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Petrographic and thermal evidence of high-temperature geothermal activity from the MH-2B slimhole, western Snake River Plain, Idaho

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ABSTRACT

The Mountain Home (MH) geothermal system of the western Snake River Plain magmatic province was discovered by the Snake River Geothermal Drilling Project on January 26, 2012, when artesian flowing water with a temperature of 140 °C was encountered at a depth of 1,745 m. We present thermal and compositional variations of geothermal fluids recorded in mineralization observed in the MH-2B core and compare them to the present-day fluid in order to characterize the evolution of the MH geothermal system and the geothermal potential of the western Snake River Plain. Mineralized fracture networks of pectolite-prehnite, calcite, and laumontite were documented in the recovered core. Observations of the core, thin section petrography, X-ray diffraction, and Electron Microprobe Analyses were performed in order to describe mineral the paragenesis of various alteration zones. Fluid inclusion microthermometry identified primary inclusions with trapping temperatures ranging from 186-368 °C consistent with a boiling geothermal system at depth.

1. INTRODUCTION

The Snake River Geothermal Drilling Project (2010-2012) drilled three slimholes in southern Idaho to investigate the geothermal potential of the Snake River Plain (SRP). The western SRP displays some of the highest high heat flow in the state of Idaho with the potential for considerable geothermal resources. The Mountain Home geothermal system was discovered in 2012 when artesian 140 °C water was encountered in the MH-2B slimhole drilled by DOSECC Exploration Services. This area, near the northeast margin of the western SRP, approximately 65 km southeast of Boise, Idaho on the Mountain Home Air Force Base (Figure 1), had not previously been known to host high-temperature geothermal activity, having been sealed from the surface by overlying bedrock. This is a blind geothermal system whose conceptual model has been poorly understood.

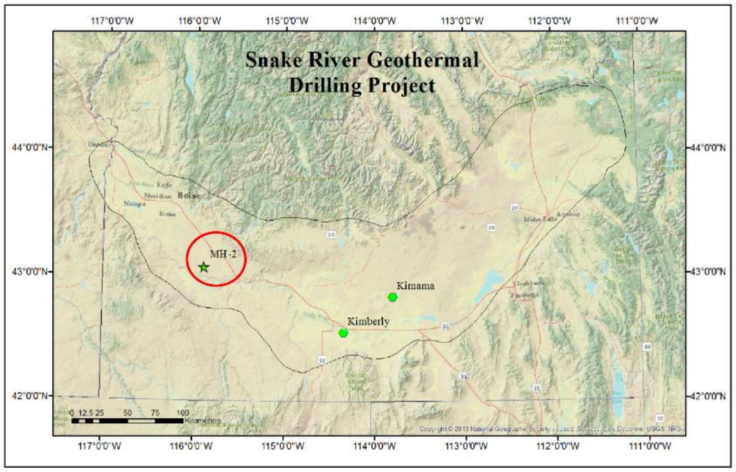

Figure 1: Map of the Snake River Plain (black outline) and the locations of the three slimholes drilled during the Snake River Geothermal Drilling Project; The Mountain Home (MH-2B-red circle) slimhole is the focus of this study. (modified after Nielson and Shervais, 2014)

Prior to this study, various investigations had been completed on the extracted core and fluids including fracture and mechanical properties analyses (Kessler et al., 2014), clay mineralogy (Walker, 2016) and geothermal fluid analysis (Lachmar et al., 2012, Freeman, 2013). In this paper, we present mineralogical and thermal data that describe the evolution of the Mountain Home geothermal system. In addition to describing the geothermal system, datasets included herein are displayed to demonstrate the types of data that can be gathered from slimhole coring operations vs. large-diameter geothermal production wells.

2. GEOLOGIC SETTING OF THE WESTERN SRP AND THE MH-2B SLIMHOLE

The western SRP is a northwest trending graben bounded by en échelon normal faults to the northeast and southwest. Volcanic activity in this region began ~11 Ma with rhyolitic composition eruptions along the flanks of the plain contemporaneous with Basin and Range extension. These serve as basement rocks for subsequent basaltic magmatism that began ~9 Ma and subsequent lacustrine sediments (Idaho Group) derived from the Pliocene-Pleistocene Lake Idaho (Jenks and Bonnichsen, 1989). Basalts younger than 2 Ma exposed as surface flows and shield volcanoes cap the lacustrine sediments (Shervais et al., 2002).

The location of the MH-2B slimhole was chosen based on multiple observations that suggested the potential for encountering a geothermal resource. This area has an elevated heat flow of approximately 80 mW/m2 (Blackwell et al., 2011). The Bostic 1A wildcat oil well, ~20 km SE of MH, had a Bottom Hole Temperature (BHT) of 175 °C at 2949 meters below ground surface (mbgs) and a geothermal gradient of 59 °C/km (Arney et al., 1984). The MH-1 hole, drilled approximately 1.5 km to the east of MH-2B in 1986, had a BHT of 93°C at 1219 mbgs and a geothermal gradient of 69 °C/km (Lewis and Stone, 1988).

