Classification of non-homogeneous basalts using Independent Component Analysis technique for MSL/ChemCam data A. Cousin[1], O. Forni[1], V. Sautter[2], C. Fabre[3], S. Maurice[1], O. Gasnault[1], R. Wiens[4], [1]Institut de Recherche en Astrophysique et Planétologie, Toulouse (agnes.cousin@irap.omp.eu.fr), [2]Muséum National d'Histoire Naturelle, Paris, [3]G2R, Nancy Université, [4]Los Alamos National Laboratory, New Mexico

Introduction: Curiosity was launched for Mars on November 26, 2011. ChemCam is a remote sensing instrument suite on board the MSL (Mars Science Laboratory) Curiosity rover. The first of its kind for planetary sciences ChemCam uses the LIBS (Laser-Induced Breakdown Spectroscopy) technique to provide geochemical data at the surface of Mars from remote distances (1.5 to 7 meters) [1,2]. The footprint is quite small (360 to 550 μm in diameter [3]) and therefore appropriate to study the heterogeneity of the samples. The LIBS technique creates a plasma of ablated material in electronically excited states, and then analyses the light with its spectrometers to obtain emission spectra representative of the composition of the sample.

We applied an Independent Component Analysis (ICA, e.g.[4]) on ChemCam calibration data to test the rock classification capability. ICA allows comparison of numerous LIBS spectra to efficiently classify them into groups of known rocks using a well-defined database of characterized samples [5,6,7]. In many cases calibration standards are homogeneous compacted powders [8,9] whilst Martian basaltic rocks analysed in Gusev by Spirit rover [10,11] are textured showing different grain size and mineral composition. The objectives of this work is therefore to test ICA as a classification tool to identify heterogeneous rocks such as phyric textured basalts with different porphyrocrysts set in fine-grained mesostasis.

Samples used and experimental setup: This study focuses on 5 basalts displaying similar bulk rock compositions (Table 1): the maximum standard deviation in composition of major elements is observed for SiO_2 content and is equal to 3.31 %. The challenge is for a experiment that measures elemental composition at 10% accuracy [12,13] to classify these basalts, which are from the Museum National d'Histoire Naturelle (Paris). The phenocrysts (olivine, plagioclase or pyroxene) differ in each selected rock .

Sample	Main phenocrysts
Basalt 205G	Labradorite (Ca)
Basalt 461G	Augite (Mg)
Basalt 863G	Augite (Mg) and Hypersthene (Fe)
Basalt 887G	Labradorite (Ca) and Hypersthene (Fe)
picrobasalt	Olivine (Mg, Fe)

Table 1 : Principal phenocrysts present on the five basalts.

The experimental setup used to analyze these basalts is the EQM (Engineering and Qualification Model) Mast Unit with commercial spectrometers. The samples were placed at 3 m from the instrument, in a dedicated chamber to reproduce Martian atmosphere (6 mbar, 95.7% CO_2, 1.6 % Ar, 2.7% N_2) [14]. For each target, 5 bursts of 10 shots were performed, at five randomly chosen locations.

Methodology: Figure 1 shows the mean LIBS spectrum obtained from each target. At first inspection, it is difficult to identify differences (emission intensity, elements, …) between the different spectra, which agrees with the similar composition amongst the targets. The ICA technique however has proved effective in removing systematic bias and therefore enhances the unique signature of each target.

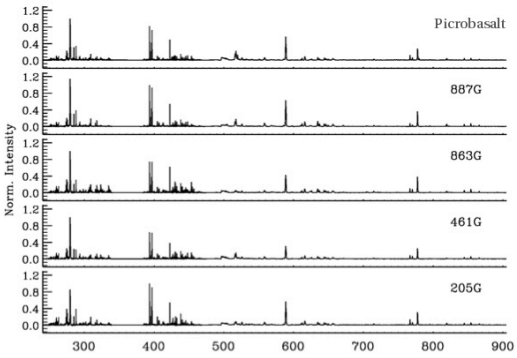

Figure 1 : Mean spectra obtained for each basalt.

The methodology applied is : (1) compute ICA components based on all 25 spectra (5 spectra per sample in Table 1), (2) select the most significant components from ICA, (3) classify the 5 mean spectra corresponding to the 5 basalt samples, (4) classify of each of the 5 spectra acquired per sample.

Results : Four ICA components are considered; They can be associated respectively to Mg, Ca, Fe+Ti, and Al+Na. Any spectrum can then be correlated with these components. Figure 2 shows the Mg component (top) and the correlation factors of that component with each of the 25 spectra (5 spectra/rock, bottom panel). For example, the 5 spectra from the basalt 205G show close to the same correlation coefficients with the Mg component, whereas the basalt 461G shows more heterogeneity: the 3rd spectrum is more correlated with Mg. These different correlations reflect to some extent the sample heterogeneity.

