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INFRARED SPECTROSCOPY FOR DRILLHOLE LITHOLOGY AND MINERALOGY

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ABSTRACT

Infrared spectroscopy has been used to identify rocks and minerals for over 30 years. The technique is sensitive to primary silicates as well as alteration products. Minerals can be uniquely identified based on multiple absorption features in reflected and emitted radiation. We are currently establishing methods and protocols in order to use the technique for rapid assessment of downhole lithology during drilling operations. Initial work performed includes spectral analysis of both chip cuttings and core sections from drill sites around Desert Peak, NV. We have recently performed laboratory measurements of 17 core sections from a variety of additional holes to examine spectral variability of ash-flow tuffs. We will describe the utility of the technique for lithologic and mineralogic discrimination as well as field methods that can be employed during drilling operations.

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 infrared (0.4 to ~ 2.5 μm), the resulting spectrum is most sensitive to iron (oxides, oxyhydroxides) and alteration cations (water, hydroxyl, carbonate) (e.g. Clark, 1999; Gaffey, 1997). In the 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 (e.g. http://www.asdi.com; Korb et al., 1996).

APPLICATION TO DRILL HOLE SAMPLES

A number of geophysical techniques are used to characterize the borehole. Geologic typing is often carried out via quick assessment in the field and core sections or chips are logged as a function of depth. As many rocks 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 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 undertook a pilot study to establish the utility of the technique for rapid assessment of samples for parameters of particular interest to the Geothermal Energy community. Of interest would be (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 (smectities, bentonite, i.e. montmorillonite and illite) at depth, (d) identify specific alteration minerals that may be used as rough geothermometers, or (e) correlate individual stratigraphic units separated by faults.

METHODS

For this "proof of concept" phase we made measurements of two 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 also have access to drill core samples from other holes in the Brady-Desert Peak geothermal fields but wanted to do a preliminary analysis of the best wavelength range to discriminate ash-flow tuff units that have been used as marker beds in geologic field mapping. The ability to correlate strata offset by faults allows determinations to be made about the timing of tectonic events and the amount of offset. This is particularly true for ash-flow tuffs with potassium-argon dates (Faulds and Garside, 2003). This report describes the analysis of 17 core pieces for use in relating geologic structure across fault zones.

Samples

Initial analysis focused on samples from six different drill holes in the Bradys/Desert Peak region. Cores from holes BCH--2, --3, --5, --8, and –10 as well as hole 35--13 were measured. All of our samples come from volcanic strata that were subjected Cenezoic normal faulting. These include 3 fine-grained basalts with varying degrees of alteration, and the remaining samples from ash-flow tuff units, varying in degree of alteration, crystal content, and lithic fragments. Figure 1 illustrates the general visual variation of the cores.

Figure. 1. Photo of representative core samples. Keys for scale.

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. 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). The samples were also taken to the reflectance lab of the Earth Remote Sensing group at the Jet Propulsion Lab for measurement from 2 to 15 µm. In this set-up a Fourier Transform Infrared Spectrometer (FTIR) system is used and the samples are measured in reflectance relative to a diffuse gold plate and using an integrating sphere (e.g. Salisbury et al., 1994). This longer wavelength range provides information on the primary silicate phases as the Si-O fundamental vibration occurs near 10 µm and absorption features vary strongly with tetrahedral coordination.

RESULTS

Table 1 (following the References) summarizes the data by core hole and sample number. The table includes a brief geologic description of the hand sample inferred by eye under a hand lens, and the major features observed in both the short wavelength region (ASD) and longer wavelengths (FTIR). This initial assessment provides a quick view of the bulk constituents of the samples. More detailed analysis that focuses on minor and/or weak contributions to the spectra is ongoing.

The majority of the samples exhibit very similar spectral characteristics in both ASD and FTIR spectra. Figures 2 and 3 show the main spectral character of these samples. At shorter wavelengths the spectra are dominated by a strong downward slope, beginning approximately 0.8 µm. This is typical for basaltic samples, although the albedo of the tuffs is typically brighter than most basalts. Features are evident at 1.4, 1.9, and 2.2 µm that are characteristic of some alteration to clay minerals, especially montmorillonite, muscovite, or illite. The stronger the features the more alteration to clay minerals has occurred. Slope variations below 0.8 µm may be due in part to the geometry of the source illumination.

