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Evaluation of the Mountain Home AFB Geothermal System for the Play Fairway Project

[1]Dennis L. Nielson, [1]Trevor A. Atkinson, [2]John W. Shervais

[1]DOSECC Exploration Services, LLC, 2075 S. Pioneer Rd. Salt Lake City, UT 84104

dnielson@dosecc.com

tatkinson@dosecc.com

[2]Utah State University, Old Main Hill, Logan, UT 84322

john.shervais@usu.edu

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ABSTRACT

The initial geothermal drilling (MH-1) at Mountain Home Air Force Base (MHAFB) in Idaho was done between November, 1985 and July, 1986. That hole was drilled to a depth of 1342 m, and continuous core was collected below a depth of 305 m. The maximum temperature measured was 93°C at a depth of 1207 m, the maximum depth to which the temperature log was run. In 2012, we cored hole MH-2 into an active hydrothermal system at MHAFB, and much of our knowledge of the Mountain Home reservoir is a result of that drilling and subsequent studies of the fluid and rock samples. With the work that has been done on samples from MH-2, we are returning to the more limited published studies on MH-1 and using them to compile a more complete geologic model of the hydrothermal system. As we have emphasized in other papers on the Play Fairway analysis of potential reservoirs in the Snake River Plain, the geologic model and data that addresses critical aspects of the model provides the basis for exploration risk maps.

We have observed that the hydrothermal system encountered at 1745 m in MH-2 is hosted by a fault zone containing hydrothermal breccias. Indications are that the well penetrated the footwall of the fault below 1793 m, and temperature decreased. Analysis of fracturing in MH-2 suggests that the fault is steeply dipping (~80°) and has a strike of about 300°. Using this information, we have constructed a cross section that shows that the fault would intersect the surface about 325 m to the southwest of MH-2. There is a great deal of cultural disruption of the surface, and we have not identified surface faulting in the area. However, there was also extensive faulting documented in MH-1, and we hypothesize that this is part of the same hydrothermal fault intersected in MH-2. This conceptual model is the basis for siting another exploration hole that could be drilled and tested to confirm the viability of the resource.

1. INTRODUCTION

The assessment of hydrothermal reservoirs is a high-risk undertaking that requires control of costs while maximizing data collection (Nielson and Garg, 2016). Slim holes can be drilled at a fraction of the cost (~25%) of large diameter production wells and, contrary to common perception, they can be tested to provide critical reservoir engineering information (Nielson et al., 2017). Therefore, in contrast to temperature gradient holes, we are advocates of slim hole reservoir assessment drilling where holes are drilled into prospective reservoirs and are designed to be tested either by flowing to the surface or, if that is not possible, by injection.

The Mountain Home study area represents a blind high-temperature geothermal system that is not associated with any mapped faults or surface geothermal manifestations. Initial investigations of the resource were prompted by elevated geothermal gradient estimates (65ºC/km) determined from a wildcat oil well (Bostic 1A, 2949 m) drilled in 1973 at a location 20 km southeast of the town of Mountain Home (Figure 1). A deep (1342 m) geothermal exploratory well (MH-1) was drilled in 1986 (Lewis and Stone, 1988) as part of an effort to assess resources at the Mountain Home Air Force Base (MHAFB). A temperature of 93ºC logged at a depth of 1207 m, and an estimated thermal gradient of 69ºC/km, suggests that temperatures at depths in the range of 1500–1800 m are high enough to support binary cycle power generation that could meet the base's present maximum electrical power requirements of 14 megawatts (Breckenridge et al., 2012), and potentially provide power to the town of Mountain Home or supply power to the grid. Subsequently, a second deep (1821 m) well (MH-2) documented artesian flow and 135-140ºC water (Nielson et al., 2012) at a depth of 1745 m.

The stratigraphy at Mountain Home, constrained by core from the MH-1 and MH-2 drill holes (Figure 2), consists of an upper section of basalt (~150-200 m thick) overlying ~600 m of fine-grained lake sediments, and a basal sequence of basalts with minor sedimentary layers. The sequence of low-permeability lake sediments that overlie the geothermal system at Mountain Home likely help maintain the resource by insulating the reservoir, preventing upward migration of the thermal fluids, and inhibiting mixing with cold meteoric water that could degrade the resource (Shervais et al., 2016). MHAFB has had a longstanding commitment to supporting research of the base's geothermal resources that would make them an ideal partner in future exploration and eventual development of this resource.

