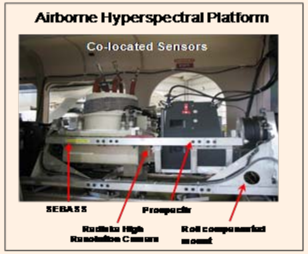

The Combination Hyperspectral Platform - SEBASS & ProspecTIR are two complementary imaging spectrometers that together collect **over 600 channels** of spectral information from the visible to the long wave infrared.

Hyperspectral Remote Sensing Techniques for Locating Geothermal Resources

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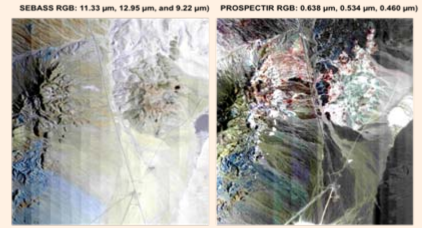


Quick Look View of SEBASS and ProspTIR Hyperspectral Sensors – Cuprite. Nevada

Introduction

Demonstrating the effectiveness of hyperspectral sensors to explore for geothermal resources will be critical to our nation's energy security plans. Discovering new geothermal resources will contribute to established renewable energy capacity and lower our dependence upon fuels that contribute to green house gas emissions.

The use of hyperspectral data and derived imagery products is currently helping exploration managers gain greater efficiencies and drilling success. However, more work is needed as geologists continue to learn about hyperspectral imaging and, conversely, as data processors begin to understand how to apply certain target minerals, mineral assemblages, and temperature data to deliver meaningful hyperspectral data products.

Hyperspectral Sensors & Data Cubes

Multispectral sensors such as those on Landsat 7 or ASTER collect data over a few relative broad wavelength bands. By contrast, hyperspectral sensors can simultaneously collect image data across hundreds of narrow, adjacent spectral bands. Depending upon the degree of resolution, hyperspectral sensors can be installed on a variety of platforms including: hand portable, truck mounted, airborne or satellite platforms. A diagram showing the reflective and emissive spectral ranges across the very near infrared (VNIR), short wave infrared (SWIR), mid-wave infrared (MWIR) and longwave infrared (LWIR) is shown in Figure 1, below:

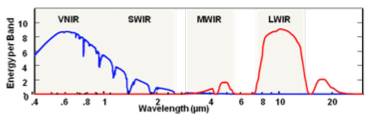


Figure 1: Reflective infrared (blue) and emissive infrared (red).
Source: The Aerospace Corporation – Spectral Applications Center

Measurements across a continuous spectrum for each image cell or pixel provides a wealth of data. "Hyperspectral cubes" or multidimensional data sets (see Figure 2) can exceed hundreds of terabytes. The data processor applies adjustments for atmospheric and terrain effects as well as georectification.

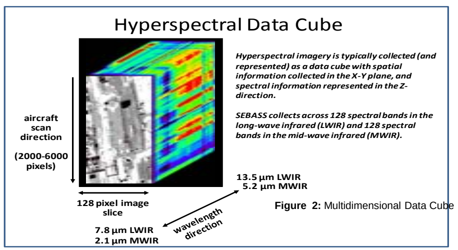
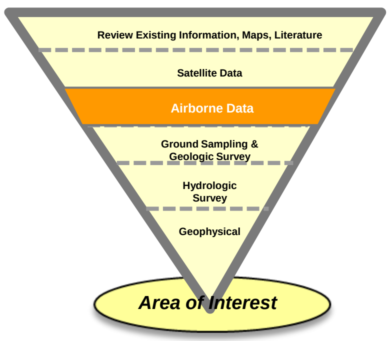


Figure 2: Multidimensional Data Cube

Geothermal Exploration Tools

The exploration phase of geothermal energy strives to answer "where to drill". Introducing an airborne hyperspectral survey early during the exploration process can help define and narrow the Area of Interest (AOI) and reduce the level of investment needed for later exploration phase surveys.

