Evidence for the Structurally Controlled Deposition of Hot Spring and Fumarolic Minerals at the Humboldt House, NV

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Keywords

Humboldt House, Nevada, hyperspectral, remote sensing, hot spring, fumarole, Basin and Range, fault, sinter, mineral mapping, permeability, fluid flow

ABSTRACT

The presence of a geothermal reservoir at the Humboldt House, NV has been known due to the outcrops of hotspring and fumarolic deposits in the Humboldt River Valley. Formally mapped in 1983, their distribution does not suggest a structurally controlled deposition, so the mechanism of deposition is unknown. In order to map the complete distribution of hotspring and fumarole deposits at the Humboldt House, NV and to constrain the mechanism of deposition we applied remote sensing techniques linked with field observations. HyMap hyperspectral imagery was acquired at the Rye Patch-Humboldt House geothermal district for its ability to detect hydrothermally associated minerals due to its high spatial and spectral resolution. Using the HyMap imagery, mineral distribution maps were made for the Humboldt House area, and the results were validated in the field using a hand-held spectrometer. Remote sensing methods revealed a more abundant distribution of hot spring and fumarole deposits in the Humboldt River Valley, and their N-NE trending linear distribution implies a structurally controlled deposition. Overlying all Lake Lahontan deposits, the hot spring outcrops can be constrained to Holocene in age, and represent the most recent faulting expressions in the Rye Patch-Humboldt House geothermal district. The fault conduits that initially brought geothermal fluids to the surface have since sealed and the hot springs are no longer active.

Introduction

The Humboldt House geothermal reservoir is located in the northern region of the Rye Patch – Humboldt House Geothermal district of the Northern Basin and Range province (NBR), adjacent to the northwestern flank of the Humboldt Range in the Humboldt River Valley (Figure 1). Extension along large range-bounding normal faults has resulted in a crustal thickness of 25-28 km in this part of the NBR, and an estimated overall extension of 100-300% (Catchings, 1992,

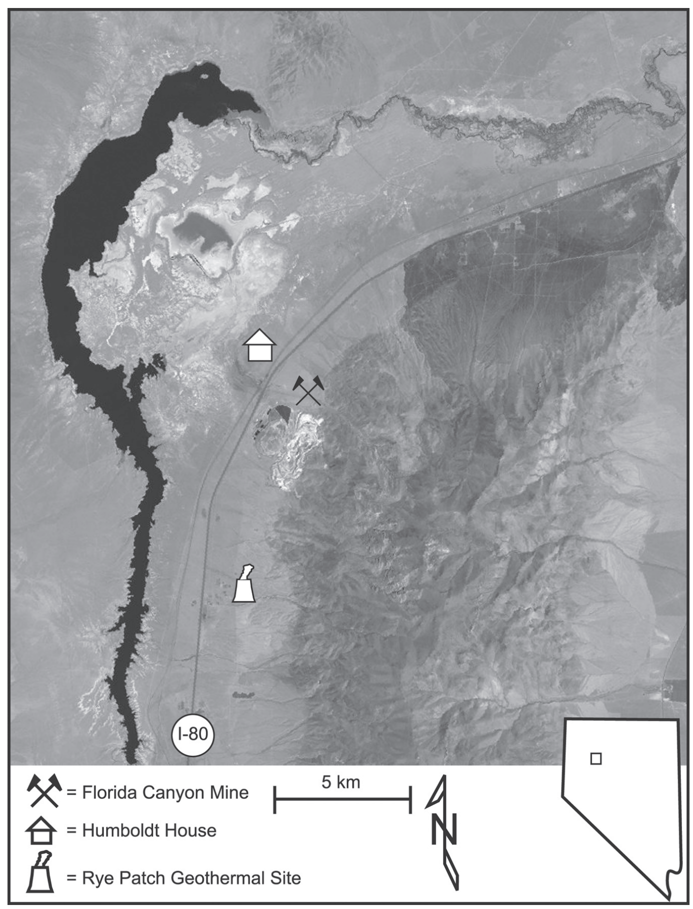

Figure 1. Outlines the general area of the Rye Patch-Humboldt House Geothermal District, and the location of the Humboldt House within it. The location of the Rye Patch-Humboldt House Geothermal District in Nevada is highlighted in the lower right portion of the figure.

