

**GLOBAL DISTRIBUTION OF ABUNDANCES OF HYDRATED MINERALS ON MARS AND DERIVED WATER CONTENT.** L. Riu<sup>1,2</sup>, J. Carter<sup>2</sup>, F. Poulet<sup>2</sup>. <sup>1</sup>Institut of Space and Astronautical Science (ISAS/JAXA), Japan, <sup>2</sup>Institut d'Astrophysique Spatiale (IAS), France. Contact : riu.lucie@jaxa.jp

**Introduction:** Mars has been one of the key targets in the space exploration of the solar system. Understanding its mineralogy has been an important asset to rebuild its history. One of the prime interests of those past, ongoing and future investigations has been set on the aqueous minerals detected at the surface and subsurface of the planet. In addition to providing information on the past aqueous subsurface and surface environments, these secondary phases have a major exobiological potential and are prospective resources for human exploration (ISRU). As such they are key drivers in the selection of current and upcoming landing sites for robotic and human missions to Mars. Several studies of the aqueous mineralogy (e.g [1], [2], [3], [4] amongst others) have shown that globally the Martian surface displays various mineral assemblages, prominently clays and salts, as well as other altered phases. This diversity of composition in diverse geomorphic contexts has helped trace the water history on Mars, *qualitatively*. The next challenge will be to have a more global and quantitative view of the altered mineralogy to be able to access the water content present at/near the surface.

Previous work showed that NIR spectroscopy could be used not only to detect but also to quantify mineralogy of hydrated deposits on Mars using radiative transfer modelling ([5],[6]). Ultimately, the modal composition can be used to provide the water content at the top surface by converting the mineralogical composition to elemental composition.

**Dataset and selection of minerals included in the mixture:** We use kilometric scale OMEGA reflectance spectra in the near infrared from 1 to 2.5  $\mu\text{m}$ , corrected from aerosols and atmospheric contributions [7]. For this study, we focus on pre-determined locations displaying hydrated features from clayey phyllosilicates, hydrated silica and carbonates. Before performing the modelling, the spectra of the mineral deposits are clustered into contiguous ROIs based on their mineralogy [8]. They are divided into 3 main classes based on spectral resemblance that enables to cover a wide variety of composition observed from orbit. At this stage, three of those mineralogical classes are used as priors and modelled. Additional classes were excluded because they contain sulphates for which there is a lack of optical constants. As a result, ~14 million OMEGA pixels with aqueous mineral detections were clustered into ~20000 ROIs. ROI down-sampling is used to enable realistic processing time and mitigate stochastic noise in single pixels. The prior

mineral classification enables a down-selection of the end-members for each ROI prior to the modelling (Table 1). This pre-selection is a trade-off between extensive modelling at planetary scale and the necessity to start with realistic mineral mixtures representative as much as possible of the diversity of Martian aqueous mineralogy. This approach thus differs from previous modelling work ([5] and [6]) that focus on very limited terrains for which a large number of minerals was also tested by iterations. Several tests were performed on well-studied specific regions (Nili Fossae, Mawrth Vallis and Meridiani) to validate the method.

Phases tested with linear unmixing :		
<i>Fe/Mg/Al phyllosilicates (Nontronite/Saponite/Kaolins), Al-smectites (Beidellite), Micas, Opal, AlSiOH, Carbonates, Serpentine, Chlorite</i>		
+		
Class 1	Class 2	Class 3
Fe & Mg phyllosilicates Micas	Al-phyllosilicates Al-smectites Opal/AlSiOH	Fe & Mg phyllosilicates Carbonates Serpentine

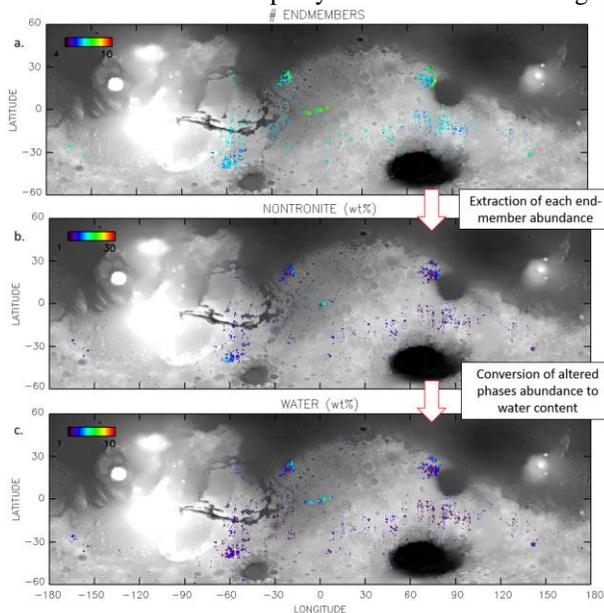
**Table 1 – List of hydrated end-members selected for the modelling depending on the ROI class.**

Spectral indexes are used to test the presence of additional mafic minerals (pyroxenes (both LCP and HCP) and olivine (both Fe-rich and Mg-rich) included in the mixture. Additionally, plagioclase and a hydrous hydroxide phase (ferrihydrite) are always included as end-members. The majority of the ROI spectra can be reproduced with 7 to 9 end-members (Figure 1a). On average, more end-members are needed to model the reflectance spectra of some low latitude highland terrains (especially at Marwth Vallis and Nili Fossae) than the southern hydrated spots. This suggests more complex assemblages at the OMEGA pixel scale in those two regions than in most of the rest of the Martian surface, in agreement with previous studies.

