

Reflectance Spectroscopy as a Drill Core Logging Technique: An Example Using Core From the Akutan

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ABSTRACT

Reflectance spectra were collected from the cores of two geothermal wells (HSB2 and HSB4) drilled during Summer 2010 as part of the Akutan geothermal exploration project on Akutan Island, AK. Spectra were collected using an Analytical Spectral Devices (ASD) portable spectrometer and used to identify mineralogy based on characteristic absorption features in the visible to shortwave infrared (0.35-2.5 μm) region of the electromagnetic spectrum. The cores were previously studied in detail by Stelling and Kent (2011) who produced a thorough summary of the mineralogy identified in thin sections and by using X-ray diffraction (XRD) and a scanning electron microscope (SEM).

The purpose of this study was to further understand the value of reflectance spectroscopy as a geothermal core-logging method by comparing findings with results from Stelling and Kent (2011). In addition, this study was done to identify any additional alteration minerals and characterize the mineralogy in core sections between samples studied by the previous authors. Reflectance spectroscopy is particularly sensitive to hydrothermal alteration minerals and precipitates, including clays, carbonates, and sulfates. Mineralogy may be used as a temperature index to characterize the thermal regime at depth and thus act as an indicator for geothermal potential.

Muscovite, kaolinite, calcite, epidote, prehnite, hematite, montmorillonite, illite, chlorite, and zeolites were identified in this study using reflectance spectroscopy. Petrography, XRD, and SEM allowed for more specific discrimination of minerals and the identification of some minerals not possible using reflectance spectroscopy (quartz, adularia, pyrite), but the large amount of spectral data allowed for basic mineral identification over the entire length of the cores.

Introduction

Akutan Geothermal Exploration Project

Geothermal exploration on Akutan Island is funded by the City of Akutan, which is located approximately 6 km from the geothermal prospect in Hot Springs Bay Valley. Located on a remote Aleutian Island, the city's current energy source is costly diesel so the community has great interest in developing the local geothermal resource. Two slimholes, HSB2 and HSB4, were drilled during Summer 2010 to 833 ft and 1500 ft, respectively. Drill locations were chosen based on a number of previous studies. A geothermal exploration program was conducted during the 1980s by the Alaska Division of Geological and Geophysical Surveys and University of Alaska Geophysical Institute (Motyka et al., 1985). Recent exploration efforts, including the temperature gradient drilling, have been completed by Kolker et al. (2010, 2012). The island contains the historically very active Akutan volcano and is composed of rocks derived from this and ancestral volcanoes (Richter et al., 1998).

Previous HSB Core Studies

Stelling and Kent (2011) completed a thorough study of the HSB2 and HSB4 cores using 60 petrographic thin sections, XRD, and SEM. Their samples were chosen based on depth and abundance of fractures, mineralization, and alteration. Representative samples were also chosen for each of the lithologies present in the cores: tuff, andesite, basalt, and lithic basalt. The authors identified up to 16 different geothermal indicator minerals within the core samples, including zeolites, secondary minerals, and clays. Stelling and Kent (2011) core data are summarized by Kolker et al. (2012).

Hyperspectral Analysis of Core

Reflectance spectroscopy has been used to identify mineralogy for almost 40 years. Many minerals are spectrally unique; characteristic absorption features occur at known wavelengths and

are used to identify mineralogy. Hydrothermal minerals (clays, chlorites, zeolites, carbonates, sulfates, opal) are particularly well suited for identification using this technique because of distinct absorption features resulting from the vibrational modes in OH, H₂O, CO₂, and SO₄.

Researchers at the University of Nevada, Reno (UNR) have used reflectance spectroscopy to identify mineralogy in core and cuttings from some geothermal wells (Calvin et al., 2005, 2010). The technique was developed in the late 1990s (Kruse, 1996; Taylor et al., 1997) but has been used primarily for mineral exploration. As the method is still relatively unused in geothermal exploration, there is a need to characterize its effectiveness for identification of important geothermal indicator minerals in core.

In Australia, CSIRO has developed the HyLogging technology, instruments used for automated scanning of core and chips. In contrast, UNR researchers use a portable spectrometer to manually collect spectra from geothermal well cuttings and core (Calvin et al., 2005, 2010). While the automated scanning of core material is faster and provides more spectral data for one surface of the core, manual data collection allows the researcher to visually inspect all surfaces of the core and collect spectra from any desired spot. Although manual data collection is more time consuming than automated scanning, it is still a fast technique when compared to traditional mineral identification methods. The portable spectrometer is easy to use and has very few logistical requirements (shipping, size, time).

