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Remote Sensing for Geothermal Exploration Over Buffalo Valley, NV

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ABSTRACT

Remote sensing is a useful tool for identifying the surface expression of geothermal systems based on characteristic mineral assemblages that result from hydrothermal alteration (Kratt et al., 2004; Vaughan et al., 2005). Buffalo Valley in Pershing and Lander Counties, Nevada, is an area of high potential for geothermal energy production (Shevenell et al., 2004). Geothermal heat is expressed by several hot springs with surface temperatures of up to 79°C (Olmsted et al., 1975). The hot springs and a chain of Quaternary cinder cones appear to be structurally controlled by a fault zone related to the Fish Creek Mountains range front fault (Olmsted et al., 1975; Wollenberg et al., 1975). The full extent of the geothermal system in Buffalo Valley is poorly understood. Remote sensing is used as an attempt to better constrain the system and explore for hidden geothermal systems in other parts of the valley.

The MASTER airborne simulator acquired data over Buffalo Valley and Jersey Valley in May 2006. MASTER simulates a combination of the Moderate Resolution Imaging Spectroradiometer (MODIS) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instruments. MASTER data have 11 m spatial resolution and 50 channels ranging from the visible to thermal infrared (0.4 to 12.9 μm). The relatively high spatial and spectral resolution of the data allows for the identification of carbonate, sulfate, silica and clay minerals.

Quartz- and clay-rich regions of Buffalo Valley were determined using methods that exploit differences in thermal infrared emissivity. MASTER visible and short-wave infrared data further define the mineralogy of areas with geothermal potential. The MASTER data show the active Buffalo Valley Hot Springs region consists mostly of carbonate deposits. Further from the hot springs, silica-rich deposits surround the carbonates. This paper presents initial mapping results of geothermal materials.

Introduction

Remote sensing can be a valuable tool for identification of surface mineralogy which is used to constrain geothermal systems. Hydrothermal alteration is often difficult to observe in the field; however associated minerals are spectrally distinct and can be identified using remote sensing data. In addition, remote sensing allows for classification of minerals over very large areas. Kruse (1999) and Vaughan (2005) mapped hydrothermal alteration using remote sensing over known hot springs at Steamboat Springs, Nevada. Hellman and Ramsey (2004) characterized fossil and active hot springs using data over Yellowstone National Park. Workers have used remote sensing to map hydrothermal alteration and identify hidden geothermal systems throughout the Great Basin. Martini and others (2003) mapped minerals using hyperspectral data over the Long Valley Caldera and Dixie Valley. Nash and others (2004) used hyperspectral data to map soil anomalies that may be related to geothermal activity. Kratt and others (2005) mapped the Brady-Desert Peak geothermal fields using multi- and hyperspectral data. Vaughan and others (2005) classified Virginia City hydrothermal mineralogy using hyperspectral data.

The MASTER remote sensing instrument is designed to collect data in regions of the electromagnetic spectrum where minerals have unique absorption features. Electronic processes result in characteristic absorption features in the visible near-infrared (VNIR) region from 0.35 to 1.0 μm . Short-wave infrared (SWIR) data from 1.0 to 2.5 μm are used to identify minerals that display atomic and molecular vibrational modes. Minerals with characteristic absorption features in the SWIR include sulfates, carbonates, clays, zeolites, amphiboles and hydrates. The thermal infrared (TIR) region from 8 to 12 μm is used to identify carbonates, sulfates, phosphates and silicates.

The Buffalo Valley Hot Springs represent a geothermal system that is not well understood. The hot springs are thought to be controlled by a Basin and Range-style fault (Wollenberg et al., 1975), but little work has been done to support the proposed relationship. The fault is not observed at the surface and has not yet been imaged in the subsurface. Buffalo Valley was the geographic focus for this remote sensing study because Shevenell and others (2004)

found the valley to be a favorable location for geothermal systems based on seismic refraction, crustal strain, gravity, seismicity and the presence of young faults and volcanics. We present an initial surface materials map in an effort to constrain the extent of the geothermal system.