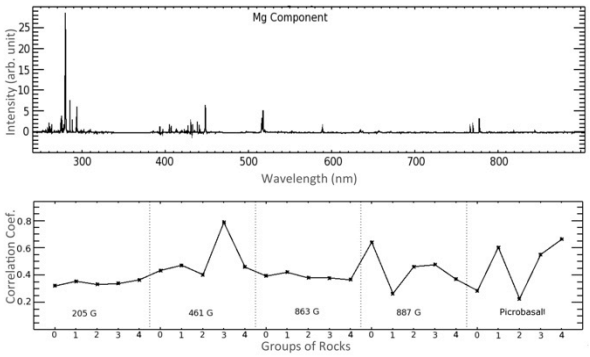

Figure 2 : Mg Component from the ICA model (top), and its correlation (bottom) of each spectrum (x axis) of the model.

The classification obtained for the mean spectrum of each basalt is shown in table 2. The use of the mean spectrum is more representative of the bulk rock composition. The basalts 863G and 887G are well classified whilst the other 3 are all classified as 887G basalt (table 2). This apparent contradiction is actually explained by their mineral similarities : 205G sample contains labradorite crystals, and 461G contains pyroxenes as for the 887G basalt. The picrobasalt is classified as 887 G (a basalt with feldspar phenocryst) due to abundant feldspar microliths in its matrix.

Sample to classify	205G	461G	**863G**	**887G**	Picro-basalt
Classification	887G	887G	**863G**	**887G**	887G

Table 2 : Classification of the mean spectrum obtained for each sample.

The classification obtained for each spectrum for all the basalts is shown in figure 3. The Y axis corresponds to the *known* samples which constitute the model, whereas the X axis corresponds to 5 spectra of each *unknown* sample. 60 % of the spectra are well classified. The five spectra for basalt 205G are misclassified as basalt 887G because both samples contain labrador phenocrysts.

Preliminary studies reveal the difficulty to classify correctly a given spectrum, which is not surprising since it could be representative of one phenocryst or a minerals mixture. We have decided to include some igneous minerals as known end-members in the ICA model : pyroxenes (augite, diopside and enstatite); feldspars (albite, labradorite, andesite) and one forsterite olivine. Using this new model, the basalt classification is better and satisfactory (72 % of success) (figure 4). All basalt spectra are still classified as basalt and not as a single mineral.

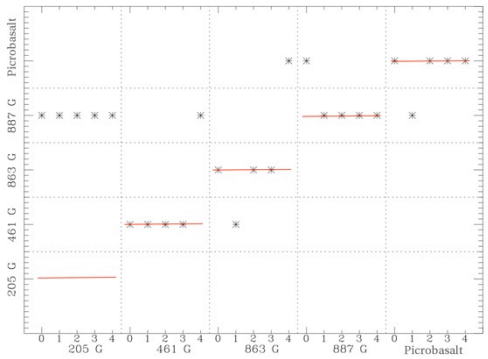

Figure 3: Classification on basalt end-members for individual LIBS spectra. The red lines correspond to the correct classification and crosses correspond to the returned ICA classification.

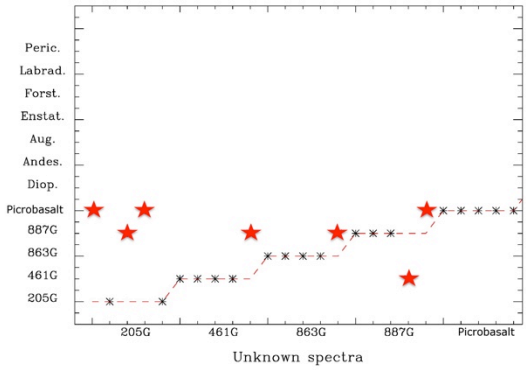

Figure 4 : ICA classification for each unknown basalt spectra, using basalts and minerals spectra in the model. The red stars correspond to the mis- classified spectra

Conclusion : This first application of ICA on LIBS spectra obtained on natural basalts is largely conclusive for fine-grained basalts. Adding minerals in the ICA model proved to be essential to improve the classification of more porphyric basalts. A comprehensive database should therefore include various well-known minerals, along with solid solutions to have a large range of compositions.

References : [1] Wiens et al. (2005), *LPSC 36th*, #1580. [2] Maurice et al. (2005), *LPSC 36th*, #1735. [3] Maurice et al. (2012) *LPSC 43rd*, this edition. [4] Comon P., (1990), *Traitement du Signal, 7*, 435-450. [5] Clegg et al. (2009), *Spec. Chim. Acta Part B*, 64, pp.79-88. [6] Forni et al. (2009) *LPSC 40th*, #1523. [7] Lasue et al. (2011) *Anal. & Bioanal. Chem.,* 400, pp. 3247–3260. [8] Wiens et al. (2010), *LPSC 41th*, #2205. [9] Clegg et al. (2012) *LPSC 42th*, this edition. [10] McSween et al. (2006), *JGR 111*, E02S10. [11] Squyres et al. (2006), *JGR 111*, E12S12. [12] Wiens et al. (2011) *LPSC 42th*, #2370. [13] Anderson et al. (2011) *Icarus 215*, 608-627. [14] Cousin A. et al. (2012) *Spectr. Chim. Acta Part B, in press.*