Methods

An Analytical Spectral Devices (ASD) FieldSpec Pro portable spectrometer was used to collect spectra from the HSB2 and HSB4

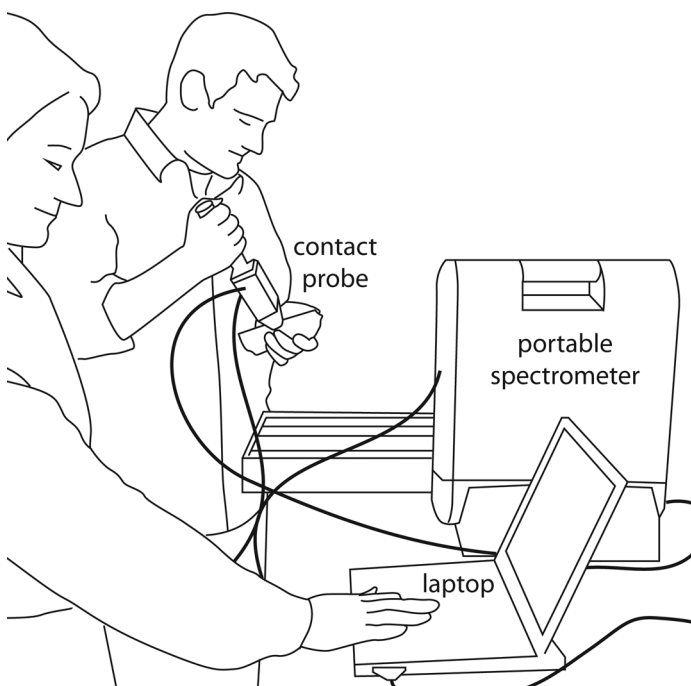


Figure 1. Schematic showing instrument set up for the spectral data collection. Instruments include a laptop for data storage, a portable spectrometer, and a contact probe with internal light source.

cores using a contact probe with a 10 mm aperture and an internal halogen light source (Figure 1). A white halon plate was used as a reflectance standard to calibrate the instrument. The ASD collects very high resolution (hyperspectral) data in 2151 spectral channels in the visible to shortwave infrared range, from 0.35-2.5 μm . Spectra collection was dependent on a visual analysis of the core; many spectra were acquired in sections of the core with visible alteration and mineralization whereas only a few representative spectra were collected from unaltered rock. In total, 1499 spectra were collected from the 833-foot HSB2 core and 2350 spectra were collected from the 1500-foot HSB4 core. Data collection took approximately 14 hours total. Individual spectra were compiled and arranged by depth into digital core logs.

Mineralogy was initially identified from the spectra using The Spectral Geologist (TSG), an automated spectral matching program produced by the CSIRO Earth Science and Resource Engineering (CESRE) Division of Sydney, Australia. ENVI software was used to confirm TSG results and further study uncommon spectral signatures. Spectra were arranged by depth into a 50 pixel-wide core image. Core images were processed in ENVI using techniques explained in Littlefield (2010). A statistics-based approach was used to highlight unique spectra: noise was removed from the data using a Minimum Noise Fraction (MNF) transformation and then coherent data were used in a Pixel Purity Index (PPI) calculation which identified spectrally unique pixels. Mineral classes were identified and a Matched Filtering method was used to derive thresholded mineral maps. Mineralogy was identified from spectra with reference to the U.S. Geological Survey (USGS) spectral library (Clark et al., 2007). Spectral signatures representing minerals were then input into TSG to produce classification images for comparison with results from previous work.

Results and Interpretations

Mineralogy identified using reflectance spectroscopy was not as specific as results from Stelling and Kent (2011) who were able to differentiate zeolite species, chlorite species, and smectite clays. Identification of quartz, adularia, and pyrite was not expected in this study because the minerals have no absorption features in the visible to shortwave infrared. Identification of specific minerals that occur in mixtures (zeolites, chlorites, clays) was also not expected; the 10 mm aperture of the ASD probe does not allow for identification of small mineral samples. In some cases, mixed spectra can be unmixed but this is often difficult as mixed spectra do not add linearly. The advantage of reflectance spectroscopy is the amount of data that can be collected quickly. Although fewer specific minerals were identified using this method than compared with conventional techniques, we derived basic mineralogy results for the entire length of the core.