2. PLAY MODEL CONCEPT

The Snake River Plain (SRP) in Idaho is a large basaltic province associated with the Yellowstone mantle plume, and is part of the largest heat flow anomaly in the USA (Blackwell, 1989; Blackwell and Richards, 2004). The eastern SRP represents the track of the Yellowstone hotspot – a deep-seated mantle plume that has remained relatively fixed in space as the North American plate moved to the southwest (Smith et al., 2009). As the plate moves over the plume, large silicic caldera complexes form. As the magma chambers beneath these calderas solidified and were able to sustain brittle fracturing, basalts were able to reach the surface and form the extensive lava flows that define the Snake River Plain surface geology.

High-resolution seismic imaging carried out over several decades has established the presence of a mid-crustal sill complex at 10-20 km depth (Smith et al., 2009; DeNosaquo et al., 2009). Geologic mapping and deep drill cores have documented the thickness and distribution of surface basalt flows. Basalt geochemistry shows that this sill complex comprises a series of layered magma chambers, which evolved by fractional crystallization and magma recharge, and fed surface eruptions (Shervais et al., 2006; Jean et al., 2014). Taken together, these data document a magma flux of ~10^4-10^5 km^3/Ma under the eastern and central SRP, with little or no extension perpendicular to its boundaries (e.g., Payne et al., 2012). This flux is similar to the one reported for Hawaii (10^5 km^3/Ma). Resurgent basalt volcanism (<800 ka, and as young as 2100 years BP) formed long after the plume passed, driven by back-flow of plume material to the west. These resurgent basalts are also plume-derived, postulated to result from delamination of subcontinental lithospheric mantle (Shervais and Vetter, 2009). Numerical models of thermal evolution during sill injection show that a single sill will result in heating of the surrounding rocks to over 300ºC after 20,000 years (Nielson and Shervais, 2014; Nielson et al., 2017); multiple sill injections will result in the continuous accumulation of heat as the ambient temperature of the host rocks is raised with each injection (Garg et al., 2017, in review).

3. RESERVOIR DESCRIPTION

Mountain Home region is characterized by high geothermal gradients and exhibits high geothermal potential on play fairway maps in areas associated with a gravity high that underlies the region (Shervais et al, 2017). The flanks of this structure are especially favorable because they likely represent large offset fault traces and associated fracture zones on the margins of an uplifted horst block. The lineaments that highlight these structures are defined by high gradients in the isostatic gravity anomaly, which delineate offsets in dense basaltic basement (Glen et al., 2017). In addition, young volcanic activity associated with the high-K transitional alkaline suite, which ranges in age from 519 ka to 355 ka locally, and as young as 2.1 ka <50 km north, implies deep magmatic intrusive activity, which provides a heat source for ongoing geothermal activity.

Most of what we know about the Mountain Home geothermal province comes from two geothermal test wells, MH-1 and MH-2, drilled in 1985 and 2012, respectively. These holes provide our best data on thermal gradients and heat flow, regional stratigraphy, subsurface structure, and water chemistry. Below we discuss these two wells in detail to characterize the geothermal reservoir.

2.1 MH-1

The initial geothermal drilling at MHAFB (MH-1) was done between November, 1985 and July, 1986 (Lewis and Stone, 1988). The hole was drilled to a depth of 1342 m with continuous core collected below a depth of 305 m (Figure 2). The maximum temperature measured in this hole was 93ºC at a depth of 1207 m, the maximum depth to which the temperature log was run.

The hole was drilled using air rotary methods to a depth of 305 m, and continuously cored below that to a total depth of 1342 m. The MH-1 hole was drilled through a stratigraphic sequence comprising an upper basalt layer, a central zone of lacustrine sediments, and a lower basalt zone (Figure 2). Beneath the upper section of basalt flows, lake beds were intersected at a depth of 137 m. The bottom of the lake section is located at 579 m depth, where Lewis and Stone logged a fault contact. Numerous other faults were mapped in the core between 570 and 1043 m.

Temperature with depth measurements from MH-1 indicate a thermal gradient of ~69ºC/km, Following drilling the well was airlifted and produced 132 L/min at a temperature of 45ºC.

