

METHODOLOGY OF HYPERSPECTRAL REFLECTANCE DATA ANALYSIS FOR MINERALOGICAL MAPPING OF PLANETARY SURFACES: APPLICATION TO OMEGA/MARS-EXPRESS IMAGES.

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Introduction: Reflectance measurements performed by imaging spectrometers are powerful tools to quantify and to map the mineralogical composition of planetary surfaces, which is a key information in geology. The OMEGA imaging spectrometer onboard Mars-Express allows studies at a global scale with a spatial resolution varying from 300 m/pixel to 4 km/pixel. Because these distances are usually large compared to the scale of spatial heterogeneity of rocks and soils, each spectrum corresponds to a mixture of different components present in the area covered by one pixel. The objective of the hyperspectral data analysis is to identify mineralogical components among spectral mixtures, and to quantify them in order to produce global maps. Methods must be designed to process automatically millions of spectra. The general principle is to compare hyperspectral data with reference spectra of minerals and rocks. The purest spectral components of an image are the most similar to mineral spectra. An efficient method is statistical analysis by Minimum Noise Fraction (MNF [1]) combined with Pixel Purity Index (PPI [2]). For identification, compositions within an image are assumed pure enough to be compared with a monomineral spectrum.

We present complementary methods to derive the composition of heterogeneous areas, with applications to the OMEGA hyperspectral dataset. The first one is based on the Modified Gaussian Model (MGM [3]) to remove effects of various conditions of acquisition. This enables a direct comparison between OMEGA spectra and a reference spectral library. The second one is a linear unmixing method, improved by a recursive choice of the spectral components.

Data calibration and reduction.

Atmosphere removal. The atmospheric component has been removed by using an empirical transmission function (the ratio of two spectra acquired at the top and bottom of Olympus Mons) scaled to the depth of the 2 μm CO₂ band.

Spectral range. OMEGA provides spectra with 352 channels using three detectors between 0.3 and 5.1 μm . This wavelength range is extended in the infrared compared to many instruments for Earth studies (usually 0.3-2.5 μm) or compared to ISM for Mars

(0.7-3.2 μm). We first focus our analysis on the 0.96-2.55 μm domain, which corresponds to a single OMEGA detector (SWIR-C). Shorter wavelengths are not used because of misregistration and difference in calibration between VNIR and SWIR-C detectors of OMEGA. We do not use the long wavelength range because the spectra of the library are limited to 2.5 μm .

Spectral modeling by MGM.

Method. The shape of reflectance spectra result of the combination of absorption bands and a continuum. Absorptions are related to the presence of chemical species. The continuum is due to diffusion of the light and depends on parameters such as grain size and conditions of illumination and observation. Consequently, one single material can have different spectra. Thus, the comparison between different spectral databases is greatly improved by the continuum removal. This can be done by the MGM algorithm that automatically provides a mathematical inversion of all the absorptions by Gaussian curves and a linear function for the continuum. This way, the continuum does not depend on absorption features. After removal of the continuum, the remaining shape is characteristic of absorption processes and spectra can be directly compared. MGM is therefore useful to validate or invalidate the composition of image endmembers.

Results. Figure 1 shows OMEGA endmember spectrum which has been derived on Aram chaos by using the minimum noise fraction and pixel purity index algorithms.

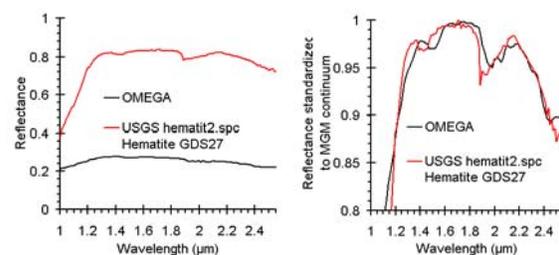


Figure 1. Comparison of spectra of an OMEGA image endmember collected within Aram chaos and a hematite from the USGS library – a. Reflectance spectra – b. Spectra standardized to MGM continuum.

Previous studies by TES [4] found gray crystalline hematite in the corresponding area. However, the spectrum of a gray crystalline hematite measured in our laboratory presents fundamental differences in shape with respect to OMEGA spectra. On the other hand, a USGS library spectrum of red particulate hematite (Figure 1, left) is similar to OMEGA spectrum after MGM continuum removal (Figure 1, right). This is a positive argument to conclude that hematite is present in Aram Chaos.

