Structural Controls on the Geothermal System at Gerlach, Washoe County, NV

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ABSTRACT

The Gerlach geothermal system, located at the southern end of the Granite Range in the southwestern Black Rock Desert in northwestern Nevada, is characterized by boiling springs and siliceous sinter. This high-temperature system is associated with the termination of an east-dipping, range-bounding fault system. However, upwelling may be controlled by additional structures locally. Detailed geologic mapping and shallow temperature surveys for this study suggest at least two zones of upwelling that may be attributed to fault intersections and/or a small step in the range front. Integration of more data will further constrain the specific structural controls on this geothermal system.

Introduction

Although the geologic requirements for geothermal activity are well understood, the specific controls on individual systems are commonly not obvious. In the Basin and Range, two interrelated problems with characterizing discrete systems include distinguishing between upwelling and outflow zones and determining the structures along which fluid flows. Upwelling may occur on blind faults, hidden beneath the surface, and lateral outflow may result in surface geothermal features that are spatially removed from their source fault systems. Furthermore, geothermal systems are commonly complicated by a combination of controlling structures. A complete understanding of the surface and subsurface relationships is necessary to develop the resource efficiently.

There are several possible controlling structures for the high-temperature geothermal system located at Gerlach in northwestern Nevada (Figure 1). The system, expressed on the surface as a set of hot springs, is in the southern portion of the Black Rock desert, along the east edge of the southern termination of the Granite Range. Detailed characterization of the structural setting at Gerlach will provide a basis for possible development, as well as aid in understanding controls on geothermal systems within the Great Basin.

This paper presents a preliminary interpretation of controlling structures on the Gerlach geothermal system. First, we present background information on requirements and settings for geothermal systems. This is followed by the tectonic and regional geologic setting of the Gerlach area, as well as a synthesis of previous work and geothermal exploration in the Gerlach area. After providing this background information, we present our observations from the area in terms of geologic mapping, kinematic...
data, and shallow temperature data. These new observations are
then integrated with the previous work in a discussion section, and
a preliminary conclusion on the structural control(s) is presented.
It should be noted that this a progress report, not a completed
structural assessment of the area.

Background
Geothermal Systems

There are three necessary criteria for the occurrence of geother-
mal activity. The first of these is heat (Blackwell, 1983). The high
heat flow of the Basin and Range provides the heat necessary for
geothermal activity. Another requirement of a geothermal system
is fluid. Fluid must be present to be heated and to transport heat
upward. The third criterion is permeability. In the Great Basin,
faults commonly provide the permeability that allows the heated
fluid to flow toward the surface (Faulds et al., 2006).

Geothermally heated fluid rises from the reservoir along
upwelling zones, and flows laterally as outflow where upwelling
zones intersect porous valley fill closer to the surface. Although
faults control upwelling, the surface manifestations of geothermal
activity commonly occur as outflow that does not reflect the posi-
tion of the permeable structure (Richards and Blackwell, 2002).
Faults along the upwelling are commonly blind because valley fill
obscures the faults. Upwelling geothermal fluids stop at the water
table and do not extend to the surface (Figure 2). For this reason,
springs and other geothermal surface features can be misleading
in locating upwelling zones. It is therefore important to determine
subsurface controls in order to accurately locate upwelling zones.

Certain structural settings seem to be distinctly favorable for
the occurrence of geothermal activity, particularly within the
northern Basin and Range Province. Some of the most common
settings include fault step-overs, fault intersections, and fault
terminations (Figure 3) (Faulds et al., 2006). These are settings in
which permeability is enhanced along fracture zones away from
the major segment of the fault. Dominant settings appear to vary
geographically within the northern Basin and Range (Cashman
et al., 2012). Furthermore, the controlling structure is not always

apparent, and commonly a combination of structures governs the
system (e.g. Coolbaugh et al., 2006; Faulds et al., 2006; 2010;
2011; Dering and Faulds, 2012).

