Drill Hole Logging with Infrared Spectroscopy

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ABSTRACT

Infrared spectroscopy has been used to identify rocks and minerals for over 40 years. The technique is sensitive to primary silicates as well as alteration products. Minerals can be uniquely identified based on multiple absorption features at wavelengths from the visible to the thermal infrared. We are currently establishing methods and protocols in order to use the technique for rapid assessment of downhole lithology on samples obtained during drilling operations. Initial work performed includes spectral analysis of chip cuttings and core sections from drill sites around Desert Peak, NV. In this paper, we report on a survey of 10,000 feet of drill cuttings, at 100 foot intervals, from the San Andreas Fault Observatory at Depth (SAFOD). Data from Blue Mountain geothermal wells will also be acquired. We will describe the utility of the technique for rapid assessment of lithologic and mineralogic discrimination.

Introduction

Optical and infrared spectroscopy has been used since the 1960's to identify specific rocks and minerals (e.g. Farmer, 1974; Hunt, 1977). The technique hinges on the interaction of light with geologic materials that absorb specific wavelengths creating a fingerprint signature. The resulting spectrum contains information on both the primary elemental composition as well as crystallographic coordination. At shorter wavelengths, the optical and near-infrared (0.4 to ~ 2.5 µm), the resulting spectrum is most sensitive to iron (oxides, oxyhydroxides) and alteration molecules and anions (water, hydroxyl, carbonate) (e.g. Clark, 1999; Gaffey, 1997). In the far infrared (5 to 50 µm) absorption features from various classes of silicates are apparent (Hook et al., 1999; Christensen et al., 2000). Instruments have been developed so the spectra of samples can be quickly and directly measured in the field, as well as in the lab.

Application to Drill Hole Samples

A number of geophysical techniques are used to characterize the geology at depth during drilling operations. Geologic typing is often carried out via quick assessment of hand sample in the field and core sections or chips are logged as a function of depth. As some alteration minerals are difficult to identify in hand sample, core samples are often warehoused for later detailed analysis using thin sections and petrographic microscope as well as x-ray diffraction (XRD) techniques. These tools are time consuming and require extensive sample preparation. We often use infrared spectroscopy as a tool for quick mineralogic assessment in the field and we have been examining a variety of test samples in order to explore the utility of the technique for rapid assessment of parameters of particular interest to the Geothermal Energy community. Desired results include (a) quick analysis of lithology and geologic units related to those expressed at the surface, (b) identification of hydrothermal alteration zones and silicification, (c) identification of the presence of swelling clays at depth, (d) identify specific alteration minerals that may be used as geothermometers, and (e) correlation of individual stratigraphic units separated by faults.

Past Work

We have made measurements of several types of drill hole products. Chip boards housed at the University of Utah, from the Desert Peak hole DP 23-1, covering 3000m down hole were measured in one afternoon. That analysis was described by Kratt et al. (2004). In summary, although there was some interference from the glue holding the chip samples onto the boards we were able to identify large alteration zones consistent with previous detailed analysis by Lutz (2003). We next analyzed 17 core pieces of ash flow tuff samples from the Desert Peak/Bradys geothermal region, in order to relate geologic structure across fault zones to assess the ability to correlate strata offset by faults. Calvin et al. (2005) discussed these results. Ash flow tuff samples were generally similar, however weak features associated with the level of alteration to clay were apparent and