In addition to these heat flow and temperature data, a prominent regional Bouguer gravity anomaly (gravity high) extends throughout much of the western SRP. Shervais et al. (2002) interprets this anomaly to represent an uplifted horst block in the subsurface. The western SRP is bounded by high-angle normal faults dipping towards the axis of the SRP and contains interpreted intrabasinal antithetic normal faults (Lewis and Stone, 1988; Shervais et al., 2002). These antithetic faults are believed to have contributed to the uplift of the horst block responsible for the gravity anomaly. Fracture density is typically greater on the flanks of gravity anomalies due to fault-related uplift making them attractive areas for geothermal exploration. The MH-2B location was chosen near the southwest edge of the gravity high near the interpreted intrabasinal faulted block because of potential for encountering thermal fluids associated with the structure and high permeabilities of faulted rocks.

The MH-2B slimhole was drilled to a total depth of 1821 m into various basalts and sediments. Figure 2 is a lithology log of MH-2B together with gamma ray and temperature logs (Shervais et al., 2013). The upper basalts are massive with large phenocrysts of plagioclase. These range in age from 100-900 ka based on dating of volcanic structures in the immediate vicinity of Mountain Home (Shervais and Vetter, 2009). Lacustrine sandstones and mudstones derived from Lake Idaho dominate from 200 to 750 mbgs. Basalt with minor intercalated sediments continues to a depth of 1200 mbgs. These basalts have been partially altered by hydrothermal activity and are recognized by slight oxidation and clay alteration. Below 1200 mbgs, a thick package of basalt flows, hyaloclastites (evidence of subaqueous eruptions) and basaltic sandstones are present and tend to be green due to the presence of clay alteration. At approximately 1700 mbgs, light gray aphanitic to dark gray and black aphanitic, massive, olivine tholeiite basalt is dominant. These thick packages of basalts that underlie the Lake Idaho sedimentary deposits are dated to be approximately 9 Ma (Jenks and Bonnichsen, 1989, Wood and Clemens, 2002, White and Hart, 2002, Bonnichsen and Godchaux, 2002).

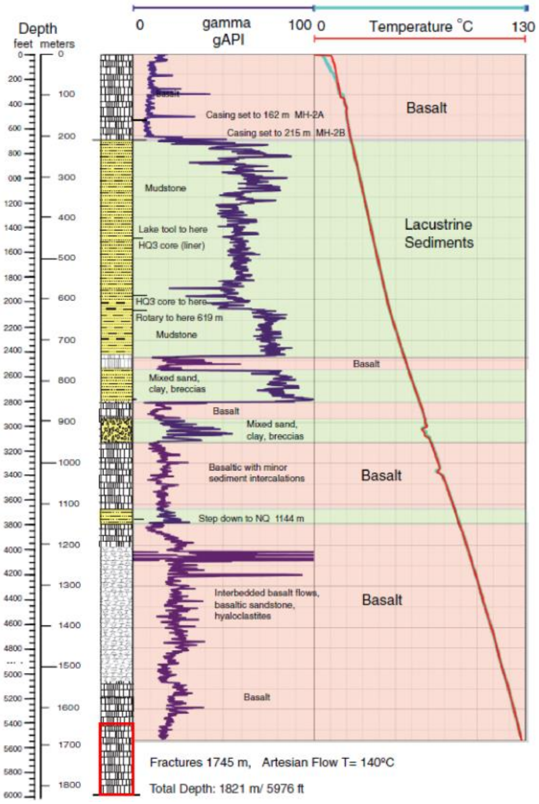

Figure 2: Lithology, gamma ray, and temperature logs of MH-2B with the Zone of Interest (ZOI) for this study (1650-1820 mbgs) outlined in red; (modified from Shervais et al., 2013)

3. METHODS

Powdered samples collected from the MH-2B core for X-ray Diffraction (XRD) were analyzed at Utah State University with a Philips PANalytical X'Pert X-Ray Diffractometer. Thin and thick sections were made from plugs taken from the MH-2B core for petrographic and fluid inclusion analyses, respectively. These analyses took place at Utah State University as well utilizing a Leica DM 2700P petrographic microscope and a Fluid Inc. adapted USGS gas-flow heating-freezing system. Temperatures of homogenization (T_h) and temperatures of melting ice (T_m) were measured followed by a calculated temperature of trapping (T_t) incorporating lithostatic and hydrostatic pressure conditions. Electron Microprobe Analysis (EMPA) took place at Brigham Young University on a Cameca SX50 Electron Microprobe.