Zoback et al., 1981, Proffett, 1977, Wernicke, 1992). Crustal thinning in the NBR has brought hot mantle material close to the Earth's surface, which has resulted in the Battle Mountain Heat Flow Anomaly (>100 mW/m^2), and a high geothermal gradient (Waibel et al., 2003). The combination of extensional faulting and high heat flow suggest that this area has potential for geothermal resources.

Exploration and Development of significant geothermal prospects in this area began in the late 1970's with the Phillips Petroleum Company; currently Presco Energy LLC owns the geothermal leases in this area (Waibel et al., 2003). Initial recognition of a possible geothermal reservoir at the Humboldt House region was made from the outcrops of hot spring and fumarole deposits, which overlie all Lake Lahontan deposits. The hot spring and fumarole deposits were formally mapped in 1983 by Jonathan Davis. However, their distribution from his maps do not suggest that these deposits are structurally related, and due to his focus on mapping Lahontan lacustrine deposits many hotspring mounds could have been overlooked. Exploration holes have been drilled in the Humboldt House region, and these wells show high temperature gradients and high shallow temperature measurements (Waibel et al., 2003). Shallow temperatures around 200-250º F have been identified in these wells, and are postulated to be laterally flowing groundwater plumes (Waibel et al., 2003).

High temperature fluids were also identified in drill holes at the Florida Canyon Mine. The mining pits are bisected by the range-front fault, which is assumed to be the conduit for high-temperature fluids. The laterally flowing groundwater plumes detected in the valley are unlikely to have the range-front fault as their source, because that would suggest the fluids traveled horizontally for 3 km along a permeable boundary. Another possibility is that these fluids migrated up faults in the valley and then traveled horizontally along a permeable horizon. To date there has only been one small fault splay mapped in the valley, but the presence of sinter and laterally flowing hydrothermal plumes suggests the possibility of significant faulting within the Humboldt River Valley that is controlling the deposition of hot spring and fumarolic minerals.

To map the distribution of fault zones and the surface distribution of hydrothermal alteration minerals along them, we applied remote sensing and field-based methods at the Humboldt House in the NBR. Identifying fault and fracture patterns and the associated hydrothermal minerals will provide knowledge of the zones of high permeability that could be exploited for geothermal energy. Mapping the mineralogy patterns along these faults will give direct indications of which fault segments have been hydrothermally active.

Geologic Setting

The sedimentary sequences in the Humboldt River Valley are up to ~2,600 m thick and contain lacustrine, alluvial, and fluvial deposits (Johnson, 1977). Basement rocks within the valley are Mesozoic marine sediments (Johnson, 1977). The sedimentary sequence is largely unknown due to lack of exposure and boreholes. A thick sequence of lake sediments was deposited during the Lake Lahontan high stand in the Pleistocene.

After the lake dried up deposition changed to fluvial and alluvial, with interfingering of the two taking place at the edges of the basin. Most recent Holocene deposition has been hot spring deposits and dune sand. The hot spring deposits consist of sinter at the base and capped by travertine, which is starting to erode away. Aeolian sands now drape the flanks of these hot spring deposits and overlie the rest of the Quaternary sediments.

Remote Sensing Imagery

HyMap hyperspectral imagery was chosen for this project for its ability to detect hydrothermally associated minerals due to its high spatial and spectral resolution. On June 1 & 2, 2003, HyMap data was acquired at the Rye Patch/Humboldt Range field area. The acquisition consisted of 19 north-south flight lines covering 500km^2, and spanning latitudes 40º 40' to 40º 28' and longitudes 118º 8' to 118º 28'. HyMap is flown at 2000 to 5000 meters above ground level. It has 126 contiguous spectral bands spanning the visible/near-infrared (VNIR) to the short-wave infrared (SWIR) (0.46-2.5µm), with an average bandwidth of 0.015µm. The spatial resolution varies between 3-5m depending on the flight elevation and the elevation of the target being imaged. Images produced are generally 2.5km wide based on the 2.5mr IFOV, and are of variable length depending on the goals for acquisition.

