Chemistry Of Coarse Particles In Soils And Their Relationship With Local Rocks.

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Introduction: The ChemCam instrument [1,2] onboard the Curiosity rover provides for the first time an opportunity to study martian soils at a sub-millimeter resolution. In this work, we analyzed 58 soil targets probed by ChemCam during the first 550 sols on Mars. Using the depth profile capability of the ChemCam LIBS (Laser-Induced Breakdown Spectroscopy) technique, we found that most of the soils contain coarse grains (> 500 µm). Three distinct clusters have been detected: Cluster 1 shows a low SiO_2 content; Cluster 2 corresponds to coarse grains with a felsic composition, whereas Cluster 3 presents a typical basaltic composition. Coarse grains from Cluster 2 have been mostly observed exposed in the Hummocky unit (Figure 1), whereas coarse grains from Clusters 1 and 3 have been detected mostly buried, and were found all along the rover traverse. The possible origin of these coarse grains was investigated. Felsic (Cluster 2) coarse grains have the same origin as the felsic rocks encountered near the landing site, whereas the origin of the coarse grains from Clusters 1 and 3 seems to be more global. Fine grained soils have been analyzed as well and will be described in a companion study [3]. Nevertheless, these fine particles have been compared to coarse grains and seem to be relatively similar to mafic coarse grains.

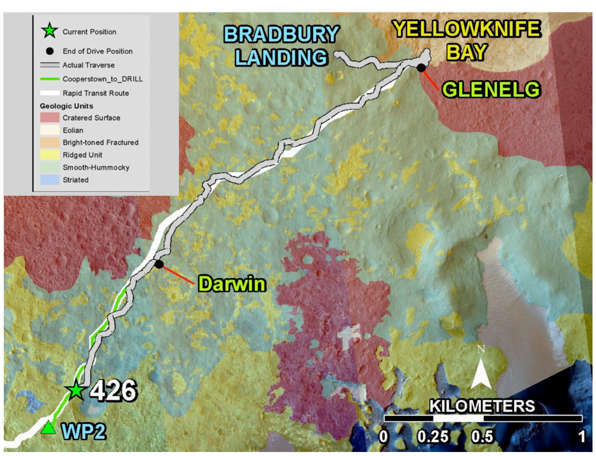

Figure 1 : Geological map of Curiosity traverse.

Technique: The ChemCam instrument is composed of two parts: one located on the mast of the rover, which contains the send and receive optics (laser, camera, telescope) and one located in the rover body (spectrometers). ChemCam also contains a remote camera called RMI [4], which is useful to understand the context of the analyses.

The LIBS technique consists of focusing a pulsed laser (1067 nm) onto a small area of the analyzed sample (350-550 µm). The laser/matter interaction ablates a small amount of the sample (a few ng) and creates a plasma. The plasma light emission is then collected by the telescope and passed to the spectrometers. ChemCam contains three spectrometers, from the ultraviolet (240 nm) up to the near-infrared (~ 900 nm). Each spectrum (from ultraviolet to near-infrared) consists of 6144 channels. Each element is characterized by various emission lines all along this range. A dedicated ChemCam library has been created under martian atmospheric pressure [5].

ChemCam observations usually involve several point analyses on the same target, with at least 30 laser pulses (shots) per location. As a spectrum is acquired for each shot, we collect at least 30 spectra per location. This technique is useful for depth profile analyses.

We have developed a technique in order to spectrally distinguish coarse grains and fine grains using shot to shot analysis: the variability of the total intensity and the Independent Component Analysis (ICA) technique. Signal obtained on a solid target (rock, coarse grain) shows a very stable shot-to-shot total intensity whereas in a loose soil the signal is highly variable. Using the ICA technique, depending on the components, it is also possible to observe clusters, revealing the presence of a solid analyzed target.

Data: All the soil analyses including blind targets have been used up to sol 550 on Mars.

The blind targeting mode [6] allows us to analyze targets after drives, without specifically selecting targets from survey images. This is very useful on long drives, where the rover moves every sol, and images of the after-drive location, normally used for ChemCam targeting, are frequently not received on the ground until the rover has moved again. The mast is pointed to -42° and the observation is taken at the right-side of the rover. This ensures a good LIBS performance with a target at a distance of ~3 m. The rover orientation must meet certain requirements on its roll and tilt, which are checked on board. An RMI image is taken before and after LIBS for geological context; passive spectra are also performed before and after LIBS [7, 8]. A dedicated study concerning the H in the blind targets is described in [8]. A MastCam image is usually also taken for context.

