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# Spectral Analyses of Well Cuttings from Drillhole DP23-1, Desert Peak EGS Area, Nevada – Preliminary Study of Minerals and Lithologies by Infrared Spectrometry

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## Keywords

*Enhanced Geothermal Systems, Desert Peak, spectroscopy, well bore*

## ABSTRACT

The primary and secondary mineralogy of rocks can be quickly evaluated by means of visible and infrared spectroscopy. Drill hole DP 23-1 at Desert Peak, Nevada, USA is the focus of an Enhanced Geothermal Systems Project. Our spectral analyses of drill cuttings from DP 23-1 have identified the major clay and mineral components of various rock types and are consistent with previous petrographic analyses. This work expands on previous measurements by exploring mineralogical variations at more frequent intervals than thin-section or X-ray diffraction sampling. Spectra sampled at 20 ft (6 m) intervals resolve changes in lithology with depth in the drill hole.

## Introduction

Drill hole DP 23-1 is the focus of the DOE-Industry (OR-MAT Nevada, Inc.) cost-shared Desert Peak East Enhanced Geothermal Systems Project located within the Hot Springs Mountains approximately 50 miles (80 km) northeast of Reno, Nevada (Schochet et al., 2002). DP 23-1 was drilled in 1979 as an exploration well to a depth of 9,641 feet (2,939m) through Quaternary to Tertiary tuffaceous and sedimentary rocks and into a Mesozoic basement consisting of metasedimentary and intrusive rocks (Lutz et al., 2003;2004). Temperatures of up to 400°F (204°C) were recorded in the basement rocks, but the well was not capable of commercial production. Because of the high temperatures and poor permeability, drill hole DP 23-1 has been targeted for hydraulic stimulation of potential reservoir units (Schochet et al., 2002; Robertson-Tait et al., 2004). Lithologic and mineralogical analyses (Lutz, 2003), well bore imaging data, and drill penetration rates have been correlated to determine zones of weakness that may compromise well bore integrity during stimulation experiments. Robertson-Tait et al.

(2004) favor hydraulic stimulation of a granodiorite interval below 7,650 ft (2331 m).

The objective of this study was to spectrally analyze the well cutting materials and to determine whether the spectral signatures could be used to distinguish different lithologies, or determine the amount and type of clay alteration with depth. The results of this preliminary study demonstrate the utility of using infrared spectroscopy as a rapid and consistent means to identify clay-rich zones and subtle mineralogic changes related to the overall history of hydrothermal alteration of the rocks. Additionally, our results complement the existing DP 23-1 data set, and may act as a reference for further spectral analyses of rocks or drill core and cuttings material from geothermal areas.

## Background

The wavelength range from 0.4 to 2.5  $\mu\text{m}$  has been used for over 30 years to identify unique mineral signatures in the laboratory (e.g. Hunt, 1977). The technique takes advantage of the interaction of light with both cations (Fe, Mg, Al) and anions (OH, H<sub>2</sub>O, CO<sub>3</sub>) in the mineral structure. The visible/near infrared (VNIR) and short-wave infrared (SWIR) range (0.4 to 2.5  $\mu\text{m}$ ) is ideal for identifying iron oxides, hydroxides, minerals with bound or adsorbed water, carbonate or sulfate. Common products of alteration such as clays, oxides and hydroxides are readily identified and distinguished. Rocks and minerals that contain molecular water will display spectral absorption features at both 1.4 $\mu\text{m}$  and 1.9 $\mu\text{m}$  due to vibrational processes that take place when light is absorbed (Hunt, 1977). Ferrous and ferric iron are identified from absorption features at shorter wavelengths, 0.4 to 1  $\mu\text{m}$ .

## Methodology

Data collection was performed at the Energy and Geosciences Institute (EGI), Salt Lake City, Utah on March 10, 2004. Chipboards of DP 23-1 were made in the early 1980s, when EGI first received the complete set of well cuttings from

Phillips Petroleum. The cuttings are glued with epoxy onto painted chipboards. The well cuttings from DP 23-1 comprise 15 separate chip boards that each corresponds to 660 ft (200 m) of rock intersected by the drill hole. The chip boards are divided into 0.5 inch (1.27 cm) segments that each represents the cuttings from a 10 ft (3 m) section of the well bore. The individual cuttings are very fine and chip sizes are generally less than 2 mm; hence, X-ray diffraction (XRD) and petrographic analyses have been employed to study these fine materials. Lutz (2003) has characterized 29 individual samples from the chip boards using thin section and XRD. For this study, the spectra were collected at a higher sampling density to assess how well spectroscopy can be used to provide rapid assessment of mineralogy and downhole lithology.