2.2 MH-2

In 2012, we cored hole MH-2 into the hydrothermal system at MHAFB (Delahunty et al. 2012), and much of our knowledge of the Mountain Home reservoir is a result of that drilling and subsequent studies of the fluid and rock samples (Lachmar et al., 2012; Kessler et al., 2016; Atkinson, 2015). Having drilled MH-2, we are in a position to optimize future drilling and sampling.

MH-2 was cored to a depth of 1821 m (Figure 2). The hole was drilled through basalt flows to a depth of 200 m where it encountered lake beds to a depth of 740 m, 76 m downhole from those encountered in MH-1. The bottom of these sediments showed indications of hydrothermal alteration that led us to postulate that relatively impermeable lake beds form the seal on the hydrothermal system (Nielson et al., 2015). Below the lake section, the hole encountered sediments and basaltic flows and hyaloclastites before it intersected hydrothermal fluids at a depth of 1745 m. The fluids were contained by a fault zone, and core shows the presence of hydrothermal brecciation with associated calcite and minor amounts of quartz, pyrite and chalcopyrite (Nielson et al., 2012; Nielson and Shervais, 2014). Subsequent more detailed analysis of fluid inclusions (Atkinson, 2015) has demonstrated boiling conditions with maximum temperatures of 340ºC, consistent with boiling at that depth.

Kessler et al. (2016) reported on a comprehensive structural analysis of the lower part of MH-2 that included the fault that hosts the hydrothermal fluids. They concluded from the analysis that the fault hosting the hydrothermal fluid has a strike of 300º.

Although there has not been a comprehensive study of the hydrothermal alteration in MH-2, Walker and Wheeler (2016) have studied clay mineralogy below the lake beds. Smectite is pervasive in the core indicating hydrothermal alteration; however, in a zone from 1708 to 1793 m, corrensite is present. The transitions are abrupt, with no mixed-layer smectite-corrensite present. Smectite again dominates below this zone to TD. The significance of the return to smectite below 1793 m is that the borehole penetrated a cooler regime that we interpret as the footwall of the fault that controls the hydrothermal fluid flow.

There were a number of temperature with depth surveys run in the MH-2 hole (Figure 3; Nielson et al., 2012) and they demonstrate that there was circulation loss below the lake beds; although, there was never a complete loss until a depth of 1719 m (Delahunty et al. 2012). In particular, loss of circulation is prevalent within basalt and mixed sediment and basalt sections and less prevalent within lake beds and hyaloclastite sequences (Figure 3). Temperature with depth measurements from MH-2 indicate a thermal gradient of ~76ºC/km, very similar to that observed in hole MH-1. Fluids encountered in the fault at 1745 m flowed artesian to the surface at a rate of 42 L/min through 63 mm id NQ drill rod. Geochemical evaluation showed that this water was on a mixing line between meteoric and magmatic fluids (Lachmar et al., 2012).

4. GEOLOGIC RESERVOIR MODEL

To summarize, we have observed that the hydrothermal system encountered at 1750 m in MH-2 is hosted by a fault zone. Indications are that the well penetrated into the footwall of the fault below 1793 m and temperature decreased. Analysis of fracturing in MH-2 suggests that the fault is steeply dipping (~80º) and has a strike of about 300º. Using this information, we have constructed the cross section shown in Figure 2 that shows that the fault would intersect the surface about 325 m to the southwest of MH-2.

Figure 1 shows MHAFB with the locations of MH-1 and MH-2. Note that there is a substantial amount of cultural disruption of the surface, and we have not identified surface faulting in the area. The red line shows the projection of the fault between the MH-2 and MH-2 holes and suggests that it is also present in that hole. Our present thought is that the fault confines the geothermal system on the south. Given the similarity of the temperature profiles between MH-1 and MH-2, the length of the hydrothermal activity is likely >4.7 km. The question of the 3D geometry of the reservoir remains and will be tested in our subsequent drilling activities. We are recommending that a test hole be sited 500 to 1000 m to the northeast of the surface projection of the fault zone.

