Orbital infrared spectroscopy : lessons learned from in situ SCAM VISIR spectrometer in Jezero

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Introduction: The investigation of the surface of Mars with Visible and near-Infrared (VISIR) spectro-imagers has revolutionized our knowledge of the planet. OMEGA and CRISM instruments revealed for instance the diversity of the alteration of the Martian crust [i.e., 1, 2]. These instruments have spatial resolution ranging from 20 m to 2 km. The received signal from such a large surface is an intimate mixture of minerals that can be challenging to decipher [i.e., 3]. On February 18, 2021, NASA's Mars 2020 Perseverance rover landed successfully on the floor of Jezero crater with for the first time a VISIR spectrometer as part of Supercam instrument suite (providing the same wavelength range as OMEGA and CRISM) to conduct in situ measurements [4]. The Jezero crater landing site was chosen for the remarkable spectral diversity observed by orbital spectrometers [i.e., 5]. This makes the analysis of SuperCam's VISIR measurement a unique opportunity to directly compare orbital and in situ spectral measurements of same geological units. Here we compare CRISM data and SuperCam VISIR data of the geological units observed within Jezero crater investigated by Perseverance Rover up to Sol 1117.

Orbital spectro-geological diversity of Jerezo crater: Four geological and compositional units had previously been identified from orbital data analysis within Jezero crater [5, 6]: a dark pyroxene-bearing floor unit (named Máaz in situ), an olivine-bearing unit exposed in erosional windows (named Séítah in situ), a deltaic deposit dominated by low calcium pyroxene signatures with olivine, clays and carbonate present locally, and a marginal unit identified as enriched in carbonate [5]. These four units have been investigated in situ by Perseverance. However, the in situ investigation of the deltaic deposits was split into two sub-units mainly because of composition and facies changes seen in situ [7]: the base of the delta and the delta top. As such, the five units are discussed in this paper as shown in Figure 1.

Dataset and method:

SuperCam: The SuperCam instrument contains a suite of techniques including passive spectroscopy in the 0.40-0.85 (VIS) and 1.3-2.6 microns (IR) wavelength ranges, Raman spectroscopy, Laser Induced Breakdown Spectroscopy and a camera (RMI; Remote Micro-Imager) providing high resolution context images [8,9]. Since the landing, SuperCam has acquired more than 14000 VISIR spectra on geological targets. The typical spot size of VISIR measurement of a rock in the vicinity of the rover (<10m) is of the order of a few mm. We analyze the entire data set labelled by geological unit described in the previous section to extract the mean spectra of natural surfaces, abraded patches and soils as well as statistics of spectral parameters of each unit.

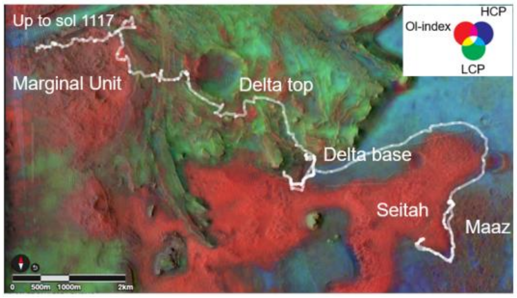

Figure 1: Spectral parameter map from [5] showing in red a spectral parameter measuring Fe2+ signature possibly referring to Olivine, green denotes the spectral parameter of Low calcium pyroxene and blue indicates the spectral parameter of High Calcium Pyroxenes. The white line is the traverse of Perseverance up to Sol 1117.

CRISM: We studied the single CRISM data cube covering the entire rover traverse: HRL 40FF at 36m per pixel. The data set has been calibrated and corrected from atmosphere contribution [10]. We use both the corrected spectra and ratioed spectra. The latter is commonly used to highlight spectral signature for mineral identification [10]. Here we apply an automatic ratioing method dividing each pixel by the median of detector column [i.e., 11]. For each geological unit, we map a region of interest around the traverse of the rover to compute statistics of > 100 pixels. We return the mean corrected spectrum, the mean ratioed spectrum and the spectral parameter statistics of each unit.

We then compare the mean CRISM corrected and ratioed spectra of each geological unit to the mean spectra of SuperCam and the spectral parameters computed from both instruments.

Results:

The example of the Máaz unit: According to Perseverance instrument suite, the Máaz unit is a magmatic, lightly altered (phyllosilicates, oxyhydroxides) rock with salts filling the voids [12]. The mean SuperCam spectra shown in Figure 2 shows a deep 1.9 µm absorption (H_2O), a reflectance drop at 2.4 µm (possibly due to sulfates) and a 2.28 µm band indicative of Fe-OH [13]. The CRISM unratioed spectrum have a faint 1.9 absorption band and a wide 2.3 µm band indicative of high calcium pyroxene. The comparison of the spectral parameter of mafic minerals (figure 2B) is similar but the comparison of spectral parameters of hydrated mineral is significatively different (figure 2C). The SuperCam's data set has spectral parameters one order of magnitude larger for the hydrated mineral parameters than CRISM data.

