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**MODAL MINERALOGY OF SEITAH UNIT IN JEZERO CRATER (MARS) RETRIEVED FROM NONLINEAR UNMIXING ANALYSES OF IRS/SUPERCAM.** F. Poulet<sup>1</sup>, C. Royer<sup>2</sup>, P. Beck<sup>3</sup>, L. Mandon<sup>2</sup>, C. Quantin-Nataf<sup>4</sup>, J.R. Johnson<sup>5</sup>, O. Beyssac<sup>6</sup>, O. Forni<sup>7</sup>, A. Cousin<sup>7</sup>, F. Montmessin<sup>8</sup>, C. Pilorget<sup>1</sup>, S. Le Mouélic<sup>9</sup>, E. Dehouck<sup>4</sup>, A. Brown<sup>10</sup>, J. Tarnas<sup>11</sup>, K. Benzerara<sup>6</sup>, T. Fouchet<sup>2</sup>, S. Maurice<sup>6</sup>, R.C. Wiens<sup>12</sup>, and The SuperCam team <sup>1</sup>IAS, Orsay (francois.poulet@ias.u-psud.fr), <sup>2</sup>LESIA, Meudon, <sup>3</sup>IPAG, Grenoble, <sup>4</sup>LGL-TPE, Lyon, <sup>5</sup>JHUAPL, Laurel <sup>6</sup>IMPMC, Paris, <sup>7</sup>IRAP, Toulouse, <sup>8</sup>LATMOS, Paris, <sup>9</sup>LPG, Nantes, <sup>10</sup>Plancius Research, Severna Park, <sup>11</sup>JPL, Pasadena, <sup>12</sup>LANL, Los Alamos

**Introduction and motivation:** The Perseverance rover performed in-situ mineralogical and geological investigations of an unique olivine-bearing unit of the Jezero crater floor (so-called *Séítah* also referred as to the Crater Floor fractured 1 (Cf-f-1)) using the multiple techniques of the SuperCam instrument [1,2]. Data acquired by its infrared spectrometer (IRS) [3] revealed the presence of various signatures including a distinct Fe<sup>2+</sup> signature at shorter wavelengths typical of olivine, an absorption near 1.9  $\mu\text{m}$  indicating the presence of water as well as several signatures in the 2.28-2.5  $\mu\text{m}$  wavelength range consistent with the presence of multiple alteration phases such as Fe/Mg phyllosilicates and possible Fe/Mg- carbonates in some locations [4]. A key question is what was the geological environment of alteration? The mineral assemblage, modal mineralogy and rock texture can provide important constraints on the formation environment and alteration sequences.

In NIR spectral data of planetary surfaces, multiple scattering dominates and spectral mixing is nonlinear. Radiative transfer models predict that the systematics can be linearized by converting reflectance data to single scattering albedo [5, 6], and applications of such radiative transfer models to laboratory data show that more accurate understanding of geologic processes is gained relative to linear mixture models [7,8]. Previous works have also demonstrated that radiative transfer modeling can be applied to NIR spectroscopic data from Mars orbiters to provide quantitative estimation of bulk mineralogy for hydrated terrains [9-11]. We here present the modal mineralogy of some olivine-rich, carbonate-bearing rocks observed in Jezero crater.

**Method:** Modal mineralogy is derived using a nonlinear unmixing modeling based on the Shkuratov radiative transfer model [6]. This modeling technique uses a selected set of optical constants for reproducing spectra. The IRS spectra (FOV=1.15 mrad corresponding to  $\sim$ a few mm<sup>2</sup> targets for typical in situ observations) are fitted in the 1.30–2.50  $\mu\text{m}$  wavelength range using a simplex minimization algorithm to retrieve the abundance and grain size of each mineral included in the assemblage. The quality of the fit is evaluated by the value of the residual mean squared (RMS). The Shkuratov model simulates the reflectance of a particulate surface (also referred to as an intimate mixture)

from a *a priori* set of minerals. The selection of minerals to be included (through their complex indices of refraction) in the modeling is thus critical. Primary minerals such as olivine, pyroxenes (both high- and low-calcium) and plagioclase are considered as potential endmembers and hence are routinely added. On the other hand, it is not possible to add per default all the potential alteration minerals (Table 1) due both to computation time and efficiency of the convergence process. Each spectrum is then examined to identify a potential metal-OH or carbonate signature and to discriminate the different altered phases. The iterative deconvolution of most of the IRS spectra of the abraded targets of *Séítah* requires a complex assemblage with up to 8 endmembers (olivine, 1 or 2 pyroxenes, one carbonate, 3 or 4 hydrated phases).

