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Conceptual Subsurface Model of the Blackfoot Volcanic Field, Southeast Idaho: A Potential Hidden Geothermal Resource

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ABSTRACT

Development of a conceptual model for the Blackfoot Volcanic field in southeast Idaho seeks to understand mechanisms and pathways for heat transfer and loss. This potential hidden geothermal resource is a young bimodal, volcanic rift system consisting of features similar to the Coso geothermal field. However the Blackfoot Volcanic field lacks significant geothermal surficial features, alteration and has relatively low temperatures at depths inconsistent with young 58 ka (Heumann, 2004) felsic volcanism. Development of a conceptual model has generated several hypotheses regarding explanations of heat transfer and loss. These hypotheses include isothermal drawdown; heat transfer and loss pathways along faults; and the intersection of two major thrusts at depths similar to the estimated depthof the rhyolitic magma chamber.

Introduction

The Blackfoot Volcanic Field (BVF) in Caribou County, Idaho is a young, bimodal, volcanic rift system adjacent to the southeast margin of the Eastern Snake River Plain (ESRP)(Figure 1). The BVF consists of late Pleistocene olivine thoeliite flows, cinder cones and three 58 ka (Heumann, 2004) rhyolite domes, associated with a significant gravity anomaly. Basalt flows are cut by more than 50 north-northwest striking graben forming normal faults, which are inferred to have formed over an arrested mass of dikes beneath the surface (Polun et al., 2010). Thermal springs are located at basin margins and are associated with large active and fossil travertine deposits with temperatures up to 33°C. Combined, these conditions suggest the potential for a hidden geothermal resource. The BVF provides an ideal opportunity for conceptual model development in an effort to improve methods for hidden geothermal exploration, an integral part of Idaho State University's research strategy.

Conceptual Model

Geothermal conceptual model development isneeded for each individual geothermal field due to the variety of parameters that exist. Conventional models focus on integrating surface geochemistry, electrical resistivity, hydrothermal alteration, geologic mapping, hydrology and structural analysis (Cumming, 2009).

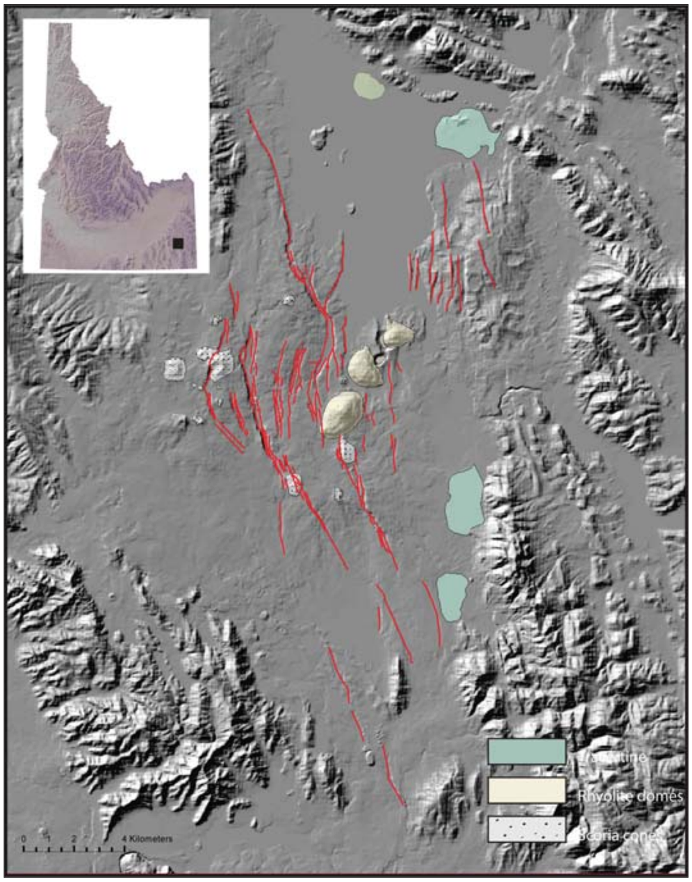

Figure 1. Location map of the Blackfoot Volcanic field, Caribou County, Idaho.

Building a model consistent with this information for the BVF will aid in assessing the capacity of this potential hidden resource. However, a conceptual model for hidden geothermal systems must include mechanisms or pathways for fluid and heat diversion.

Conceptual model development relies on the integration of multiple sources including extensive literature research and comparison of BVF geology with other known geothermal resources associated with young rhyolite volcanism. In particular, the BVF closely resembles the Coso geothermal field in many aspects: both include bimodal rhyolitic and basaltic volcanism, basin and range faulting, warm springs and the lack of significant surficial geothermal features (Olson and Robinson, 1980; Feighner and Goldstein, 1990; Monastero et al., 2005). Considering these factors, the BVF is a potential geothermal resource at depth that may reflect heat derived from these young rhyolites.

