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Remote sensing of geothermal-related minerals for resource exploration in Nevada

Wendy M. Calvin[a,*], Elizabeth F. Littlefield[a], Christopher Kratt[b]

[a] *Great Basin Center for Geothermal Energy, University of Nevada, Reno, MS 172, 1664 N. Virginia St., Reno, NV 89557, United States*
[b] *Zonge International, 9595 Prototype Court, Reno, NV 89521, United States*

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ABSTRACT

We use remote sensing data from a variety of satellite and airborne instruments to characterize mineral and thermal properties as surface indicators of geothermal resources in Nevada. We generally use satellite data as a reconnaissance tool to target higher resolution airborne data collections. Spectral data are collected from field surface locations and samples to validate remote identifications and refine mineral maps. Spectral validation is done using an ASD portable spectrometer (0.4–2.5 μm) in both field and lab configurations. We also have a Thermo/Nicolet Nexus 6700 FTIR spectrometer and shared use of a Designs and Prototypes FTIR field instrument for thermal infrared data collection. Past work has identified sinter, tufa, travertine, argillic hydrothermal alteration minerals, evaporites, vegetation concentration near springs, and thermal anomalies as indicative of resource potential and structural controls on fluid pathways. Our methodology places mineral maps into GIS databases with other geologic information to make comparisons and site assessments. We recommend target areas for subsequent exploration including shallow temperature measurements, detailed geologic mapping, and structural analyses. This paper reviews over a decade of remote sensing geothermal exploration in Nevada and summarizes the common and unique features identified by our surveys.

1. Introduction

Spectrally resolved remote sensing imagery has been used over a number of volcanic, active hydrothermal, and geothermal sites for temperature, structure, and mineral mapping. For example, Kruse (1999) compared the mineral mapping abilities of AVIRIS data collected in 1995 and 1998, and identified opaline sinter terraces and areas of alunite and kaolinite in data collected over Steamboat Springs, Nevada. Hellman and Ramsey (2004) used ASTER and AVIRIS to examine hot spring deposits in Yellowstone National Park. Vaughan et al. (2012) later used ASTER and MODIS data to estimate radiant heat flux at Yellowstone. Martini et al. (2003) used HyMap data to map hydrothermal alteration within the Long Valley Caldera, California. Silver et al. (2011) combined LiDAR data with imaging spectrometer data over the Humboldt-Rye Patch geothermal field.

For over a decade our group has used remote sensing data for geothermal exploration, focusing on sites within Nevada that have strong potential for electrical power production from modest to high-temperature systems at depth. We generally use satellite remote sensing data in combination with other existing geologic data to define targets for higher resolution, more expensive, airborne surveys. We have refined techniques to make remote sensing an efficient and effective way to do preliminary geothermal exploration over large areas of the Great Basin, western US. We have used these techniques on more than seven geothermal fields in Nevada, and have plans to continue to refine our methods and expand our data coverage (Fig. 1).

Geothermal systems in the Great Basin (a hydrologic province incorporating portions of the western states of Idaho, Utah, Oregon, California and most of Nevada) are generally amagmatic; water heated by deep circulation within the crust ascends along fault pathways produced by regional extension (Wisian et al., 1999). Hot springs and fumaroles may be surface indicators of a geothermal system, however blind geothermal systems may have very little or no surface expression at all. Our work indicates that remote sensing data can be used to identify both obvious and more subtle surface expressions of geothermal systems, including sinter deposits, evaporites, and hydrothermal alteration. We collect data in the field to

* Corresponding author at: Department of Geological Sciences and Engineering, University of Nevada, Reno, 1664 N. Virginia St., MS 172, Reno, NV 89557, United States. Tel.: +1 775 784 1785.
E-mail address: wcalvin@unr.edu (W.M. Calvin).