Imagery Analysis

The HyMap data were processed using the RSI commercial software package ENVI. This software allows the user to discriminate and map the distribution of mineralogy within spectral images using a variety of different algorithms. The data was spectrally subset to the NIR and the SWIR range and spatially subset to regions that are 1.6km wide and 3 – 6km long. Algorithms embedded in ENVI were used to focus spectrally on the most pure endmembers that could be used for identification and mapping. These spectral endmembers were identified using the Spectral Analyst in ENVI, and were mapped using the Spectral Angle Mapper algorithm and the Mixture Tuned Matched Filter algorithm. Through this process a mineral distribution map was made for the Humboldt House.

We made two field excursions to the Humboldt House field area to obtain field spectra as a ground truth for the mineral mapping, field-check the fault maps, and to obtain geologic field observations. We used an ASD Field Spec Pro and located points with GPS. The ASD Field Spec Pro is a handheld spectrometer with 2150 bands spanning a spectral range of 0.35-2.5µm.

Results

Mineral mapping was focused over a 4 km x 8 km area located northwest of the Florida Canyon Mine and east of the Humboldt River. The distribution of hot spring and fumarolic minerals like sinter, travertine, gypsum, and hematite are mapped over the Rye Patch/ HRV area and specific areas of interest were then targeted for field investigation (Figure 2). We discovered four previously unmapped faults in the Humboldt River Valley. These faults lie west of Interstate 80 and trend 10º at their southern extent, but curve to a 30-40º trend as they continue north (Figure 2). They are inferred to continue north of the Humboldt House with a trend of 50 degrees. The four faults are mapped by the linear distribution of hot spring and fumarolic deposits in the valley, and by exposed young escarpments. The sinter mounds are located approximately 2km west of the range-front fault along the northwestern flank of the Humboldt Range. At this location along the Humboldt Range, the range-front fault strikes 10-20 degrees and dips 70 degrees to the west. Many of the sinter deposits are elliptical with their long axis N-S (Figure 2). Other smaller hot spring deposits are aligned with these larger outcrops along a N-NE trend.