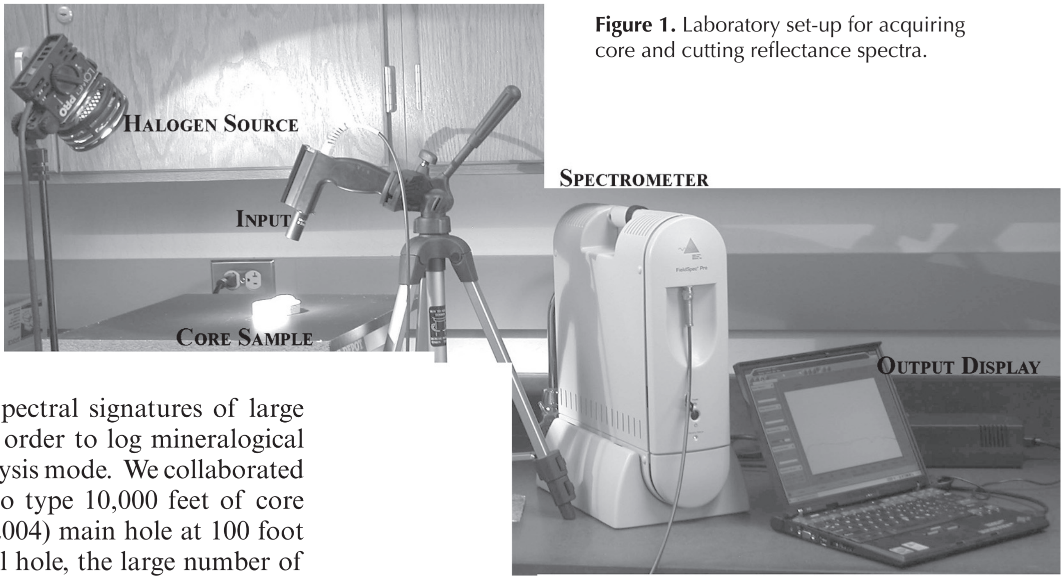

Figure 1. Laboratory set-up for acquiring core and cutting reflectance spectra.

varied in strength with degree of alteration. Carbonate and chlorite dominated samples were readily identified based on their reflectance spectra at optical and near-infrared wavelengths.

This Study

Having proven the ability of the technique to identify major mineralogy in cuttings and core the next step is to begin systematic and automated analysis of spectral signatures of large sections of downhole samples in order to log mineralogical changes with depth in a rapid analysis mode. We collaborated with the USGS in Menlo Park to type 10,000 feet of core from SAFOD (Hickman et al., 2004) main hole at 100 foot intervals. While not a geothermal hole, the large number of cuttings and other detailed logging (Vp, Vs, natural gamma, FMI, ECS, etc.) associated with this drilling effort allows us to test initial rapid algorithms for spectral differencing and compare our data with many other types of analysis on the core and cuttings.

The SAFOD hole is drilled into a structurally complex assemblage of clastic sediments and granitoids with marked geologic contrast to Franciscan mélange on the east side of the fault (Thayer et al., 2004; Thurber et al., 2004; McPhee et al. 2004). It is believed that phyllosilicate minerals influence the mechanical behavior of rocks at depth (see the review in Lockner and Beeler, 2002) and may contribute to the creeping and microseismic behavior observed along the fault at this section near Parkfield, CA (Thurber et al., 2004; Nadeau et al., 2004). Solum and van der Pluijm (2004) examined samples from the SAFOD Pilot Hole to identify clay minerals as a baseline for the main hole. The objective of the infrared spectroscopy study was to identify samples with strong contamination from the drilling mud or those with significant clay content in a rapid assessment mode. XRD had already been performed for the main hole from 4000 to 10000 ft measured depth, allowing preliminary comparison between the sensitivity of the two techniques.

Measurements

The samples were measured using an Analytical Spectral Devices (ASD) spectrometer using a small halogen source and a white halon calibration panel for correction to absolute reflectance (Figure 1). This instrument provides spectra from 0.4 to ~ 2.5 µm and is analogous to standard laboratory techniques for this wavelength range (e.g. Clark et al., 1990). Drill cuttings from the SAFOD main hole were transported to UNR in small envelopes and plastic cups, marked by drill interval. They were individually placed on measurement trays, spectra recorded, and then returned to the sample envelopes. The entire interval (~100 spectra) was measured over an afternoon, including set up and calibration time, with additional measurements of bulk, core, and standard samples. Approximately 30 each of bulk and clay-size fraction samples from the SAFOD Pilot Hole were also measured. For reference the reflectance spectrum of an individual sample can be acquired in less than 2 seconds compared to ~ two hours for a typical XRD measurement. Two samples each were measured in the interval from 3300 to 3700 feet. A quick initial analysis of relative band depths as a proxy for amount of phyllosilicates present was accomplished on the second day of the visit.