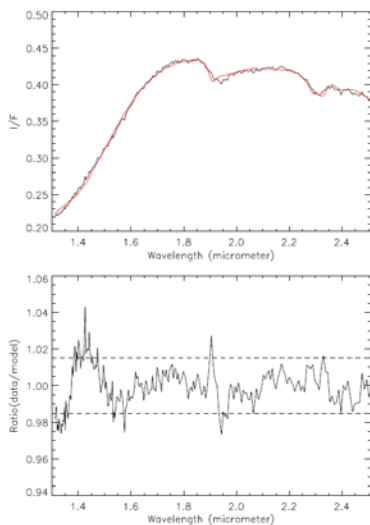
Fe/Mg phyllosilicates (Nontronite, Saponite, Montmorillonite, Serpentine, Talc)
Carbonate (Magnesite, Siderite)
Al-OH phyllosilicate (Kaolinite)
Opal, Al/Si-OH bearing phase
Hydrous Fe <sup>3+</sup> oxyhydroxide (Ferrihydrite)

**Table 1.** List of secondary phases used as candidates for the modeling procedure.

Sensitivity tests were performed to constrain the robustness of the results especially about the required presence of some phases such as plagioclase, Fe/Mg smectites, carbonates, serpentine, talc. The assemblage that is able to reproduce the major signatures of the studied spectra (Dourbes, Garde and Quartier abraded targets, Ciné rock) is quite complex and it includes olivine (Fo40), augitic pyroxene, Mg-serpentine, Fe-carbonate and Mg/Fe-smectites. An example of the quality of the fit is shown in Figure 1.

It is important to keep in mind that this spectral modeling technique has some limitations [13]: the *a priori* assemblage is limited by the availability of optical constants of any given species especially the sulfate one; because of the considerable compositional variability of hydrated phases and changes in spectral properties related to hydration state, the alteration minerals may prove more challenging to model than mafic minerals; the photometric effects that play a role in the absolute level of the reflectance are not taken into account; the spectrally featureless minerals such as amorphous glassy phases and feldspars are poorly con-

strained even if their presence partly controls the overall albedo and reduces the spectral contrasts of the absorption bands; the grain size is a parameter that also controls the shape and the depth of an absorption, which questions the uniqueness of the final solution. Finally, the refined calibration of IRS is still a work in progress with  $\sim 10$  nm of uncertainties on the position of some features [12]. For olivine/nontronite/basaltic glass ternary mixtures with hydrated minerals at high ( $>65\%$ ) or low ( $<20\%$ ) abundance, estimates of modal mineralogy are accurate to within 10% [14]. The predictions of the modal mineralogy have to be evaluated against other in situ analyses (RMI context image, LIBS normative mineralogy, PIXL, Sherloc) and therefore, we first focus on the modeling of IRS of Seitah abraded patches (Gardes, Dourbes, Quartier) to compare the inferred modal mineralogy and grain size with other in situ analytic techniques.



**Figure 1.** (top) IRS spectrum (black line) from one point on the Dourbes abraded patch acquired during sol 278 (FOV $\sim 4$  mm $^2$ ) compared to its best-fit (red line). (bottom) Ratio of the two spectra shown in the top panel. The horizontal dashed lines indicate the threshold of detection. A small shift of the 1.9  $\mu$ m water vibration signature is observed, which implies the presence of another unknown hydrated phase responsible of the shift to longer wavelength.

**Modal mineralogy of olivine-bearing abraded patches:** The averaged modal mineralogy is dominated by primary phases with olivine and pyroxene as the first and second major phases respectively, which is in agreement with other in situ measurements including LIBS [15]. Some variations of alteration phases are observed from one abraded patch to another one and from IRS point to point. These variations (up to 10-15% for the hydrated phases) could mean that the solution is non-unique, these phases are at the detection

threshold and/or the variations are due to the local-scale heterogeneity as clearly visible in Quartier observations (sol 294). The abrasion process may also produce small grains that could remain on the cut surface artificially modifying their abundance. The tailing-based modal mineralogy could be more representative of the averaged composition and is reported in Table 2.

Mineral	IRS abraded patch (vol%)	IRS Dourbes Tailing (vol%)	LIBS (wt%)
Olivine	30-50	67 $\pm$ 11	24-61%
Pyroxenes	10-35	10 $\pm$ 5	22-50%
Plagioclase	<10	-	10-15%
Mg/Fe-carbonate	Up to 20	9 $\pm$ 6	2 points (TBC) over a few tens
Fe/Mg smectites	Up to 20	<5	Low H content
Mg-serpentine	Up to 20	<5	Low H content
Fe-hydroxide	<10	-	Low H content

**Table 2.** Averaged modal mineralogy retrieved from IRS observations of the abraded patches of the Seitah unit compared to preliminary LIBS CIPW norm.

**Implications on alteration:** Several altered/hydrated minerals are required to fit the IRS signatures. The modeling favors Fe-carbonates to explain the shape of the 2.3  $\mu$ m signature, Fe/Mg-smectites rather than talc to reproduce the overall shape of the 2.2-2.4  $\mu$ m spectral range. Of special interest is the required inclusion of Mg-serpentine that improves the fit of the 2.33  $\mu$ m signature. Other possible phase could be Mg-hydroxide such as brucite but can be excluded due to the lack of any 2.2  $\mu$ m feature. The co-occurrence of carbonate-serpentine (if confirmed) could suggest carbonation of serpentinized ultramafic rocks.

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