Buffalo Valley Geology

Surrounding Ranges

Buffalo Valley is located in Pershing and Lander Counties, Nevada, southwest of Battle Mountain. The valley is bounded by the Tobin Range to the west and the Fish Creek Mountains to the southeast (Figure 1). The Tobin Range is primarily composed of siliceous clastic rocks (Muller et al., 1951). A normal fault clearly defines the entire eastern front of the Tobin Range (Stewart and Carlson, 1978). To the east of Buffalo Valley, the Fish Creek Mountains are primarily composed of the Fish Creek Mountains tuff with some younger sedimentary rocks and olivine basalt flows (McKee, 1970). The Fish Creek Mountains Tuff is a rhyolitic ash-flow tuff that was erupted from the Fish Creek Mountains caldera during the early Miocene (McKee, 1970).

A 15 km-long chain of olivine basalt cinder cones trends north-east along the edge of the Fish Creek Mountains. The volcanic field is thought to be controlled by the Fish Creek Mountains range-front fault (McKee, 1970). The fault is observed to the south along the southwestern front of the Fish Creek Mountains. Morton and others (1977) dated the basalt at 1.24 to 1.40 Ma old using K-Ar dating methods, which is consistent with the morphology of the cinder cones. Coolbaugh et al. (2002) found correlation of young basaltic volcanism with extensional-type geothermal systems.

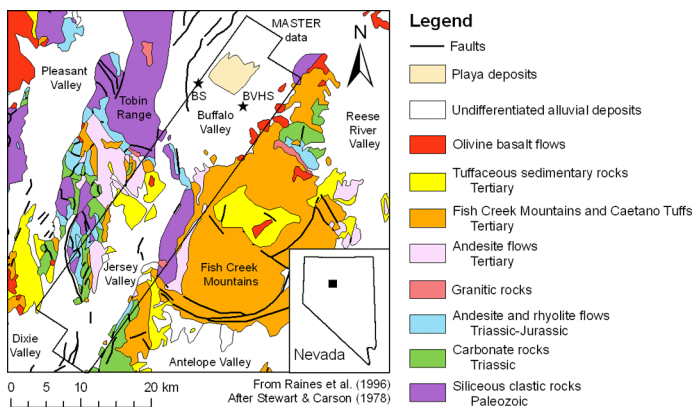


Figure 1. Simplified geologic map of the southern end of Buffalo Valley and Jersey Valley, with index map. BS represents Buffalo Springs and BVHS represents Buffalo Valley Hot Springs. The outline of the MASTER data is also shown.

Hot Springs

Buffalo Valley is filled with unconsolidated Quaternary alluvium. On the western side of Buffalo Valley are the Buffalo Springs. These are warm springs with temperatures ranging from 14 to 19°C (Wollenberg et al., 1977). There is a large playa in the center of Buffalo valley overlying Pleistocene lake deposits. A cluster of springs near the southeast edge of the playa are the

Buffalo Valley Hot Springs. The hot springs have surface water temperatures up to 79°C (Olmsted et al., 1975). The springs are surrounded by calcareous clay deposits; there does not appear to be any siliceous sinter associated with the hot springs (Trexler et al., 1978). Siliceous sinter is typically associated with relatively high temperature systems. Instead, Hose and Taylor (1974) observe travertine deposits at the hottest springs at Buffalo Valley. Travertine is an indicator of relatively lower temperature systems because of the retrograde solubility of calcite.

The Buffalo Valley Hot Springs are believed to be related to a steeply dipping fault that acts as a conduit for meteoric water (Wollenberg et al., 1975). Wollenberg and others (1975) map this fault along the northwestern edge of the Fish Creek Mountains, trending the same direction as the cinder cones chain. Trexler and others (1978) observe a fault scarp cutting young basalt and alluvium in air photo. However, the fault is not mapped by Stewart and Carlson (1978) in the Geologic Map of Nevada and work must be done to further understand the structure.

Methodology

Data Collection

MASTER is a combination of Moderate Resolution Imaging Spectroradiometer (MODIS) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) technology. Both MODIS and ASTER are instruments on board the Terra satellite, launched in 1999 (Hook et al., 2001). MASTER seeks to maintain the wide spectral range of the two spaceborne instruments but collect data at a higher spatial resolution (Hook et al., 2001). The MASTER instrument was flown over Buffalo Valley in a KingAir Beachcraft B-200 at an altitude of 4.4 km on May 30, 2006. Two flight lines of data were collected with a spatial resolution of 11.1 m, which is better than the resolution for ASTER and MODIS data. Data were collected in 50 spectral channels ranging from 0.4 to 12.9 μm .

