EVALUATING LIBS AS A GEOCHEMICAL RECONNAISSANCE TOOL FOR THE K10 LUNAR ROVER

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Background: In June of 2009, the Intelligent Robotics Group from NASA Ames Research Center carried out a robotic reconnaissance of the Black Point Lava Flow (BPLF) in northern Arizona using the K10 lunar rover (Fig 1). This field test was a precursor to the Desert Research and Technology Studies (D-RATS) field test in September 2009. The purpose of the test was to quickly assess the geology of the site and to collect high resolution surface data that would complement orbital remote sensing data, thereby increasing the a priori understanding of the site. The collected data was then used to plan crew traverses and extra-vehicular activities, and to improve situational awareness during crew operations.

Field site: BPLF is part of the San Francisco volcanic field, and is located ~50 km north of Flagstaff, Arizona, U.S.A. The study area contains late Cenozoic basalt flows of compositions similar to hawaiite emplaced on top of sedimentary materials of varying age [1]. Near the western section of the field area are exposures of Mesozoic-age shale and sand- and siltstones of the Moenkopi Formation, while to the east are older sandstones and dolomites of the Paleozoic-age Kaibab Formation. Although the materials in the field site have relatively well documented compositions, for the purposes of this exercise no assumptions about composition were made beforehand.

The K10 rover: The K10 rover is a development platform used extensively at NASA Ames to study the roles robots can play in support of human science and exploration in space [2]. As a research platform, the design of K10 emphasizes high flexibility with respect to target scenarios and payload instruments, and aims to provide adequate operational analog fidelity as well as serviceability in a cost-effective manner. This is achieved through the use of inexpensive commercial off-the-shelf parts, and without requiring physical similarity to flight hardware [3].

Fig. 1. The K10 rover at Black Point Lava Flow, W. field site.

Instruments onboard the rover include black and white hazard cameras, a Gigapan high resolution full color panoramic camera for context imaging [4], a 3D scanning light detection and ranging (LIDAR) instrument for terrain topography, and a microimager camera for 50μm/pixel images of surface materials. Here, we evaluate the benefits of including a laser-induced breakdown spectroscopy (LIBS) geochemical instrument as part of the K10 instrument package.

The LIBS technique: LIBS is an emission spectroscopy technique used to determine the elemental composition of a target material. This technique uses a pulsed laser to create a plasma on the surface of the target, which in turn emits light of wavelengths characteristic of the constituent species [5]. The first LIBS instrument for extraterrestrial applications has been selected as part of the ChemCam instrument package onboard the 2011 Mars Science Laboratory (MSL) rover. LIBS has also been proposed for future missions to the Moon [6,7]. The LIBS technique has many benefits for planetary exploration, including:

- Standoff capabilities ranging from a few meters up to ~100 m [5];
- Quick analysis times;
- Sensitivity to all elements, including light elements such as H, C, N, O, Li, Be, and B [8];
- No sample preparation [5];
- Ability to operate in a variety of atmospheric conditions, including vacuum [6];
- Ability to analyze and remove dust coatings;
- Low power requirements [8].

These characteristics make LIBS ideally suited for use as a reconnaissance tool on the Moon.

Methods: *Sample collection*. Sampling locations were selected in advance of the field work based on the PanCam, Microimager, and LIDAR data returned by K10 during the June 2009 field test. Samples were collected by hand using K10 traverse coordinates and imagery as guidance. In all cases, a person standing in approximately the same location in the field (within 10s of meters) could readily identify outcrops and other features from PanCam images, and then sample from areas identified in the recon data. Samples were only collected from outcrops that were visible in K10 recon data and that would have been accessible to the rover in order to determine what information LIBS would have provided had it been part of the K10 instrument suite.

LIBS. A Big Sky Nd:YAG laser operating at 1064 nm, a repetition rate of 10 Hz, and an energy of 17 mJ/pulse was used. The laser beam was focused onto the sample surface, which was positioned at a standoff distance of 7 m to simulate collection of data in the field. Some of the plasma emission was collected with a telescope and then directed to a demultiplexer connected to three Ocean Optics HR2000 spectrometers, each covering a different spectral region ranging from ~245-800 nm (UV, VIS, and VNIR). The integration time was set to 1 s and five spectra were averaged for each LIBS spectrum, so that each recorded spectrum is the combination of 50 laser shots. Shot locations on individual samples were selected in regions that appeared representative of the rock as a whole. In cases in which an exterior varnish or coating was apparent, both the exterior and interior of the rock was measured.