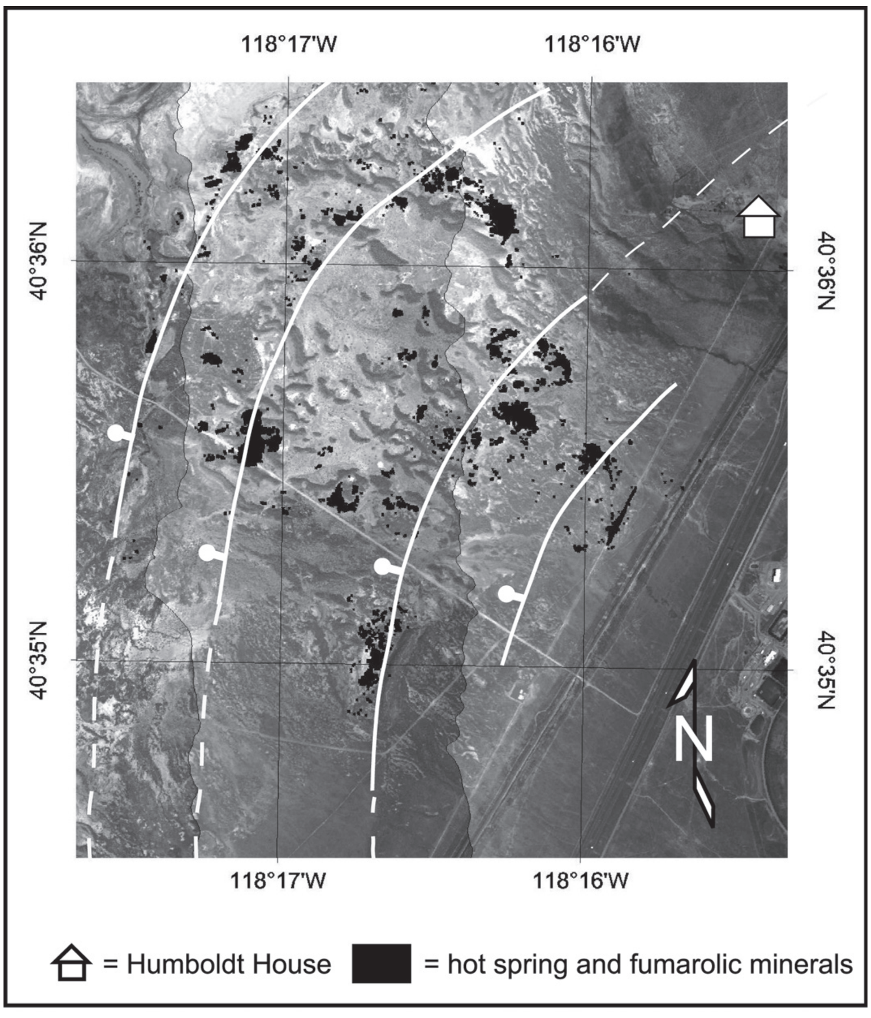

Figure 2. Displays the location of hot spring and fumarolic minerals in the Humboldt House region, and the newly discovered N-NE trending normal faults. The location of the Humboldt House is highlighted for orientation from Figure 1.

Field spectra confirmed the presence of minerals mapped with the airborne imagery and revealed interesting geologic relationships. Many of the hot spring deposits are elliptical and are approximately 3-10m tall. They range in composition from silicified sediments at the base, bulk sinter sheets in the center, and mixed sinter and travertine bedding at the top. In some cases the hotspring deposits are overprinted by fumarolic deposits such as gypsum, hematite, and jarosite.

Discussion

The surface distribution of hot spring & fumarole deposits in the Humboldt House represents the recent expression of the geothermal reservoir at depth. Their linear distribution implies structurally controlled deposition, where fluids rich in silica were migrating to the surface along a series of four faults (Figure 2). During or immediately following seismic events these conduits became highly permeable and allowed fluids from the geothermal reservoir to reach the surface (Lutz et al., 2002). They overlie early Holocene lacustrine deposits and represent the most recent expressions of Quaternary faulting in the Rye Patch-Humboldt House geothermal district.

The sinter mounds that were identified as opal in the hyperspectral mineral mapping suggest reservoir temperatures of >200 ºC (Adams et al., 2000). Gypsum and hematite associated with some sinter outcrops represent a shift from an active hot spring to an active fumarole. This shift indicates subsurface boiling and a decrease in vertical fluid flow probably caused by fault sealing. Based on field evidence from the Humboldt House we propose a model for the evolution of the hot spring mounds (Figure 3, overleaf). During a seismic event, fault permeability increased and fluids from the geothermal reservoir were brought to the surface along structurally controlled conduits. This vertical fluid flow resulted in cemented lacustrine sediments, and vertically built hot spring mounds. As vertical fluid flow continued the fault-conduit began cementing and vertical permeability was reduced, resulting in a decrease of vertical fluid flow and enabling boiling to occur near the surface. Fumarolic minerals were then deposited, overprinting previous hot spring deposits. Eventually the cementing of the conduit reached a critical depth and the hot spring was completely shut off.

Conclusion

Surficial hot spring and fumarolic deposits at the Humboldt House in the Humboldt River Valley were structurally deposited along a series of four faults, which were active post Lake Lahontan (Figure 2). The complete distribution of these deposits and their correlation with recent faulting was previously unmapped. Our work suggests that the recent Quaternary faulting within Rye-Patch – Humboldt House geothermal district was focused in the Humboldt River Valley, rather than along the range-front fault. The age of these deposits can also be constrained to Holocene (<10,000 years). Seismic activity in the Holocene