4. RESULTS

The Zone of Interest (ZOI) for this study (Figure 2-red box) includes the depth range from 1650-1820 mbgs where mineralized veins, vugs, and fractures, as well as hydrothermal breccias, are prevalent in the core indicating the highest intensity alteration.

Secondary mineralization in the upper ZOI (1650-1700 mbgs) includes veins of prehnite-pectolite and disseminated quartz while calcite and laumontite, with minor pyrite and chalcopyrite, are prevalent in the lower ZOI (1700-1820 mbgs). Calcite occurs as veins and vugs with occasional euhedral crystals approximately one inch in diameter. Laumontite forms euhedral crystals scattered on the core surfaces and in large aperture veins. The pyrite/chalcopyrite combination is minor but associated with the calcite mineralization. Alteration clays have been identified as smectite and corrensite, a 1:1 chlorite-smectite layered clay (Walker, 2016).

Petrographic analysis reveals high degrees of alteration, primarily to clays. The prehnite-pectolite assemblage, identified using petrography, XRD, and EMPA, is observed in the upper zone to fill large veins and veinlets with fine-grained prehnite along the margins and pectolite filling the majority of inner sections of the veins. This zone is isolated from the lower zone of calcite by a distinct lithologic boundary. Calcite veins are characterized by fairly homogenous interlocking grains and occasionally are cross cut but a microcrystalline quartz. This quartz occasional fills amygdules and other voids throughout this lower ZOI.

Primary fluid inclusions in calcite samples are vapor-rich and abundant throughout the ZOI (Figure 3). Primary inclusions T_h's average 239 °C, with an observed maximum of 358 °C. T_h measurements of secondary inclusions had an average of 153 °C. Bulk salinities were calculated using a H_2O-NaCl model composition (Bodnar 1993). Based on the measured T_m of each sample, the salinity of fluid inclusions were found to be low-moderate (maximum of 4.2 wt % NaCl).

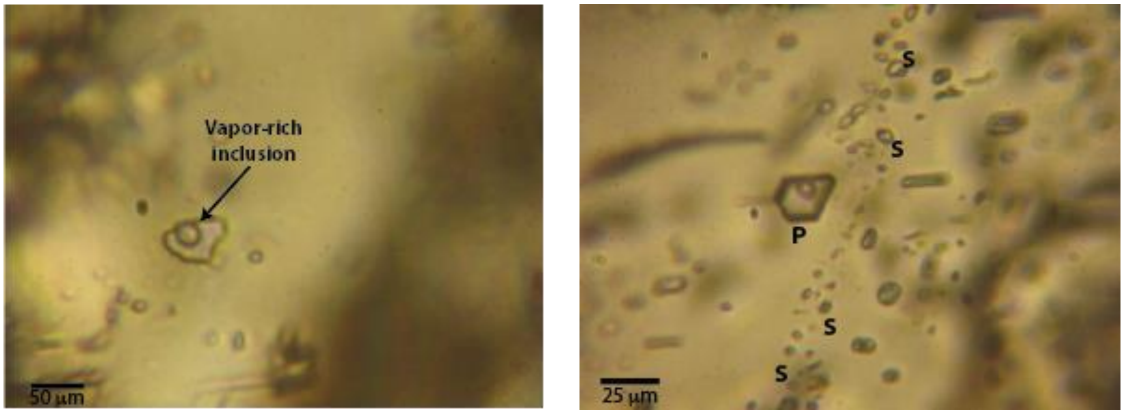

Figure 3: Plain light images of vapor rich primary fluid inclusions in calcite from the MH-2B core (500x).

5. DISUCSSION

5.1 History of Mountain Home Geothermal Activity

Mineralization related to hydrothermal activity records thermal and compositional variations in past fluids of the MH geothermal system. Hydrothermal temperature estimates based on fluid inclusion T_t's reveal that temperatures reached as high as ~368 °C. Integration of these temperatures with a boiling point curve and core textural observations such as the presence of hydrothermal breccias suggests that boiling likely occurred during peak hydrothermal temperatures. Figure 4 presents boiling point curves for hydrostatic and lithostatic conditions along with calculated T_t's assuming a hydrostat (blue). Increased pressures would result in higher temperatures (orange). Based on the BPC, assuming hydrostatic conditions, boiling in this zone of the borehole would require temperatures ~350-360°C, consistent with measured and calculated T_t's. Vapor-rich inclusions and core textures, such as hydrothermal breccias throughout the ZOI, are consistent with these high temperatures and boiling geothermal fluids (Muffler et al., 1971, Hedenquist and Henley, 1985).