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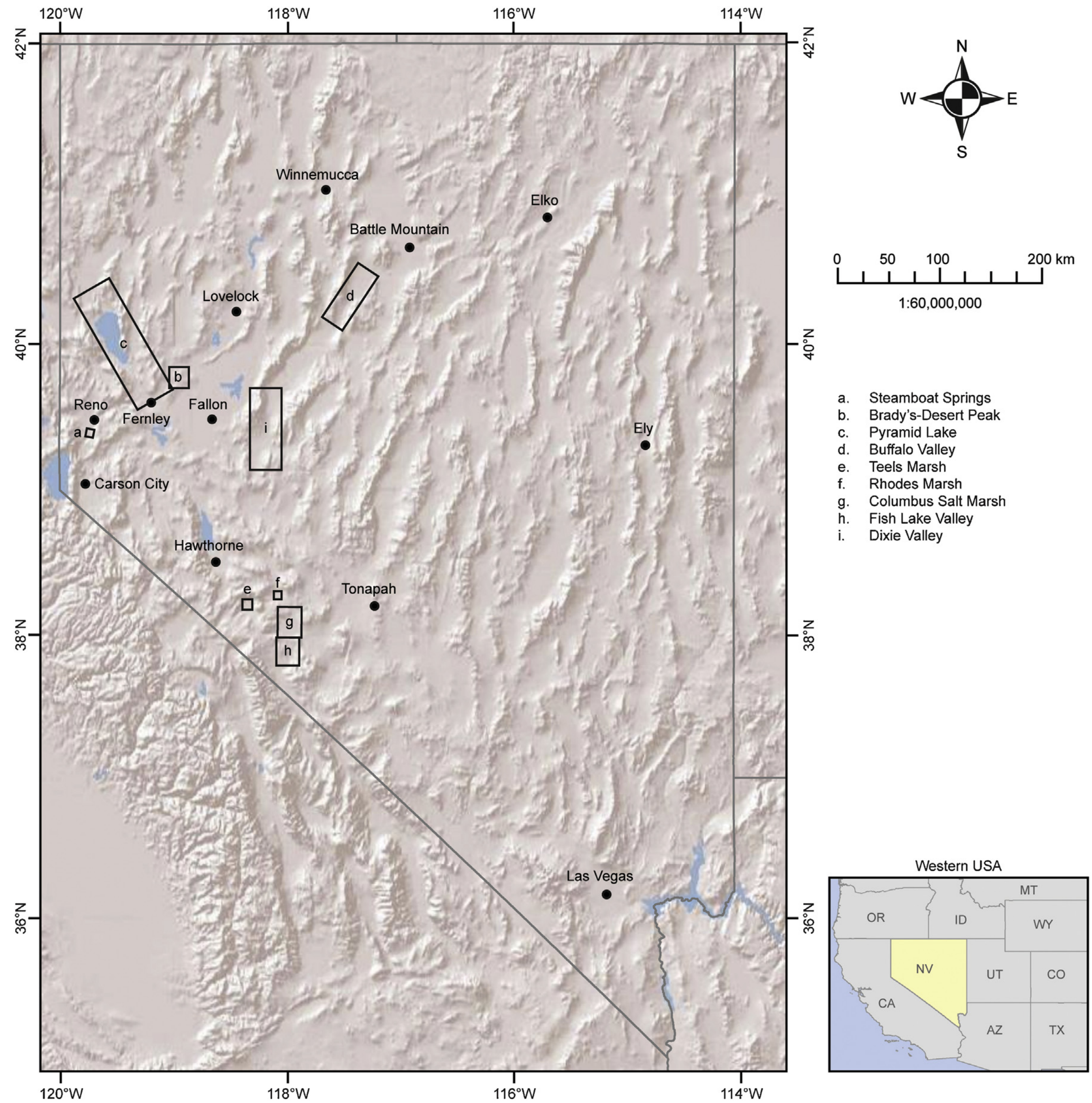

Fig. 1. Map of Nevada showing the locations of geothermal fields studied using remote sensing data.

confirm identifications made using satellite and aerial sensors. Field and lab measurements corroborate our detections and help refine mineral maps.

Although many of our techniques are similar to those used for other geological remote sensing applications, we have refined some for specific geothermal purposes and Basin and Range geology. We have also accumulated a working library of geothermally significant spectral signatures, including alteration minerals, hot spring deposits, and evaporites.

2. Background

2.1. Mineral spectroscopy overview

Many minerals have unique and diagnostic spectral properties, and features such as the band center, strength, shape, and width are used to identify species with high confidence. Both laboratory and remote sensing spectral data are commonly divided into wavelength ranges based on the cause of absorption features and the atmospheric windows through which the Earth's surface can be measured.

In the visible, near infrared, and short-wave infrared (VNIR/SWIR) (0.4 to ~2.5 μm), moderate and low-temperature surfaces are sensed due to the sunlight they reflect. Absorption features arise due the electronic orbital configuration of transition metals (generally iron or copper) in various crystallographic sites and from the combination and overtones of molecular vibrations from species such as hydroxyl, water, carbonate, and sulfate. This region of the electromagnetic spectrum is most sensitive to iron oxides, oxy-hydroxides, and ligands resulting from high- or low-temperature alteration (Clark et al., 1990). This region is especially useful for discrimination among sheet silicate (clay) minerals as well as argillic versus propylitic alteration. The former is dominated by kaolinite and smectite group minerals (montmorillonite, illite) and the latter by chlorite, epidote, and carbonate. In addition, opaline silica is determined by features arising from inclusion of water in the amorphous structure. The ready discrimination of these minerals has been the basis for the use of the technique in economic mineral exploration (e.g. Thompson et al., 1999) as well as our own work in geothermal exploration.

The thermal infrared (TIR), typically 7–14 μm for terrestrial remote sensing, is so called because it senses the heat energy