**Methodology:** We aim at mapping modal composition of the hydrated mineral on Mars at the global scale using NIR spectral data. To do so, we use Shkuratov radiative transfer model that mimics a particulate mixture of minerals [9]. This model has already been applied and tested on OMEGA dataset at local and/or global scale to retrieve the composition in terms of mafic and only very locally in terms of hydrated mineral abundances ([10] and [6]). We use the same methodology here adapted to global scale analysis with hydrated minerals included in the mixture. For each modelled spectrum, the quality of the fit is evaluated by the root mean square (RMS) at the end of minimization. If the  $\text{RMS} < 0.025$  the fit is qualified as ac-

ceptable and kept for the global mapping. When several observations overlap at the same location, the resulting abundances are average with a weight on the RMS of each fit to put a higher weight on the best fit [6]. Once a minimum is reached, the abundance of each phases is evaluated. If one of the retrieved abundance is lower than 1 wt%, the end-member is removed from the mixture and a second run is performed for the same spectrum with the new priors. The resulting modal abundances are then converted into water content. To do so, we use the elemental composition of each end-member and their bulk density and sum all normalized H<sub>2</sub>O contributions.

**Preliminary results & perspectives:** Global maps of all the phases listed in Table 1 are obtained at a resolution of 64 px/° (< 1 km/px at the equator) over the entire planet and for the majority of the OMEGA observations indicating the presence of these phases. The remaining observations (~1/4 of the considered dataset) are still under modelling computation and will be added to the final maps by the time of the meeting.



**Figure 1 – (a) Spatial distribution of the number of end-members included in the mixture for each modelled spectrum. (b) Preliminary abundance map of Fe-smectite (vol%). (c) Preliminary water content (wt%) map.**

Only 8% of the modelled surface is dominated by hydrated minerals (i.e. total abundance of hydrated phases > 50 vol%). The corresponding areas are close to Marwth Vallis, Nili Fossae, Meridiani and for a few smaller spots in the southern hemisphere (north west of Argyre basin). This tend to show that the regions with the highest abundance of altered minerals are also the ones with the larger number of hydrated end-members modelled. In-depth investigations will be

performed on the final global maps to validate this observation.

Hydrous hydroxide (ferrihydrite end-member) and Fe-phyllsilicate (nontronite end-member, Figure 1b) are the two most widespread hydrated phases to be found on the surface as modelled here, with respective coverage of 92% and 65% of the considered areas. Additionally, hydrous hydroxide is the most abundant one with on average ~13 vol% abundance. Micas (celadonite end-member) are also quite widespread as they are modelled in half of the considered terrains. However, their average abundance is quite small with only 4 vol% on average. Al-phyllsilicates (kaolins end-member) are also found in half of the hydrated modelled terrains, with significant average abundance of 8 vol%. Mg-phyllsilicates (saponite end-member) are less abundant than Fe-phyllsilicates and Al-phyllsilicates and are found in only 30% of the hydrated modelled terrains. Al-smectite (beidellite end-member) is more localized (mainly in Nili Fossae, Marwth Vallis and north west of Argyre basin) but have relatively high average abundance of 11 wt% when present. All the other phases are mostly restricted to the northern hemisphere with fewer positive detections in the southern altered terrains. They are present in less than 10% of the altered terrains and have close average abundances of only a few percent (5 vol% for hydrated silica and AlSiOH phase and 3 vol% for chlorite and lizardite). Carbonate (magnesite end-member) is the less widespread and the less abundant phase with only few positive detections in Nili Fossae (as predicted in previous studies [6]) with average abundance of a few percent (but can reach 10 to 15% in and around Jezero crater).

The water content resulting from the modelling based on the mineral abundances distribution is shown on Figure 1c. We find on average 2.5 wt% of H<sub>2</sub>O. The water content increases with latitude and appears to be highest in Meridiani and Marwth Vallis reaching up to 10 wt% in a few locations. Nili Fossae shows lower water content with only 3 wt% on average which is closer to what is observed in the less water-rich regions modelled in the southern hemisphere.

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**References:** [1] Bibring et al. (2006), *Science*, 312. [2] Murchie et al. (2009), *JGR*, 114. [3] Carter et al. (2013), *JGR*, 118. [4] Ehlmann et al. (2011), *Nature*, 479. [5] Poulet et al. (2014), *Icarus*, 231. [6] Poulet et al. 2018, *LPSC #1283*. [7] Riu et al. (2019), *Icarus*, 319. [8] Carter et al. (2018), *LPSC #1166*, [9] Shkuratov et al. (1999), *Icarus*, 137. [10] Riu et al. (2019), *Icarus*, submitted.