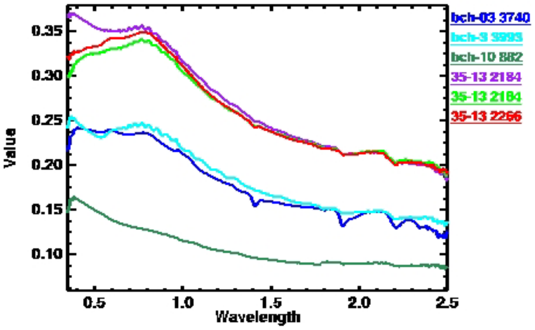

Figure. 2. Spectra of typical samples from the ASD instrument. Features at 1.4, 1.9, and 2.2 µm suggest varying levels of clay alteration.

In the infrared, these same samples again show varying contributions from clay, exhibited now by a narrow peak near 9.3 µm (Fig. 3). This feature matches well with montmorillonite. The FTIR spectra also show clear evidence of quartz in these samples, by the absorption edge near 8 µm, by an extremely narrow, well-defined absorption at 8.6 µm, and twin peaks between 12 and 13 µm. All these samples have broad wings from 10 to 12 µm. These wings vary in width. Amphiboles, pyroxenes and potentially biotite can contribute to the shape of this wing. The samples do not show unique, narrow features that would help discriminate among these additional potential silicates. Detailed modeling of the spectra can be performed and yield better estimates of contributions from other minor constituents (e.g. Ramsey and Christensen, 1998) and will be the subject of future analysis.

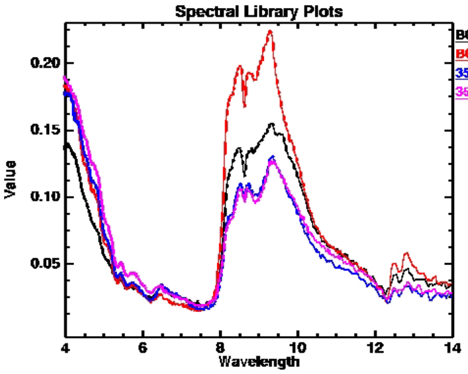

Figure. 3. Spectra of typical samples from the FTIR instrument. The peak near 9.3 μm is associated with clays, especially montmorillonite and the very narrow absorption at 8.6μm is due to quartz.

Additionally, a few samples show a shift in the clay peak to slightly longer wavelengths in the FTIR spectra. This is well matched by saponite from the mineral libraries, but not by either biotite or muscovite as might be expected based on the ASD spectra. Assignment of these features is still preliminary.

Two samples, BCH-03 4065 and 35-13 1947, showed very unique spectra in the optical and near infrared (Figure 4). However, their FTIR spectra are quite different, largely due to the stronger presence of quartz features in the spectrum of BCH-03 4065 (Figure 5). These spectra are consistent with either amphiboles and/or iron layer silicates such as chlorite or antigorite.

Only one sample, BCH-08 447, showed the diagnostic spectral features of carbonate. This was true for both the ASD and the FTIR spectra (Figure 6), and this sample shows almost no other features in either spectrum. Subtle band shifts are identified with cation substitution and the well-defined absorption and peak centers identify this sample as calcite dominated.

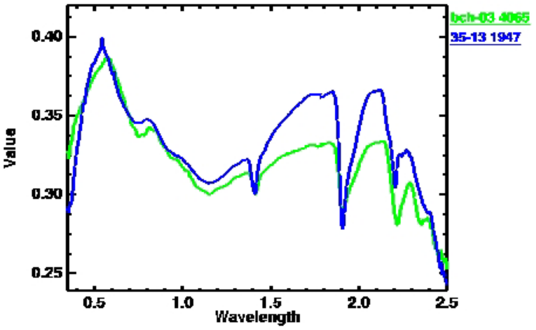

Figure 4. ASD spectra of two samples showing unique optical and near-infrared spectral character due to either amphiboles or iron bearing serpentine minerals.