For this work we employed a portable field spectrometer manufactured by Analytical Spectral Devices (ASD) Inc. of Boulder, CO. As part of the standard measurement practice the spectra are measured relative to a diffuse, white target so the output of the instrument is a direct measurement of reflectance. The target was illuminated with a halogen lamp while the viewing optic was positioned approximately 1.2 inches (3 cm) above the surface looking directly down (Figure 1).

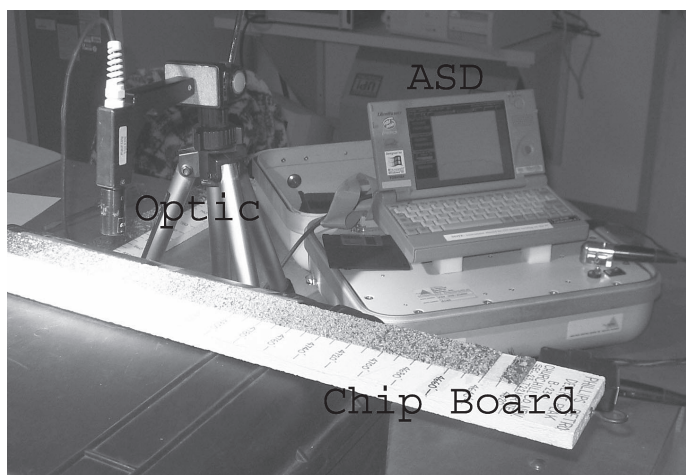


Figure 1. Portable field spectrometer.

In this geometry the spectrometer is sensing an area roughly 1 inch (2.54 cm) in diameter, or the approximate width of a 20 ft (6 m) depth interval. Single spectra were acquired at the 10 ft mark on the first chip board and then subsequently at 20 ft intervals. A total of 33 spectra were collected for each board, with the exception of the last board that represented the final 300 ft (91 m) of borehole. After some initial set-up and experimentation with the viewing geometry, the 477 individual spectra were acquired in a few hours.

### Initial Results

During the spectral acquisitions, several characteristic patterns were immediately apparent. These include the diagnostic signatures of chlorites, muscovite, illite and the relatively flat spectra of clay-poor, silicified metamorphic rocks (Figure 2). Many spectra exhibited multiple unusual features that are not

typical of common minerals and these were determined to be absorptions associated with the epoxy glue used for mounting the cuttings on the board. We acquired spectra of several regions where the glue was visually predominant in order to have a spectral endmember for this contribution. A broad absorption feature at 1.7 $\mu$ m is not common in the spectra of most minerals and was particularly diagnostic of the epoxy. We then used relative absorption at 1.7 $\mu$ m to qualitatively evaluate the presence of epoxy in each sample.

