

REMOTE LASER INDUCED BREAKDOWN SPECTROSCOPY (LIBS) ANALYSES OF DaG 476 AND ZAGAMI MARTIAN METEORITES.

J.R. Thompson¹, R.C. Wiens¹, S.M. Clegg², J.E. Barefield², D.T. Vaniman³, and H.E. Newsom⁴, ¹Space Science and Applications, MS D466, Los Alamos National Laboratory, Los Alamos, NM 87544, ²Advanced Chemical Diagnostics and Instrumentation, MS J565, Los Alamos National Laboratory, Los Alamos, NM 87544, ³Geochemistry and Geology, MS D462, Los Alamos National Laboratory, Los Alamos, NM 87544, ⁴Institute of Meteoritics, University of New Mexico, Albuquerque, New Mexico 87131

Overview: Remote Laser-Induced Breakdown Spectroscopy (LIBS) was selected as part of the ChemCam instrument package for the Mars Science Laboratory (MSL) rover to be launched in 2009. Here we investigate the ability of LIBS to remotely determine differences between basaltic rock types on Mars by analyzing two different shergottite meteorites from Mars at a standoff distance in a simulated Martian environment.

Introduction: Laser Induced Breakdown Spectroscopy (LIBS) is a rapid and quantitative analytical tool for elemental analysis in terrestrial, Martian, and many other environments [1,2]. As a member of the ChemCam package onboard MSL, LIBS will be the first active remote sensing instrument to fly on a NASA rover. The ChemCam LIBS system will be designed to interrogate samples at distances up to 9 m [3]. In preparation for the MSL mission, we are working to improve our ability to extract quantitative results under the Martian environment.

Here we investigate the ability of LIBS to remotely determine differences between basaltic rock types on Mars by extracting quantitative elemental concentrations and calculating the oxide concentrations from two Martian basaltic shergottite meteorites, Dar al Gani (DaG) 476 and Zagami. The ability of LIBS to remotely distinguish between basaltic and andesitic compositions in a Martian environment was also investigated by analyzing a known andesite standard and comparing its spectra to the Martian basaltic shergottite spectra.

Samples: In this study we analyzed two Martian basaltic shergottite meteorites: Dar al Gani 476 (DaG 476) and Zagami. Both samples were in the form of sawn slabs. We also analyzed andesite rock powder standard JA-2.

DaG 476 is a basaltic shergottite with olivine phenocrysts/megacrysts up to 5 mm in size set in a fine-grained groundmass of pyroxene, maskelynitized plagioclase and mesostasis. Consequently this rock type is classified as an olivine-phyric Shergottite [4]. The modal mineralogy is ~60% pyroxene, 15% olivine, 15% feldspathic glass (maskelynite), with minor carbonates, chromite, ilmenite, whitlockite, Cl-apatite, and pyrrhotite with Ni-rich exsolution. The olivines are zoned from Fo76 (core) to Fo58 (rim). The sample used in this study measures 3 x 1 cm.

Zagami is a shergottite basalt that appears to be a

composite of up to three related basaltic lithologies and minor shock-melted glass. Zagami consists of 70-80% fine-grained pyroxene, with most of the rest as maskelynite, but the meteorite also contains small amounts of amphibole, phosphates, and groundmass glass [6, 7]. The sample used in this study was obtained from the Institute of Meteoritics at the University of New Mexico, and measures 2 x 1.5 cm.

The andesite sample analyzed in this study was JA-2, a certified NIST rock powder standard. For this sample ~3 g of powder was pressed into a 31 mm preflared Spec Cap.

Experimental: The current LIBS laboratory setup involves ablation of material from an area ~400 μm in diameter with a focused Nd:YAG (1064nm) laser. The ablated material produces a supersonically expanding plasma of electronically excited atoms. A dispersive spectrometer and an ICCD camera are used to record the spectral signatures emitted from the electronically excited atoms. In our experimental set-up, samples were placed at a distance of 5.4 m from the instrument in a vacuum chamber filled with 7 Torr CO₂ to simulate the Martian atmosphere.

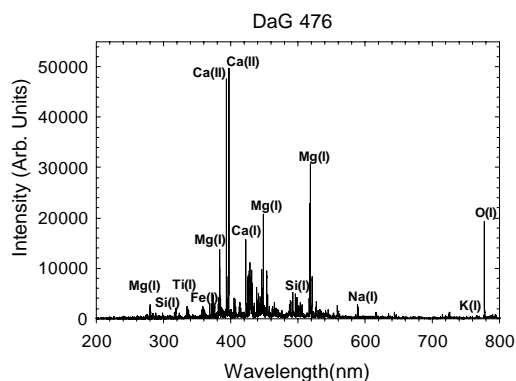


Figure 1. Typical LIBS spectrum for DaG476.

Terrestrial basalt standards were used to generate calibration curves for all of the major elements and some of the minor and trace species including Si, Fe, Mg, Ca, Ti, Al, and Na. LIBS was then used to distinguish between the two different basaltic Martian meteorites utilizing 14 analysis spots of ~400 μm diameter on DaG 476 and 9 analysis spots on Zagami. A typical LIBS spectrum from DaG 476 is shown in Fig. 1. Finally, to illustrate LIBS capability to distinguish differences in compositions for a large

range of materials, a LIBS analysis of an andesite rock powder standard was conducted. Five LIBS analysis spots were analyzed on the andesite standard.

