Hyperspectral Mineral Mapping for Geothermal Exploration on the Pyramid Lake Paiute Reservation, Nevada

Chris Kratt, Wendy Calvin and Mark Coolbaugh

Great Basin Center for Geothermal Energy, University of Nevada, Reno

Keywords

Geothermal, hyperspectral, remote sensing, gypsum, carbonate, clay, spectral, vegetation, warm springs, faulting patterns

ABSTRACT

Over 2000 km^2 (772 mi^2) of 5 m resolution Hymap hyperspectral data was acquired over the Pyramid Lake Paiute Reservation in the Fall of 2004. Subsequent image processing and data analysis has identified reflectance spectra for alunite, kaolinite/halloysite, illite, gypsum, vegetation, and carbonate. A portable spectrometer is being used for in situ validation, along with laboratory measurements and X-ray diffraction analyses of samples collected in the field. We are in the process of producing and validating mineral maps that will be used to narrow the scope of exploration to areas where mineral and vegetation distributions suggest the possible presence of geothermal activity. So far, remotely-sensed gypsum anomalies have led to the identification of at least two previously unknown groups of warm and hot springs. These springs are thought to occur where sulfate-rich groundwater is mixing with calcium in the soil and being precipitated as an evaporite crust.

Introduction

The Pyramid Lake Paiute Reservation is located in west-central Nevada, Washoe County and is about 60 km east of Reno (Figure 1). The lake itself covers over 315 km^2 (122 mi^2) and the remainder of the reservation is over 1574 km^2 (608 mi^2). Elevations range from less than 1158 m (3800 ft) at lake level, to over 2493 m (8180 ft) in the surrounding mountains. Geothermal exploration began at Needles Rock on the north end of Pyramid Lake in the 1960s but at the time temperatures were not high enough for production. More recently, Department of Energy funding has prompted a complete assessment

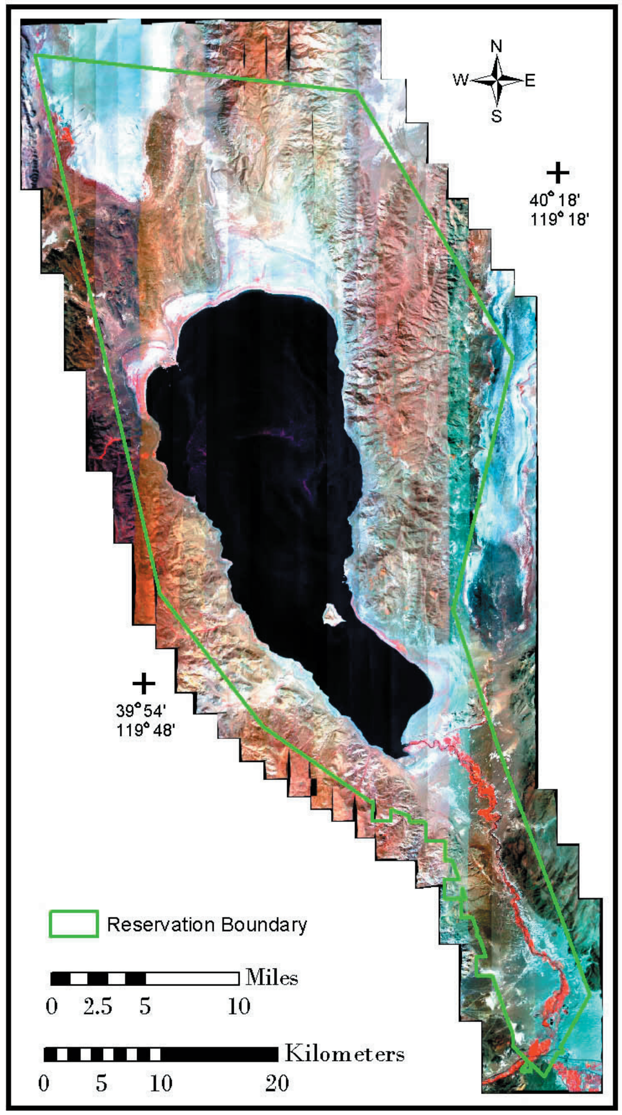

Figure 1. Color composite image showing the Pyramid Lake Hymap data coverage.