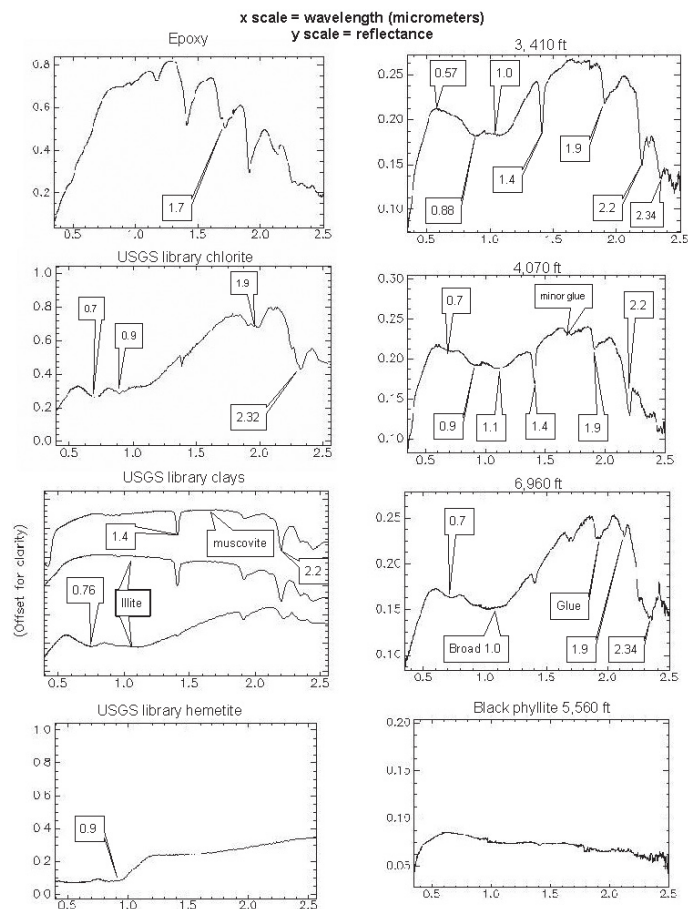


Figure 2. Illustration of the main spectral types.

Figure 2 illustrates the main spectral types observed compared to library spectra of pure minerals. Material from 3,400 ft has been described by Lutz (2003) as muscovite and chlorite clays. This agrees well with ASD spectra from 3,410 ft (Figure 2) that suggests a chlorite – muscovite mixture, based on absorption features at 2.2 $\mu$ m, 2.34 $\mu$ m and a peak at 0.57 $\mu$ m. These features match library spectra for muscovite and chlorite respectively (Figure 2). ASD spectra from 4,070 ft are more characteristic of an illite – chlorite mix which are also validated by petrographic analysis and compared with library spectra in Figure 2. Strongly propylitized (epidote-chlorite altered) diorite (Lutz, 2003) spectra from 6,960 ft closely matches library chlorite spectra. Black phyllite from 5,650 ft displays a featureless spectral signature due to low reflectivity (Figure 2). It should be noted that hematite, calcite, epidote and dolomite

have spectral absorption features that overlap with diagnostic bands of illite, muscovite and chlorite. The presence of calcite, dolomite and hematite in many of the ASD spectra is strongly implied but their spectra is not observed exclusively; this is not surprising since these minerals occur in subequal concentrations along with muscovite, illite, and chlorite (Lutz, 2003). Future work will use more systematic methods of matching spectra in order to more accurately assess mineral abundance in spectral regions with mixed signatures of various minerals as well as the epoxy glue.

ASD spectra in Figure 3 illustrate gradational changes corresponding to the abundance of diorite within this mixed-lithology section of the drill hole. The spectra at this depth range exhibit features at 1.4 and 1.9  $\mu\text{m}$  and other bands consistent with chlorite. These features become progressively weaker with the transition into the bland spectra of black phyllite with depth. The mineralogy indicated by the ASD spectra is validated by the description of strongly propylitized hornblende diorite sampled at 5,280 ft (Lutz, 2003). Phyllite from 5,560 ft is also described as strongly propylitized, and the Figure 3 spectra indicate that chlorite alteration is more intense above 5,550 feet.

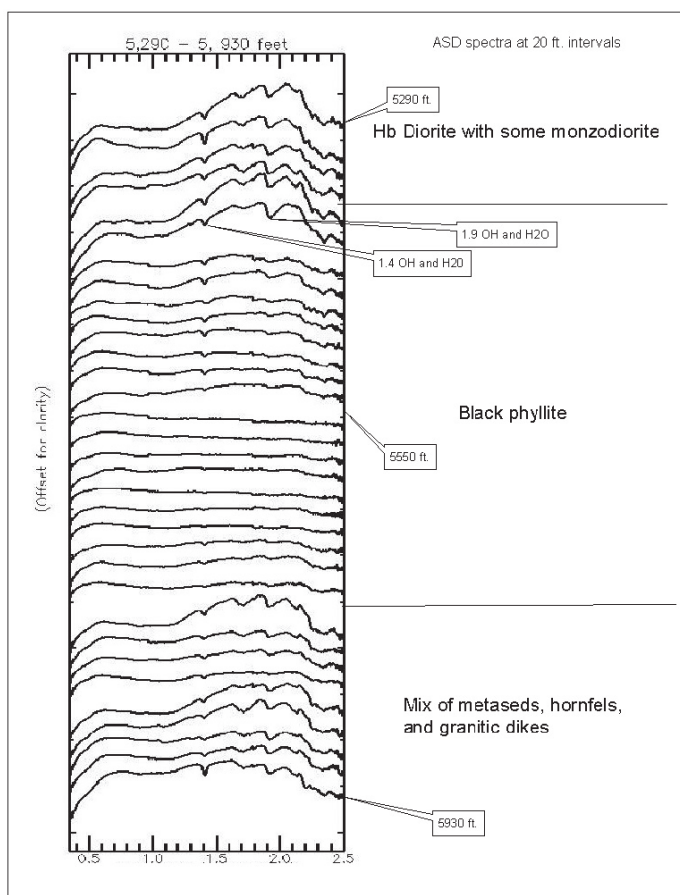


Figure 3. ASD spectra at 20 ft. intervals.

