IMPROVED TECHNOLOGIES FOR GEOTHERMAL RESOURCE EVALUATION FY 2001 RESEARCH SUMMARY

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Project Background and Status

Background

This project explores the use of geomatics technologies, including remote sensing and geographic information systems, to solve specific problems in geothermal exploration and technology transfer. This includes a primary focus on the testing and use of new remote sensing data types and data processing techniques that facilitate the interpretation of features on the surface of the Earth that can indicate hidden faults and areas of permeability, and that may lead to the discovery of hidden hydrothermal convection systems.

This work directly addresses *DOE Program Objectives* related to "Economic Competitiveness – Reducing Geothermal Power Development Costs", as these new techniques can provide important geologic information leading to greater success in drilling to find and develop vitally needed new geothermal resources. This research also specifically addresses the "Geoscience and Supporting Technologies, University

Research – Active Faulting Areas" area of the DOE Geothermal Strategy which will be discussed below.

Status

Excellent progress has been made on this project during FY 2001 with an emphasis on two geographic areas: Cove Fort-Sulphurdale, Utah and Dixie Valley, Nevada.

Work for the Cove Fort-Sulphurdale area has focused on using hyperspectral data, acquired using a field spectroradiometer, to determine if geobotanical anomalies, related to the hydrothermal convection system and geologic structures, could be detected. This work has been completed and a final paper, "Vegetation Anomalies at Cove Fort-Sulphurdale Area, Utah: Implications for Use in Geothermal Exploration," has been completed.

Work for Dixie Valley has also progressed very well. Several hyperspectral data preprocessing and processing techniques were tested leading to two cost-effective methods of detecting and mapping soil-mineralogy anomalies that are related to buried structures and hydrothermal convection. A paper describing this work has been completed and is listed below.

Remote sensing data analysis for geologic structure mapping has also been done in support of the Andesitic Hosted Geothermal Systems subtask. A paper describing this work has been completed and is listed below.

Project Objectives

The principal objective of this project is to determine if remote sensing data can be used in novel ways for geothermal exploration. This includes testing different data types and data processing methodologies that can facilitate interpretation leading to the detection of hidden faults, zones of permeability, and hidden hydrothermal convection systems. This includes gobotanical analyses, soil-mineralogy analysis, and geologic structure mapping.

A secondary objective is to improve the delivery of technology transfer using the Internet to augment the classical approach of paper publication and presentation.

Research Results

Cove Fort-Sulphurdale, Utah

It was hypothesized that geobotanical anomalies, related to geologic structure, might exist over this hydrothermal convection system. Reservoir pressure decreases in the past, resulting from production, may have increased boiling and the possibility of gasses reaching the surface through permeable structures. This would allow toxic gasses, such as H_2S, to penetrate the soil and directly affect vegetation. Deleterious soil acidification could also occur from this process. To test this hypothesis, big sagebrush spectra were acquired using a field spectroradiometer with a 10 nm sampling interval over the 400 – 1000 nm (visible and near-infrared) spectral region. Specific parameters of the resultant spectral curves were used to classify the vegetation as anomalous or non-anomalous. These included: (1) the 699 nm/ 765 nm ratio described by Carter and Miller, 1994, (2) the red-edge point-of-inflection to determine if blue-shifting was occurring (Miller et al., 1985), and (3) the position, in nanometers, of the visible green maximum reflection, which was observed during this project as being a potentially useful parameter. Upon inspection and statistical analysis of the stated parameters, four classes were determined to describe the big sagebrush that were analyzed including: Healthy, Probably Healthy, Probably Stressed, and Stressed.

Figure 1 shows the results of the spectral analysis for the area adjacent to and surrounding the Utah Municipal Power Agency power plant (south study area). It can be seen that a clearly defined major anomaly lies in the area marked as “A”. This anomaly was spatially correlative with the range-front fault of the Tusher Range and suggests that geothermal gasses were escaping along this structure. It also suggests that synthetic faults were present to the west and also acting as conduits for upwardly migrating reservoir gasses. Geophysical work, done by Ross and Mackelprang (2001), also shows evidence that unmapped synthetic faults exist to the west of the range-front fault corroborating this postulation.

The area marked “B” shows several anomalous samples that are sporadically intermixed with healthy vegetation. The random nature of these anomalies may indicate that gas leakage, along the several associated faults that cross the area, was present, but not consistent. This is the only area in the study where this pattern exists. Area “C” shows a single shrub anomaly directly on a fault.