MVA. Two multivariate analysis (MVA) methods were used to analyze and classify the LIBS data: partial least squares (PLS) and principal component analysis (PCA) [9, 10]. PLS relates a model of elemental composition (standards) to measured compositions (unknown materials). In addition to elemental abundance, whole rock composition may be predicted using PCA. PCA is a measure of spectral similarity; rocks with similar compositions will plot together in PCA space. Here, the training set consisted of several geochemical reference material standards of basalt, andesite, and dolomite. Models were built using the commercial software Unscrambler.

Results: The PLS model correctly identified the presence and general abundance of the major elements Si, Al, Mg, Ca, Fe, K, Na, and Ti as compared to values from [1] (basalts) and [11] (sedimentary materials). The model produced values that tended to be somewhat lower than data obtained for BPLF materials in previous studies, especially for Si; however, this is likely the result of the differences between bulk analysis methods and LIBS point analysis on rock surfaces. The integration of additional LIBS shots would likely reduce the differences between these two analysis methods.

The PCA model correctly differentiated the sedimentary and igneous materials found within the field site (Fig. 2). In addition, our model also indicated the degree of weathering. Both exterior and fresh surfaces were measured for each rock. Basalts with a distinct rind or varnish plotted further from the igneous standards than did the fresh surfaces of those same rocks. Sand- and mudstones with a weathering rind or surface varnish also tended to plot in a different location in PCA space than the fresh surfaces of those same rocks. The sampled wash sediments plot in between weathered sandstone and weathered basalt, suggesting that materials within the wash may be a mixture of the two.

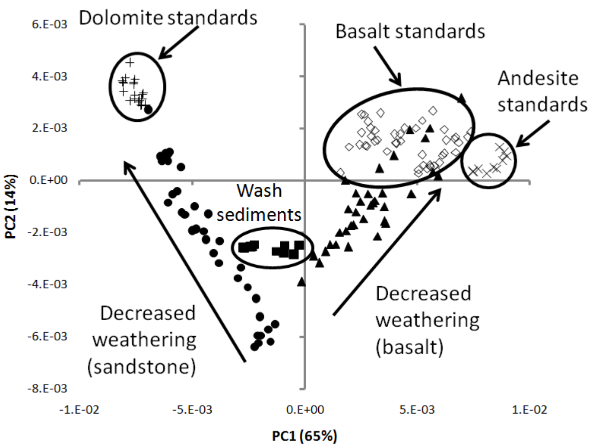

Fig. 2. PCA plot of BPLF samples (closed symbols) and standards (open symbols). For samples, only data from rock exterior surfaces are shown. Standards are basalt (open diamonds: BIR1, GBW07105, GUWBM), andesite (exes: JA1, AGV2), and dolomite (pluses: GBW07114, GBW07216a). Samples include sandstone (closed circles), basalt (closed triangles), and wash sediments (closed squares).

Discussion: These results suggest that LIBS can quickly differentiate between unknown materials in the field. In addition, LIBS can also provide accurate geochemical information that will aid in determining whether a target warrants closer inspection or sampling during a crew traverse. LIBS provides substantial additional information about the geology of the BPFL site, with low power, low mass, small volume, and fast acquisition time. The discriminatory power and operational efficiency of LIBS makes it an ideal candidate instrument for robotic reconnaissance.

References: [1] Ulrich, G.E. and Bailey, N.G. (1987) *USGS Miscellaneous Field Studies Map* MF-1956. [2] Fong, T. et al. (2008) *AIAA Space 2008*, San Diego, CA, #7886. [3] Deans, M. C. et al. (2009) *AIAA Space 2009*, Pasadena, CA, #6781. [4] www.gigapan.org [5] Cremers, D.A. and Radziemski, L.J. (2006). *Handbook of Laser-Induced Breakdown Spectroscopy*. [6] Cremers, D.A. (2004) *LPSC XXXV*, #1589. [7] Harris, R.D. et al. (2005) *LPSC XXXVI*, #1796. [8] Wiens, R.C. et al. (2009) *LPSC XL*, #1461. [9] Clegg, S.M. et al. (2009) *Spectrochim. Acta B, 64*, 79-88. [10] Sirven, J.B. et al. (2006) Anal. Chem. 78, 1462-1469. [11] See et al. (2002) NASA/TM–2002–210787.

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