Listening to hard rock (and softer ones) at Jezero crater, Mars. Baptiste Chide[1], Iona Tirona[2], Sarah Yearicks[2], Olivier Beyssac[3], Nina L. Lanza[1], Ann Ollila[1], Jérémie Lasue[4], Kyle Kaplan[2], Timothy Szwarc[2], Sylvestre Maurice[4], Roger C. Wiens5. [1]LANL, Los Alamos, NM, USA (bchide@lanl.gov), [2]JPL, Pasadena, CA, USA, [3]IMPMC, Paris, France, [4]IRAP-CNRS, Toulouse, France, [5]Purdue University, West Lafayette, IN, USA.

Introduction: Mechanical properties of rocks are key data for geophysics and are controlled mainly by mineralogy and texture. Rock hardness is highly sensitive to rocks mineralogy, and particularly to the degree of alteration they experienced, weathered rocks being usually softer than the basaltic rocks from which they derive [1]. The *in situ* rock hardness on Mars has thus far only been obtained opportunistically on the few rocks selected for drilling, using the performance data from robotic arm and drill system operations [2, 3]. However, using this "rock hammer" method to estimate hardness requires too many resources to be used on a daily basis on Mars. The SuperCam instrument [4, 5] onboard the NASA Perseverance rover provides a new and rapid method to estimate rock hardness on Mars at remote distance using a microphone. Each time the SuperCam laser ablates rocks to infer their elemental composition by LIBS, its companion microphone records the acoustic signal generated by the expansion of the laser-induced plasma; the sound amplitude is an indicator of the rock hardness [6].

Since its landing in 2021 in Jezero Crater, Perseverance has roved across two crater floor formations: *Maaz*, a basaltic unit, and *Seitah*, an olivine-rich cumulate, both showing signs of alteration reflecting fluid-rock interaction [7]. The rover has now reached the sedimentary rocks at the front of the western delta. These three distinct geological units feature rocks with contrasted physical properties such as density [8] or hardness. The goal of this study is twofold: (i) validate the "acoustic hardness" measurement on Mars by comparing its results to the "drillability" derived from the coring operations of the sample caching system and (ii) study to what extent the hardness could be linked to the alteration degree of the rocks targeted.

Datasets: Here, we use the sounds recorded by the SuperCam microphone during laser operations and data acquired during coring with the rotary percussive drill that is mounted on the robotic arm of Perseverance.

Acoustic Hardness: Recording the laser sparks over a burst of shots shows that the amplitude of the acoustic signal decreases as a function of the number of shots, as the laser penetrates into the target (see Fig. 1). It has been demonstrated that the decrease rate of the acoustic amplitude, *i.e.* the slope of the linear trend fitted, is correlated to the Vickers hardness number [9]: the steeper the slope, the softer the target is. In order to have a reliable estimation of the slope (acoustic amplitudes are randomly scattered by the atmospheric turbulence), we use only the SuperCam depth profile observations, *i.e.* with high number of shots, 125 or more.

Drill "prodapt" level: During coring or abrading, in order to keep the penetration rate within allowable bounds, the drill system automatically adjusts its strength and percussion rate by assessing its own performance in real time. This algorithm is called proprioceptive adaptive, prodapt in short. The prodapt levels can range from 0, rotary only, to 20 with most force and full percussion. Abrasion does not go below 3.

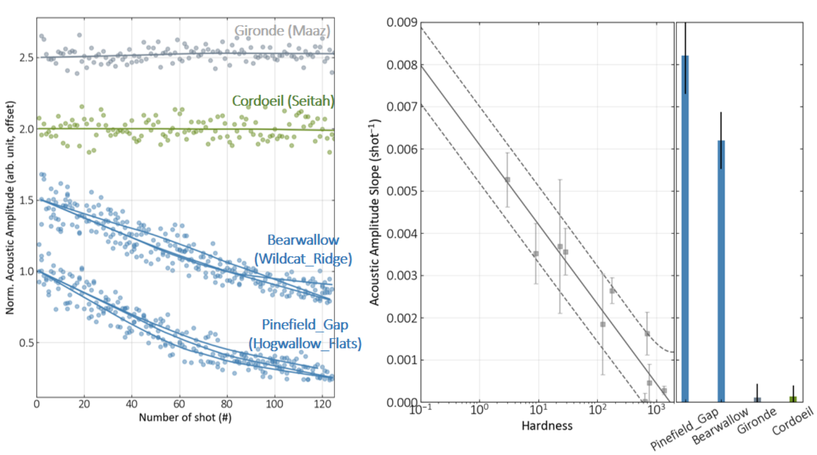

Fig.1 – Laser-induced acoustic signal amplitude variation for four targets acquired along the Perseverance traverse (left). Amplitudes were normalized by the amplitude of the first shot and offseted for display purposes. (right) Decrease rates (bars) for the four targets, compared with the hardness calibration curve. Grey and green target (resp. Gironde and Cordoeil) were sampled in Maaz and Seitah, respectively. The two blue targets were sampled on two members on the front of the sedimentary delta.

The range of prodapt levels reached during a coring or abrading operation is used as an indicator of rock drillability. Although ground testing indicates that rock hardness is a major factor in drillability, it is not the only factor, resulting in the distinction between the two. Prodapt levels also vary due to factors such as drill bit wear, temperature, and fracture mechanics.