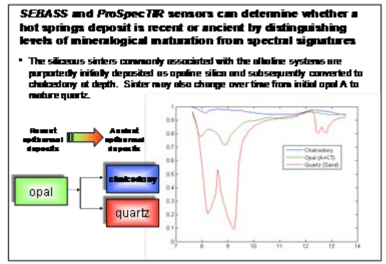


Data Exploitation Process

Each material has a unique spectral signature within each wavelength. From a broad range of channels, the processor can select the spectral channels that provide distinctive spectral signatures. After an airborne collection and initial data processing for calibration and georectification, the processor can "mine" the reflectance and radiance cubes for various minerals and rock types. To optimize the results from the data set, the geologist should work closely with the hyperspectral experts to:

- Share Geologic Knowledge of the Area – identify known faults, surface and subsurface features and geomorphology
- Identify Relevant Spectral Targets - spectral targets are those that are indicative of hydrothermal systems (e.g. cinnabar, quartz, opaline, chalcedony, etc…)
- Provide Ground Truth - while the data processor can mine the data applying an established spectral library, capturing spectral measurements from actual ground samples can often yield more precise results.

Hyperspectral Identification of Geothermal Mineral Deposits



A few example minerals that can indicate the presence of a hydrothermal system are listed below. Each of the five minerals has distinctive signatures (see Figure 3) and these can be mapped as mineral assemblage maps (see Figure 4).

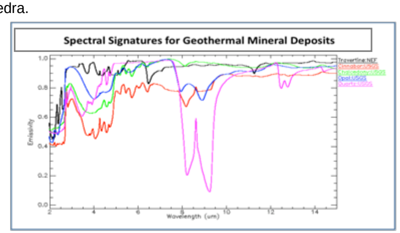
Cinnabar (HgS) – Cinnabar sometimes called "cinnabarite", is a name applied to mercury sulfide , the common ore of mercury. Generally cinnabar occurs as a vein-filling mineral associated with recent volcanic activity and alkaline hot springs.

Tufa and Travertine ($CaCO_3$) – Geothermal springs sometimes produce similar, less porous carbonate deposits known as travertine. Mono Lake, California, is famous for its Tufa columns – a form of travertine where $CaCO_3$ is precipitated when carbonate rich source waters emerge into alkaline soda lakes.

Opal – SiO_2 *nH_2O – a hydrated silica that usually includes 3-10% water content.

Chalcedony –SiO_2 - chemically identical to quartz, but has a cryptocrystalline structure.

Quartz – SiO_2 – second most abundant mineral in the earth's continental crust, comprised of a continuous framework of SiO_2 tetrahedra.



Conclusions

ProSpecTIR collects spectral data from 357 channels in the visible-short wave infrared to map surface minerals such as kaolinite, illite, montmorillonite, halloysite, alunite, jarosite, chlorite, calcite, amorphous silica, and travertine. *SEBASS* collects spectral data from 256 spectral channels to map surface minerals such as: quartz, albite, adularia, orthoclase, kaolinite, Na- and Ca-montmorillonite, opal, chalcedony, alunite, gypsum, jarosite, calcite, and other sulfates.

The use of hyperspectral data and derived imagery products is currently helping exploration managers gain greater efficiencies and drilling success. However, more work is needed as geologists learn more about the capabilities of hyperspectral data and, conversely, as data processors begin to understand how to apply certain target minerals, mineral assemblages, and temperature data to deliver meaningful hyperspectral data products.

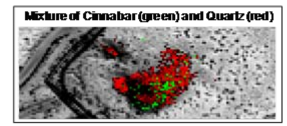


Figure 4: Mineral assemblage map, Coso Geothermal Power Plant Area, California.

Sources cited

Energy Sprawl or Energy Efficiency: Climate Policy Impacts on Natural Habitat for United States of America"; The Nature Conservancy and Northwestern University.

Williams, Colin F., Reed, Marshall J., Mariner, Robert H., DeAngelo, Jacob, Galanis, S. Peter, Jr., "Assessment of Moderate and High-temperature Geothermal Resources of the United States"; U.S. Geological Survey Fact Sheet 2008-3082, 4 p.

Draft National Geothermal Action Plan; DOE National Renewable Energy Labs.

Discussions with: Geothermal Resource Association (Washington, DC); and University of Nevada at Reno – Great Basin Research Center (Reno, NV).

Wendy M. Calvin, Mark Coolbaugh, Chris Kratt, and R. Greg Vaughan; "Application of Remote Sensing Technology to Geothermal Exploration"; Great Basin Center for Geothermal Energy (GBCGE) and the Department of Geological Sciences University of Nevada – Reno.

Eric Charles Barrett, Leonard Frank Curtis; Introduction to Environmental Remote Sensing; Section 14.2.1 "Thermal Infrared Scanning"; Edition 2, 1982, p. 247.

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