A SYSTEMATIC TESTING APPROACH USING THE MODIFIED GAUSSIAN MODEL (MGM) FOR MAFIC MINERALOGY MAPPING IN NATURAL CONDITIONS (EARTH, MARS).

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Introduction: Mineralogical 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, can be used to evidence crustal or mantle petrology. Because of the Fe^{2+} electronic transition effect, hyperspectral remote sensing in visible/near-infrared delivers very useful information for characterizing the petrology of igneous rocks. Olivine has three characteristic absorptions in the 1µm domain, distinct from pyroxenes ones. Indeed, orthopyroxene, or Low Ca pyroxene (LCP), and clinopyroxene, or High Ca pyroxene (HCP), have each one an absorption in the 1µm and 2µm domains [1,2].

Methodology: To deconvolve hyperspectral data, we use the Modified Gaussian Model (MGM) originally developed by Sunshine et al. [3]. MGM technique aims at deconvolving the absorption bands in reflectance spectra. It is achieved considering a sum of Gaussian functions and assuming that the spectral continuum can be modelled by a polynomial shape. Here we approximate the continuum by means of a degree 2 polynomial in wavelength term to deal with variable shapes of spectra, including negative slopes. Each Gaussian function (characterized by its band center, width and strength) or combination of Gaussians permits the identification of a mineralogical absorption band, indicative of the presence of the predominant mafic minerals [4].

As we deal with an unknown mineralogy in the real world (either on Earth or Mars), we set an automatic procedure implemented on the original MGM approach. This procedure is applied systematically on each pixel (or spectrum). We use different numbers of gaussians, depending on the potential complexity of the mixture, i.e. two gaussians for simple pyroxene composition up to seven gaussians for an olivine/HCP/LCP mixture. Additional Gaussians centered at 1.4, 1.9 and 2.3µm 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.

Each time, 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. Moreover, gaussians strength and width are initialized as a function of the global shape of the present absorptions. Relative coefficients applied to each gaussians parameter are estimated based on [5,6]. The uncertainties are taken large enough to set a large degree of freedom on the parameters. Finally, we obtain for a pixel, seven mathematical solutions returned by the MGM. Produced mathematical solutions are then sorted in order to keep only those which verify the mineralogical constraints corresponding to the mineral initial search. The potential identification of minerals is carried out through a systematic search relying on laboratory spectroscopic studies addressing separately pyroxene mixtures and olivine suite [2,5,6,7]. The resulting band parameters (center, strength, width) are used to assess the best modeling on the spectroscopic viewpoint [4].

Implementation: This automatic procedure has been applied on different spectra as shown in Fig. 1. We first consider laboratory powder spectra taken from the Relab spectral library corresponding to simple compositions, i.e. either pure olivine (Fig 1.*a*) or pyroxene mixture [2,5]. We then use spectra with more complex mineralogies involving olivine and one or two pyroxenes (e.g. Fig 1.*b*). In a number of cases, we are able to get a good detection of each present phase. However, the relative proportion of olivine is determinant for its detection, especially when it is mixed with orthopyroxene. We also recognise that the occurrence of feldspars which are almost spectrally featureless in the near-infrared has basically no bearing on the deconvolution process, meaning that the plagioclase is generally not identified but from its contribution to the reflectance level of the spectrum.