Results

Figure 2 shows the spectrum of a typical cutting sample compared with several clay standard spectra. Large features at 1.4 and 1.9 µm are caused by H_2O and OH in the silicate

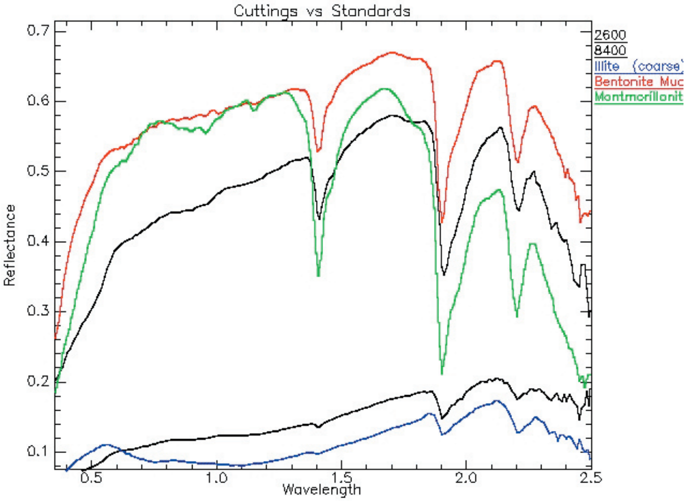

Figure 2. SAFOD Samples (black lines) compared with phyllosilicate standards (blue and green lines) and drilling mud (red). The sample at 8400 feet is the lower line with a close match to a standard coarse illite. The sample at 2600 feet is the upper (higher albedo) with a good match to montmorillonite. The bentonite drilling mud also matches montmorillonite as expected. Scale shows true reflectance values.

structure, and can be common to many hydrated minerals, including zeolites. Features near 2.2 µm are diagnostic of phyllosilicates, and band center, shape, and the appearance of doublet or multiple absorption peaks can uniquely identify some clay minerals. As shown, the bentonite drilling mud has a spectral signature characteristic of montmorillonite.

As a first rapid assessment of clay content we can measure the strength (relative band depth) of the absorption features at 1.9 and 2.2 µm. The feature at 1.9 µm gives an indication of the presence of alteration minerals, especially when they may be only a minor component. The band strength at 2.2 µm directly relates to the abundance of phyllosilicates. A simple measure of the band strength is to subtract the reflectance (R) at the band center from the reflectance on an adjacent shoulder. This simple difference was made for R(1.78 µm) – R(1.92 µm) to give a band depth of the 1.9-µm feature, B(1.9), and R(2.13 µm) – R(2.22 µm) to give the depth of the 2.2-µm feature, B(2.2). The sample brightness, or albedo is monitored by plotting R(1.12 µm). These feature strengths versus depth are shown in Figure 3, along with the sample brightness.

The first thing to notice is that the clay band strength, B(2.2) varies considerably with depth in the SAFOD hole. Examples of the weakest signatures, at 7100 feet, and the strongest, at 2600 feet are shown in Figure 4. This simple measure appears to give a good sense of the relative abundance of clays in the sample. B(2.2) is generally correlated with B(1.9) which is not surprising as most clays have strong features at 1.9 µm as seen in Figure 2. To be noted are intervals where B(1.9) remains high, but B(2.2) is low (3500 to 6400 feet). In this interval zeolites or other non-phyllosilicates are probably responsible for the spectral signatures and an example from this range (at 6200 feet) is also shown in Figure 4. In general, both B(2.2) and B(1.9) are correlated with albedo, an expected result since feature strength is often suppressed in darker samples.