Figure 2 shows the results of the spectral analysis of big sagebrush in the north study area, which was located approximately 5 km north of the power plant. The most significant anomaly in this area is marked “A”. This anomaly was located around and adjacent to an old sulfur mine where host rocks were hydrothermally altered. Several NNE trending faults, that could be acting as conduits for geothermal system gasses, cut through this anomaly. The area marked “B” had three anomalous samples, which may indicate buried permeable structures that are allowing gasses to escape into the soil. The sample station marked “C” may be either a spurious result or an anomaly that was related to the WNW trending fault that passes just to its south. The sample station marked “D” had two anomalous samples that were relatively close to an old sulfur mine where active fumaroles are found. Both of these anomalies are on a known fault.

The results of this study indicate that mapping geobotanical anomalies, using high spatial resolution hyperspectral data, can be useful for geothermal exploration and for siting new wells in areas proximal to producing steam fields. This technique can directly aid industry for field expansion by facilitating the detection of buried faults and zones of permeability. Portable field spectroradiometers, which provide spatial resolution at the sub-shrub level, can provide a cost-effective method of data collection at the local level and would be useful in areas with moderate to heavy vegetation cover. High spatial resolution airborne hyperspectral data could provide data over larger areas and would be particularly useful where vegetation cover is relatively dense.

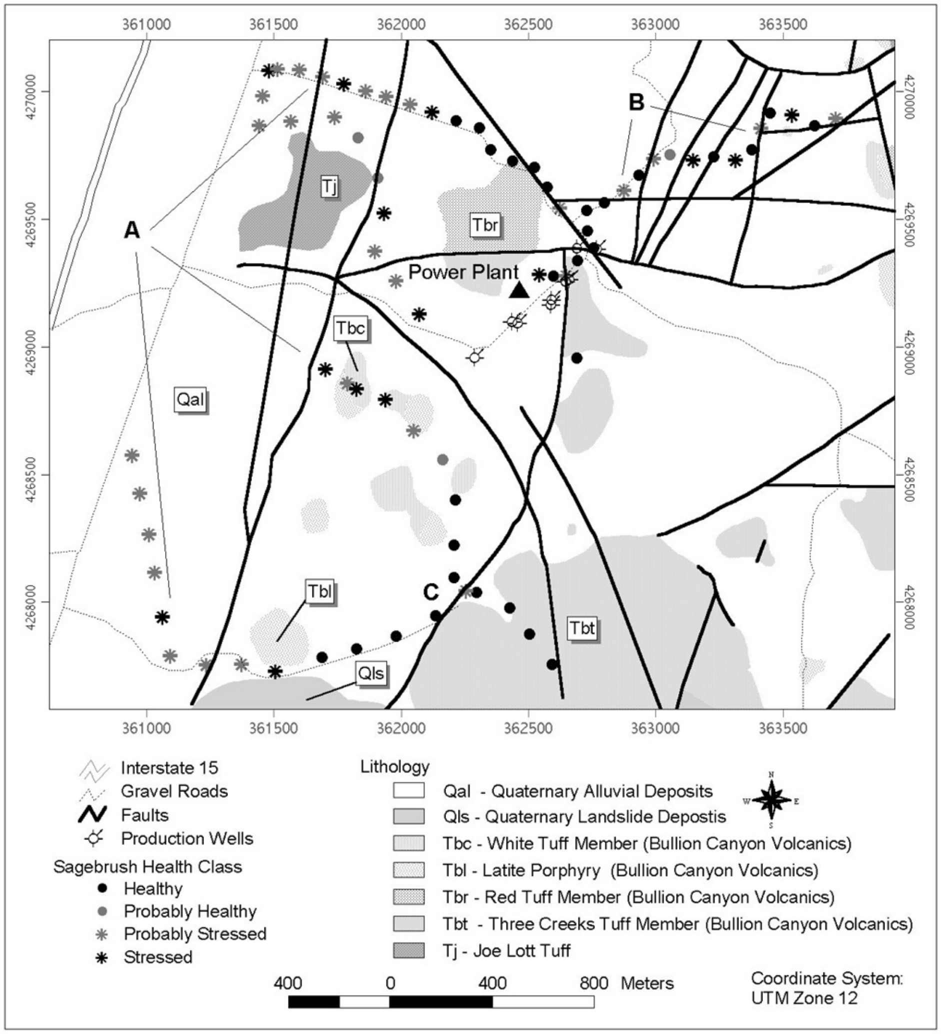

Figure 1. South study area. A major vegetation anomaly, marked "A" is spatially correlative with the Tusher Mountains range-front fault (shown on map) and synthetic faults to the west (not shown). Sporadic anomalies are associated with the faults near "B" and a single shrub anomaly can be seen at site "C", which is located directly over a fault.

