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Geothermal exploration using imaging spectrometer data over Fish Lake Valley, Nevada ☆

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ABSTRACT

The U.S. currently leads the world in installed geothermal capacity with power plants in eight states, and exploration for new electrical-grade geothermal systems is ongoing. Geothermal systems at depth may be identified at the surface by hot springs and fumaroles or by minerals produced by thermal fluids (hydrothermal alteration and hot spring deposits). Northern Fish Lake Valley, Nevada hosts two previously known geothermal fields. This study expanded prospects and identified new areas for future exploration within the valley. We demonstrated the potential for using remote sensing data to evaluate regions that are not well explored. We used visible, near, and shortwave infrared (0.4–2.5 μm) remote sensing data to map surficial mineralogy. Data were collected by three airborne imaging spectrometer instruments, AVIRIS, HyMap, and ProSpecTIR, each over different parts of Fish Lake Valley. Minerals were identified using diagnostic spectral features. We verified remote sensing results in the field using a portable spectrometer to confirm agreement between field and remote spectra.

The discovery of additional geothermal resources in Fish Lake Valley may provide the necessary added incentive to build costly transmission lines to this remote location. We used remote sensing data to delineate four new targets for future geothermal exploration in northern Fish Lake Valley. Two new areas of sinter and travertine deposits were identified northwest of the playa, likely deposited around fault-controlled hot springs during the Pleistocene when the water table was higher. Previously undocumented Miocene crystalline travertine was identified within the Emigrant Hills. Argillic alteration was mapped within ranges, where thermal fluids were likely discharged from faults to alter rhyolite tuff. Here we explain our data processing techniques which include a novel decorrelation stretch designed for geothermal prospecting, and discuss how remote sensing results guided our interpretation of the region's geothermal systems.

1. Introduction

Many geothermal systems are associated with magma bodies that supply heat (e.g., Yellowstone, Long Valley), however, most of the geothermal systems in Nevada are amagmatic. Amagmatic systems occur in extensional settings; meteoric water circulates along faults deep into the crust where it is heated (Wisian, Blackwell, & Richards, 1999). Ascending thermal water may result in hot springs or fumaroles at the surface, generally at favorable structural settings where faults step, splay, or intersect thus increasing fracture density (Faulds, Coolbaugh, Vice, & Edwards, 2006). Geothermal systems do not necessarily have hot springs and fumaroles at the surface; they may have only subtle surface expression including siliceous sinter, travertine, or tufa deposits, and/or hydrothermally altered rocks. Playas above a geothermal system may display borate or sulfate crusts. Vegetation may concentrate around fault-controlled springs or become stressed near faults leaking high concentrations of gasses such as SO_2, H_2S or CO_2. Many obvious geothermal systems in Nevada are currently exploited for energy production and there is increasing interest in the detection and understanding of “blind” geothermal systems without obvious surface features.

Fish Lake Valley in Esmeralda County, Nevada (Fig. 1) was selected for geothermal exploration because of high temperatures in drill holes, the presence of Quaternary borates, and young displacements along nearby faults. The northern part of the valley is a pull-apart basin opened where the dextral strike slip Fish Lake Valley fault zone (FLVFZ) makes a right step into the central Walker Lane via the Emigrant Peak fault zone (EPFZ) (Reheis & Dixon, 1996). Some work has been done to define two geothermal prospects in the region: the Emigrant and Fish Lake Valley prospects (Fig. 1). Surface expression of the geothermal systems are limited and spatial extents poorly constrained. The Fish Lake Valley prospect includes a cement tub of hot water piped from a deep well but no natural hot springs or fumaroles. The prospect is associated with localized deposits of siliceous sinter and travertine. The Emigrant prospect includes a small abandoned sulfur mine, a small fumarole, argillic alteration near faults, limited silicification, and some quartz and calcite veining (Hulen, Nash, & Deymonaz, 2005).

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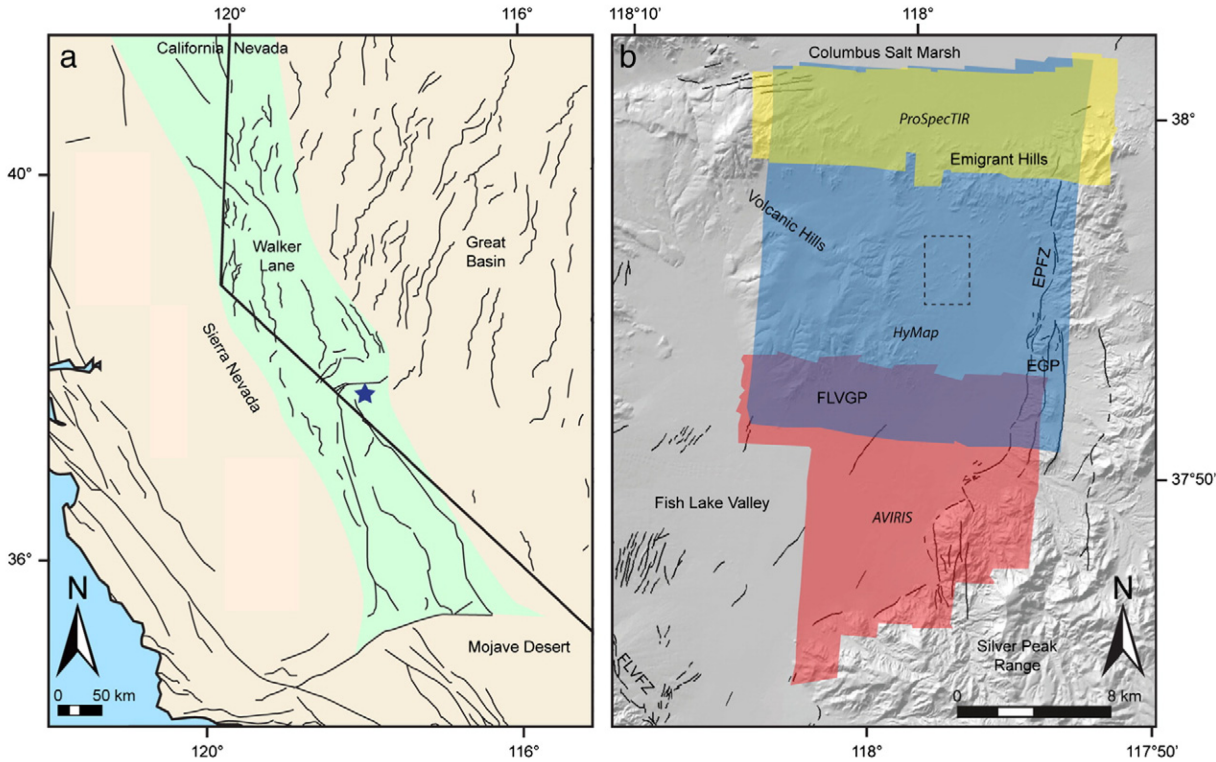