TSG was useful in the identification of most minerals, but misidentified bland spectra and did not identify any zeolites. These issues highlight the necessity of additional manual data inspection. The best TSG results were derived from inputting manually chosen reference spectra instead of using the standard TSG library. Zeolite minerals proved to be difficult to identify using both TSG and ENVI. Zeolite spectra collected from the cores have a unique shape and are a close match to the library reference spectrum for

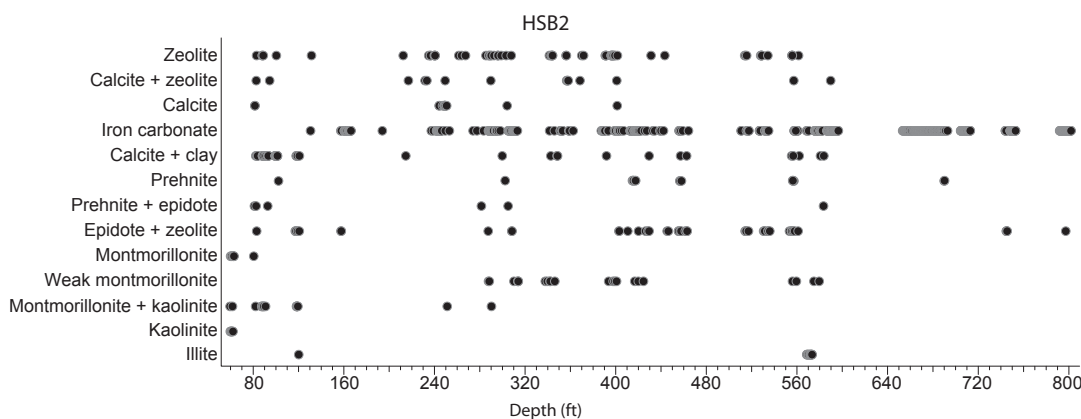


Figure 2. Preliminary mineral classification for spectra from the HSB2 core. Black dots show mineral occurrence at depth.

laumontite, which is the most common zeolite mineral observed by Stelling and Kent (2011). However, laumontite, heulandite, clinoptilolite, and mordenite have very similar spectra; specific zeolite mineralogy could not be identified with high confidence. Stelling and Kent (2011) were able to identify six species of zeolites within the cores using XRD.

Using a combination of TSG and manual data processing in ENVI, mineralogy was identified from the spectra for the HSB2 (Figure 2) and HSB4 cores. Calcite, with and without hematite, was pervasive throughout the cores, consistent with XRD and petrography results. The calcite occurs in veins, fractures, and vugs. Prehnite and epidote (in combination with zeolites and prehnite) were identified within the HSB2 core. Prehnite and epidote were not identified in the HSB4 core; this is consistent with the findings of Stelling and Kent (2011) who found only small amounts of epidote within calcite veins and identified only trace amounts of epidote. Chlorite and montmorillonite were identified throughout both cores. Montmorillonite is likely a better indicator of drilling mud content than hydrothermal alteration; some parts of the core were covered in drilling mud. Kaolinite was identified at the top of the HSB2 core and at 1000 ft depth in the HSB4 core. Limited muscovite and illite were identified in both cores. Zeolite group minerals were also identified in both cores.

Discussion

Reflectance spectroscopy is a useful technique for an initial and/or quick analysis of geothermal core. This reconnaissance technique is fast and can be used to develop a comprehensive understanding of core mineralogy. In this study it is clear that propylitic alteration dominates throughout the cores given the pervasive chlorite, zeolites, calcite, and in HSB2, epidote and prehnite. Argillic alteration is limited to depths where kaolinite was identified, ~60 ft depth in HSB2 and ~1000 ft depth in HSB4. Digital core logs produced using spectral data highlight interesting parts of the core that could be further studied using petrography, XRD, SEM, or other techniques to understand mineralogy and paragenesis.

Manual spectral data collection and processing are valuable for geothermal core analysis. In this study, spectra were collected from many vugs and veins, which would have been poorly represented by an automated method. Calcite-coated fractures are common in the Akutan core; manual data collection allowed for the researcher to examine each fracture surface. Similarly, the automated mineral mapping software, TSG produces the best results with user input derived from manual data processing.

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