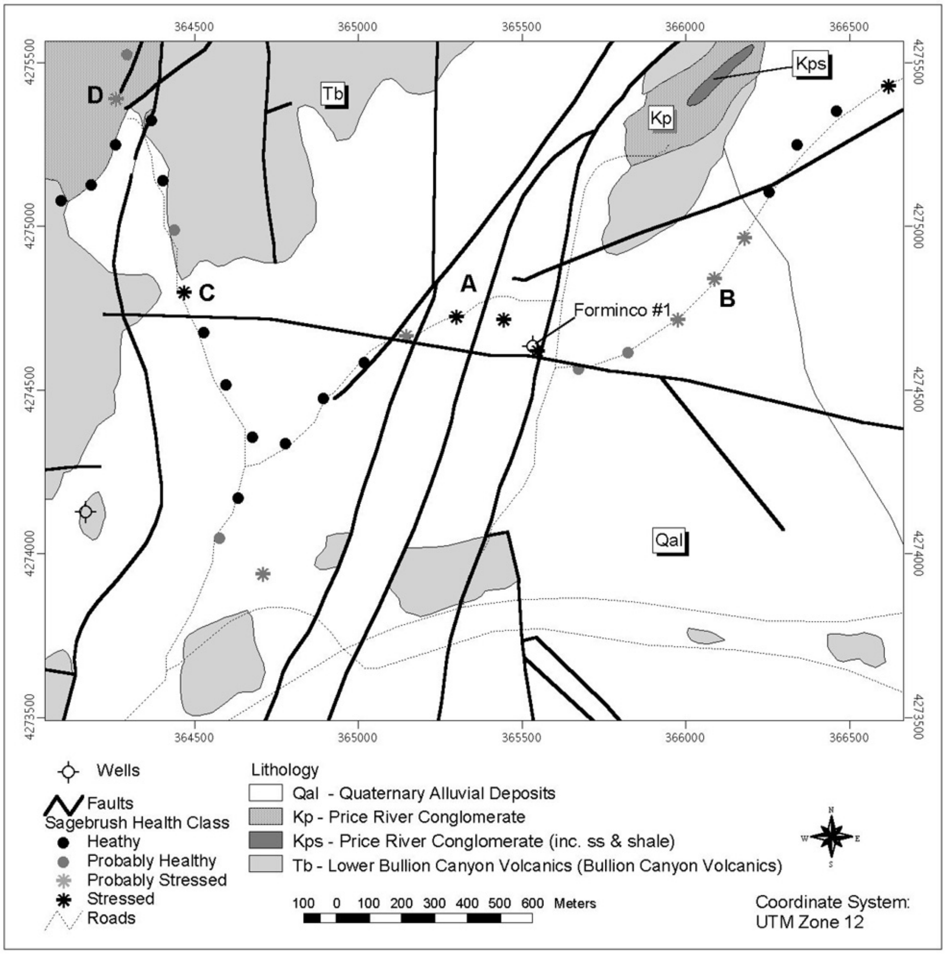

Figure 2. North study area. The area marked "A" is the strongest anomaly. The center of this anomaly is hydrothermally altered, faulted, and has been mined for sulfur. Area "B" has no apparent hydrothermal alteration at the surface or mapped faults, but may be underlain by permeable structures. Area "C" may be a spurious anomaly or may be related to the WNW trending fault nearby. Area "D" shows two anomalies from shrubs that were on a fault and in relatively close proximity to active fumaroles and hydrotherally altered rock exposed in an old sulfur mine.

