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Hydrothermal Alteration Mineral Mapping Using Hyperspectral Imagery in Dixie Valley, Nevada

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Abstract: Hyperspectral (HyMap) data was used to map the location of outcrops of high temperature, hydrothermally altered minerals (including alunite, pyrophyllite, and hematite) along a 15 km swath of the eastern front of the Stillwater Mountain Range in Dixie Valley, Nevada. Analysis of this data set reveals that several outcrops of these altered minerals exist in the area, and that one outcrop, roughly 1 square kilometer in area, shows abundant high temperature alteration. Structural analysis of the altered region using a Digital Elevation Model (DEM) suggests that this outcrop is bounded on all sides by a set of cross-cutting faults. This fault set lies within the Dixie Valley Fault system (Caskey et al. 1996). Both the intense alteration in this area and the presence of cross-cutting faults indicate a high probability of recent hot fluid escape.

Introduction: In recent times, the reality of limited energy resources has become increasingly evident. While much of the world's supply of fossil fuels lies in the Middle East, relations between the east and west are tense. At the same time, awareness of the negative effects of burning fossil fuels is growing. As global population and consumption of fossil fuels increase, these effects will be intensified and human and ecosystem health may be compromised. Alternative sources of energy will become increasingly valuable to the success of this nation in the future. Many types of alternative energy are currently available, such as wind, hydroelectric, and geothermal. While alternative energy production doesn't yet compare to that of fossil fuel, maximizing the potential of these resources is important. It is probable that in the Basin and Range extensional region of the western United States many sites associated with normal range-front faulting could support geothermal power plants.

Remote sensing can greatly improve the efficiency of locating new sites for productive geothermal power plants. With this goal in mind, the geothermal consortium of UCSC, LLNL, UNR, and UU collected a HyMAP hyperspectral dataset at Dixie Meadows, which lies several kilometers south of the Dixie Valley geothermal field, in August of 2002. This area is an ideal location for such a study because a geothermal power plant already exists and has proven to be productive (the largest plant in Nevada). Location of these sites is closely linked to the presence of hydrothermally altered minerals along faults. HyMAP uses 126 spectral bands to collect data in visible through the short wave infrared. The spectral sampling in the range between the wavelengths of

2.0 and 2.5 μm is tailored to the needs of geologic mineral identification. The airborne high-resolution hyperspectral imagery has a spatial resolution of about 3 meters.

Faults can form conduits that accommodate the escape of large amounts of hot water and other volatiles. As the water escapes it alters the surrounding rock. These alteration minerals can be recognized in remotely sensed imagery and can indicate the temperature of formation. In this way, alteration due to surficial weathering processes can be distinguished from high temperature alteration related to hot water escape. High temperature alteration minerals can indicate the location of faults if distributed linearly. Regions of cross-cutting faults are prime targets for the location of geothermal power exploration because of the potential for both hot waters and high fracture permeabilities. Martini (2002) has used this technique with HyMAP and AVIRIS hyperspectral data to gain an understanding of the local tectonic, hydrothermal, biological, and volcanic systems in Long Valley Caldera (Martini 2002), and Crowley and Zimbelman (1997) used AVIRIS to map alteration on Mt. Rainier.

Dixie Valley geothermal field is a highly productive 62 MW electrical plant operated by the Caithness Energy Corporation. It is powered by the escape of high-temperature (240 ˚C) fluids produced at depths of 2-3 km within the Stillwater (or Dixie Valley) fault zone. Both active and ancient fumeroles are present at the surface (Lutz et al. 2002). Escape of hot fluids at the surface is easily recognized by the presence of alunite, pyrophyllite, travertine, sinter deposits, and other high temperature alteration minerals. Nash and Johnson (2002) used AVIRIS to map mineralogy anomalies in Dixie Valley.

Methods: The airborne high-resolution hyperspectral imagery consists of eighteen North-South trending flightlines that have a spatial resolution of about 3 meters. HyVista Corporation conducted post-processing to atmospherically correct and georectify the data that were made available to Lawrence Livermore National Laboratories in November of 2002. Simultaneously, UCSC began its analysis of the data using RSI ENVI™ software.

Initially, the large data set was subset into smaller areas of interest along the range front. Two algorithms included with ENVI software were used to reduce the number of mixed pixels within the subsets, Minimum Noise Fractionation (MNF) and Pixel Purity Index (PPI). MNF is an algorithm designed to find pixels with the least noise, which is accomplished by comparing each pixel to a user-defined noisy pixel. PPI is an algorithm used to find the pixels within the dataset that are the more spectrally distinct. Endmembers were then selected from the remaining pixels. Finally, these endmembers were mapped using matched filtering.

The 3D SurfaceView function allows the user to view a Digital Elevation Model (DEM) with georectified imagery draped over it. This tool was used to map faults scarps where lineations related to changes in elevations were visible.

Results: Initial spectral analysis of the HyMap data lead to the location of a large outcrop of hydrothermally altered minerals hereafter referred to as Outcrop 1. Although alteration mineralization is found along the entire extent of the range-front of the Stillwater range, Outcrop 1 is the only one in which alunite is found in abundance. Hematite is also abundant in the area. Lower temperature alteration minerals such as montmorillonite and kaolinite dominate the rest of the outcrop. The pixels with spectra that most closely matched those of the USGS spectral library for these four minerals were used as endmembers (Figure 1). Figure 2 illustrates the matched filter results for alunite on Outcrop 1.

Structural analysis using the 3D SurfaceView tool in ENVI resulted in the location of two faults that confine Outcrop 1 and intersect the Dixie Valley Fault. The lineation along these faults that is visible when the data is viewed in true color is related to mineral alteration. Using the combination of these two tools (altered rock lineation and depressions in elevation), figure 3 was produced showing the locations of proposed faults.

Discussion: We conclude that this would be a good site for further, detailed exploration for geothermal resources. This conclusion is supported by evidence of hot air and steam emission along the Dixie Valley Fault (Caskey et al., 1996). Recent mineral precipitation related to this vapor escape has occurred on Outcrop 1. We further propose that the intersections of the fault traces shown in Figure 3 may be sites of increased fracture permeability.

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Figure 1. Endmember spectra extracted from the data plotted against USGS spectral library spectra.

Figure 2. Alunite matched filter results shown in white, topography shown in greyscale.

Figure 3. Postulated fault locations as determined from lineation of alteration, as well as, structural analysis of Digital Elevation Model.