Figure 3 is an interpreted cross section of MH-2. The normal offset along the fault is based on the upper contact in MH-1. Also shown in Figure 3 are the temperature logs run in both wells. The T_{corr} values show temperatures recorded during the drilling operations. This shows the lake beds are relatively impermeable; however, in the basaltic sections below the lake beds, there is permeability as shown be cooler temperatures resulting from the penetration of drilling mud. During drilling, temperatures up to 150º C are inferred from temperature build up. However, these temperature have since cooled (PPS survey). We believe this to be a function of the well penetrating through the fault and entering a cooler footwall block.

5. DRILLING PROPOSAL

The resource reservoir at MHAFB is blind and likely located at depths of 1.5 to 2.3 km, based on the deep wells described above. Validating our assessment here will require drilling to intersect permeability, since the geothermal gradients are well-known and regional in extent.

Our plan calls for a 2100 m (~7000-foot) drill hole, cored below 1500 m (~5000 feet) to intersect the resource. The hole will be deviated in order to enhance probability of intersecting fractured reservoir, which consists of relatively steeply dipping, ~E-W striking faults. The objective of this well is to test our reservoir model and acquire geological and reservoir engineering information that will refine the information assembled from MH-1 and MH-2.

A successful well at this location would be significant because it would validate our conceptual model for blind geothermal systems in the western Snake River Plain of Idaho. This could lead to a new era of geothermal exploration in SW Idaho, and to its application to other regions with similar geologic settings.

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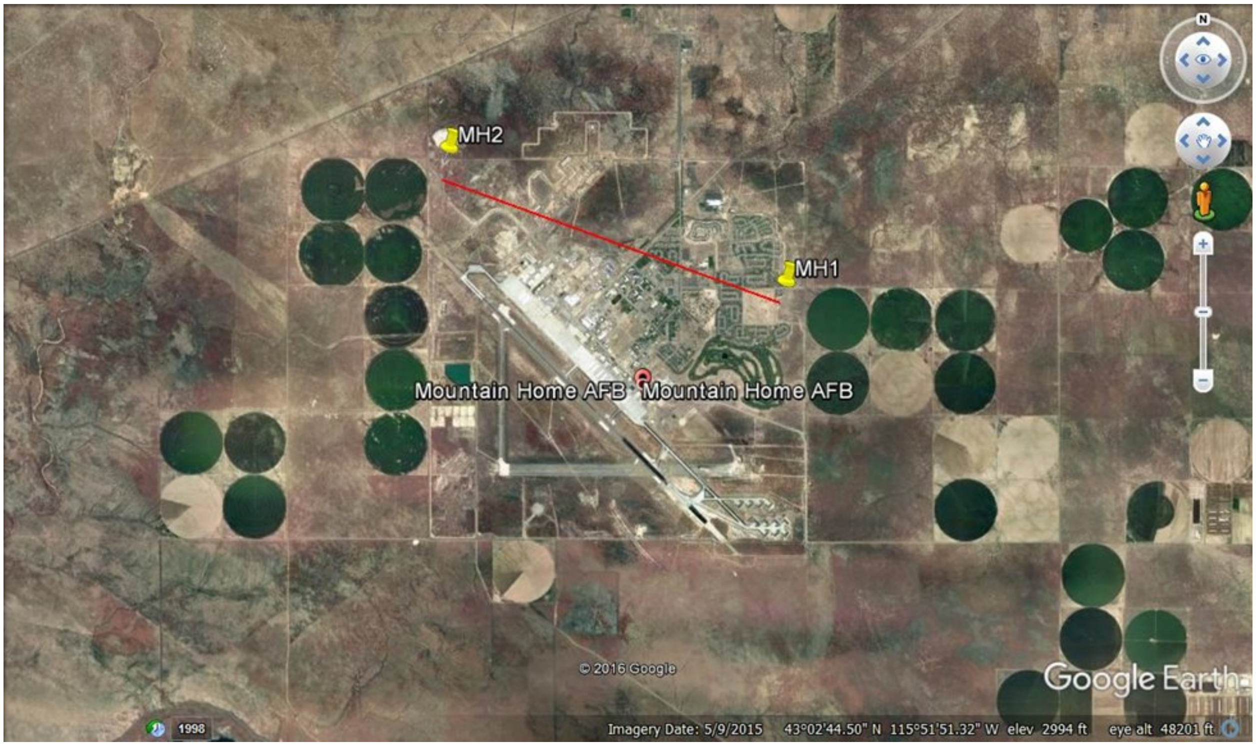

Figure 1. Image of Mountain Home AFB showing the locations of MH-1 and MH-2. The red line shows the surface projection of the hydrothermal fault penetrated by drilling in MH-2 that is also consistent with lithologic logging of MH-1 (Lewis and Stone, 1988).

