PRISTINE PYROXENE-BEARING BOULDERS ANALYZED BY SUPERCAM IN THE JEZERO WESTERN FAN, MARS.
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Introduction: During its exploration of the upper surface of the Jezero western fan, the Mars 2020 *Perseverance* rover encountered a population of boulders that likely represents a late-stage deposit from high-energy floods [1]. These boulders can be divided into two groups based on their inferred mineralogy: olivine-rich and pyroxene-bearing. The first group, the most abundant one, is described in ref. [2]. Here, we present the analyses performed by the SuperCam instrument on the pyroxene-bearing boulders and show that they are among the most pristine rocks encountered so far in the mission. We also draw a comparison with the Boston Knob outcrop, located on the fan front, which may be a buried and stratigraphically lower equivalent of the pyroxene-bearing boulders of the upper fan.

Methods: The SuperCam instrument suite onboard *Perseverance* combines several analytical techniques [3-4], including laser-induced breakdown spectroscopy (LIBS) to measure the major-element chemical composition of the targets, and time-resolved Raman spectroscopy (TRR) as well as visible/near-infrared reflectance spectroscopy (VISIR) to characterize their mineralogical composition.

VISIR properties: Reflectance spectroscopy is a powerful tool to identify olivine-bearing or pyroxene-bearing rocks [e.g., 5-6]. Accordingly, both Mastcam-Z multispectral [7] and SuperCam VISIR observations were used to remotely classify the boulders encountered by *Perseverance* during its exploration of the upper fan. The SuperCam spectra show very distinct signatures between the two groups (Fig. 1). The pyroxene-bearing boulders display a broad absorption band in the infrared domain, with a reflectance minimum slightly below 2 µm, consistent with a low-calcium type of composition (LCP) [e.g., 5]. Importantly, there is no discernible hydration band at 1.9 µm, nor metal-OH bands in the 2.0–2.5-µm region, indicating a lack of alteration phases. This is in contrast to the olivine-rich boulders, most of which display clear signatures of Mg-rich phyllosilicates (Fig. 1) [2]. Additionally, it differs from the igneous rocks of the Máaz and Séitah formations on the crater floor, which frequently show signatures of alteration phases, including phyllosilicates, oxyhydroxides, sulfates, and some carbonates [8-10]. As such, the pyroxene-bearing boulders of the western fan are among the most pristine rocks encountered so far by *Perseverance* along its traverse.

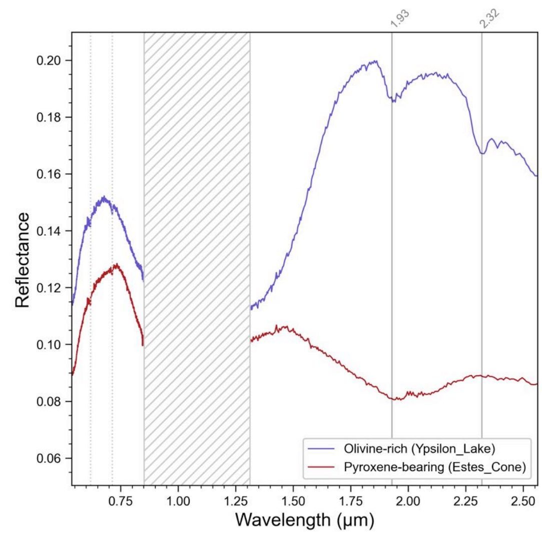

Figure 1 – Comparison of the SuperCam VISIR spectra of two representative boulders: an olivine-rich one (blue) and a pyroxene-bearing one (red).

LIBS elemental composition: The LIBS analyses performed on the pyroxene-bearing boulders (Fig. 2) reveal compositions that are inconsistent with rocks solely composed of pyroxene grains, but instead compatible with a mixture of pyroxenes and feldspars (VISIR is not sensitive to feldspars, which explains the discrepancy). However, the Al content is slightly higher than expected for typical compositions of pyroxenes and feldspars, as also shown by the PIXL analyses [11]. For this reason, the search for pyroxene grains based on expected stoichiometry [12-13] in the LIBS shot-to-shot data gives no positive detection, despite the rock showing some relatively large grains. This enrichment in Al cannot be attributed to Al-bearing phyllosilicates such as montmorillonite or kaolinite because such phases would be readily detectable in the VISIR spectra. Therefore, the “excess Al” must be borne by igneous phases.

Comparison with Boston Knob: While exploring the lower part of the western fan earlier in the mission, the *Perseverance* rover encountered a unique outcrop named Boston Knob, which measures ~1.5 by 2 m and appears to be a fractured, degraded and partially buried boulder (Fig. 3). The texture and VISIR properties of the Boston Knob targets are very similar to the pyroxene-bearing boulders of the upper fan. The chemical composition is consistent with a mixture of pyroxenes and feldspars, although with even higher Al (Fig. 4). Therefore, the Boston Knob outcrop, if truly in place, may represent a stratigraphically lower equivalent of the pyroxene-bearing boulders observed on the upper fan.

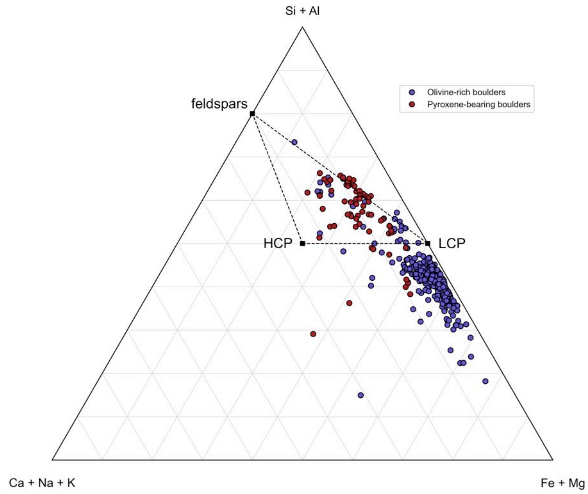

Figure 2 – Comparison of the chemical compositions of the olivine-rich (blue symbols) and the pyroxene-bearing (red) boulders, as measured by SuperCam LIBS.

