Infrared Reflectance of Rocks and Regolith at Jezero Crater: One Year of SuperCam Observations

L. Mandon, C. Quantin-Nataf, C. Royer, P. Beck, T. Fouchet, J. R. Johnson, O. Forni, Franck Montmessin, C. Pilorget, F. Poulet, et al.

INFRARED REFLECTANCE OF ROCKS AND REGOLITH AT JEZERO CRATER: ONE YEAR OF SUPERCAM OBSERVATIONS L. Mandon[1], C. Quantin-Nataf[2], C. Royer[1], P. Beck[3], T. Fouchet[1], J. R. Johnson[4], O. Forni[5], F. Montmessin[6], C. Pilorget[7], F. Poulet[7], S. Le Mouélic[8], E. Dehouck[2], O. Beyssac[9], A. Brown[10], J. Tarnas[11], S. Maurice[5], R. C. Wiens[12], and The SuperCam team . [1]LESIA, Meudon (lucia.mandon@obspm.fr), [2]LGL-TPE, Lyon, [3]IPAG, Grenoble, [4]JHUAPL, Laurel, [5]IRAP, Toulouse, [6]LATMOS, Paris, [7]IAS, Paris, [8]LPG, Nantes, [9]IMPMC, Paris, [10]Plancius Research, Severna Park, [11]JPL, Pasadena, [12]LANL, Los Alamos

Introduction: The Mars 2020 Perseverance rover landed in Jezero crater, Mars on February 18th, 2021. The main science objectives of the mission are the characterization of past habitable environments, the search for preserved biosignatures and the collection of samples to be returned to Earth by the MSR (Mars Sample Return, NASA/ESA) program [1]. The payload includes the SuperCam instrument, which plays a critical role in the exploration strategy, as it combines various remote-sensing techniques to investigate the elemental and mineralogical composition of rocks and soils [2,3]. In particular, the SuperCam reflectance spectrometer covers the visible and near-infrared range, a novelty on the Martian surface, while this range is primarily used from orbit to detect and map minerals. As of Sol 300 (December 2021), the rover has driven onto two geological units of the crater floor: the Máaz formation (mapped from orbit as the Crater Floor fractured rough, or the Cf-fr), a dark-toned, crater retaining unit that shows some signature of pyroxene from orbit, and the Séítah formation (in a wider geological unit mapped as the Crater Floor fractured 1, or Cf-f-1), a lighter-toned unit, less resistant to erosion and that exhibits a signature of olivine from orbit, similarly to the olivine-unit that spans the Nili Fossae region where Jezero crater is located [4,5]. Here we present the initial results of the SuperCam near-infrared spectrometer, with calibrated spectral data collected in the first year of operation of the instrument, with a focus on the rocks and soils present in the vicinity of the rover [6].

Data and methods: The SuperCam VISIR spectrometer measures the reflected light from 385 to 475 nm, 535 to 855 nm and 1.3 to 2.6 μm [2,3,7]. In this contribution, we focus on the 1.3–2.6 μm spectral range, which enables the identification of a wide variety of minerals, especially mafic minerals and secondary phases such as phyllosilicates, sulfates, or carbonates. VIS data are presented in [8]. The calibration of the IR spectra [9] includes smoothing of the dark current spectra, I/F conversion, removal of anomalously high-values "spikes", and preliminary atmospheric correction. At wavelengths longer than ~2.5 μm, the calibration is still uncertain (owing to temperature sensitivities in the IRS instrument) and data are not yet usable. For targets a few meters from the rover mast, the analytical footprints of individual locations within a raster are a few mm, hence encompassing several mineral phases and combining the spectra of

different components. To unmix these components, several data types are presented: single-point spectra, ratios, and Independent Components Analysis (ICA) components. In particular, the ICA computational approach aims at finding independent components whose relative variations could explain a set of multivariate signals – in our case the different minerals affecting the measured spectra.

Rocks of the Máaz formation: Most of the spectra measured on rocks of the Máaz formation exhibit an absorption near 1.9 μm (indicating the presence of water), a band that is usually not observed as strongly in the soils. Some spectra of poorly dusty rocks make the exception, with relatively featureless spectra that indicate a low mafic minerals content, or that these minerals have a grain size too small to be detected. In addition to the common absorption at ~1.9 μm, subtle absorptions near 1.4, 2.28 and 2.39 μm show up locally, suggesting the presence of an Fe-rich phyllosilicate (e.g., nontronite or hisingerite), potentially mixed with an oxyhydroxide (e.g., ferrihydrite) as some spectra with weak or non-existent 2.28 and 2.39 μm bands are observed, along with a shift of the 1.9 μm band position from 1.92 to 1.94 μm (Fig. 1c). Additionally, some spectra ratioed by the median spectrum of the raster exhibit an absorption at 1.93 μm, a drop at 2.4 μm, often paired with an absorption at 2.14 μm (Fig. 1b); such spectral features are consistent with a relative enrichment in mono and poly-hydrated Mg-sulfates. Also, an absorption at ~2.2 μm is commonly observed and can either be explained by gypsum, an Al-phyllosilicate or hydrated silica (Fig. 1c). Finally, results of the ICA analysis highlighted a component with a large absorption centered at 2.3 μm and consistent with high-Ca pyroxene (Fig. 1a).