Data Processing

The MASTER data were supplied as a Level-1B at-sensor radiance product and processed using ENVI image processing and data analysis software. Atmospheric effects were corrected for using Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes (FLAASH) on the VNIR/SWIR data. The resultant at-surface reflectance data were then used to identify scene mineralogy. A temperature-emissivity separation (T&S) was performed to obtain surface emissivity from the TIR data.

A Minimum Noise Fraction (MNF) translation removed unnecessary noise from the data, which were then analyzed using a Pixel Purity Index (PPI) calculation. Statistically pure pixels were studied using the n-dimensional visualizer tool which allowed for classification of pixels with distinctive spectra.

To further process the MASTER data, distinct regions of interest were chosen by the analyst using techniques that visually highlight spectral features. A Normalized Difference Vegetation Index (NDVI) image was created to determine vegetation distribution. Also useful was the decorrelation stretch (DCS), a rotation that uses color to display emissivity differences. A DCS of channels 48, 45 and 44 (11.30, 9.71 and 9.07 μm , respectively)

is used to highlight regions where there may be siliceous sinter or clay-alteration (Vaughan et al., 2005) (Figure 2). The 48-45-44 DCS image displays silica-rich regions as yellow due to the relative emissivity low at $9.07 \mu\text{m}$ (Figure 3). Clay-rich regions are shown as magenta because of relative emissivity low at $9.71 \mu\text{m}$ (Figure 3). End member spectra were chosen for both yellow and magenta regions.

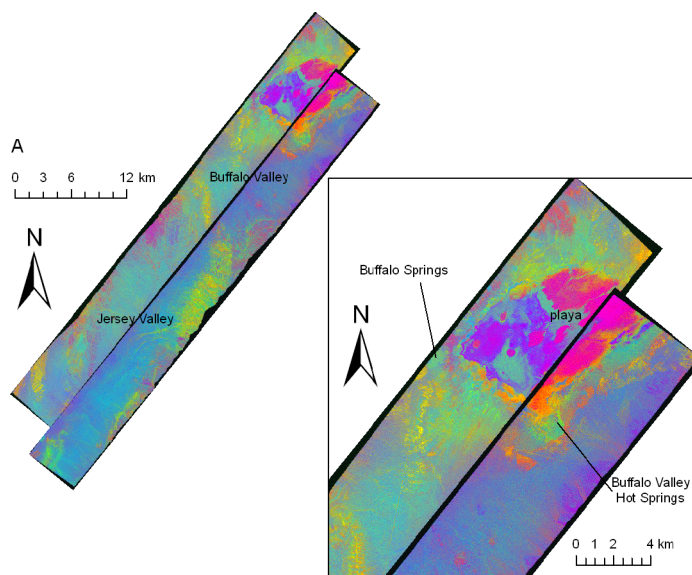


Figure 2. A. MASTER TIR DCS image over Buffalo Valley and Jersey Valley. MASTER channels 48, 45 and 44 are displayed as red, green and blue, respectively. Silica-rich regions are displayed as yellow and clay-rich regions as magenta. B. Enlarged version of MASTER TIR DCS showing only Buffalo Valley, the focus for this study.

Silica- and clay-rich end member spectra were used in the Spectral Angle Mapper (SAM) to create a TIR mineral map. Unique spectra from the VNIR/SWIR data were compared with reference spectra from the USGS spectral library to identify mineralogy. A VNIR/SWIR SAM image was created to display calcite and green vegetation. This image was combined with the TIR SAM image to create the mineral map shown in Figure 5. Future field work will confirm identifications made using the MASTER data.

Results and Discussion

Thermal Infrared

Figure 2 shows a DCS image of MASTER TIR bands 48, 45 and 44 over Buffalo Valley. Silica- and clay-rich regions are displayed in yellow and magenta, respectively. More specific mineralogy is not identifiable with MASTER data due to a lack of spectral resolution and the SWIR spectra for the highlighted regions do not display distinguishing absorption features. Vaughan and others (2005) used MASTER data in conjunction with higher spectral resolution SEBASS data. The authors determined that yellow silica-rich regions may be composed of quartz, opal, alunite or albite, and magenta clay-rich regions may contain kaolinite, montmorillonite or muscovite (Vaughan et al., 2005). The Buffalo Valley playa is clay-rich while a ring of silica-rich deposits surrounds the dry lake.