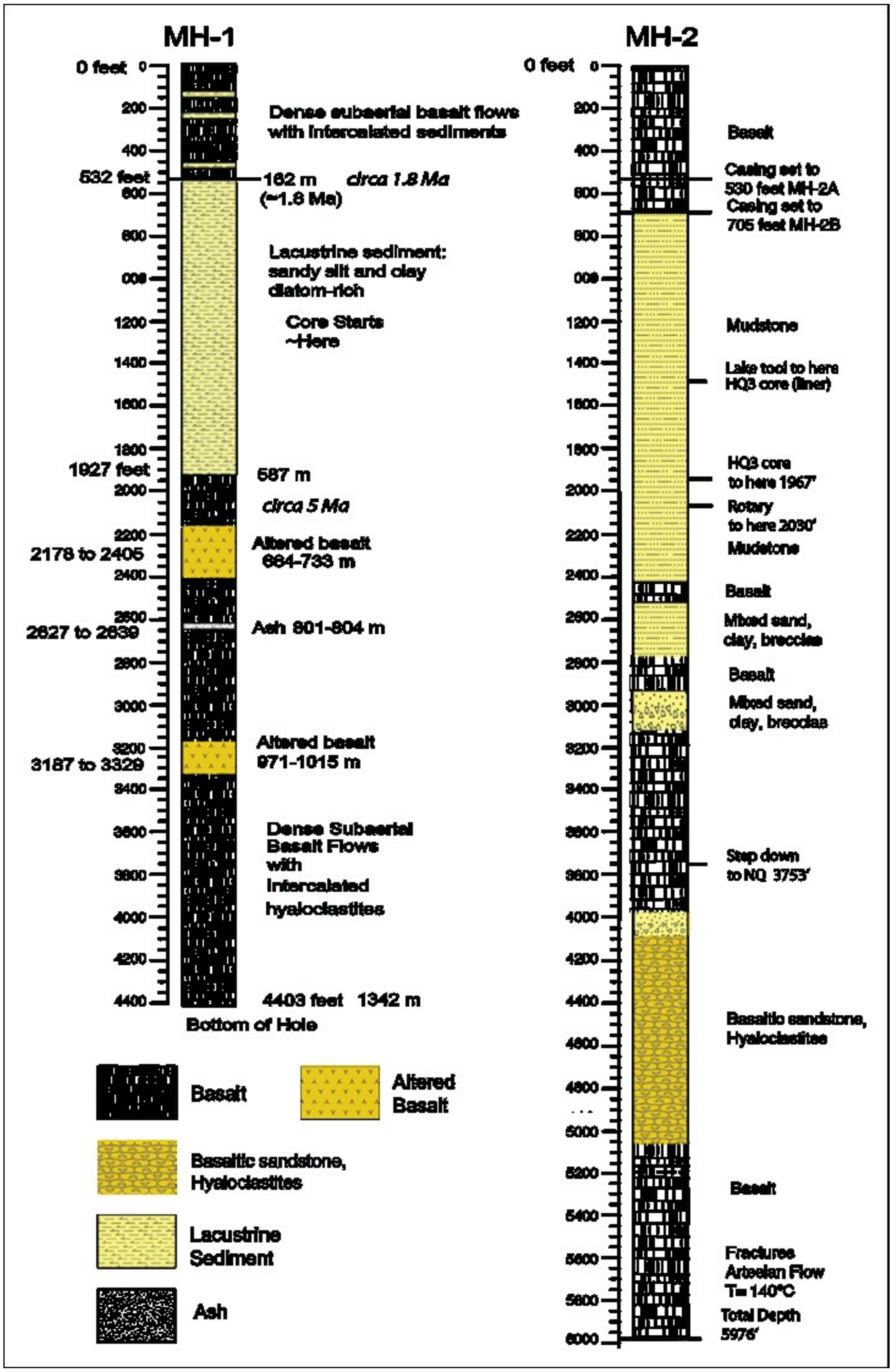

Figure 2. Lithologic logs of MH-1 and MH-2.