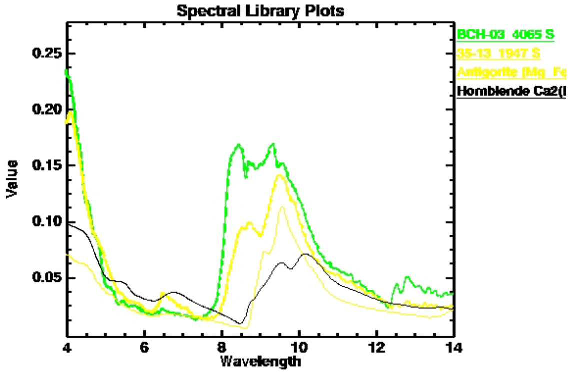

Figure 5. FTIR spectra of BCH-03 4065 and 35-13 1947, corresponding to Figure 4. These are compared with hornblende and antigorite from the JHU mineral library.

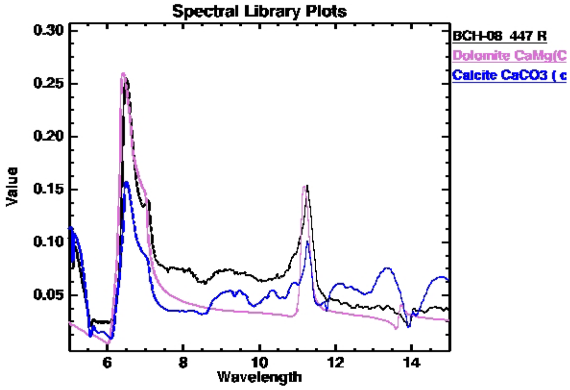

Figure 6. Sample BCH-08 447(black line) is clearly identified as calcite when compared with library spectra of dolomite (purple) and calcite (blue).

SUMMARY

Infrared spectroscopy can identify both broad mineral similarities and differences among core hole samples rapidly and without extensive sample preparation. 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 as well as correlating stratigraphy across fault zones.

Future work will emphasize detailed mineralogic identification of existing samples and pilot studies during actual field operations. Our ASD instrument is fully portable and can be run on battery power enabling spectral measurements at remote field sites. Chip or core samples can be monitored quickly during drilling operations to assist geologists in sample identification and characterization.

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Table 1: Core samples from Bradys/Desert Peak. Brief description of hand samples and major spectral features.