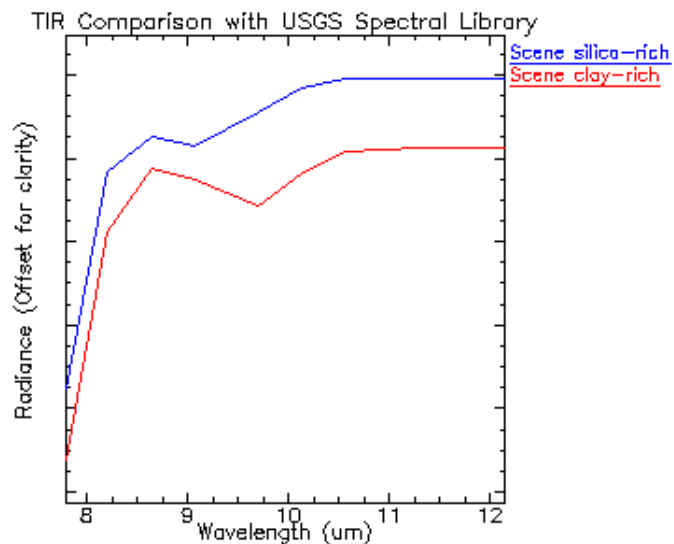


Figure 3. MASTER TIR spectra of silica- and clay-rich regions. Silica-rich minerals display an absorption feature at $9.07 \mu\text{m}$ whereas clay minerals display an absorption feature at $9.71 \mu\text{m}$.

Visible Near- and Short-Wave Infrared

The VNIR/SWIR data were used to identify calcite and healthy vegetation. Healthy vegetation displays a strong chlorophyll absorption feature in the VNIR region (Figure 4). There is clear vegetation signature within the Buffalo Valley Hot Springs and the Buffalo Springs areas.

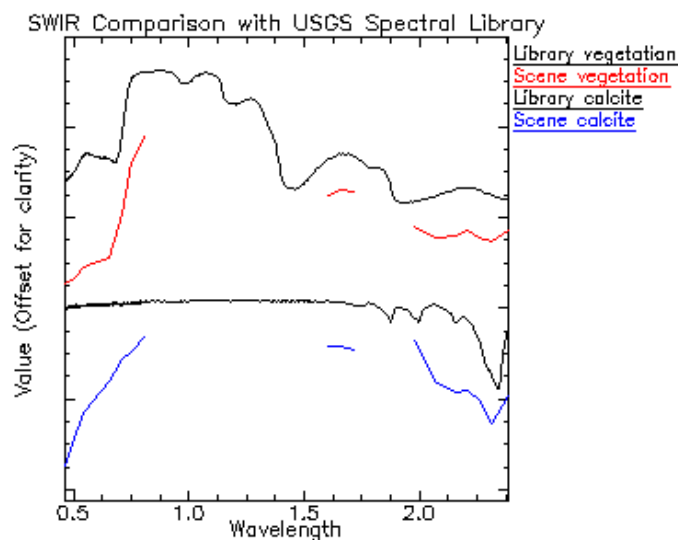


Figure 4. MASTER VNIR/SWIR spectra compared with USGS library spectra for sagebrush and calcite. Chlorophyll absorption is observed around $0.66 \mu\text{m}$. The absorption feature at MASTER band 21 ($2.318 \mu\text{m}$) represents a carbonate band. Note that four channels are not used for analysis due to remnant water absorption features.

An absorption feature in MASTER channel 21 was used to map calcite distribution as carbonate has a characteristic band near this wavelength (Figure 4). Calcite is shown to completely surround the Buffalo Valley Hot Springs, consistent with field observations stating that the area is composed of calcareous mud and travertine deposits (Hose and Taylor, 1974; Trexler et al.,

1978). No mineralogy could be detected near Buffalo Springs in western Buffalo Valley. The lack of calcite, silica- or clay-rich deposits associated with these springs suggests they are part of a low temperature system.