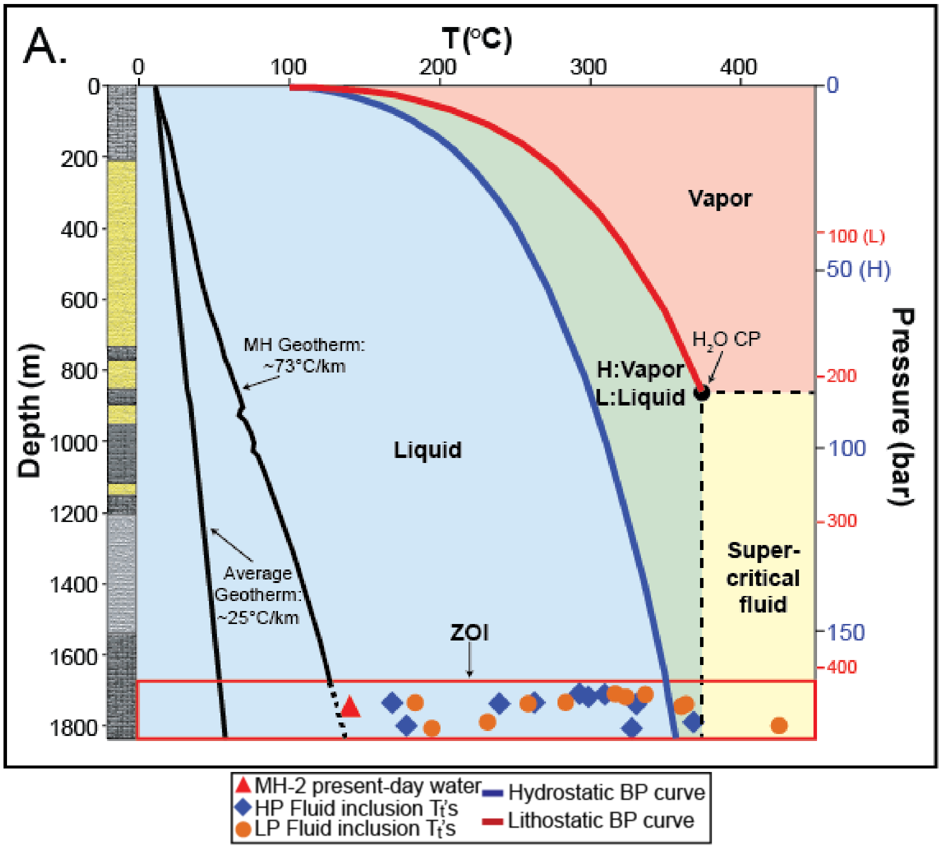

Figure 4: A-Hydrostatic and lithostatic boiling point curves (BPC) and water phase diagram for the entire MH-2B core; HP represents hydrostatic pressure conditions and LP represents lithostatic pressure conditions. Note the proximity of the high temperature fluid inclusions to the BPC.

5.2 Benefits of Slimhole Drilling for Resource Assessment

Slimhole drilling for geothermal resource assessment has many advantages over traditional production hole drilling. It reduces uncertainty in geothermal development as it improves understanding of reservoir quality, size, productivity, and sustainability (Nielson and Garg, 2016). This risk reduction comes primarily through collection of subsurface datasets such as in-situ mineralogy, fluid chemistry, and fault orientations, distribution, and geometries, among others. Nielson and Garg have shown that slimholes can be drilled and tested for ¼ of the cost associated with traditional production hole drilling. These cost savings, in addition to the knowledge gained from datasets gathered from core, helps to reduce the overall risk in the exploratory phases of geothermal exploration. This is done as more insight is gleaned into the geologic, thermal, and compositional characteristics of a geothermal system.

Had the MH-2B been drilled as a production hole and encountered lost circulation as it did, the data described in this report would not have been gathered and the evolution of the Mountain Home geothermal system would be largely unknown. Analyses such as those described in this paper, among many others, provided indispensable information to describe the geothermal system and have helped to create a more complete conceptual model of what lies beneath the western Snake River Plain.

6. CONCLUSIONS

Multiple geological and geochemical techniques are used to describe this fossil basalt-hosted geothermal system in the subsurface beneath the western SRP. Hydrothermal brecciation occurred early in the history of the system when temperatures were highest. Fluid inclusion microthermometry indicates that the temperature of the past hydrothermal was as high as 368 °C, consistent with the temperature stability of observed secondary mineralization. Boiling in the geothermal system may have occurred at the peak temperature and is supported by the presence of hydrothermal breccias and vapor-rich fluid inclusions. This boiling is interpreted to have occurred at depth and not near the surface due to evidence in the rock textures and fluid inclusions. This information into the evolution of the system was gained primarily due to the fact that it was drilled as a slimhole where subsurface samples allowed for in-situ observations and thermal considerations. Data such as these are indispensable in reducing risks of geothermal drilling and development.

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