Results: Three chemically distinct groups have been distinguished among the coarse grains using the soils up to sol 250 in previous studies [9, 10]. Cluster 1 shows a mafic composition due to its low SiO_2 content and is enriched in H. Cluster 2 is enriched in Na_2O, K_2O, Al_2O_3 and SiO_2, revealing a felsic composition. Cluster 3 consists of basaltic coarse grains, enriched in Mn and Cr. One coarse grain shows a distinct composition as it is enriched in F and Ca, suggesting fluorite and fluorapatite [11], and is not taken into account in this study.

Figure 2 shows an independent component analysis (ICA) classification [12, 13] of these coarse grains, one color representing each group as determined in the previous study. Data points acquired after sol 250 are superposed and we can observe that all new coarse grains belong to one of these groups (no new compositions have been detected).

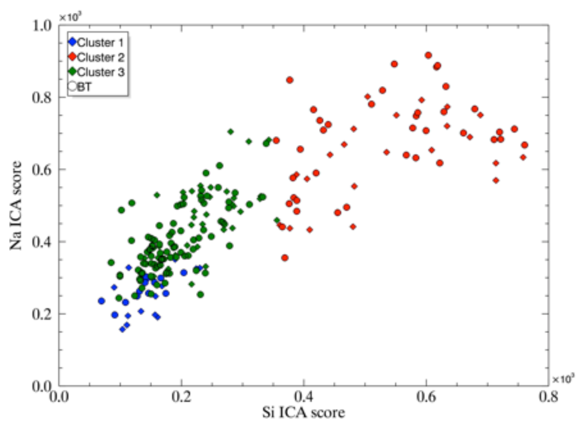

Figure 2: ICA Na vs Si scores for all the pebbles/coarse grains encountered up to sol 550.

Along the traverse, we observed a change in the distribution and size of the pebbles. Figure 3 is an example of each kind of surface we observed. In the Hummocky unit close to the landing site, coarse grains were numerous and relatively small (< 10 mm) whereas their size tends to increase along the traverse as well as their density is decreasing. This distribution and size of coarse grains seem to be related to an increase of felsic coarse grains detection, once the rover came back into the Hummocky Unit after the YellowKnife Bay area. We found a positive correlation between the number of felsic coarse grains observed and the number of felsic float rocks analyzed all along the traverse.

The origin of these coarse grains is important to understand in order to better constrain the formation process of soils. We compared each coarse grain with all the rocks analyzed so far in Gale, using the Sammon's map technique [14], and the minor contents in each coarse grain cluster and each geologogical unit showing some similarities with them, from the Sammon's map. We found that only the felsic pebbles seem to be related to the felsic rocks encountered. Clusters 2 and 3 do not seem to be related to any rocks analyzed so far in Gale crater.

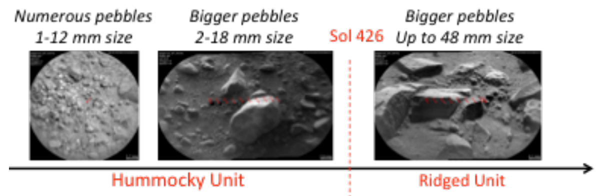

Figure 3: Overview of the type of observed and analyzed soils along the traverse.

Conclusion: The high spatial resolution of ChemCam gives the opportunity to study in detail the pebbles and coarse grains present in the soils, as well as the analysis of the fine grained particles without the contribution of these coarse grains.

In this study we show that the coarse grains can be distinguished depending on their chemistry in three distinct groups.

The distribution of these grains varies along the traverse, with the felsic coarse grains increasing, which is consistent with the increase of felsic float rocks analyzed also along the traverse.

The origin of these coarse grains has been investigated and only felsic coarse particles seem to have a local contribution.

References: [1] Wiens R. et al., Space Science Reviews 170 (2012); [2] Maurice S. et al., Space Science Reviews 170 (2012); [3] Meslin et al., this issue; [4] Le Mouélic, Icarus, in-press; [5] Cousin et al., SAB 66 (2011); [6] Cousin et al., LPSC (2014); [7] Schröder et al., Icarus, submitted; [8] Schröder et al., this issue; [9] Cousin et al., Icarus, in press; [10] Meslin et al., Science 341 (2013); [11] Forni, LPSC # 1328 (2014), [12] Hyvärinen et al., Wiley (2001); [13] Forni et al., SAB 86 (2013); [14] Lasue et al., J. Anal. Bioanal. Chem., (2011).