Geologic Setting

The tectonic setting of the Great Basin accounts for the high
occurrence of geothermal activity. The Basin and Range is an
extensional province characterized by thinned crust, high heat
flow, and active normal faults. These interrelated characteristics
lend themselves to a geothermally favorable environment (Faulds
et al., 2004).

The northwest Basin and Range Province hosts the highest
volume of geothermal systems and is the most active area of
the province tectonically (Faulds et al., 2012). Extension rates
are estimated at 2-5 mm/year (Hammond and Thatcher 2005),
which results in abundant faulting and an increase of pathways
through which fluid can flow. This active west-northwest exten-
sion is evidenced by Quaternary faults, expressed as scarps and
north-northeast-striking mountain ranges and valleys. Gerlach
lies at the southern end of one of two typical northwestern Basin
and Range fault zones.
The geology of the Gerlach area consists of four main lithologies: Permian-Triassic metavolcanic and metasedimentary rocks, Cretaceous granitic rocks, late Oligocene-early Miocene volcanic rocks, and Quaternary sedimentary deposits (Grose and Sperandino, 1978). The Permian-Triassic basement rocks are exposed at the northern end of the Granite Range. Cretaceous granodiorite comprises much of the Granite Range. These granodiorites are heavily jointed and fractured. Late Oligocene-early Miocene rocks represent a complex history of volcanism and range from silicic to basaltic in composition. These rocks only crop out in the northern part of the Granite Range. Quaternary deposits in the area include pre-Lahontan alluvial fan deposits, Lahontan lacustrine deposits, post-Lahontan alluvial fans, active alluvial fans, and playa and eolian deposits (Faulds and Ramelli, 2005).

The Granite Range is bounded by a north-northeast-striking, east-dipping normal fault on the east side and a north-west-striking, west-dipping normal fault on the west side (e.g. Olmsted et al., 1975; Grose, 1978; Faulds and Ramelli, 2005). These faults have been active in Quaternary time, as they offset the Cretaceous rocks and cut some Quaternary deposits.

The geotherm system at Gerlach is marked by considerable surface expression of both active and inactive systems. There are two sets of hot springs: Great Boiling Springs, located to the east of Granite Point, and Mud Springs, located just southeast of Granite Point (Figure 1). The geochemical character of the springs in terms of water chemistry is the same, and geothermometry indicates reservoir temperatures over 175° C (Anderson, 1979). Siliceous sinter deposits around Great Boiling Springs are consistent with the geothermometry data. A topographic “bench” of altered granodiorite between Great Boiling Springs and the range front (Figure 4) represents an inactive geothermal system (Romberger, 1978). The exposed remnant system displays propylitic alteration that is common to many high-temperature systems (Romberger, 1978).

Observations

Reconnaissance and air photo mapping of the Gerlach area for this study refined delineation of geologic units and constrained ages on fault segments. High shorelines from Lake Lahontan are visible on the range front but are obscured by younger drainages and alluvial fans in many places. The eastern range front fault cuts these alluvial fans, indicating that it must be <13,000 years old (Adams and Wesnousky, 1999).

A topographic bench on the east flank of the southernmost Granite Range (Figure 4) is a remnant geothermal system. Features of the remnant geothermal system were mapped in detail because they may be analogous to features of the currently active geothermal system. Near-vertical to east-dipping veins of chalcedony and calcite occur in two main orientations. The veins are primarily north-northeast-striking, and there is a secondary set of northwest-striking veins. Bench-front joints are largely north-northeast-striking with a steep eastern dip. Black line indicates location of joints and the inferred bench-front fault. Red lines show the range-perpendicular lineaments of interest discussed in the text.

Figure 4. Altered granodiorite “bench” shown in Figure 1 and orientations of structures within. Veins are oriented near-vertical with a primarily north-northeast strike and a secondary set of northwest-striking veins. Bench-front joints are largely north-northeast-striking with a steep eastern dip. Black line indicates location of joints and the inferred bench-front fault. Red lines show the range-perpendicular lineaments of interest discussed in the text.
Spring temperatures measured from the surface, though more directly related to outflow, can provide some constraints on locations of upwelling. The surface geothermal expression at Great Boiling Springs is at a relatively low elevation, which is consistent with a result of outflow. However, spring temperatures are as high as 94° C. While geothermometry estimates are much higher, temperatures this high at the surface suggest that the springs are relatively near the upflow zone. Temperature measurements also revealed two very hot areas separated by tens of meters of colder water (Figure 5), which may represent upwelling of hot water along two different structures.