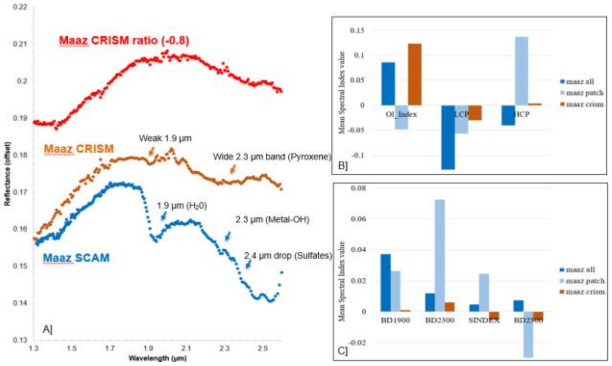

Figure 2: A) Comparison of SuperCam and CRISM spectra of Máaz Unit. B) Comparison of spectral parameters related to mafic minerals between CRISM and SuperCam of Máaz unit. C) Comparison of spectral parameters related to hydrated minerals between CRISM and SuperCam of Máaz unit. In B and C patches refer to abraded patches observations

Others units: The Séítah formation is interpreted by the suite of Perseverance instruments as an olivine cumulate, locally lightly altered with phyllosilicates and carbonates with salts filling the voids [12]. CRISM data are dominated by an olivine signature [7]. This olivine signature is also dominant in SuperCam data, and the spectral parameters of both orbital and in situ instrument have similar range of values. The difference again lies in the alteration signature. CRISM shows very weak signatures of alteration (possibly clay minerals and carbonates [14]) while in situ measurements of rock targets are dominated by signatures consistent with a mixture of phyllosilicates and carbonates [13]. As in Máaz, the hydrated mineral spectral parameters are one order of magnitude stronger for in situ data than orbital data.

The base of the delta is dominated by olivine signature in CRISM data plus a weak signature of phyllosilicates [5]. The Perseverance's instrument suite revealed a more diverse composition with layers enriched in sulfates and other layers enriched in phyllosilicates (i.e., 15). The SuperCam VISIR signature is dominated by the alteration minerals. The spectral parameters of phyllosilicates and H_2O band are again larger when measured in situ compared to orbital data. No sulfates signatures or sulfate-related spectral parameter are observed in orbital data.

The delta top orbital spectral signature is dominated by low calcium pyroxene [7]. Two facies are observed in situ. The first one, the curvilinear unit shows a spectral signature dominated by a mixture of olivine and alteration minerals, in particular carbonates. A few inverted channels filled by unaltered boulders are also observed forming the second facies, some of which exhibit low calcium pyroxene signatures [17]. Lastly, SuperCam confirm the strong contribution of carbonate to the VISIR spectra of the marginal unit as highlighted in CRISM data.

Discussion: Orbital data made overall good predictions of the presence of olivine mineral. It is observed in situ everywhere that CRISM detected it, and with similar spectral parameters values. Pyroxene orbital detection is more contrasted when comparing to in situ bedrock VISIR spectra, but the differences may be explained by fine grained regolith contribution, which from SuperCam data displays weak signature consistent with pyroxene and olivine. The presence and the diversity of secondary phases are significantly underestimated from the orbit with a major spectral loss. It is important to remind that most of the IRS data were acquired on rocky targets and not on regolith. The orbital/in situ discrepancies could be again explained by the presence of dust and regolith that attenuate the spectral signatures of these phases. In addition, the multi-scattering due to the atmosphere could also a play a significant role in the spectral contrast loss. Lessons learned from SuperCam seem therefore to converge to a combined contribution of both bedrock and regolith.

Conclusion : After two years of in situ VISIR investigation of Jezero, we learned: 1) That all mineral phases detected with orbital data have been confirmed, including minor alteration phases highlighted from advanced statistical analyses (like factorial analysis [i.e. 14]) 2) The mineral diversity observed in situ is larger than that detected form orbit (e.g. sulfates were not detected in this part of Jezero) 3) The alteration and especially the water-related absorption bands are an order of magnitude stronger in situ than from orbital data, likely a consequence of contributions from regolith.

References: [1] Bibring et al., Science, 2006 [2] Ehlmann et al., Nature, 2011 [3] Riu et al., Icarus, 2022 [4] Fouchet et al., Icarus, 2022 [5] Horgan et al., 2020 [6] Goudge et al., 2015 [7] Stack et al., JGR-planet, 2024 [8] Wiens, et al., 2021 [9] Maurice et al., , 2021 [10] Murchie et al., JGR, 2009 [11] Bultel et al., IEEE, 2015 [12] Wiens et al., Science Advances, 2022 [13] Mandon et al., 2020. [14] Tarnas et al., JGR, 2021 [15] Dehouck et al., 2024 [17] Poulet et al., this conference