

MODAL MINERALOGY OF PHYLLOSILICATE- AND CARBONATE-BEARING TERRAINS NEAR NILI FOSSAE AND IMPLICATIONS ON ALTERATION DEGREES. F. Poulet¹, A. Martinez^{1,2}, J. Carter¹, L. Riu¹, J.-P. Bibring¹, B. Gondet¹ ¹IAS, CNRS/Université Paris-Sud, 91405 Orsay Cedex, France, ²LATMOS, CNRS/Université Pierre et Marie Curie, Paris, France.

Introduction and motivation. The Noachian terrain west of the Isidis basin hosts a diverse collection of alteration minerals distributed over varied geomorphic units within a 100,000 km² region in and near the Nili Fossae [1,2]. These minerals have been identified thanks to vibrational absorption features in visible/near infrared (VNIR) spectroscopic data. Although the observed VNIR spectral diversity in this region is remarkable for Mars, the extent of alteration and the complete mineral assemblages present in this region are still poorly unconstrained [3]. This area is of great interest for at least two reasons: 1) it is home to two landing sites of Mars2020 (Jezero crater and NE Syrtis) in addition to the most extended carbonate units on Mars; 2) it contains a great diversity of hydrated phases, which makes this region as a test region for investigating modal mineralogy of other altered terrains on Mars [6].

Recent work using TES data has been used to estimate the bulk mineral assemblages of this region [4]. While the observed VNIR spectral signatures throughout this region are largely dominated by olivine and various alteration phases, the mineral assemblages modeled from TES are still largely basaltic, very homogenous with a total abundance of hydrated phases of 15-30% (consistent with modeled abundances elsewhere across Mars). Another surprising aspect is that there is very little difference between unaltered and altered units. This could be due to the poor resolution of TES and the difficulty to differentiate alteration mineral phases using TIR spectroscopy. In any case, this result is surprising and despite of positive statements by [4] on the astrobiological interest of this area, we believe in contrast that such a low alteration degree and the similar content of hydrated phases between this region and the rest of the planet could potentially jeopardize the benefit of Mars2020 catching samples.

Previous works have demonstrated that radiative transfer modeling can be applied to VNIR spectroscopic data from Mars orbiters to provide quantitative estimation of bulk mineralogy for hydrated terrains [3,5]. We here present the modal mineralogy of the major phyllosilicate-bearing and carbonate-bearing deposits near Nili Fossae derived from the modeling of OMEGA spectra using a radiative transfer model. We show that the modeling approach is able to reproduce the spectral diversity of this region including the carbonate-bearing deposits. The modal mineralogy is clearly different of those of the nearby Syrtis basalts, but yet it is still dominated by anhydrous phases, which

confirms that aqueous alteration could have been limited in this region.

Method. Signatures of hydrated minerals are detected in each single OMEGA cube over the region of interest [63°E-81°E, 12°N-30°N] with specific and validated algorithms defined by [6]. The spectral modeling is applied to pixels exhibiting features related to H₂O and OH (total number of 80000 pixels over the studied area) and then the modeled abundances (vol%) are averaged when overlapping observations (up to 5) occur for a specific location. Modal mineralogy is derived using a nonlinear unmixing modeling based on the Shkuratov radiative transfer model [3]. The spectra are fitted in the 0.99–2.50 μm wavelength range using a simplex minimization algorithm. 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 plagioclase and pyroxenes (both high- and low-calcium) are considered as potential endmembers and hence are systematically added. Previous tests have also showed that a hydrous hydroxide phase (ferrihydrite) is required [3,5].

Nontronite, Saponite, Montmorillonite
Chlorite
Prehnite
Kaolinite
Opal, Al/Si-OH bearing phase
Magnesite

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

On the other hand, it is not possible to add per default all the potential altered minerals considered in this study (Table 1). Each OMEGA spectrum is then examined to identify a specific metal-OH or carbonate signature thanks to a set of spectral criteria able to discriminate the different altered phases. If the spectral criterion of a given endmember is positive, it is then added in the mixture. Most of the pixels are well reproduced with 5-6 endmember (plagioclase, 2 pyroxenes, ferrihydrite, one or two hydrated phases), but the mineral diversity increases eastward with the carbonate unit requiring up to 9 minerals (same minerals than before plus one carbonate and two olivines).

Results. The model provides excellent fits (RMS <0.25%) for 90% of the pixels exhibiting hydrated features, but only half of the pixels requires the presence of altered phases, ferrihydrite excluded. The signatures being very small, the model does not indeed require the presence of any altered phase listed in Table 1. Note that we performed several simulations to test the robustness of the results and the consistency of the results. These tests are not described here.