Fig. 1. (a) Regional fault map; orange shows the Walker Lane and the blue star shows the location of northern Fish Lake Valley (Figs. 1b, 3). (b) Hillshade of northern Fish Lake Valley showing local faults. Yellow shows ProSpecTIR data coverage, blue shows HyMap data coverage, and red shows AVIRIS data coverage. Dashed box shows the location of Fig. 2. FLVGP, Fish Lake Valley geothermal prospect; EGP, Emigrant geothermal prospect; FLVFZ, Fish Lake Valley fault zone; EPFZ, Emigrant Peak fault zone.

Developing geothermal resources for electricity production requires expensive transmission lines. Fish Lake Valley's remote setting has prevented development at either the Fish Lake Valley prospect or Emigrant prospect thus far because ~50 km of transmission lines would be required (Hulen, Nash, Deymonaz, & Schriener, 2005). The discovery of additional geothermal resources in the region may facilitate development by providing added incentive to build transmission lines.

Remote sensing may be used to remotely identify and map mineralogy based on spectral signatures of materials in the visible to shortwave infrared region of the electromagnetic spectrum (0.4–2.5 μm). Imaging spectrometer data have previously been used to identify and map surface expression of other Great Basin geothermal systems (Kratt, Calvin, & Coolbaugh, 2005; Kratt, Calvin, & Coolbaugh, 2006; Kratt, Coolbaugh, Peppin, & Sladek, 2009; Kratt, Calvin, & Coolbaugh, 2010; Kratt, Sladek, & Coolbaugh, 2010; Kratt, 2011; Martini, Silver, Pickles, & Cocks, 2003; Martini, Hausknecht, & Pickles, 2004; Silver et al., 2011; Vaughan, Calvin, & Taranik, 2003). In this study, we used imaging spectrometer data to map geothermal deposits and argillic alteration within northern Fish Lake Valley, and identified areas as targets for future geothermal exploration.

2. Background

2.1. Geothermal indicator minerals

Many minerals are associated with geothermal systems, but the most commonly remotely sensed geothermal indicator minerals in Great Basin geothermal fields include alunite, kaolinite, opal, calcite, muscovite, montmorillonite, chlorites, gypsum, and tincalconite. Alunite can indicate alteration of potassium feldspars as a reaction with sulfuric acid or it may form from fumarolic activity. Kaolinite may be a product of argillic alteration of feldspars, a low temperature reaction which may result from acidic thermal fluids moving through the rock, or chemical weathering. It also forms in shallow steam-heated or fumarolic environments where rising steam condenses and/or mixes with shallow groundwater. Opal is an amorphous silica gel deposited in low temperature environments; it may fill fractures or form siliceous sinter deposits surrounding hot springs. The presence of sinter is of particular relevance in geothermal exploration because significant sinter deposits typically do not form unless the thermal waters have been at temperatures greater than 180 °C at depth because of the enhanced solubility of silica at high temperatures. Calcite (or aragonite) can be an important geothermal indicator as it may represent travertine and tufa deposits. Hot springs with Ca-rich water precipitate travertine as the water is depressurized subaerially (Pentecost, 1995) whereas tufa is deposited when Ca-rich spring water reacts with CO_2-rich lake water (Benson, 1994). Muscovite and montmorillonite may be related to geothermal activity or weathering and cannot be used as decisive indicators of hydrothermal alteration. Chlorites may be a product of propylitic alteration of amphibole, pyroxene, and biotite. Gypsum and tincalconite are evaporites deposited by sulfur- and borate-rich springs, respectively.

2.2. Regional geology

Geothermal systems in the Great Basin are strongly controlled by local fault structure. Understanding of regional tectonics allows for structural understanding and therefore better exploration at the local scale. East–west directed extension is typical in the Great Basin, however, the Walker Lane, along the western edge of the region (Fig. 1a), is characterized by northwest-trending dextral faults (Stewart, 1988; Wesnousky, 2005). The Mina deflection is a belt of east–northeast-trending sinistral faults within the central Walker Lane (Wetterauer, 1977). The Mina deflection is expressed as a right step in a dextral fault system, a displacement transfer that formed pull-apart basins including northern Fish Lake Valley.

Bounding Fish Lake Valley to the west is the FLVFZ with a lateral slip rate of 5 mm/yr since ca. 10 Ma, or about half the shear transferred from