A reconnaissance shallow temperature survey at 2 m depth was designed to test several hypotheses for the structural control of the geothermal system. One traverse parallels the range front, west of Great Boiling Springs (Figure 6). Three thermal areas can be identified from the data. 1) One anomalously hot zone is located at the very southeastern end of the range (Figure 6). It is fairly high topographically. It is uphill of, and appears to be associated with, Mud Springs. 2) The other thermal anomaly is located near a small eastward step in the rangefront (Figure 6). It is northwest of, but not directly uphill of, Great Boiling Springs. It is also fairly high topographically, although somewhat lower than the first anomaly. 3) A zone of colder shallow temperatures separates the two thermal anomalies. This area lies directly across the range-perpendicular lineaments.

Discussion

Distinguishing between upwelling and outflow can be difficult, and the geothermal features at Gerlach are no exception. The hot springs and geothermometry in the Gerlach area indicate the presence of a very hot geothermal reservoir at depth. However, the springs occur in topographically low areas, which is typical of outflow features. Furthermore, while the surface temperatures of the springs are generally very hot, temperature estimates from geothermometry are much higher. There are several possibilities for what may be controlling the system at depth.

Surface expression of the geothermal system occurs on the east side of the range, slightly north of the southern termination of the Granite Range. For this reason, this study focused on reconnaissance mapping and surveying on the east side. Faults here are very young (<13,000 ka), and recent movement along faults creates more permeability.

There appear to be at least two zones of upwelling at Gerlach. The shallow temperature survey was designed to test the distribution of shallow temperatures specifically across the area directly uphill of the springs, which is where the set of joints crosses the range. The survey yielded the coldest temperatures in this area. From this, we can effectively rule out any interaction of hot water with the joint set. Additionally, the upwelling on either side of the cold zone must be along different structures.
One anomalously hot zone is located at the southeastern tip of the Granite Range (Figure 6). Permeability here could be enhanced by a number of things. The oppositely dipping range front faults appear to intersect just south of here. There is also the possibility of an east-west-striking fault across the end of the range. This fault could intersect one or both of the range-bounding faults, enhancing permeability locally.

The other anomaly is located along an eastward step on the eastern side of the range (Figure 6). This anomaly could be associated with enhanced permeability from small stepover features. It could also be associated with the range-perpendicular lineament at the boundary if the step. Detailed field mapping in progress will test these possibilities.

The exposed geothermal system in the altered bench of granodiorite indicates the presence of a synthetic fault east of the eastern range-bounding fault. The orientation of this fault, as well as orientations of veins within the bench, suggests that a WNW-ESE extension direction contributed to the development of this geothermal system.

Conclusions

The surface expression of geothermal activity at Gerlach occurs at the termination of the range, where two fault zones intersect. This has led previous workers to interpret it as both a fault termination-controlled system and a fault intersection-controlled system (Faulds et al., 2006). However, upwelling-likely occurs on a more complex combination of structures within these two. The springs occur on the eastern side of the range where there are multiple faults and a small right step, and on a more local scale, there are several possibilities for what may be controlling the geothermal system structurally.

This study has helped constrain the structural interpretation of the geothermal system at Gerlach. Faults along the upwelling are Holocene in age. Upwelling occurs along the eastern side of the range in at least two separate places. Complexity of faulting related to the termination of major faults creates zones of enhanced permeability that facilitate upwelling.

Ongoing work is focusing on developing a detailed structural model for the Gerlach geothermal system. Continued geologic mapping, more shallow temperature surveys, and integration of geophysical data will aid in modeling and interpreting the subsurface.

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