Recursive linear unmixing.

Method. The spectrum of a mixture of several components is supposed to be a linear combination of spectra. [5]. The classical linear unmixing methods [6] are able to retrieve absolute proportions of such a mixture if all the components are known. However, when the reference library does not correspond exactly to the components of the mixture, the algorithm compensates by negative coefficients, which have no physical sense. To avoid this effect, the inversion is run recursively and independently for each pixel. Moreover, two synthesized linear spectra are included in the spectral library. One has a constant reflectance at 0.1 while the second one has a positive slope with maximum at 1 and minimum at 0. These spectra allow for a better match of slope and albedo of the mixture and therefore compensate at first order for grain size and photometric effects.

Let be N mineral endmembers. At the first iteration, the unknown mixture is modeled by N linear mixtures. Each of them is computed by the same method of inversion described in [7] using one mineral and the two synthesized spectra. The modeled spectrum that has the smallest angle [8] with respect to the measured spectrum is subtracted, and mixture coefficients are memorized. The following iterations begin with the residual spectrum. The iterative process stops when none positive coefficients are found for all the endmembers.

Results. A library with 35 mineral spectra was chosen and two regions of Mars around Arabia and Syrtis were investigated. For each endmember, an image of the absolute coefficients of the linear unmixing is provided. Good fits are obtained for most of the spectra (Figure 2) with RMS lower than 0.4 %, which can be attributed to noise in the signal and limits of the calibration. The RMS is mainly due to calibration residues. The weights obtained by this unmixing process do not correspond to absolute proportions. However, the variations within each image fraction provides a valuable information concerning the spatial repartition of each component.

Hematite is one of the main minerals which is derived by the linear mixing model performed on the same spectra as Figure 1 for Aram Chaos. This is in good agreement with the MGM analysis. In conclusion, this method is able to automatically select the most relevant mineral endmembers. It provides the distribution of each of these endmembers within a scene.

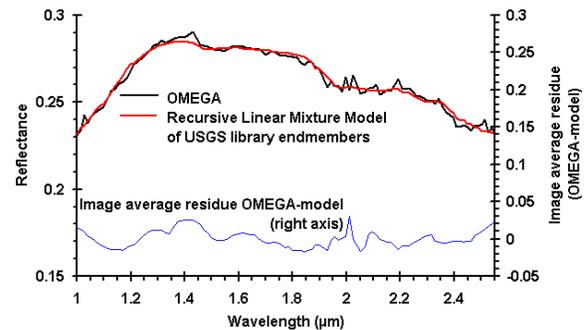


Figure 2. Spectral matching between OMEGA (dark) and a linear mixture composed of hematite, and to a lesser extent jarosite and kieserite obtained by the recursive inversion method (red).

Conclusion and Perspectives: The MGM can be performed to quantify all absorption band parameters. This method works particularly well for minerals such as pyroxenes and olivine. We show that the modified linear unmixing model can be used to derive the main components within each pixel of the OMEGA data set. Our first results are in good agreement with previous studies such as the hematite detection by TES in Aram Chaos [5], even if the mineral type is not exactly the same. Further efforts will be directed toward the quantification of the relative proportions of each mineral. The visible part of OMEGA spectrum will also be included once the registration/resolution discrepancy between VNIR and SWIR-C channels will be fixed. Acquisition of reference spectra with an extension in the infrared, beyond 2.5 μm , will be investigated.

References: [1] Boardman et al., 1994, *Proc., ERIM Tenth Thematic Conference on Geologic Remote Sensing*. [2] Boardman et al., *Summaries, Fifth JPL Airborne Earth Science Workshop, JPL Publication 95-1, v. 1*. [3] Sunshine et al., 1990, *JGR*, v. 93. [4] Christensen et al., 2001, *JGR*, v. 106, 23873-23886. [5] Singer and McCord, 1979, *LPSC 10.1835S*. [6] Boardman, 1989, *Proc., IGARSS'89, 12th Canadian Symposium on Remote Sensing*, v. 4. [7] Ramsey and Christensen, 1998, *JGR*, v. 103, 577-596. [8] Kruse et al. 1993, *Rem. Sens. of Environment*, v. 44.