<u>Dixie Valley, Nevada</u>

This study was undertaken to determine if any hydrothermal convection system related soil-mineralogy anomalies could be detected using hyperspectral data. The dataset used was NASA Jet Propulsion Lab's (JPL) Airborne Visible/Infrared Imaging Spectrometer (AVIRIS), which was acquired on May 20, 1995. This data had 224 channels, with a sampling interval of approximately 10 nm, ranging from 383 nm to 2508 nm. The spatial resolution of the dataset (pixel footprint size) was 20 m and the image is 614 x 512 pixels.

Before analysis, this dataset was first preprocessed to correct for atmospheric effects and to convert from radiance to apparent reflectance. This was necessary to allow proper data interpretation.

The preprocessed data were then processed to accomplish spectral unmixing. This was necessitated as each pixel generally contains a mix of materials. Unsupervised and supervised methods were tested. The unsupervised method, Polytopic

Vector Analysis (Johnson et al., 2001), was tested as a cost-effective method that could eventually be applied by industry using personnel with minimal training. This analysis resulted in the extraction of five spectral end-members including kaolinite, chlorite, muscovite, olivine (from an outcrop), and a mixture of what was probably calcite and chlorite. Tests are now being run to resolve the pure fifth end-member from the image.
The more conceptually complicated supervised methodology included the following processing steps:

1. Minimum noise fraction (MNF) transformation;
2. Pixel purity index (PPI) generation;
3. Selection of mineral spectra end-members from the PPI;
4. Mixture tuned matched filtering (MTMF) using end-members; and
5. Color enhancement (optional).

This processing was done using RSI ENVI software. Five spectral end-members including kaolinite, chlorite, muscovite, calcite, and olivine (from an outcrop) were derived. An example end-member can be seen in Figure 3. It is anticipated that additional end-members will be found through refined interpretation using mineral spectra from field samples.

This work has resulted in the identification of a significant linear calcium carbonate soil anomaly that is clearly associated with the hydrothermal convection system (Figure 4). This anomaly falls in line with recent fumarole activity, along a buried fault, that was first noticed shortly after the image was taken. The fumaroles were the result of pressure reductions, related to production, which led to reservoir boiling.

Initial results also indicate that there may be elevated levels of kaolinite associated with this anomaly. If this is the case, the kaolinite may be the result of previous hydrothermal alteration along buried structures. Additional statistical analysis will be done to determine if the kaolinite is truly anomalous. The calcium carbonate anomaly was likely the result of previous fumarole or hot spring mineralization that could not be visually detected due to burial.

Soil-mineralogy anomaly detection, which can be facilitated using hyperspectral data analysis, can be an important exploration tool both in close proximity to producing steam fields and for new targets. It will be useful for detecting buried hydrothermally altered faults, within reasonable proximity of the surface, and buried fumarole and hot spring deposits, which can indicate potentially permeable structures and possibly lead to the discovery of new hidden systems.

