**ACOUSTIC AND LIBS PROFILING OF SOILS AT JEZERO CRATER, MARS.** Noah Martin[1,2], Baptiste Chide[1], Amanda Sheridan[1], Agnès Cousin[3], Elisabeth Hausrath[4], Olivier Beyssac[5], Roger Wiens[2], and Nina Lanza[1], [1]LANL, Los Alamos, NM, USA (ndmartin@lanl.gov), [2]Purdue University, West Lafayette, IN, USA, [3]IRAP-CNRS, Université Toulouse III, Toulouse, France, [4]University of Nevada, Las Vegas, Nevada, USA, [5]IMPMC, Paris, France

**Introduction:** The SuperCam instrument [1, 2] onboard the NASA Perseverance rover uses Laser-Induced Breakdown Spectroscopy (LIBS) to retrieve the elemental composition of rocks and soils at Jezero crater. The SuperCam microphone complements LIBS analysis by recording the acoustic signal generated by the laser-induced plasma expansion, whose amplitude variation over a burst of shots was shown to depend on the physical properties of the target [3]. In particular, this acoustic signal is used to infer the rock hardness along the rover traverse [4].

In addition to rock, regolith covers a large portion of the Mars surface, and thus is important for understanding the history of the planet. It has been shown that much of the fine grain regolith across the surface exhibits little chemical variation [5]. However, when comparing fine grain regolith to coarse grain regolith in Jezero crater, fine grains tend to be more enriched in Fe and Mg, showing that chemical composition can vary with grain size. In addition to this, varying acoustic behavior is observed in regolith targets, which suggests that soil physical properties (*e.g.*, grain size, compaction, presence of a dust crust at the surface [6]) might drive the acoustic signal caused by the laser ablation. Therefore, this study aims at studying how regolith targets can be further characterized combining acoustics and LIBS measurements.

**Acoustics and Grain Sizing:** A LIBS typical analysis on soils consists of 5 to 10 points with 30 to 50 laser shots at each point. The microphone records simultaneously the acoustic signal resulting from the ablation. Each of the points are separated by a few millimeters and a context image (acquired by the Remote Micro Imager, RMI, of SuperCam) is taken after few bursts (typically one at the first point, one at the middle, and one at the last point). The ablation pits on soils are due to a small amount of matter that was ablated, plus some loose material excavated away by the shock wave.

*Acoustics.* For acoustic data, the peak amplitude of the signal is known to decrease as a function of the number of shots [7]. Therefore, for each target point, the amplitude over a burst, $p$, is fitted with a decreasing exponential function, $p = p_0 * exp(-a*x)$, with $p_0$, a scaling value that corresponds to the amplitude of the first shot, and $a$, the exponential decay rate. For each point the amplitude is normalized by $p_0$ in order to account for the amplitude difference caused by changes in distance from the microphone to the target. The decay rate value that is calculated is used as a primary characterization tool for this study.

*Grain Sizing.* To measure the grain sizes of soil targets, the RMI images of each target are used. The images are imported into ImageJ, an image processing software, and 100 grains are manually measured by drawing a line across the visually identified grain edges. Then, the distribution of grain sizes is found for each target, and the mean and standard deviation of sizes are computed. However, this method can be biased to larger grains and overestimate the average grain size of the target due to low image resolution, which causes smaller grains to be blurred and difficult to visually pick out from an area of similarly small grains.

**General Acoustic Behavior of Soils:** Because the points are so close together, there is a possibility that craters get covered by loose soil blasted from later points. Moreover, because a RMI image is not taken after every point, the received images may not precisely display the ablated spot as it was just after the LIBS shots (see Fig 1). However, an acoustic signal is recorded for each shot, and therefore sound could be a real-time tracer of the ablation conditions.

The overall acoustic behavior of soils can be sorted into three main categories, that mostly depend on the grain size of the target with regard to the LIBS laser footprint: ablation of fine-grained soils (< 300 µm), ablation of a pebble (> 300 µm), and an intermediate scenario that consists of a pebble or rock buried beneath a layer of finer grain soil. These differences in behavior are exhibited in Fig. 1 and detailed in the following.

*Fine Grain Soils (Grain size < 300 µm).* It consists of the smallest grain sizes and tend to be characterized by a strictly and rapidly decreasing acoustic amplitude from shot to shot (see Fig. 1 points #1-#3). Indeed, the ablation-induced crater grows fast, due to the low cohesion of the small grains that facilitates their excavation under the force of the shockwave. It results in a deep and wide ablation crater, which explains this drastic decrease of the acoustic amplitude. Moreover, the high porosity walls of the crater might absorb a fraction of the acoustic energy and contribute to the fast shot-to-shot decrease.