of geothermal potential on the reservation. This work includes hyperspectral remote sensing to identify and map geothermal-related minerals and vegetation. The reflectance spectra of minerals and vegetation display diagnostic absorption features in the 0.4-2.5 μm wavelength region (Hunt, 1977). The Hymap (hyperspectral mapper) sensor scanned the terrestrial surface while flown aboard a Twin Otter aircraft and made spectral measurements in the 0.4-2.5 μm region. Our objective was to apply image processing techniques to the Hymap data to 1) locate and map areas with unique geothermal identifier minerals 2) make structural interpretations and focus more detailed field work.

Spectroscopy and Remote Sensing Background

Geothermal-related minerals such as iron oxides, clays, sulfates and carbonates display diagnostic absorptions in the 0.4-2.5 μm range of reflected light (Clark, 1999). Spectral measurements in this range are commonly made with laboratory and field spectrometers, in addition to airborne and spaceborne imaging spectrometers deployed for mineral identification and exploration over large areas (Goetz et al., 1983; Green et al, 1998; Rowan et al., 2003). Recent work has applied this technology specifically to geothermal exploration. Martini (2002 and 2004) and Kratt (2005) used Hymap data (http://www.hyvista.com) to recognize mineral distributions related to structurally-controlled upwelling geothermal fluids. The Hymap instrument uses 127 contiguous channels to resolve mineral and vegetation spectra in the 0.45-2.5 μm range for each image pixel. The altitude at which the instrument is flown can be adjusted to attain between 2 and 10 m spatial resolution. At 5 m spatial resolution for this data set, each flightline was approximately 2.2 km wide. Twenty-six overlapping flightlines of varying length were required to cover the entire reservation.

Geologic Background

The Walker Lane Belt (WLB) is a system of northwest-striking right-lateral faults that generally parallel the eastern side of the Sierra Nevada Mountains. The WLB presently accounts for 15-25% of motion between the North American-Pacific Plates (Thatcher et al., 1999). Offset in the southern WLB is between 50-100 km and decreases to ~20-30 km in the northern Walker Lane where the study area is located. It has been proposed by Faulds et al. (2005) that this disparity in offset is caused by the transfer of strain to northeast-striking left-lateral faults that extend into the Basin and Range and are associated with a concentration of high-temperature geothermal systems.

Neotectonic faults on the Pyramid Lake reservation are characteristic of transfer of strain relationships in the northern Walker Lane. The northwest-striking right-lateral strike-slip Pyramid Lake fault trace extends over 45 km and shows evidence of at least four different earthquake events in the past 15 ka (Briggs and Wesnousky, 2004a). The Olinghouse fault is a northeast-trending left-lateral strike-slip fault that can be traced for 25 km and has ruptured at least twice in the past 4 ka (Briggs and Wesnousky, 2004b). Also on the reservation are normal range-front faults in the southern end of the Smoke Creek desert and Winnemucca Dry Lake, but have received little attention to date.

These faults displace Tertiary basalts, ash-flow tuffs, and lacustrine deposits. Furthermore, numerous tufa (calcium carbonate) mounds, some tens of meters tall, stand where structurally controlled spring water once mixed with the waters of late-Pleistocene Lake Lahontan (Benson, 1994) . Located at the north end of the lake, hot springs around northwest-trending tufa mounds were the focus of geothermal exploration in the 1960s. Temperatures at depth did not exceed 116° C (242° F) and further exploration on the reservation was not extensively pursued (Geothermal Development Associates, 1988).