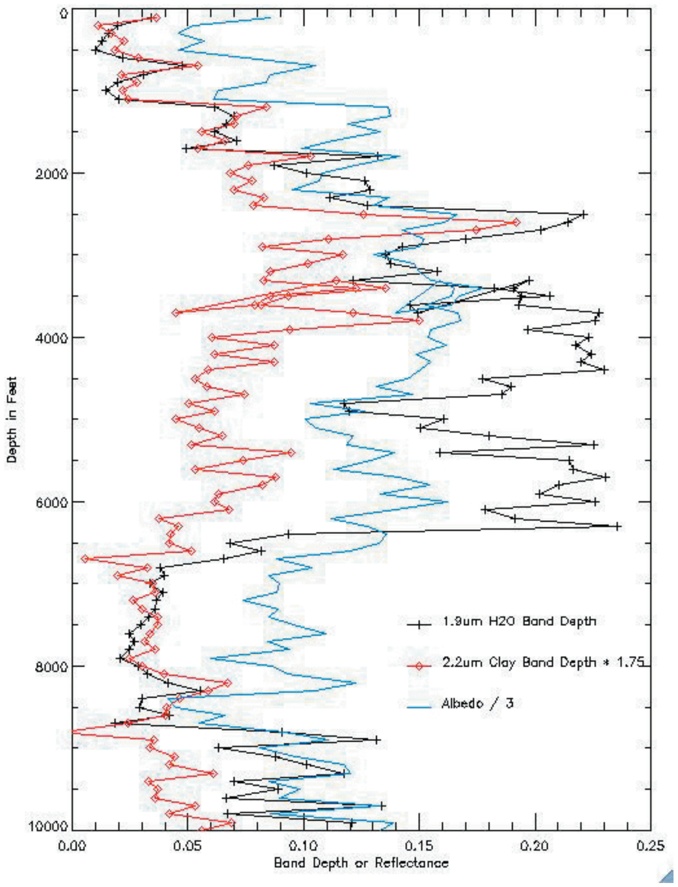

Figure 3. Albedo (blue), B(1.9)(black), and B(2.2)(red) with depth in the SAFOD hole. Values for albedo were divided by 3 and values of B(2.2) were multiplied by 1.75 to display on the same scale.

Preliminary comparison with XRD results shows generally good agreement; however it appears that the abundance of clays is underestimated in low albedo samples. More sophisticated analysis techniques, such as integrated band strength and monitoring band center shifts or deconvolution of spectra into constituent components are being explored. Various methods to attempt to correct for feature suppression in low albedo samples are also under examination.

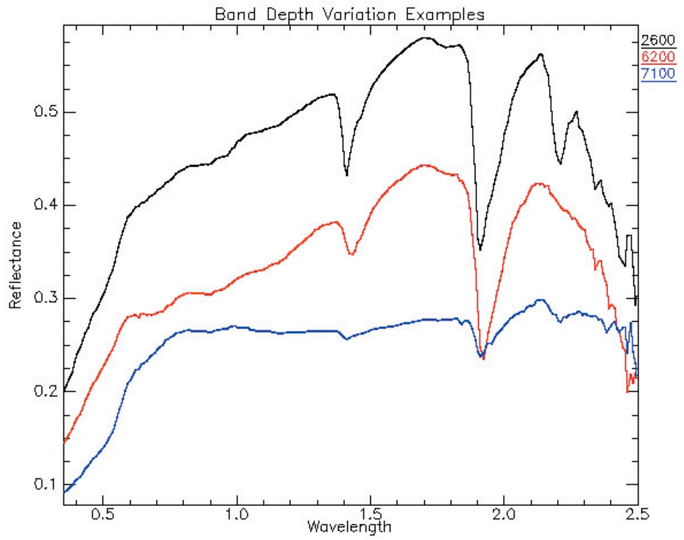

Figure 4. Examples of weakest clay signatures at 2.2 µm (7100 feet, blue line) and strongest clay signatures (2600 feet, black line) from the drillhole. Also shown is the interval with no clay minerals (6200 feet, red line), as evidenced by the lack of an absorption feature at 2.2 µm; however the 1.9 µm band is still strong, indicating potential zeolites. The quick band ratio method provides a reasonable first assessment of the abundance of phyllosilicate minerals in the sample.

Summary

Infrared spectroscopy can identify both broad mineral similarities and differences among drill hole samples rapidly and without extensive sample preparation. The initial screening shown here was accomplished in two work days, with preliminary conclusions corroborated by subsequent, more detailed analysis. The technique shows promise for use in the field to quickly identify geologic and lithologic changes down hole. The technique is especially useful for identifying alteration zones and degree of alteration at depth. Initial comparisons with XRD suggest the technique may underestimate alteration components in very dark samples. Future work will explore more sophisticated methods of spectral analysis including detailed mineralogic identification of existing samples and pilot studies during drilling operations.

Acknowledgments

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