Results: Hardness data from both methods are displayed and compared in Fig. 2. Overall, there is a good agreement between the two datasets: igneous rocks from Maaz and Seitah are hard and sedimentary rocks from the delta front are soft, which is expected regarding their respective lithologies. This confirms the reliability of the two hardness measurement techniques. The Issole outcrop (~Sol 300) is showing the softest rocks of the crater floor: geochemical data from this outcrop also confirm that Issole is the most altered group visited in Seitah, with detections of carbonates, perchlorates, sulfates and secondary silicates [10, 11]. This tends to confirm the relationship between hardness and the degree of alteration. For the Sid outcrop (~ Sol 480), acoustic data show an intermediate hardness whereas the drill data show the hardest core sampled so far. This difference might be due to the fact that the microphone samples the rock surface hardness, *i.e.* over the few hundreds of µm ablated by the laser, whereas the drill system integrates the drillability during core acquisition from a depth of 5 mm to a depth of 66 mm. This might be due to surficial alteration or to the presence of a rock coating at the surface, which are ubiquitous in Jezero [12].

Conclusion and Perspective: Perseverance offers the capability to measure the hardness of rocks along its traverse, using the combination of the SuperCam laser with its microphone and by drilling rock samples. The good agreement between the two techniques demonstrates that the acoustic hardness test is a fast and efficient way to assess the hardness of a potential core sample. Therefore, it could represent a critical operational test before deploying the arm on a sample of unknown hardness. Moreover, the hardness is new information to be compared with the chemistry data. Especially, we have shown for the Seitah formation that hardness is correlated with the alteration degree of igneous rocks (hard pristine Brac versus soft weathered Issole). In the future, a broader set of hardness data could be obtained by analyzing not only the SuperCam depth profiles but also the 30-shot analyses which are much more common.

References: [1] Pola A. et al., (2014) *Eng. Geology*. [2] McSween H. Y. et al., (2006) *JGR*. [3] Peters G. H. et al., (2018) *GRL*. [4] Wiens R. C. et al., (2020) SSR, [5] Maurice S. et al., (2021) SSR. [6] Chide B. et al., (2019), SAB [7] Farley K. et al., (2022), Science [8], Wiens R. (2022), Science Adv. [9] Chide B. et al., (2020), SAB, [10] Beyssac O. et al. (submit), JGR, [11] Clavé E. et al., (2022), JGR, [12] Garczynski B. J., et al. (submit), JGR.

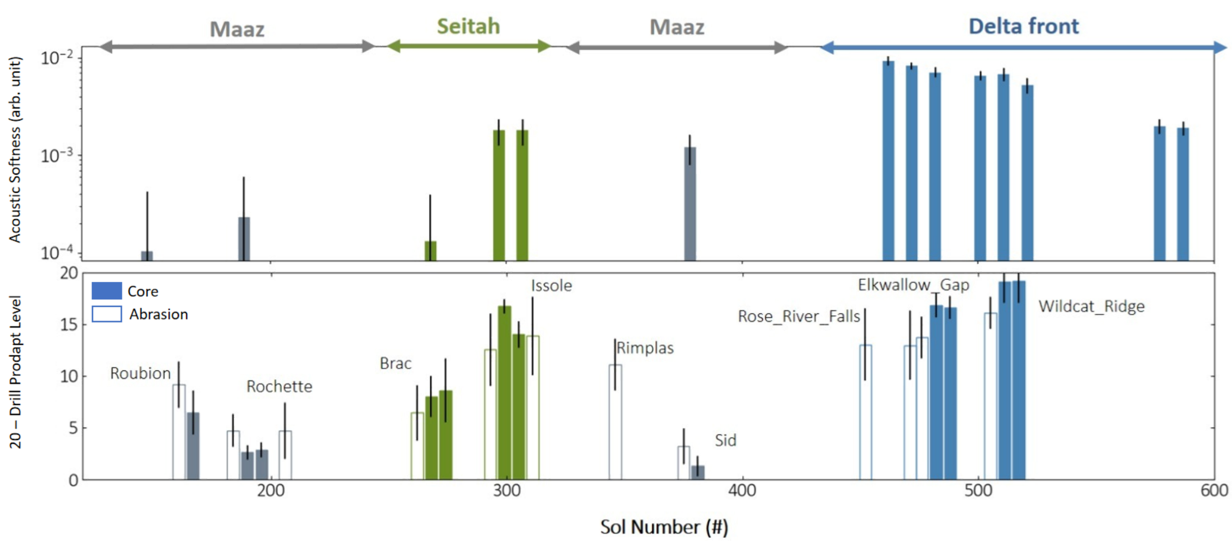

Fig.2. Hardness measurements retrieved along the Perseverance traverse from the acoustic data (top panel) and from the drill data (bottom panel). Data are sorted by the members they were acquired (see annotation). The color code refers to the geological unit: Maaz in grey, Seitah in green and Delta front in blue. For the acoustics, the data displayed is the slope of the amplitude decrease as a function of the number of shots. The higher the bar, the softer the target is. Errorbars represent the 1-σ confidence interval of the retrieval of this slope (see Datasets). For the drill, data show the difference between the highest prodapt level reached and the maximum prodapt level accessible by the drill, 20. Hence, as for the acoustics, the higher the bar, the softer the target is. Plain bars refer to core samples whereas empty bars refer to abrasion targets.