

MAFIC MINERALS MAPPING ON MARS AND CHEMICAL COMPOSITION CHARACTERIZATION USING A SYSTEMATIC APPROACH BASED ON THE MODIFIED GAUSSIAN MODEL (MGM). H. Clenet¹, P. C. Pinet², Y. Daydou², J. Flahaut¹, J.-P. Bibring³, C. Rosemberg², G. Ceuleneer² and P. Allemand¹, ¹Laboratoire des Sciences de la Terre, UMR CNRS 5570, Université Claude Bernard/Ecole Normale Supérieure de Lyon, 2 rue Raphaël Dubois, 69622 Villeurbanne Cedex, France, ²UMR 5562/DTP, Observatoire Midi-Pyrénées, Université Paul Sabatier, Toulouse, France, ³IAS, Orsay, Université Paris Sud, France (harold.clenet@ens-lyon.fr)

Introduction: Mineralogic composition is essential for the understanding of planetary evolution. In this respect, detection, identification and quantification of the relative abundance of mafic minerals, such as olivine and pyroxenes, are of prime importance for petrologic history. Hyperspectral remote sensing in the visible/near-infrared wavelength region delivers very useful information for characterizing the petrology of igneous rocks. Olivine has three characteristic absorptions in the 1 μ m domain, distinct from that of pyroxenes. Indeed, both orthopyroxene and clinopyroxene have an absorption in the 1 μ m and 2 μ m domains [1,2].

Methodology: To process hyperspectral data, we use the Modified Gaussian Model (MGM) originally developed by Sunshine et al. [3]. MGM technique aims to deconvolve the absorption bands in reflectance spectra. This is achieved considering a sum of Gaussian functions and assuming that the spectral continuum can be modelled by a polynomial shape. Each Gaussian function (characterized by its band center, width and strength) or combination of Gaussian functions permits the identification of a mineralogical absorption band, indicative of the presence of the predominant mafic minerals.

As most of the study areas have unknown mineralogy as an input parameter, we set an automatic procedure, described hereafter, implemented on the original MGM approach. This procedure is applied systematically on each pixel. We use different numbers of Gaussian functions, depending on the complexity of the mixture. Additional Gaussian functions centered at 1.4, 1.9, and 2.3 μ m may be requested to account for the hydration/alteration effects. Considering all the mixture possibilities with the three mafic components, we run the MGM modeling seven times on a given pixel.

[4] have shown that MGM results are sensitive to the initial Gaussian function centers. To supplement this previous work, we have tested the MGM considering the initial strength of the Gaussian functions compared to the strength of the spectral absorptions. For this purpose, a synthetic set of spectra simulating weaker absorptions while keeping a strictly identical chemical composition has been produced with artificially flattened laboratory spectra. Results show that MGM calculated parameters are in agreement with the

mineralogic absorption parameters when the initial conditions account for the spectral absorption strength.

Consequently, for each mineralogical combination, the starting values for the continuum are derived on the basis of a spectral shape smoothing analysis, determining the relevant local maxima along the spectrum. Gaussian function strength and width are also initialized as a function of the global shape of the present absorptions. Relative coefficients applied to each Gaussian parameter are estimated based on [5,6]. The uncertainties are taken large enough to set an appropriate degree of freedom on the parameters. Finally, seven mathematical solutions are returned by the MGM for a single pixel.

Produced mathematical solutions are then sorted in order to keep only those which verify the mineralogic constraints corresponding to the initial mineral search. The potential identification of minerals is carried out through a systematic search which relies on laboratory spectroscopic studies that address separate pyroxene mixtures and olivine suites [2,4,5,6]. The resulting band parameters (center, strength, width) are used to assess the best model [7,8].

Validation process: This automatic procedure has been applied on different spectra. We first consider laboratory powder spectra taken from the RELAB spectral library corresponding to simple compositions [2,5,6]. Spectra with more complex mineralogies, involving olivine and one or two pyroxenes, were used later. In a number of cases, we are able to get a good detection of each phase when present as demonstrated on a suite of SNC meteorite spectra [7]. However, the relative proportion of olivine is determinant for its detection, especially when it is mixed with orthopyroxene. We also assess that the occurrence of feldspars has basically no bearing on the estimates of mafic relative proportions.