Previous efforts on conceptual model development for Coso have predominately focused on geophysical and structural data. Bouger gravity data has been used to characterize lithologic constraints and estimated approximate depth of the heat source (Olson and Robinson, 1980; Feighner and Goldstein, 1990). A more recent conceptual model with a structural focussuggests Coso is a nascent metamorphic core complex(Monastero et al., 2005). Conceptual model development of the BVF usessome of these models as a frame of reference for approaching this hidden system.

The BVF conceptual model integrates shallow and deep perspectives, regional and local geologic structures, Bouger gravity data, aeromagnetic data, well bore stratigraphy and temperature data (Figure 2). Constraints used from Hubbard #1 borehole include: basalt thickness of 230 m; basalt dikes, flows or sills within the Tertiary sediments at various depths; temperatures of 37.7°C from 915–1844 m, and 93.3°C from 1844–4105 m which corresponds with borehole collapse. Total borehole depth is 4335 m. Archean, Neoproterozoic and Paleozoic boundaries as well as fault locations are used from Dixon (1982); Tertiary basin sediment and Quaternary basalt thicknesses were estimated from the Hubbard borehole and Bouger gravity data (Mabey and Oriel, 1970).

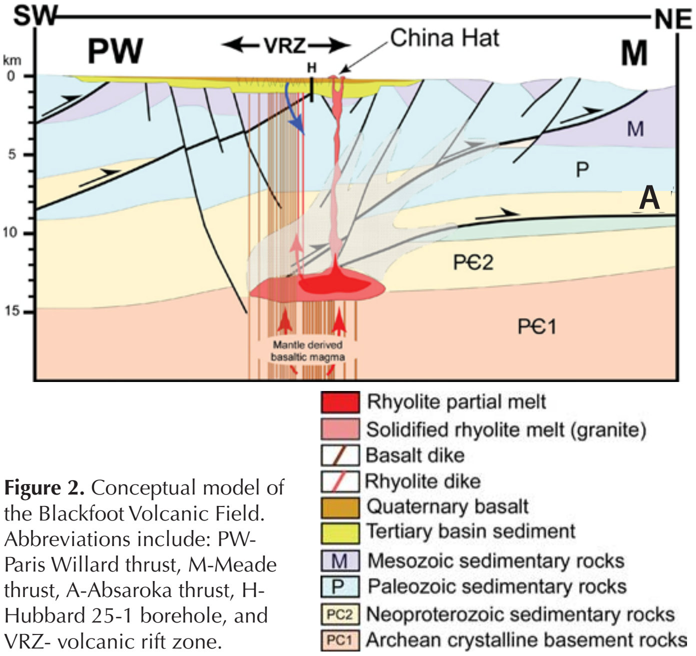

Figure 2. Conceptual model of the Blackfoot Volcanic Field. Abbreviations include: PW-Paris Willard thrust, M-Meade thrust, A-Absaroka thrust, H-Hubbard 25-1 borehole, and VRZ- volcanic rift zone.

The following briefly describes emplacement of igneous bodies from deep to shallow levels. For a more detailed discussion of underlying geologic, hydrologic and geothermal features upon which this model is based see McCurry et al. (this volume).Geothermally relevant thermal evolution of the system begins with emplacement of a silicic magma reservoir at ~13 km depth, based upon geochemistry and hornblende thermobarometry for China Hat (Ford, 2005).Note that this magma storage area is located near the boundary of 3 major structures: two thrust faults and the crystalline basement contact. In addition, adike swarm composed of basalt or rhyolite propogated to the base of the Tertiary basin, became arrested and is inferred to be the mechanism for volcanic rift zone faulting (Polun et al., 2010). The blue arrow indicates potential cooling effects from rift zone faulting discussed below.

Further development of the conceptual model involves making a three-dimensional model using Maptek Vulcan software. The 3D model contains borehole, gravity, magnetic, lithologic and structural data. Initial observations from the model have already aided in relationships that were previously unrecognized for the BVF. One observation is a large magnetic anomaly located in the center of the rift zone south of China Hat rhyolite dome, see McCurry et al. (this volume). Its significance is unknown. Current hypotheses include a thicker basalt mass, possible sulfide mineralization or a shallow dike. Another important observation stems from projecting the bouger gravity as a 3D surface where a potential hidden normal fault exists. The estimated projection of this fault coincides with borehole collapse and a temperature spike in the Hubbard borehole.

Discussion

Young rhyolitic systems generally have accompanying surficial geothermal expressions and heat signatures. The lack of surficial geothermal features, alteration, and relatively low temperatures in the Hubbard borehole for the Blackfoot Volcanic Field is of particular interest, begging the question: where did all the heat go and where is its footprint? Building a conceptual model helps visualize potential mechanisms and pathways for fluid and heat escape. Initial observations and interpretations identifyseveral mechanisms that could be masking heat and will be discussed below.

