

Utilizing Laser-Induced Breakdown Technology for the Identification and Quantification of Volatiles in Lunar Regolith. F. Diotte¹, M. Lemelin¹, F. Doucet², ¹Département de géomatique appliquée, Université de Sherbrooke, Québec, Canada, J1K 2R1 (Frederic.diotte@usherbrooke.ca, Myriam.Lemelin@USherbrooke.ca), ²Elemission Inc., Montréal, Québec, Canada, H4R 1V6 (fdoucet@elemission.ca).

Introduction: Deepening our understanding of the processes leading to accumulation of water ice in lunar cold traps will be of great importance to better evaluate its potential as an essential survival resource during upcoming crewed missions on the Moon. Studies based on remote sensing have allowed to detect volatiles in permanently shadowed regions [1] as well as on the sunlit surface [2], but the local distributions and relative abundances of those molecules have yet to be defined. It is also thought that a water-loss regime dominated by space weathering and meteoroid impacts would lead to higher water concentrations in subsurface layers [3], with surface regolith being faster depleted in volatiles. In-situ characterization of water ice in the subsurface regolith will thus be required to reach those objectives and will help targeting optimal sampling sites for prospective crewed missions, as well as identifying the adequate extraction process.

Forthcoming landing of laser-induced breakdown spectroscopy (LIBS)-carrying rover Perseverance on Mars is a new confirmation of the relevance of this instrumentation in the context of space exploration. However, major challenges are still to be overcome when applying LIBS to lunar conditions. For instance, low atmospheric pressure leads to poor signal to noise ratio [4], which complicates the detection of trace elements. The current project aims to evaluate the performances of LIBS-based imagery for quantitative analysis of volatiles and platinum group elements (PGE) in lunar regolith. The instrument used for this matter is developed and manufactured by Elemission (Montréal, Canada). Here we introduce preliminary results of qualitative and semi-quantitative analysis of data acquired by the LIBS instrument for lunar regolith simulants LHS and LMS produced by CLASS Exolith Lab, and which chemical compositions correspond to highlands and maria respectively. Both samples include the same major mineral compounds, although their concentrations vary according to Apollo samples compositions. Expected results for subsequent phases of the project will also be introduced.

LIBS based imagery: The imaging capabilities of the LIBS instrument allow to analyze the inherent heterogeneity of simulant samples (Fig. 1). With nearly 65% of the simulant particles being larger than the spatial resolution of the pixel, LIBS-based images clearly show aggregates in homogeneously mixed, pressed powders. Whereas discrete LIBS may allow to detect and quantify H in a single pixel, hyperspectral emission cubes could be used to determine whether a

regolith sample contains adsorbed water, bulk ice or distinct ice grains. It has been demonstrated that unstable ice would undergo changes of state on a diurnal basis as temperature fluctuates [5], bulk ice being most stable below temperatures of 95 K. Hence a technique allowing to discriminate between various forms of ice could be relevant for in-situ analysis of volatiles, especially to help describe the processes involved in the lunar water cycle.

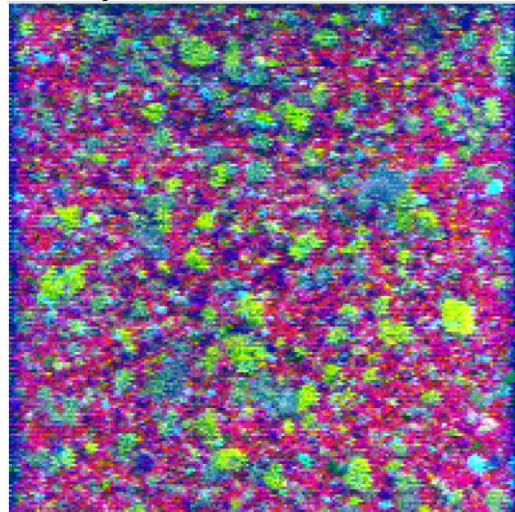


Fig. 1: Enhanced false color composite of PCA 1 (red), 2 (green), 3 (blue) applied to emission hyperspectral data acquired from highlands simulant LHS pressed into a pellet. Image covers area of 10mm*10mm, and laser spot size of 50µm corresponds to spatial resolution

Estimations of chemical concentrations: Qualitative analysis has been conducted using National Institute of Standards and Technology (NIST) spectral emission library on averaged spectra from LHS and LMS samples. Fig. 2 shows elements known to be present in both simulants, and intensities of emission peaks appear to vary as a function of their relative abundance in a way that is coherent with bulk chemistries provided by Exolith.

Further analysis will involve controlling for various experimental conditions such as composition and hydration of samples. Pressure will also be a key parameter that is yet to include in prospective setups, and which will help evaluate the relevance of LIBS in hard vacuum conditions. For hydration, base simulants LHS and LMS will be dried until constant mass and used as blanks. Different amounts of water will be mixed to the simulants to create solutions with varying hydrogen concentrations. Another protocol for intra-

mixed ice samples made using a nebulizer, as suggested in [6], will allow to include micrometric-sized particles of water ice into the base simulants. Thereby we hope to evaluate the ability of LIBS-based imagery to distinguish between different forms of ice in geologic materials. Optimal experimental conditions for the analysis of non-coherent simulants will also be studied in order to maximize emission from the regolith.