In order to assess the efficiency of the procedure described above in natural conditions, i.e. when addressing non-controlled rocks mineralogy combined with alteration effects such as serpentinization, we use field spectra acquired in Maqsad Massif, Sultanate of Oman, in January 2006. This area is quite appropriate for hyperspectral remote sensing purposes as it is located in an arid desertic environment and presents large rock exposures. Maqsad Massif is known to be part of the Oman ophiolite section [e.g., 8] and the local mineralogy is prevailingly controlled by olivine / pyroxenes mixtures. In this viewpoint, this area presents valuable spectroscopic analogies with some low-albedo Martian terrains, such as the Syrtis Major shield known to present strong mafic signatures [9,10,11,12,13].
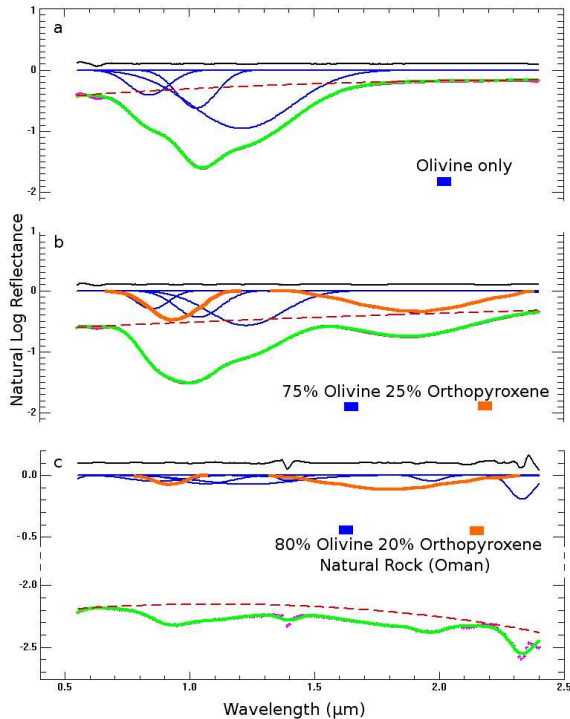
Figure 1. MGM deconvolutions of laboratory powder spectra from Relab. Each graph shows the final output of the entire procedure (only one configuration is correct for a spectrum). **1.***a (top)* olivine only, **1.***b (middle)* olivine (75%) with orthopyroxene (25%), **1.***c (bottom)* olivine (80%) with orthopyroxene (20%), spectrum measured on a harzburgitic rock surface in natural conditions.

Constraints have been set on Oman rocks composition by means of optical microscopy and microprobe analyses. In our study, we also use spectra of Oman samples measured by the Relab facility at Brown University.

We notice that the presence of desert varnish leads to flatter spectra. This effect is taken into account in our procedure through the automatic initialisation of gaussians parameters (see above). However, in some cases, the signal in the 2 µm domain is so reduced that it prevents from detecting properly the minerals in presence. We have then to rely only on the 1µm absorption deconvolution to retrieve the mineralogy. Alteration effects around 2.3µm (serpentinization) are modeled with a dedicated Gaussian (see Fig. 1.*c*).

Mapping application: An airborne campaign over Oman ophiolite has been conducted in December 2002 with the HyMap imaging spectrometer. Its spatial (6m/pixel) and spectral resolution are well adapted to a regional study of this geological context [14,15]. Despite the occurrence of hydration processes of the pri-

mary minerals resulting in the development of serpentinization, and of weathering processes resulting in the presence of an alteration varnish, olivine and pyroxenes can be detected. Indeed, spatially organized variations are revealed that can be used to produce a new type of predictive lithology / mineralogy maps.

The systematic analysis realized by our procedure leads us to a good detection of two lithologies. The mantle part is dominated by an olivine / orthopyroxene mixture while the crustal part is dominated by clinopyroxene, mixed with a variable amount of orthopyroxene. Cartographic products can be generated from the MGM processing of the Hymap hyperspectral dataset. It is then possible to compare field and hyperspectral results on local testing sites. Across the peridotite field, harzburgite and dunite are identified, while in the crustal section, rocks present lithologies consistent with troctolite, wherlite and gabbros [14,15]. These results show that hyperspectral mapping can be used to predict the mineralogy and to some extent the rock petrology of particular outcrops, that we validated afterwards with field work on a campaign in March 2007.

Conclusions: Both the implemented methodology and the produced scientific outputs are of interest for interpreting the hyperspectral data acquired for the Martian surface by Omega / Mars Express or with CRISM/ Mars Reconnaissance Orbiter, with a particular emphasis on structures like Syrtis Major volcano and Nili Fossae which are keys to improve our knowledge of Mars petrology [16].

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