastern Snake River Plain signing strong degrees of melting. Thermal processes of extension under the eastern Great Basin result in cumulative heat flow along the N-S strike of the state totalling approximately 5 GW above background stable interior (Edwards and Chapman, 2013).

We are modernizing understanding of geothermal prospectivity of the eastern Great Basin by emphasizing a combination of magnetotellurics (MT), structural geology, and fluid chemistry integrated in a context of heat flow, seismicity and volcanology. High-temperature geothermal systems elsewhere in the Great Basin and other parts of the world show MT low-resistivity roots connecting to probable magmatic underplating and fluid release in the deep crust (Wannamaker et al., 2007, 2011; Bertrand et al. 2012, 2015). Such roots represent large-scale permeability and potential heat upwelling. Thus we acquire and examine MT data in the extensional eastern Great Basin in a fully 3D fashion for such roots as evidence toward the existence of previously blind geothermal systems. MT structures are verified by coincidence with a dilatent structural setting and isotope geochemistry attuned to deep heat sources. Subsequently, integration of additional geoscience data such as proximity to igneous sources and major element fluid chemistry allows derivation of common risk segment maps of prospectivity (Wannamaker et al., 2016).
**Figure 1.** Left: DEM map of western Utah showing extension-dominated physiography. Black polygon represents play fairway of our project with 5 mgal gravity contours. Producing geothermal systems include Roosevelt Hot Springs (RHS), Cove Fort (CF) and Thermo (TH). Important Q volcanic extrusives are Crater Bench (CB), Pavant Butte (PB), Twin Peaks (TP) and Crater Knoll-Red Knoll (CK). Urban centers are Delta (DL) and Milford (MF). Upper right: Middle Cenozoic tectonism in Utah is dominated by voluminous plutonism in E-W belts: Tuscarora-Bingham (T-B), Eureka-Tintic (E-T) and Reno-Pioche-Marysvale-San Juan (R-M-S) separated by mid-Utah magmatic gap (MUMG). Prominent structural lineaments along the R-M-S belt are the Cove Fort transverse zone (CFtv) and the Blue Ribbon transverse zone (BRtv). Lower right: Mid-Miocene to present Basin and Range extension overprints previous tectonic and plutonic episodes creating numerous intersecting trends and magmatic heat sources. Quaternary basalts (Qb) of abnormally high potential temperatures are erupted in a N-S trend the length of the state.

**MT RESISTIVITY STRUCTURE**

The PFA area contains ~550 high quality MT soundings acquired by ENEL Inc, the State of Utah, and the University of Utah. The highly clustered site distributions are associated with individual known geothermal prospects and are downsampled to a total of 294 sites to provide uniform coverage over the PFA. The 3D inversion images of the soundings are produced using the direct-solution, edge finite element algorithm of Kordy et al (2016). The algorithm simulates topography precisely using deformable hexahedral elements and uses the entire MT tensor set of 12 quantities (four complex impedance elements and two complex tipper elements) per frequency per site. Images are stabilized (regularized) by damping model slope in the three local x-y-z directions at a mesh cell.

The period range used is 0.01 through 320 s. Cell widths among the sites are typically 600 m and the total finite element mesh is 214 (N) x 132 (E) x 46 (Z) cells with the upper 13 element layers devoted to the air. A narrow rim of finite elements around the mesh sides and bottom is kept fixed so the inversion domain is 212 x 130 x 31 = 854,360 parameters. Error floors were 5% of max{ |Zij| ; |Zxy-Zyx|/2 } and 0.04 tipper for tipper. The starting model was 40 ohm-m and a final nRMS of 1.1 was achieved monotonically in 25 iterations. Run times were ~22 hours/iteration.

Plan views at four depth levels appear in Figure 2 for a portion of the mesh focusing upon the transition from the southern Sevier Desert and onto the Reno-Pioche-Marysvale-San Juan plutonic belt (Figure 1). At the shallowest levels (2.5 and 5.7 km), MT anomalies are associated with the northern Crater Knoll (CK) volcanic occurrence and a northern extension (NCF) of the Cove Fort producing system. At deeper levels, the CK and NCF conductors persist and align E-W with a possible additional conductor just west of the MT site coverage along the Cove Fort transverse structural trend (Figure 1). Under a regime of E-W extension, these auxiliary structures may suffer dilatency and provide conduits for upward geothermal fluid flow. Only a rather subtle low-resistivity structure appears in the model in the 2.5 km depth slice near the Roosevelt Hot Springs system (Allis et al., 2015), and specifically underlies the Quaternary Bailey Ridge (BR) rhyolite
dome and flow (Figure 2). However, sampling here is coarse and further data collection is needed to clarify possible sources to the Roosevelt system as reflected in electrical resistivity structure.

**Figure 2.** Plan views at two depths of preliminary MT resistivity inversion. Wells from Roosevelt Hot Springs (13-10), Cove Fort (42-7) and Pavant Butte (PB-1) thermal areas noted. Structural features discussed in text include northern Twin Peaks (NTP), Bailey Ridge (BR), Crater Knoll MT anomaly (CK), and northern Cove Fort MT anomaly (NCF). A number of deep geothermal or oil wells (Allis et al., 2015b) are marked by X.

**FAIRWAY GEOCHEMICAL TRENDS**

Geochemistry is the third initial leg of the platform from which the search for hidden geothermal systems proceeds, together with MT low resistivity and structural geology. Geochemistry of produced fluids in western Utah systems show that the rock volumes through which these fluids move are much greater than those represented by the reservoir rocks themselves. Geothermometry values suggest temperatures higher than those of produced fluids exist at some depth below the recognized systems (Simmons et al., 2015). Geological evidence suggests that the main deep lithology is made up of crystalline basement rocks (i.e., gneiss, granite) but unclear sources of aqueous Cl, SO4, and HCO3 exist. Presence of 3He (Figure 3) suggests that the regional western Utah thermal anomaly owes much of its origin to deep intrusion of magma(s). Geochemical followup work in this PFA analysis will include new 3He surveying using novel passive soil sampling instrumentation that does not require acquisition of fluids from either springs or wells (Dame et al., 2015).

**CONCLUSIONS**

Efforts in the central-eastern Great Basin PFA have generally confirmed, but also modified, understanding of possible geothermal resource controls in this region. Use of upper-middle crustal MT resistivity, dilatent structural potential, and isotope geochemistry in our view remain pathfinder techniques for identifying blind and possibly high-temperature systems. Preliminary 3D MT inversion of the newly sampled site coverage
Wannamaker et al., Geothermal Play Fairway Analysis with MT

confirms and narrows resistivity upwellings associated with Crater Knoll and Cove Fort prospect areas. Of these, Cove Fort remains the most pronounced extending well to the north of the producing area similar to the heat flow distribution. Followup effort aimed at establishing potential new exploitable geothermal systems will include isotope geochemical surveying, structural mapping and analysis, and modelling of existing thermal gradient drilling.

Figure 3. Distribution of silica geothermometry values and $^3$H/Ra values (labeled) in the eastern Great Basin PFA study area (Simmons et al., 2015).

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REFERENCES