In order to assess the efficiency of the procedure described above under natural conditions, we use field spectra and airborne data acquired over Maqsad Massif, Sultanate of Oman. This area is quite appropriate for hyperspectral remote sensing purposes as it is located in an arid desertic environment and encompasses large mafic rock exposures [8,9,10]. Maqsad Massif mineralogy is dominated by olivine-pyroxenes mixtures and, therefore, this area presents valuable spectro-

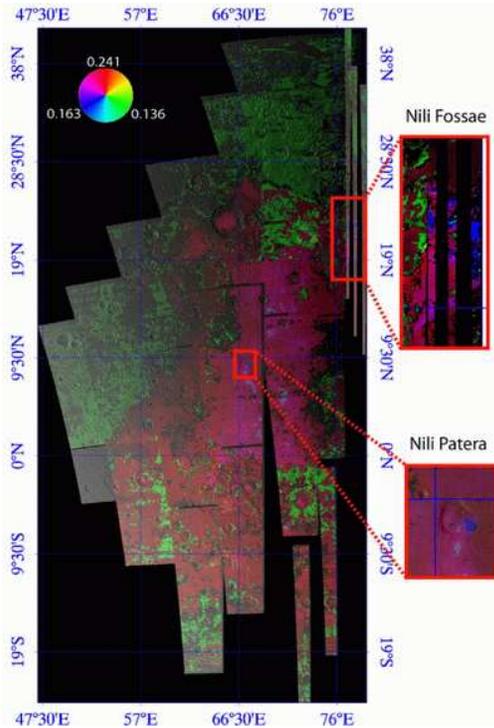


Fig 1. Mafic minerals mapping on Syrtis Major as revealed by our approach (Red: clinopyroxene; Green: orthopyroxene; Blue: olivine)

scopic analogies with some Martian terrains [e.g. 11,12,13].

The results lead us to a good detection of two lithologies [8]. As expected, the mantle part is dominated by harzburgite while the crustal part is dominated by clinopyroxene. Moreover, comparison between field sample analyses and MGM results shows that i) olivine abundance can be correctly estimated in harzburgite and ii) variations of clinopyroxene chemical composition can be mapped in the area. Thus, our procedure is adapted to extract mineralogic information from areas that have not been ground truthed.

Martian applications: The Syrtis Major volcano is known to possess strong mafic signatures and was the first study area [e.g. 11]. We used OMEGA/MEx data to produce a map of the mafic mineral distribution (Fig 1). This shows differences between the Noachian crust, the peripheral lava field, and the central part of the shield. We identify a relative enrichment in olivine, compared to clinopyroxene, in this central part. Relying on the plagioclase abundance estimates from the literature on thermal infrared, we assess the olivine content in the rocks which can locally reach up to 20%. Olivine composition is about Fo_{50-80} , but grain size can affect the interpretation. Data from [14] were used to characterize pyroxenes. It appears that orthopyroxene corresponds to an enstatite composition while clinopy-

roxene has a wider Ca-content range (i.e. pigeonite to augite). Based on [15], two hypotheses can explain the pyroxene chemical compositions: either lavas are constituted by a three component mixture (Fig 2) or they did crystallize at high temperature.

In a second step, we analyze MRO/CRISM data acquired in the Valles Marineris area. Indeed, rock outcrops in the walls offer access to old basaltic terrains. Mafic minerals have been first detected with spectral parameters [12], pointing at targets to be analysed with our procedure. This work is currently underway for Coprates Chasma where a global analysis has already been done [16].

Conclusion: Our automatic procedure based on the MGM permits mapping of mafic mineral distribution on Mars. We can deal with complex olivine and pyroxene mixtures. Moreover, we can now determine more precisely the chemical compositions of the minerals, which is essential for the characterization and comprehension of the petrologic processes related to the formation and the evolution of planetary surfaces (e.g. [17]).

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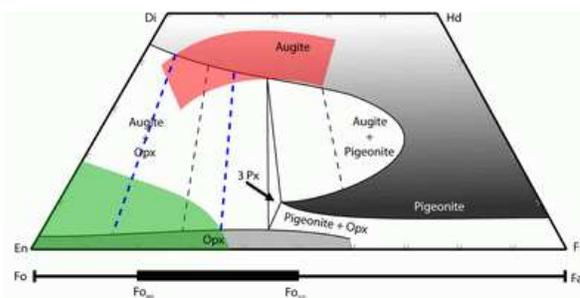


Fig 2. Pyroxenes compositions (red: clinopyroxene; green: orthopyroxene) and data from [16] at 1 atm and 1000°C