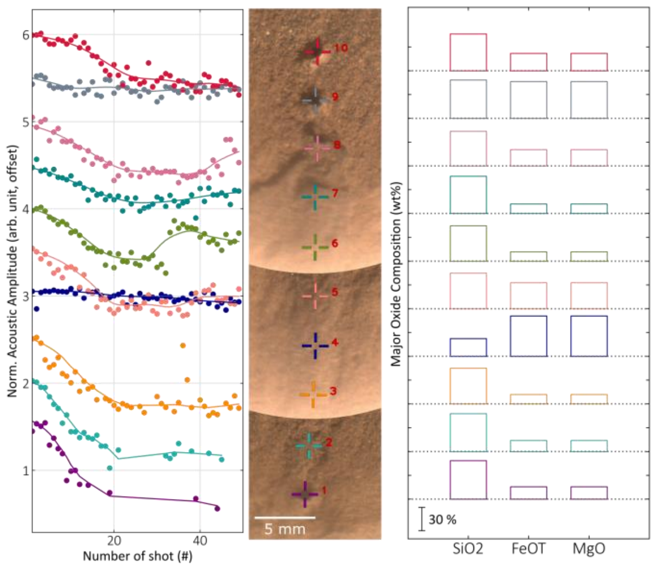


*Figure 1 - Shot-to-shot acoustic evolution (left), RMI context mosaic (center) and few elemental compositions (right) of the ten LIBS points sampled at Fulton_Falls_SCAM (Sol 596). This soil target was acquired within a wheel scuff, which explains why it is disturbed. The RMI mosaic is made of 3 images acquired after the ablation on points #4, #7 and #10 respectively. For the composition only SiO2, MgO and FeOT are given as an example.*

*Pebbles (Grain size > 300 µm).* When laser shots occur on pebbles, the shot-to-shot acoustic amplitude appears to remain nearly constant, with only slight variations. This occurs because the laser ablates only one single grain, and therefore the ablation rate remains low from shot to shot. This is observed on the Fulton_Falls_SCAM target (Fig. 1), where acoustic data suggest that points #4 and #9 hit a pebble, contrary to what is observed on the RMI. It is also consistent with the composition, significantly different for these two points, with a composition close to a pure olivine grain as often observed for coarse grains [8, 9].

*Buried Pebbles.* There might be a case where the laser starts ablating fine grain soil, then reaches a larger pebble buried beneath. This is illustrated for point #6 and likely #8 in Fig. 1. The first part is typical of an exponential decrease on fine grain soils. Then, the amplitude suddenly increases (likely once it starts ablating the pebble) and the behavior of the acoustics becomes more similar to that of a pebble.

**The specific case of fine grain soils:** Within the fine grain soils category alone, there are differences in the decrease rate of shot-to-shot acoustic amplitude, from target to target (Fig. 2). These differences in behavior could be linked to multiple differences in soil characteristics, including the presence of soil crusts likely indurated by groundwater of salts transported by the atmosphere, wheel tracks and therefore a lower porosity because of the increased compaction, and differences in grain size.

The presence of a soil crust may cause the acoustics to initially behave in a way that is more similar to pebble behavior, followed by the typical behavior of soils after the laser has penetrated through the crust. This is because the soil crust acts as a more cohesive layer of soil that causes the ablation rate to initially be lowered. The presence of wheel tracks would cause a difference in acoustic behavior from point to point for the same target. Target points that exist within wheel tracks occur directly on fine gain soil as the wheels break through any existing soil crust, but points that are outside of the wheel tracks may initially have to break through a layer of soil crust, causing the point-to-point acoustic behavior to vary. Grain size could also be a cause of this as acoustic behavior varies with point-to-point hardness/density, which also varies with grain size. To study these such factors, we can use both the chemistry of the LIBS shots and the acoustic data.

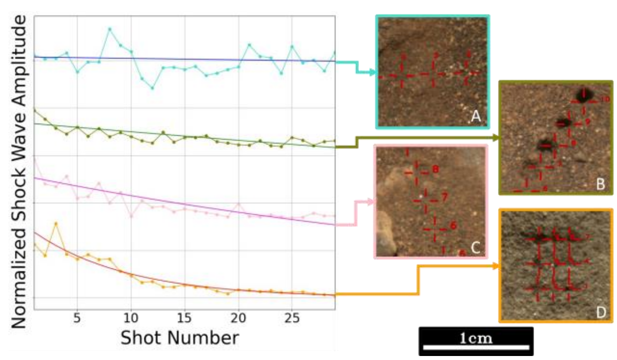


*Figure 2 - Acoustic Behavior Differences in Fine Grain Soils. 1 cm x 1 cm RMI Images: (A) Sei Point 3 - Exhibits almost no acoustic decay, (B) Whoosh Point 9 – Exhibits only a very slight amount of decay. (C) Queh_eh_SCAM Point 7 – Exhibits a moderate amount of decay. (D) Bellegarde_191a Point 1 - Drill cuttings exhibit the strongest acoustic decay.*

**Perspective of this Work:** Acoustic data is seen to have very different behaviors between soil types, which is thought to be mostly due to differences in grain sizes. Even within the same grain size range, fine grain soils exhibit different acoustic behavior that need to be investigated with regard to other parameters such as the chemistry and especially the hydrogen signal measured by LIBS that could be indicative of the presence of a soil crust.

**References:** [1] Wiens, R.C. et al. (2020), SRR [2] Maurice S. et al. (2021) SSR, [3] Chide B. et al. (2020) SAB, [4] Chide B. et al. (this issue), [5] Cousin A. et al. (2015) Icarus, [6] Hausrath E. et al. (submit), JGR. [7] Chide B. et al., (2019), SAB, [8] Cousin A. et al., (this issue) [9] Beyssac et al., (this issue).