Implications: LCP-bearing igneous rocks are thought to be representative of the earliest magmatic activity on Mars. Indeed, based on orbital reflectance data, the Noachian terrains show a higher proportion of LCP relative to HCP (high-calcium pyroxene) compared to the Hesperian and Amazonian ones [5; 14-15]. This compositional evolution may be due to a steadily decreasing degree of partial melting throughout the history of the planet [16]. A sample of such LCP-bearing rocks returned to Earth may thus shed light on the mechanisms of early crust formation on terrestrial planets. However, it remains uncertain if the pyroxene-bearing boulders found at the Jezero western fan, despite their LCP-bearing composition, are truly fragments of the Noachian crust. First, the lack of hydration and alteration phases is somewhat at odds with the intense and widespread aqueous activity, both at the surface and at depth [e.g., 17-18], that is the hallmark of the Noachian period. Second, the elevated Al content of the boulders analyzed by *Perseverance* may indicate that these are in fact impact melt rocks derived from a weathered protolith [11]. Finding pyroxene-bearing rocks in place within the Jezero rim or on Nili Planum later in the mission would help decipher the origin and formation mechanism of the boulders.

Regarding the history of the Jezero western fan, the similarity between the pyroxene-bearing boulders of the upper fan and the Boston Knob outcrop lower in the stratigraphy suggests that boulders may have been delivered to the fan several times during its construction, and not only as a late-stage deposit related to high-energy floods.

References: [1] Mangold, N., Gupta, S., et al. (2021) *Science,* 10.1126/science.abl4051. [2] Beyssac, O., et al. (2024) *this conf.* [3] Maurice, S., et al. (2021) *Space Sci. Rev.,* 10.1007/s11214-021-00807-w. [4] Wiens, R. C., et al. (2021) *Space Sci. Rev.,* 10.1007/s11214-020-00777-5. [5] Mustard, J., et al. (2005) *Science*, 10.1126/science.1109098. [6] Poulet, F., et al. (2009) *Icarus*, 10.1016/j.icarus.2008.12.025. [7] Vaughan, A., et al. (2024), *this conf.* [8] Mandon, L., et al. (2023) *JGR-Planets*, 10.1029/2022JE007450. [9] Clavé, E., et al. (2023) *JGR-Planets*, 10.1029/2022JE007463. [10] Wiens, R. C., et al. (2022) *Sci. Adv.*, 10.1126/sciadv.abo3399. [11] Treiman, A., et al. (2024) *this conf.* [12] Beyssac, O., et al. (2023) *JGR-Planets*, 10.1029/2022 JE007638. [13] Udry, A., et al. (2023) *JGR-Planets*, 10.1029/ 2022JE007440. [14] Baratoux, D., et al. (2007) *JGR-Planets*, 10.1029/2007JE002890. [15] Poulet, F., et al. (2009) *Icarus*, 10.1016/ j.icarus.2008.12.042. [16] Baratoux, D., et al. (2013) *JGR-Planets*, 10.1029/2012JE004234. [17] Ehlmann, B., et al. (2011) *Nature*, 10.1038/nature10582. [18] Carter, J., et al. (2013) *JGR-Planets*, 10.1029/2012JE004145.

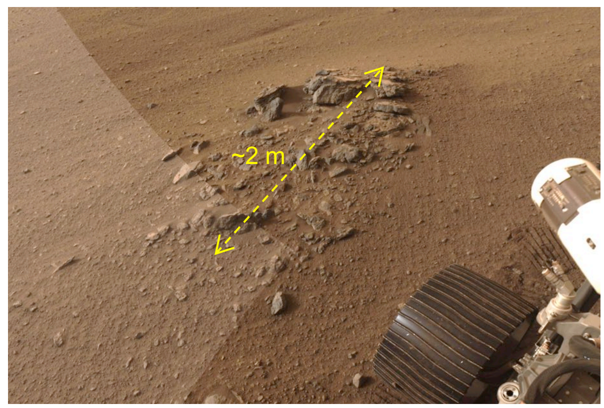

Figure 3 – Navcam image of the Boston Knob outcrop (NASA/JPL-Caltech/CAMP team).

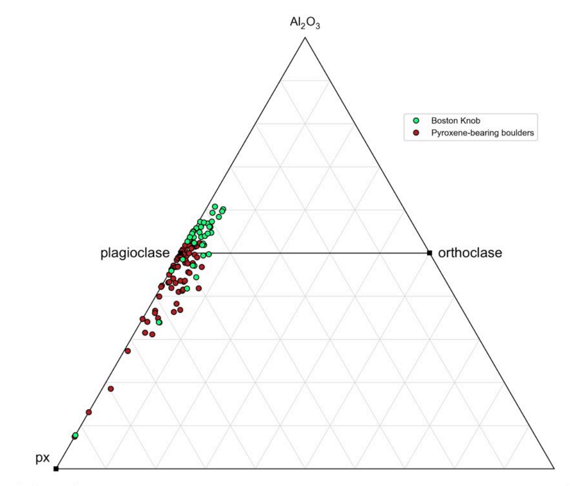

Figure 4 – Comparison of the chemical composition of the pyroxene-bearing boulders of the upper fan (red symbols) with that of the Boston Knob targets (green).