An overall assessment focused on the dominant spectral properties of different rock types and a comparison with the mineralogy of the 29 samples previously analyzed by Lutz (2003). Table 1 summarizes the correspondence of mineralogy

Table 1. Correspondence of mineralogy and lithology determined by thin section and X-ray diffraction analyses with that indicated by the infrared spectra.

M = MAJOR c = common m = minor * = < trace				
Thin section and XRD analyses are compared with spectra for 20 ft intervals above and below the listed depth.				
Analyses method	Depth (ft)	chlorite	clay	hemetite glue
Spectra		M	*	* m
TS/XRD	3060	*	c	*
Spectra		M	*	* m
TS/XRD	3160	c	c	*
Spectra		c	M	M m
TS/XRD	3400	M	M	M
Spectra		c	M	c m
TS/XRD	3800	c	M	M
Spectra		c	M	c m
TS/XRD	4060	c	M	M
Spectra		m	M	* m
TS/XRD	4200	M	M	*
Spectra		m	M	* m
TS/XRD	4440	M	M	m
Spectra		M	M	m m
TS/XRD	4780	M	M	*
Spectra		c	M	* m
TS/XRD	4900	M	M	*
Spectra		c	*	* m
TS/XRD	5140	m	m	*
Spectra		M	*	* m
TS/XRD	5280	M	c	*
Spectra		c	*	* m
TS/XRD	5560	M	M	*
Spectra		M	*	m m
TS/XRD	5940	M	c	*
Spectra		c	*	m c
TS/XRD	6340	M	c	*
Spectra		*	*	m M
TS/XRD	6500	*	*	*
Spectra		M	*	* c
TS/XRD	6640	c	m	*
Spectra		M	*	* c
TS/XRD	6800	M	m	*
Spectra		M	*	* c
TS/XRD	6960	M	m	*
Spectra		c	*	* c
TS/XRD	7040	c	m	*
Spectra		c	*	* M
TS/XRD	7240	c	m	*
Spectra		*	*	m M
TS/XRD	7480	M	m	*

Spectra below 7,840 ft are dominated by glue and show subtle absorptions due to the presence of minor goethite and hematite.

and lithology determined by thin section and X-ray diffraction analyses with that indicated by the infrared spectra. A large number of samples show strong features associated with the epoxy, however large sections of the boards are not affected.

In addition to getting a clear signature of minerals such as chlorite, muscovite and illite some spectral samples show development of narrow features at 1.4 and 1.9  $\mu\text{m}$  that are consistent with water ( $\text{H}_2\text{O}$ ) or hydroxyl ( $\text{OH}$ ) in the sample (Figure 3). Future work will set out to systematically determine the strength of these features as a function of depth for comparison with other downhole information and as a possible proxy for vein mineralization, fracturing or the presence of fluids at depth. Detailed analysis of the several hundred spectra acquired is ongoing and a synthesis of final results will be presented at the meeting.

## Summary

Spectroscopy is an effective tool for identifying mineralogy and the associated gradational changes with depth that are sometimes difficult to discern with only a hand lens, or with spotty petrographic or X-ray diffraction analyses. The time/cost increase for sampling and processing at more frequent depth intervals is negligible; therefore a greater number of ASD spectra may then be corroborated with detailed petrographic analyses that are more costly and usually sampled less frequently. Spectroscopy may also be used to rapidly select which samples are likely to yield the most unique information upon thin section or X-ray diffraction analyses. Issues of spectral fouling caused by artifact paint, glue or epoxy can easily be avoided by placing samples in partitioned trays and or separate sample jars. Our ASD spectra concur with the major and common mineralogy identified by X-ray diffraction and petrographic means. Additionally, based on the depth of spectral absorption features our results show the potential to indicate qualitative to semi-quantitative mineralogical abundances.

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