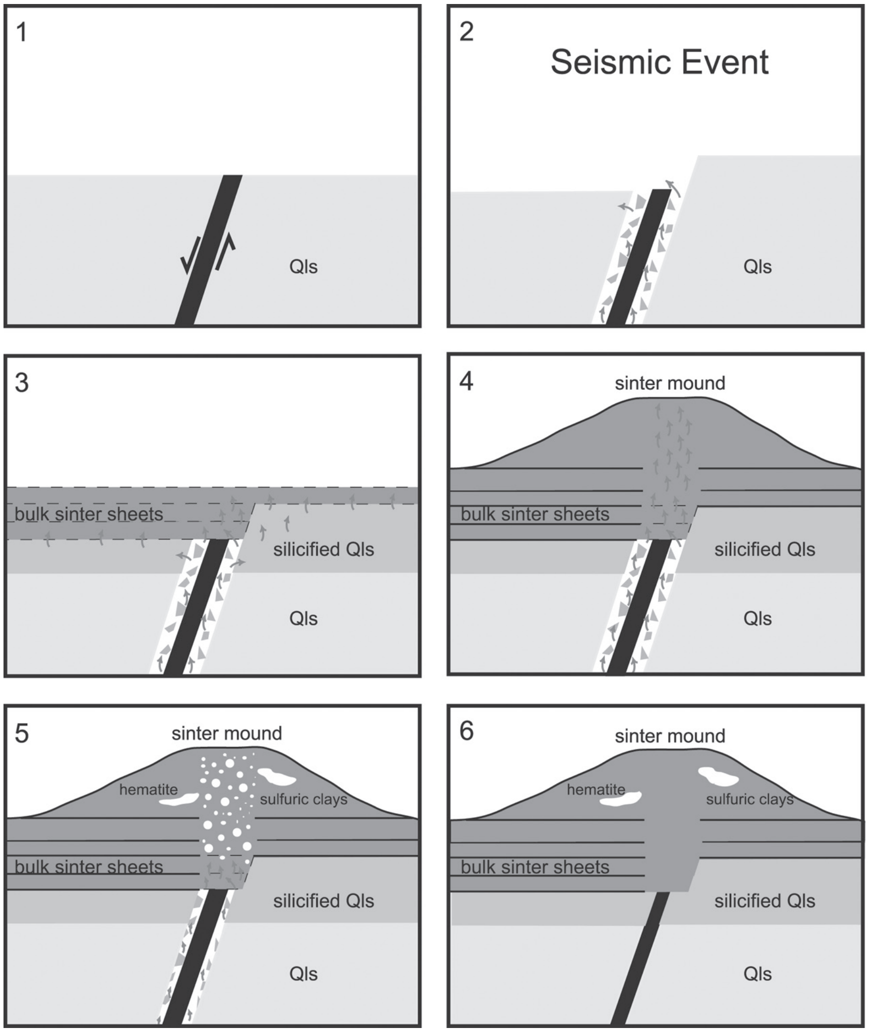

Figure 3. Illustrates the proposed time series model for the evolution of hot spring mounds in the Humboldt River Valley. 1=Time Step 1, where a normal fault exists in lacustrine sediments. 2=Time Step 2, during a seismic event vertical permeability increases and geothermal fluids rise to the surface. 3=Time Step 3, geothermal fluids rise through lacustrine sediments thereby cementing them and begin to deposit horizontal sinter sheets. 4=Time Step 4, geothermal fluids continue to migrate vertically up the fault and a hot spring mound forms. 5=Time Step 5, the fault conduit begins to seal and the amount of hydrothermal fluids reaching the surface decreases, therefore resulting in boiling below the surface and transition to a fumarole. 6=Time Step 6, the fault completely seals and the fumarole is completely shut off.

created permeability along the faults, thereby allowing fluids from the geothermal reservoir to reach the surface (Figure 3). Those conduits have since sealed at the surface, but are still permeable at depth, which explains the existence of the laterally flowing discharge plumes.

The motion of the faults in the valley is currently assumed to be normal, but both displacement and sense of motion are difficult to document on older fault scarps in unconsolidated sediment. In the summer of 2005 we will acquire LiDAR data, which will provide high vertical (15cm) and horizontal (.5m) resolution. We hope that this imagery will help to constrain the motion on the faults in the valley and to display the current deformation patterns.

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