Methodology

Nearly all pixels in a hyperspectral data set are linear spectral mixtures of pure substances or "end-member" spectra, each weighted by their areal abundance. A "shakedown" of the entire data set is necessary so that pixels occupied by "end-member" materials can be identified; these pixels are spectrally distinct and may represent unique geothermal identifiers. This process requires a multi-step image processing approach described by Kruse (1999) and performed separately on each of the twenty-six flightlines. Those spectra of interest were then treated using Mixture-Tuned Matched Filtering (Boardman et al., 1995) from which respective minerals maps were produced, based on both qualitative and quantitative analyses. Mineral map overlays were then combined with other spatial data in a geographic information system (GIS) database and evaluated for structural relationships related to fluid flow. A portable spectrometer was used to validate our mapping results both in the field and in the laboratory; these measurements were then backed up by X-ray diffraction analyses of samples taken from several field locations.

Initial Results

Salt and sulfate minerals are widely distributed on most playa surfaces and they typically appear white to the human eye, due to their spectral similarity at visible wavelengths. These minerals have been found in 3 broad locations in the study area: Winemmucca Dry Lake, Southern Smoke Creek Desert, and the south end of Pyramid Lake. The Short Wave Infrared (SWIR) portion of the spectrum from 1.0-2.5 μm is capable of distinguishing some playa minerals. Figure 2 shows reference library spectra of gypsum, thenardite and halite, all of which are found in the study area. Gypsum is a known indicator of geothermal activity in a steam-heated environment, as documented by Kratt (2005) at the Bradys geothermal system in Churchill County, Nevada. Field inspections show that gypsum crusts at Pyramid Lake form as evaporite minerals; and two of these occurrences were found to be associated with thermal springs. At one of these localities, the presence of remotely sensed gypsum encouraged us to investigate and subsequently discover a previously unknown warm spring with a temperature of 27°C. At another locality, a strong gypsum

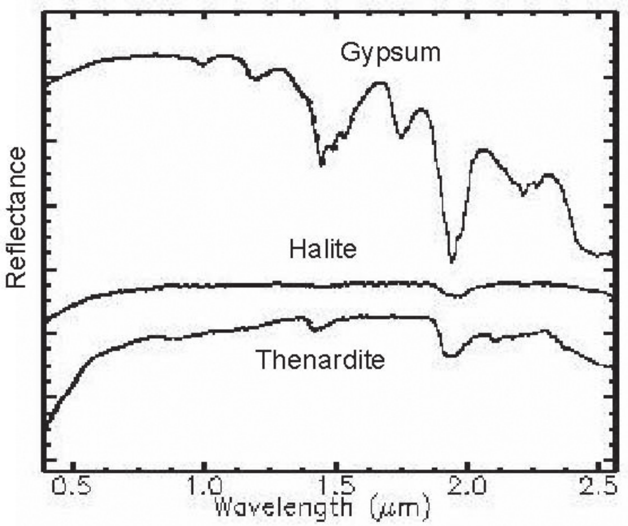

Figure 2. Reference library spectra for evaporite minerals occurring in the study area.

anomaly was used to help delineate the near-surface extent of what now appears to be a previously unknown high-temperature geothermal system.

Carbonate rocks that commonly occur as tufa were also mapped with the hyperspectral imagery. Alignments of tufa are being used to help recognize faults and other structures that control groundwater flow. Additionally, we have mapped alunite and argillic alteration which are likely associated with a mineralized Tertiary-aged porphyry system.

References

Adams, K. D., and Wesnousky, S. G., (1999). Isostatic Rebound, Active Faulting, and potential geomorphic effects in the Lahontan Basin, Nevada and California. GSA Bulletin, v. 111, n. 12, pp. 1739-1756.

Benson, L., (1994). Carbonate Deposition, Pyramid Lake Subbasin, Nevada: 1. Sequence of Formation and Elevational Distribution of Carbonate Deposits (Tufas). Paleogeography, Paleoclimatology, Paleoecology, v. 109, no. 1, p. 55-87.

Boardman, J. W., Kruse, F. A., and Green, R. O., (1995). Mapping Target Signatures Via Partial Unmixing of AVIRIS Data. *Proceedings of the Fifth JPL Airborne Earth Science Workshop*, JPL Publication 95-1 (1), p. 23-26.