A database of emission spectra acquired from regolith simulants will be used to create predictive models for the estimation of relative concentrations of major elements, ice and PGE in synthetic samples. Several multivariate models will be compared,

including the linear mixture model elaborated in [7]. An approach combining several quantitative analysis methods will be evaluated to improve estimations of major, minor as well as trace elements concentrations.

References: [1] Li S. et al. (2018) Proc. NAS, 115, 36. [2] Honnibal C. I. et al. (2020) Nat. Astron. [3] Benna, M. et al. (2019) Nat. Geosci. 12, 5. [4] Lasue, J. et al. (2012) J. Geophys. Res. Planets, 117. [5] Cocks, F. H. et al. (2002) Icarus, 160, 2. [6] Pommerol, A. et al. (2019) Space Sci. Rev. 215, 5. [7] Konstantinidis, M. et al. (2019) J. Chemom. 33, 10.

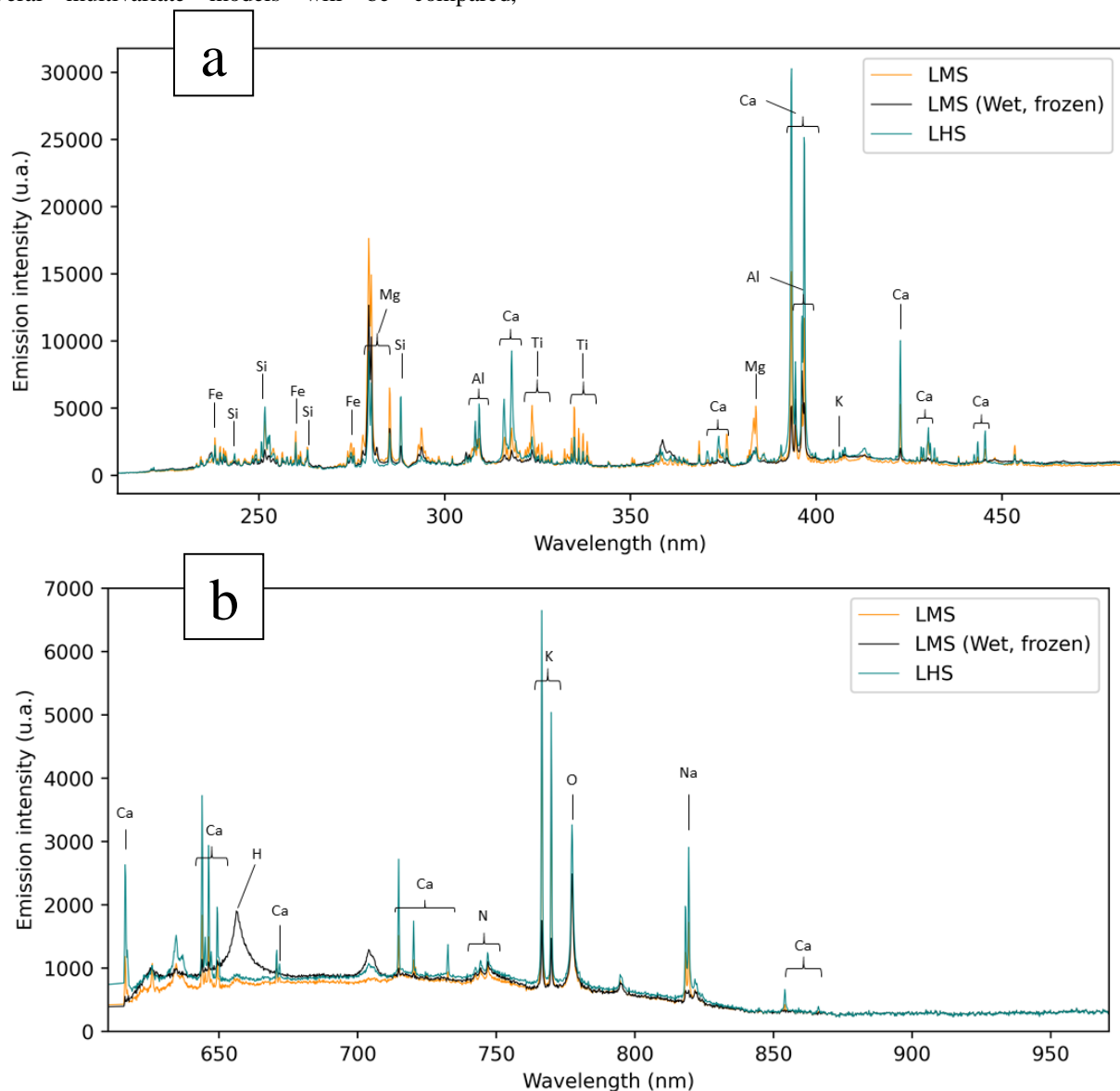


Fig. 2: Emission lines of major, minor and trace elements contained in LHS and LMS simulants based on NIST LIBS Database, in the spectral range between (a) 212.0nm and 484.3nm and between (b) 615.8nm and 971.0nm