Rocks of the Séítah formation: The VISIR spectra of Séítah rocks are significantly different from those measured in the Máaz formation, with a distinct downturn toward shorter wavelengths typical of olivine. A different secondary mineral assemblage from that of the Máaz formation is inferred: possible Fe-phyllosilicate (e.g., nontronite or hisingerite) and Mg-phyllosilicate(s), as expressed by a narrow 2.32 μm band – the consistent association with the absorptions at 2.28 and 2.39 μm might be indicative of talc. In some spectra, a significant enlargement of the 2.32 μm absorption is observed (Fig. 1c), consistent with the presence of the Fe/Mg-carbonates

that were also detected in some locations by the LIBS and Raman techniques of SuperCam (although the 2.5 µm band of carbonates is not unambiguously observed owing to calibration uncertainties described above). By comparison with laboratory measurements, we estimate that the carbonates are present in the rock at a few wt.%. Additionally, the ICA components of abraded rocks are consistent with unaltered high-Ca pyroxene, and olivine with carbonate and/or Fe/Mg-phyllosilicates (Fig. 1a); this suggests that the alteration products might be preferentially spatially associated with olivine than with pyroxene (e.g., in cracks or on the rims of the olivine crystals).

Máaz formation soils: ICA analysis of the Máaz formation regolith spectra highlighted the three following components (in no preferential order): a primary component consistent with intermediate-Ca pyroxene or a mixture of various pyroxene types of distinct composition, a second component consistent with olivine mixed with carbonates and/or Fe/Mg-phyllosilicates (similarly to Séítah rocks), and a hydrated phase of uncertain nature (Fig. 1a). Individual point spectra show that the olivine:pyroxene ratio varies with soil type: fine soils (µm-scale particles) exhibit a weak signature of pyroxene mixed with olivine, while coarser soils showing additional dark-toned mm-sized granules have spectra with deeper absorption bands and the distinct features of olivine, carbonates and/or Fe/Mg-phyllosilicates.

Discussion: One of the implications regarding the history of Jezero is that hydration pervasively affected its crater floor, with hydrated minerals present at least to some degree in most of the rocks analyzed. The mineralogical assemblage shows a diversity of secondary phases, with both Fe^{3+} and Mg-phyllosilicates, oxyhydroxides, carbonates and sulfates. On the other hand, Al-phyllosilicates do not appear to be abundant. In Séítah, the aqueous alteration was likely limited, or the rock burial was fast, in order to preserve a significant amount of olivine crystals, which alter rapidly at geological timescales when interacting with water [10]. Nevertheless, the carbonates detected by SuperCam are likely products of olivine alteration, and the rocks in Séítah might have been marginally altered through the carbonation process, an alteration environment that could have been favorable for life. Additionally, the Mg-sulfates observed by SuperCam might record some late aqueous environment corresponding to the evaporation of the lake.

As SuperCam measures the first near-IR spectra on the surface of Mars, it provides some insights into the complex effects of spectral mixing and scaling between orbital and in situ measurements. In particular, the Máaz formation was interpreted as a lava flow given its pyroxene signature from orbit and its dark-toned, crater-retaining morphology. SuperCam data suggest that py-
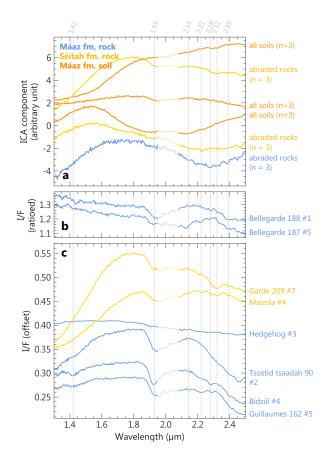

Figure 1: Spectral endmembers identified in the rocks and soils of Jezero crater floor: **(a)** selected ICA components (n: number of ICA components in input), **(b)** point spectra ratioed by the raster median, **(c)** point spectra. Target names along with point number in the raster are indicated on the right side. The white mask corresponds to CO_2 absorptions domain.

roxene is spectrally more dominant in the soils than in the rocks of the Máaz formation, whose spectra are more strongly affected by hydrated minerals. Hence, the soils might be significant contributor to the signature measured from orbit, at least at the Máaz formation locations explored by the rover so far. Also, this regolith has a variable composition, and shows similar features to the rocks in Séítah, which likely provide local inputs of material through eolian processes [11].

References: [1] Farley et al. (2020) *Space Sci. Rev.* 216.8, [2] Wiens et al. (2020), *Space Sci. Rev.* 217.1, [3] Maurice et al. (2021) *Space Sci. Rev.* 217.3, [4] Stack et al. (2020) *Space Sci. Rev.* 216.8, [5] Goudge et al. (2015) *JGR: Plan.* 120.4, [6] Mandon et al., *in prep.*, [7] Fouchet et al. (2022) *Icarus* 373, [8] Johnson et al., *this conf.*, [9] Royer et al., *this conf.*, [10] Stopar et al. (2006) *Geoch. et Cosmo acta* 70(24), [11] Beyssac et al., *this conf.*