The averaged modal mineralogy shown on Figure 1 is dominated by anhydrous phases, which confirms previous studies [3,4]. This suggests that aqueous alteration was likely insufficient to thoroughly alter the terrains in this region. We have to keep in mind that the averaged mineralogy is however biased by the spatial distribution of altered phases as some of them such as kaolinite, chlorite, prehnite and magnesite are found on localized spots with abundances larger than 10% (Figures 2 and 3). Moreover, the distribution of the altered terrains are relatively patchy and discontinuous [1,2,4,7], and so the relatively low abundances of altered phases modeled in this investigation could represent minimum estimates due to the spatial resolution of the OMEGA instrument.

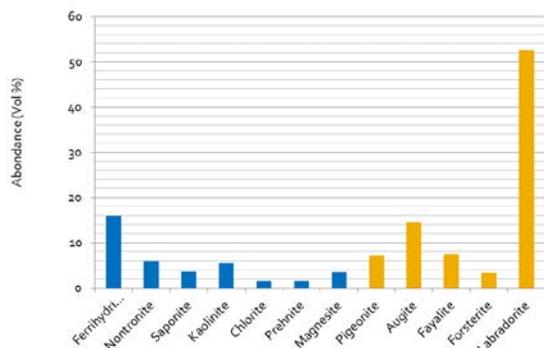


Figure 1. Average abundance of each mineral required for the modeling.

The spatial distribution of total abundance of all altered phases is shown on Figure 2. It is remarkably well correlated with previous studies based on spectral indexes [1,2]. Of special interest are the locations of terrains exhibiting the largest abundances of kaolinite and chlorite/prehnite, which also correspond very well to previous mapping based on CRISM data (see Figure 2 of [2]). The carbonate endmember is restricted in the eastern part of the studied region (Figure 3), where the greatest number of occurrences of carbonates was also mapped by [2]. These magnetite-bearing terrains are mapped as mottled terrains [7]. They constitute one of the most altered area in the region, with a total abundance of altered phases near 40-50 vol% (30% Fe/Mg clays and 15% magnesite).

Summary. The various altered phases including minor ones (kaolinite, chlorite, prehnite, carbonates) are extremely well retrieved by the model. The modal mineralogy is diverse but overall dominated by non-altered phases and relatively high-T altered products. Given this successful investigation, this region can be considered as a proxy region for further investigations of hydrated terrains detected on the Martian surface at planetary scale [8].

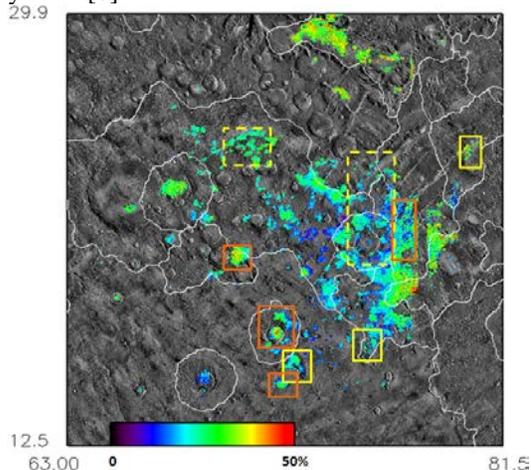


Figure 2. Abundance (vol%) map of all altered products (minerals of Table 1 plus ferrihydrite) over the studied region of Nili. The altered mineralogy is dominated by ferrihydrite and Fe/Mg smectites except for spots dominated by kaolinite (yellow rectangles) or chlorite/prehnite (orange rectangles). When the pixels are scattered, the rectangles are in dashed line.

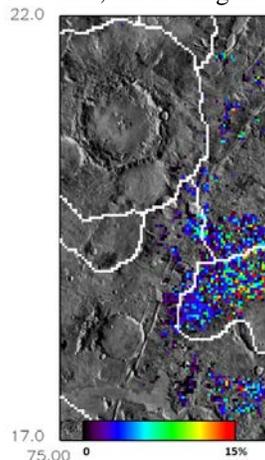


Figure 3. Mineral abundance map of carbonate endmember. The spatial distribution is very well correlated with the mottled terrain unit that exhibits olivine and carbonate signatures [7].

References: [1] Mangold N. et al. (2007) *JGR*, 112, E08S04 1-25. [2] Ehlmann B. et al. (2009) *JGR*, 114, E00D08, 1-33. [3] Poulet F. et al. (2008) *A&A*, 487, L41-L44. [4] Salvatore M.R. et al. (2018) *Icarus*, 301, 76-96. [5] Poulet et al. (2014) *Icarus*, 231, 65-76. [6] Carter J. et al. (2013) *JGR*, 118 (4), 831-858. [7] Carter J. (2016) *LPS* 48, Abstract #1964. [8] Goudge T et al. (2015) *JGR*, 120, 775-808.