Results: Using 14 analysis spots of ~400 μm diameter on Dar al Gani (DaG) 476 and 9 analysis spots on Zagami, the LIBS technique at a 5.4 m stand-off distance clearly distinguished the olivine-phyric (DaG 476) from the fine-grained (Zagami) shergottites on the basis of MgO and CaO. As shown in Table 1, the elemental abundances agreed with literature values for these meteorites to within ~5% for most of the major elements. Fig. 2 shows the MgO and SiO₂ compositions obtained from individual LIBS analysis spots on Zagami and DaG 476, along with the mean composition and the literature values. There is a clear discrimination of the two samples in terms of MgO abundances, with no overlap of the LIBS analytical data.

Five LIBS analysis spots were analyzed on the andesite standard. The average oxide weight percent for the major oxides found in the andesite standard calculated by LIBS compare very favorably (<12% with most oxides <6%) with the literature compositions with the exception of Na₂O. The high error in Na₂O is most likely due to a chromatic aberration observed in the laboratory breadboard

Table 1. LIBS-derived oxide weight percentages, and comparisons to compositions in the literature for DaG 476 and Zagami.

Oxide	DaG 476			Zagami		
	LIBS	Lit ^e	% Diff	LIBS	Lit ^a	% Diff
SiO ₂	51.59	47.46	8.7%	53.86	50.86	5.9%
FeO	15.76	16.58	4.9%	17.45	17.88	2.4%
CaO	6.56	7.11	7.7%	10.11	10.39	2.7%
MgO	19.49	19.84	1.8%	11.05	11.24	1.7%
Al ₂ O ₃	5.23	4.28	22.2%	5.67	5.96	4.9%
Na ₂ O	0.69	0.55	25.5%	0.70	0.9	22.2%
TiO ₂	0.68	0.37	83.8%	1.04	0.79	31.6%

^aLiterature values for Zagami and DaG 476 were obtained by averaging analyses from the Mars Meteorite Compendium and references therein [8].

system, resulting in low counts at the longer wavelengths, where the Na peak is found.

Conclusions: This experimental investigation is a demonstration of LIBS capabilities as a short-distance remote sensing instrument on Mars. Here we investigated the ability of a remote LIBS instrument to determine the differences between very similar rock types on Mars. The data illustrate LIBS ability to determine even subtle differences in rock types from remote distances.

References: [1] Wiens R.C. et al. (2002) *J. Geophys. Res. Planets.*, 10.1029/2000Je001439. [2] Knight A.K. Et al. (2000) *Appl. Spectrosc.* 54, 331-340. [3] Wiens R.et al., ChemCam science objectives for the Mars Science Laboratory (MSL) rover. *Lunar Planet. Sci.* XXXVI, 1580. [4] Goodrich C.A. et al. (2003) Spinel and oxygen fugacity in olivine-phyric and lherzolitic shergottites. *Meteoritics & Planet. Sci.* 38, 1773-1792. [5] Zipfel J. et al. (2000), Petrology and chemistry of the new shergottite Dar al Gani 476, *Met. Planet. Sci.* 35, 95-106. [6] Easton A.J. et al. (1977), Analysis of some meteorites from the British Museum (Natural History) collection, *Meteoritics*, 12, 409-416. [7] McCoy T.J. et al.(1992) , Zagami: product of a two-stage magmatic history. *Geochim. Cosmochim. Acta*, 56, 3571-3582. [8] Meyer, C. (2003), Mars Meteorite Compendium, <http://curator.jsc.nasa.gov/antmet/mmc.htm>

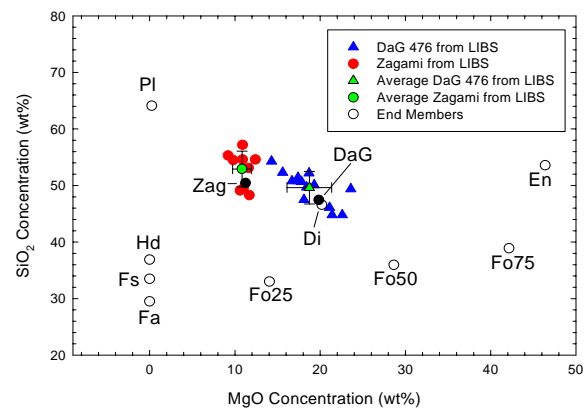


Figure 2. MgO vs. SiO₂ concentrations in weight percent from individual LIBS analyses spots and mean compositions (green) for Zagami and DaG 476 and average whole-rock compositions from the literature (filled black circles), plotted against compositions of olivine end-members (forsterite = Fo, fayalite = Fa), pyroxene end members (Diopside=Di, Hedenbergite=Hd, Ferrosillite=Fs, Enstatite=En), and plagioclase (Pl). The plotted plagioclase composition corresponds to that measured by electron probe for phases surrounding the DaG 476 LIBS analysis spots.