Mineral Map

SAM images were combined to create the mineral map shown in Figure 4. The clay-rich playa is surrounded on most sides by silica-rich deposits that are interpreted as lacustrine due to their distribution. Kratt and others (2004) found that diatomite was highlighted by methods used to identify siliceous sinter in remote sensing data. The silica-rich deposits in Buffalo Valley could be composed of diatomite. Green vegetation is present at both the Buffalo Valley Hot Springs and Buffalo Springs where there is sufficient water. The Buffalo Valley Hot Springs are entirely surrounded by carbonate deposits. A large area to the northwest of the hot springs is mapped as a silica-rich. This region may contain diatomite or the material could be hydrothermal in origin. MASTER spectral resolution does not allow for identification if more specific mineralogy so it is unclear if the deposit is related to the geothermal system. No silica- or clay-rich deposits appear to be associated with the Buffalo Springs on the west side of the valley.

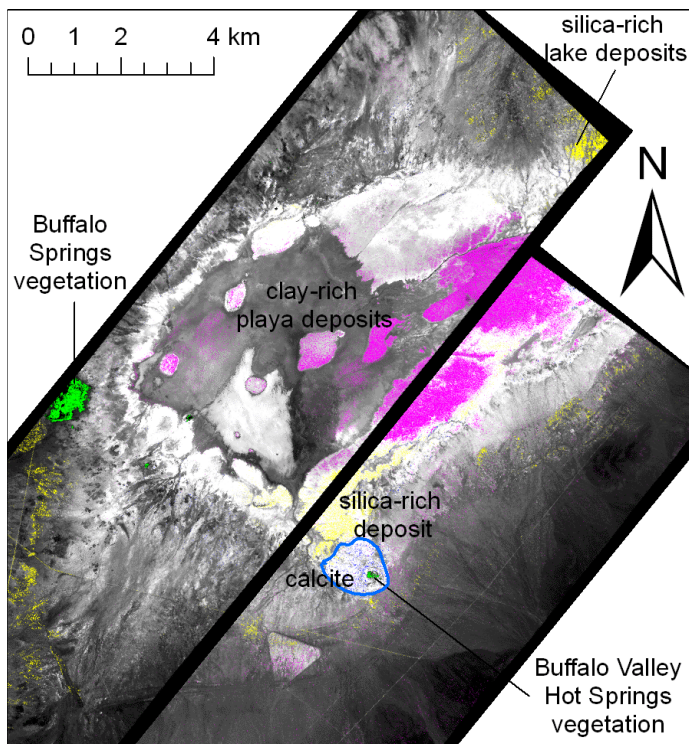


Figure 5. Mineral map of Buffalo Valley overlaying greyscale image. Magenta shows clay-rich regions, yellow shows silica-rich regions, green shows healthy vegetation and blue, which has been outlined, shows calcite distribution.

Although hydrothermal minerals are not identified in the MASTER data over Buffalo Valley, other areas of the scene are highlighted in the TIR DCS. Silica-rich regions correspond with siliceous clastic rocks of the Tobin Range and Fish Creek Mountains. Tuffaceous sedimentary rocks mapped on the west

side of Jersey Valley appear to be clay-rich due to weathering of the tuff. The correlation of remote sensing data with regional geology helps to validate results.

Conclusions

The MASTER data over Buffalo Valley cover a large area at high spatial resolution, but do not reveal any significant hydrothermal mineral deposits. The carbonate minerals surrounding the Buffalo Valley Hot Springs are presumably of hydrothermal origin, deposited as a result of the interaction between geothermal water and cold water containing dissolved carbonate. The silica-rich region to the northwest of the Buffalo Valley Hot Springs is possibly related to the geothermal system. This deposit could be composed of alunite, quartz or opal, which are hydrothermal minerals, but it is also likely that the deposit is related to the dry lake. Better spectral resolution is needed to identify the specific minerals that comprise a silica-rich deposit. The clay-rich regions in Buffalo Valley generally appear to be playa deposits and some related to weathering. No hydrothermal clays were specifically identified with the MASTER data. The MASTER mineral map correlates well with geology mapped by Stewart and Carlson (1978).

The geothermal system at Buffalo Valley has little surface expression. Despite the lack of spectral resolution, any hydrothermal minerals should have been generally identified in the TIR DCS image. Even if the one questionable silica-rich area is indeed related to the geothermal system, the surface expression is minimal. The Buffalo Valley Hot Springs geothermal system appears to be restricted and relatively low temperature due to the deposition of carbonates. The warm Buffalo Springs system in western Buffalo Valley has no surface mineralogical expression as no associated deposits were identified.

Acknowledgements

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