Briggs, R. W. and Wesnousky, S. G., (2004a). Late Pleistocene paleoearthquake activity of the Olinghouse fault zone, Nevada. Bulletin of the Seismological Society of America, submitted June 2004.

Briggs, R. W., and Wesnousky, S. G., (2004b). Late-Pleistocene fault slip rate, earthquake recurrence, and recency of slip along the Pyramid Lake fault, northern Walker Lane belt, USA, Journal of Geophysical Research, doi: 10.1029/2003JB002717, in press 2004.

Clark, R. N., (1999). Spectroscopy of Rocks and Minerals, and Principles of Spectroscopy. Remote Sensing for the Earth Sciences: Manual of Remote Sensing, 3 ed., Vol. 3, p. 3-58.

Faulds, J.E., Henry, C.D., and Hinz, N.H., (2005). Kinematics of the northern Walker Lane: An incipient transform fault along the Pacific - North American plate boundary: Geology, v. 33, p. 505-508.

Geothermal Development Associates (1988). Pyramid Lake Paiute Tribe Needles Geothermal Power Plant: Phase I Feasibility Study. Prepared for Pyramid Lake Paiute Tribe. Geothermal Development Associates, Reno, NV.

Goetz, A. F., Rock, B. N., and Rowan. L. C., (1983). Remote Sensing for Exploration: An Overview. Economic Geology, v. 78, no. 4, p. 573-588.

Green, R. O., Eastwood, M. L., Sarture, C. M., Chrien, T. G., Aronsson, M., Chippendale, B. J., Faust, J. A., Pavri, B. E., Chovit, C. J., Solis, M., Olah, M. R., and Williams, O., (1998). Imaging Spectroscopy and the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS). Remote Sensing of Environment, v. 64, p. 227-248.

Hunt, G. R., (1977). Spectral Signatures of Particulate Minerals in the Visible and Near Infrared. Geophysics, v. 42, p. 501-513.

Kratt, C. B., (2005). Geothermal Exploration With Remote Sensing From 0.45 – 2.5 μm Over Brady-Desert Peak, Churchill County, Nevada. Masters Thesis, University of Nevada, Reno.

Kruse, F. A., Hungtington, J. F., and Green, R. O., (1996). Results from the 1995 AVIRIS Geology Group Shoot. Proceedings, 2nd International Airborne Remote Sensing Conference and Exhibition: Environmental Research Institute of Michigan (ERIM), Ann Arbor, v. I, p. I-211 - I-220.

Martini, B. A., (2002). New Insights Into the Structural, Hydrothermal, and Biological Systems of Long Valley Caldera Using Hyperspectral Imaging. Ph. D. Thesis, University of California, Santa Cruz.

Martini, B. A., Hausknecht, P., Pickles, W. L., and Cocks, P.A., (2004). The Northern Fish Lake Valley Pull-Apart Basin: Geothermal Prospecting with Hyperspectral Imaging. Geothermal Resources Council Transactions, v. 28, p. 663-667.

Rowan, L.C. and Wetlaufer, P.H., (1981). Relation Between Regional Lineament Systems and Structural Zones in Nevada: American Association of Petroleum Geologists, Bulletin, v. 65, n. 8, p. 1414-1432.

Rowan, R. C., Hook, S. J., Abrams, M. J., and Mars, J. C. (2003). Mapping hydrothermally altered rocks at Cuprite, Nevada, using the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), a new satellite-imaging system. Economic Geology, v. 98, no. 105, p. 1019-1027

Stewart, J. H., (1988). Tectonics of the Walker Lane Belt, western Great Basin; Mesozoic and Cenozoic Deformation in a Zone of Shear. Metamorphism and crustal evolution of the Western United States. Ernst, G. W., editor, Rubey Volume, vol.7, p.683-713

Thatcher, W., Foulger, G. R., Julian, B. R., Svarc, J., Quilty, E., and Bawden, G. W., (1999). Present-day deformation across the Basin and Range province, western United States. Science, v. 283, p. 1714-1718.