Core name and depth	Brief Description	ASD		FTIR	
		Avg Albedo	Major Features	Reflectance Peak	Major Features
BCH-2, 2450'	Ash-flow tuff, light maroon/grey/green, rich in a variety of lithics, up to 2cm, minor quartz veining, some sanidine	0.29	Lots of structure. Curious spectrum in NIR, 0.7, 0.93,1.16 features. Narrow 1.4. Large 1.9, 2.2, shoulder at 2.25, narrow 2.35, weak 1.8	0.18	Quartz + clay, seconday shoulder at 9.0um.
BCH-2, 3850'	Ash-flow tuff, light grey/maroon/green, rich in sanidine, up to 3mm	0.12	Large slope down. Modest 1.9, 2.2. Weak 1.4.	0.18	Strong quartz, broad wing 10 to 12um.
BCH-2, 3950'	Ash-flow tuff, light maroon, fiamme rich, some lithics up 1cm	0.14	strong iron oxide edge - strong 0.5, peak at 0.8, big slope down. Weak 2.2 and very weak 1.9	0.16	Qartz+clay, no shelf at 9.0 um
BCH-2, 3979'	Ash-flow tuff, pink, some bitotite, some sanidine, up to 3mm, some lithics, up to 1cm	0.28	similar to 3950 - strong 0.5, peak at 0.8, another peak at 1.05 (wk Fe 0.85) slope down. Strong 1.9 and 2.2, weak and narrow 1.4	0.16	Quartz + clay, shelf rather than band at 9.0um.
BCH-03, 3740'	Ash-flow tuff, grey/white/green, rich in feldspar with lesser amounts of biotite	0.18	strong slope down, 1.4, .9, 2.2 - weak clay development possible subtle 2.35	0.15	Strong quartz plus clay, shoulder at 10.5 um. Possible feldspar 9.6um.
BCH-03, 3993'	Ash-flow tuff, light maroon/grey, some feldspar, up to 3mm, lithic-rich, up to 2cm	0.18	0.55, strong slope down, weak 2.2, and very weak 1.9	0.22	Strong qartz+clay, shoulder at 10.5um.
BCH-03, 4065'	Ash-flow tuff, very light grey/green, some sanidine, up to 2mm, abundant lithics up to 1.5cm, some lithics are dark	0.32	Olivine + clay (montm) broad 1um narrow 1.4, triangle 1.9 typ 2.2 for illite/mont. Also 2.3 ledge and narrow 0.75	0.17	Quartz, clay, feldspar. Narrow 9.3 and 9.55 peaks.
BCH- 5, 1878'	Basaltic andesite, black with tint of dark green, aphanitic	0.08	Apparent FeOx ledge, pk at 0.7. Strong 1.4, Very Noisy	0.20	Clay combination - peak matches saponite
BCH-05, 3044'	Ash-flow tuff, light grey/green, vitric, biotite-rich, up to 2mm	0.26	Strong slope down. Apparent FeOx 0.7, weak 1.9 broad and rounded 2.2	0.13	Quartz. Possible feldspars at 9.4 and 9.8 um. Broder wing at 11um.
BCH-8, 447'	Ash-flow tuff, tan, some quartz, aphyric	0.55	Carbonate, calcite dominant. Add'tl contribution at 1.4 and 1.9 broad Fe slope to 1um	0.26	Carbonate. Best match to calcite.
BCH-8, 565'	Basalt, dark green, aphanitic, abundant amygdules that have been altered to clay, up to 5mm	0.13	Fe3+ traingular 1.9, narrow 2.3, very weak 1.4	0.19	Clay. Quartz shoulder at 8.5, but no narrow 8.5 absorption. Good fit to saponite.
BCH-10, 882'	Basalt, black, aphanitic	0.12	Strong slope down. Maybe weak and broad 2.2	0.14	Distinct from others. More clay dominated, broader wing from 10 to 12 um.
35-13, 1947'	Ash-flow tuff, light grey/green groundmass, some quartz, rich in biotite, and feldspar altered to clay, up to 3mm	0.35	serpentines or amphiboles? Broad 1um with additional 0.75. Narrow and strong 1.4, 1.9 and 2.2 narrow peak at 0.55	0.14	Strong clay, including 6.5 um peak. Quartz
35-13, 2184'	Ash-flow tuff, light grey, rich in lithics of other tuffs and a few from basalt up to 1.5 cm, some biotite and feldspar, up to 1mm	0.25	strong slope down. Weak 1.9 and narrow pointy 2.2	0.12	Quartz + clay, seconday shoulder at 9.0um.
35-13, 2266'	Ash-flow tuff, medium grey, rich in lithics of other tuffs and a few from basalt < 0.5cm, some biotite and feldspar, up to 1mm	0.25	nearly identical to 2184	0.12	nearly identical to 2184'
35-13, 2436'	Ash-flow tuff, maroon/tan groundmass, rich in feldspar, up to 5mm, abundant green clay lithics	0.17	similar to 2266 and 2184 but lower albedo, stronger 1.4. 2.2 could be kaolinite well developed hematite+ goethite .6 and .78 peaks (limonite)	0.15	Qartz + clay, clay peak shorter - montmorillonite
35-13, 2559.5'	Ash-flow tuff, medium maroon groundmass, rich in feldspar altered to clay, up to 3mm, biotite, up to 1mm, minor lithics	0.17	odd structure .4 to .8, large slope down. Good 1.4, 1.9 and 2.2 bands	0.15	Strong clay, including 6.5 um peak. Quartz