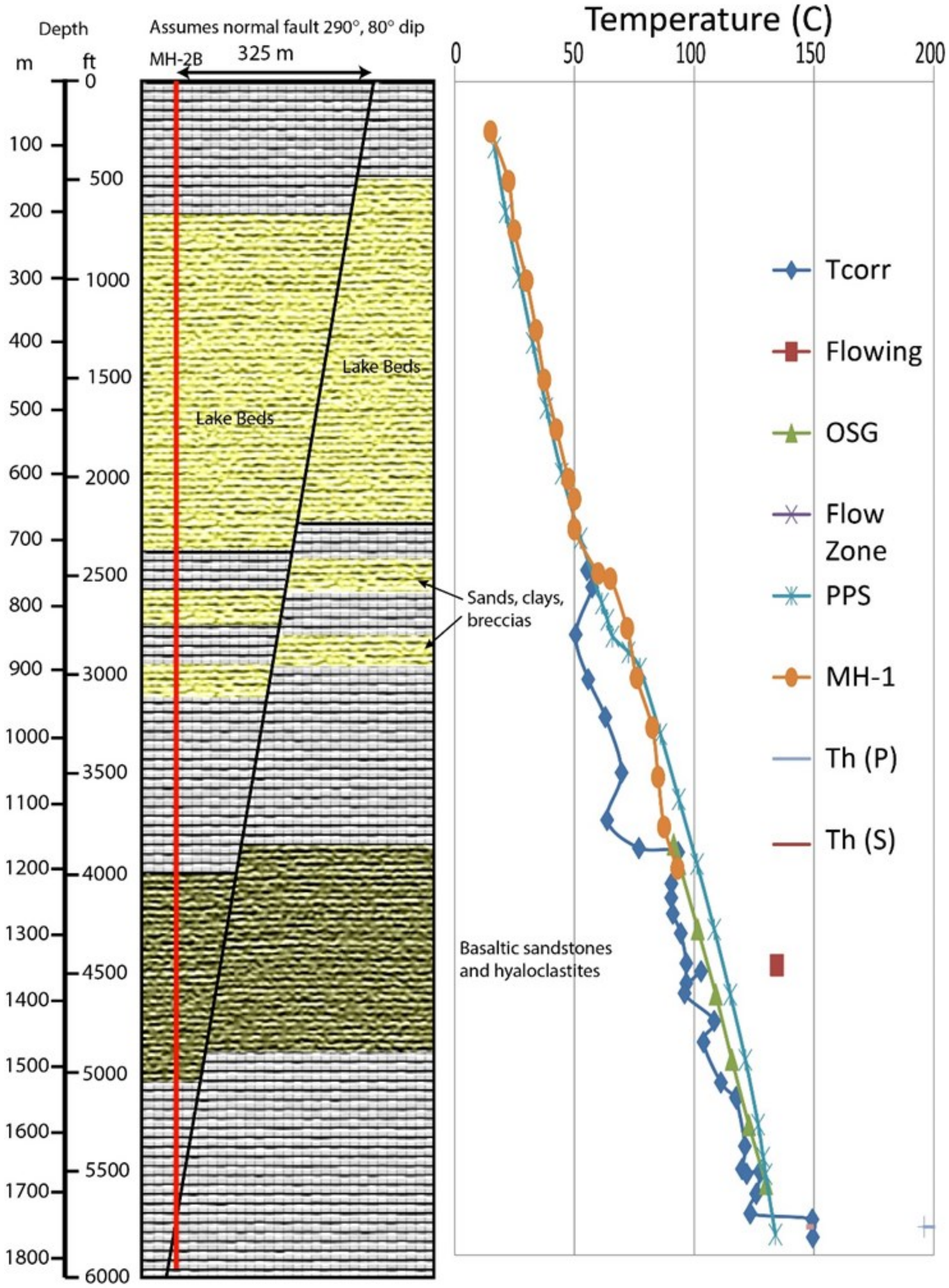

Figure 3. Interpreted cross section of Mountain Home 2 drawn perpendicular the hydrothermal normal fault that strikes about 290°. Temperature profile is from Nielson et al., 2012. The T_{corr} measurements were taken during drilling operations and the PPS values are equilibrated temperatures.

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