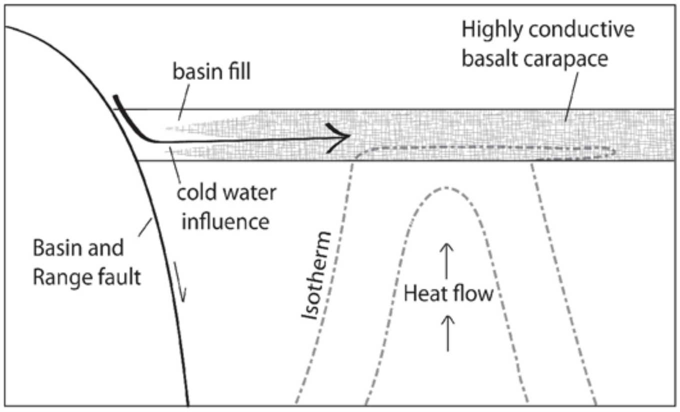

Figure 3. A thick conductive basalt carapace leads to isothermal drawdown from cold water influence.

The BVF has a distinct shallow hydrogeology with ahighly hydrologically conductive 230 m thick basalt carapace capping the field. The high conductivity of this basalt carapace, combined with cold-water input may lead to isotherm drawdown via mixing, dilution and redirection of upward directed geothermal waters (Figure 3). The Blackfoot reservoir lies several km north of the rhyolite domes, providing a source of continuous cold-water influence. This scenario could explain the lack of geothermal surficial expressions. However, temperatures within the Hubbard borehole do not significantly increase beyond the basalt. Thus, isotherm drawdown may play a significant role in masking surficial features, but it does not explain the muted temperatures below the carapace.

Mid-level cooling effects on heat flow, heat sources and related geothermal fluids may also be taking place within the rift zone. A downward infiltration of cold meteoric water along the closely spaced rift-related normal faults could be taking place, which could explain potential isothermal drawdown below the basalt carapace (Moore, J., and Fink, R., personal comm, 2011).

Lack of alteration in sediments from the Hubbard borehole is unusual for a young felsic magmatic system with a relatively deep water table. Rhyolite phenocryst populations indicate a 3-5 fluid wt% not seen at the surface. Therefore supercritical fluids are being diverted from the system, an efficient heat loss process, further indicating the need for some mechanism or pathway to divert magmatic and connate fluids.

The structural setting of the Blackfoot volcanic field may provide a unique environment for potential heat losspathways. The BVF contains a volcanic rift zone, is located within an actively extending portion of the Basin and Range province, as well as the Cretaceous Sevier fold and thrust belt, all of which combine to provide a myriad of fractured zones.

Travertine deposits proximal to Basin and Range faulting are interpreted as potential heat transfer pathways along normal faults. These deposits predominately occur in the eastern portion of the basin, as well as in the north to a lesser degree. This could suggest fluid and heat transfer to the north-east towards Grays lake, a temperature anomaly distal from young magmatic sources.

Several major thrust faults cross underneath the BVF, including the Meade and Absaroka thrusts. Approximate thrust fault locations and starting depths (Dixon, 1982) were incorporated into the conceptual model, revealing several interesting relationships. The contact between Archean crystalline basement and Neoproterozoic sedimentary rocks is located approximately at 14 km depth, which is also the starting depth of the Meade and Absaroka thrust faults. This depth relationship is significant because it is also the estimated storage depth (Ford, 2005) of the felsic magma body suggesting that the thrust faults may provide significant pathways for fluid transfer and subsequent heat loss from the slow cooling magma body.

Summary

The Blackfoot Volcanic Field (BVF) is a young bimodal, volcanic rift system that may be a hidden geothermal resource. The BVF consists of features similar to the Coso geothermal field, including: bimodal volcanism, basin and range faulting, warm springs and a lack of surficial geothermal features. These similarities are significant and suggest a potential geothermal resource in southeast Idaho.

The Blackfoot Volcanic Field field lacks significant geothermal surficial features, alteration and has relatively low temperatures at depth. Combined, the BVF lacks a heat signature that should correlate with young 58 kafelsic volcanism. Development of this conceptual model seeks to understand mechanisms and pathways for heat transfer and loss. The absence of surficial features may be a result of isotherm drawdown within the thick conductive basalt carapace. The combination of volcanic rift zone, Basin and Range and the Sevier thrust belt structures, may all contribute to heat loss. Volcanic rift zone faults might provide pathways for meteoric water, masking the surficial geothermal signature of a young volcanic system. Travertine deposits and warm springs adjacent to Basin and Range normal faulting may indicate heat transfer pathways along faults to the surface. Also, the depth of the China Hat magma chamber, constrained by hornblende geobarometry corresponds with the depth of the crystalline basement contact and several thrust faults, which may provide significant fluid and heat loss pathways.

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