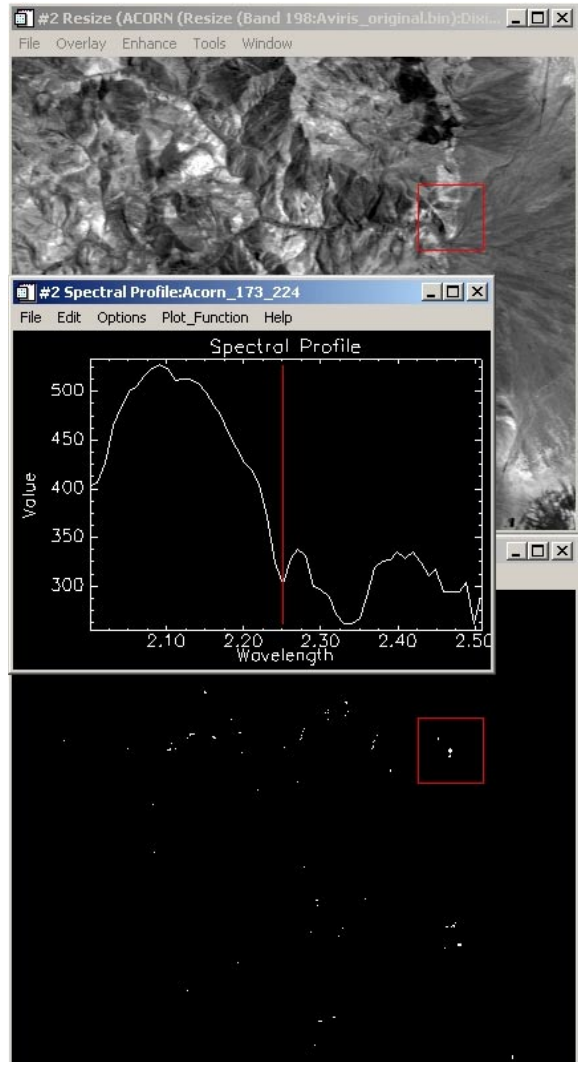

Figure 3. An example of the interactive extraction of a spectral end-member from the Dixie Valley apparent reflectance image (top). The PPI image (bottom) guides the analyst to pixels that are the most likely to have unique spectra. This example shows a good chlorite spectral end-member (center).

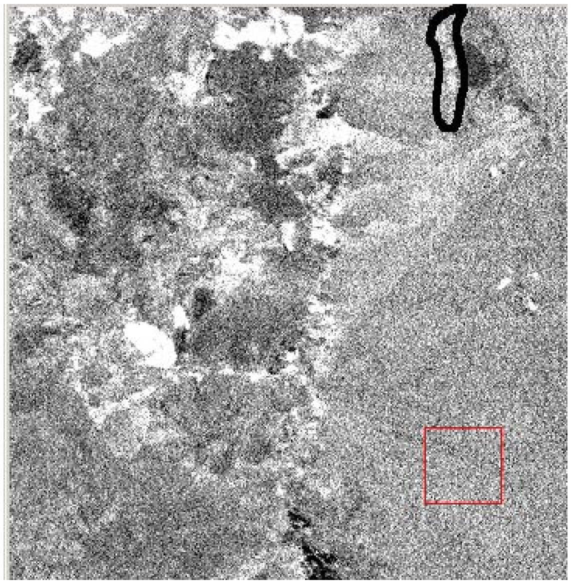

Figure 4. A soil calcium carbonate anomaly, bounded by a dark black outline, was mapped using the supervised hyperspectral unmixing methodology.

This cost of this type of a hyperspectral soil-mineralogy survey would vary depending on the data type used and its acquisition cost. It is estimated that there would be a range from about \$60.00 - \$250.00 per km^2 for data and processing/interpretation costs. Fieldwork would be additional and may be necessary to verify the interpretation.

Future Plans

The initial success of the Dixie Valley soil-mineralogy anomaly study suggests expanding the geographic area beyond the rather restricted limits of the current study. Therefore, we will work closely with Caithness Energy to choose new data, in adjacent or nearby areas, that will enhance this research and also benefit them in their drilling program. Remote sensing studies of the very promising Salton Sea area, California, will also be done during FY 2002.

In addition, we plan on working closely with Lawrence Livermore National Laboratory and their geothermal remote sensing program. This will allow us maximize data acquisition, reduce costs through cooperation, and allow better cross-fertilization of ideas.

Collaborations, Papers Published, and Technology Transfer

The work described in the document has been done in cooperation with the Utah Municipal Power Agency (Cove Fort-Sulphurdale) and Caithness Energy (Dixie Valley).

Papers resulting from FY 2001 research include:

Nash, G. D. and M. W. Hernandez (2001), "Cost-effective Vegetation Anomaly Mapping for Geothermal Exploration," *Twenty-Sixth Workshop on Geothermal Reservoir Engineering Stanford University*, Stanford, California, January 28-30, 2001.

Nemcok, M, J. McCulloch, G. Nash, and J. Moore (2001), "Fault Kinematics in the Karaha-Telaga Bodas, Indonesia, Geothermal Field: An Interpretation Tool for Remote Sensing Data," *Geothermal Resources Council Transaction*s, 25, 411 – 415.

Nash G. D. (2002), "Soil Mineralogy Anomaly Detection in Dixie Valley, Nevada using Hyperspectral Data," *Twenty-Seventh Workshop on Geothermal Reservoir Engineering Stanford University*, Stanford, California, January 28-30, 2002.

In addition to the presentation and publication of research results, a web site, http://www.egi-geothermal.org, has been established to aid in this endeavor. Numerous papers generated by the *Western U.S. Geothermal Systems Grant* have been linked both by subtask and geographically using ArcIMS Internet mapping technology. This gives ready access to research results to interested parties through multiple spatial and standard queries. Data resulting from this project is also being added to a readily accessible archive in the most widely used GIS format.

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