NON-LINEAR SPECTRAL UN-MIXING USING HAPKE MODELING: APPLICATION TO REMOTELY ACQUIRED M3 SPECTRA OF SPINEL BEARING LITHOLOGIES ON THE MOON

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Introduction: Rocks and soils are mostly an *intimate mixture* of component minerals. Photons of light falling onto such a target are multiply scattered and in the process interact with more than one type of mineral. The reflected photons received at the detector therefore carry information from multiple components present in the mixture, with individual components contributing to the reflected photons, in proportion of the number of times a photon interacted with a component and not necessarily in proportion to their abundance.

The non-linear nature of photon interaction with the intimate mixtures makes it difficult to quantify the proportions of endmembers present in remotely sensed VNIR spectra of natural surfaces using linear combination of contributions from individual components. Non-linear mixing models [e.g. 1,2] provide physically reasonable solutions to such problems and aid in computing proportions of component minerals in a mixture which are more realistic. Non-linear unmixing is an especially important tool in maximizing the interpretation of planetary remote sensing datasets where the availability of ground truth is always a problem.

Objectives: The present study aims at carrying out non-linear un-mixing analysis on a suite of remotely acquired spectra from a Mg-spinel bearing lithology identified recently on the surface of the Moon [3, 4] by Moon Mineralogy Mapper instrument (M3) onboard Chandrayaan-1, India's first mission to the Moon [5,6]. M3 is an imaging spectrometer operating in the wavelength range of ~400-3000 nm with spectral resolution of 10-20 nm & spatial resolution of 140 m in the global mode (coarse resolution).

The occurrence of Mg-spinel bearing lithology on the Moon in the form of relatively large exposures was not known until very recently [3,4]. In view of the discovery of the spinel lithology occurring on a scale of hundreds of meters to kilometers, it is important to understand the geological setting of the region in terms of associated mineralogy, structural setting, presence of any anomalies etc.

The present study is focused towards identifying the mineral assemblage occurring with spinel and quantifying the proportions of each endmember to the first order. The results of this study are expected to have important implications for understanding the character and origin of this spinel-bearing lithology & accordingly on the development of suitable models for explaining its formation.

Approach: In the present study, we are using Hapke's radiative transfer model [1] to generate a look-up table of reflectance spectra for various mathematical mixtures of probable end-members. These are generated by first converting reflectance spectra of each endmember into single scattering albedo using Eq. 11.6 from Hapke [7] followed by their linear addition in various proportions to form all possible mixtures. Once a complete set of mixtures is available, each target reflectance spectrum to be unmixed is compared with all available mixture spectra. Endmember proportions from the best fit mixture spectrum are then reported.

Assumptions: Several assumptions are inherent in our non-linear mixing analysis that affect interpretation of the obtained results. (a) *Endmember spectra* – Laboratory spectra of lunar and terrestrial minerals with a defined grain size (mostly <45 microns) have been selected from RELAB database along with a M3 spectra of shocked plagioclase. They are assumed to be similar in nature to the target spectra. (b) *Grain size* – The grain size of the end members is assumed to be similar as the target area. As grain size affects spectral contrast, inappropriate grain sizes will result in incorrect retrieved endmember abundances[8]. Analysis of lunar samples has indicated that the finest fraction dominates the spectral properties of a mineral and therefore the chosen size fraction of < 45 microns seems to be appropriate for this problem. (C) *Hapke model assumptions* - The model assumes that the size of the particles is significantly larger than wavelength of the interacting radiation. Based on the lunar sample analysis, the average lunar soil grain size is between 40-130 μm [9] which is significantly larger than the 0.7 – 2.5 μm wavelength range that is being used in the present study. The laboratory endmembers are also reasonably larger than interacting radiation. Isotropic single and multiple scattering were assumed. Apart from this, for simplicity, it is assumed that the target spectra are from relatively fresh areas and flat terrain. Detailed analysis at a later stage will include the effects of space weathering as well as local slopes.

Initial Results: Based on the analysis of M3 data, Mg-spinel has been observed to be occurring with plagioclase [4]. There are also suggestions of association with olivine and orthopyroxenes [3,4]. In the present study, the initial set of calculations have been carried out with various combinations of plagioclase and spinel using four different combinations:

i) Crystalline Plagioclase and Spinel 1 & 2

ii) Shocked Plagioclase and Spinel 1 & 2

Spinel 1 and 2 are two different samples. In case of crystalline plagioclase, the feature at 0.9 microns might be due to contamination from small amounts of Opx. The endmember details are provided in Table 1. All the spectra have been trimmed at shorter wavelengths due to scattered light issues in M3 data and at longer wavelengths to minimize effects of thermal emission in M3 data, thereby making the target spectra and modeled mixtures comparable. It should however be noted that selection of appropriate endmembers is a highly iterative process. The presented results represent four such iterations and they should be considered preliminary. At the same time, such iterations act as useful guide in endmember selection.

A comparison of the various modeled spectra with a M3 test spectrum is illustrated in Figure 1. Comparison with test M3 spectrum indicates wavelength and reflectance offsets in the modeled spectra that might be due to inappropriate end member choice, effects of space weathering and contribution from thermal emission in the target (M3) spectrum. Apart from this, brightness and shape differences are also attributable to difficulties in making laboratory and remote sensing datasets comparable. An updated report on this anlysis will be presented.

References: [1] Hapke B. (1981) *JGR, 90,* 1151–1154. [2] Shkuratov Y. et al. (1997) *Icarus, 32,* A74. [3] Pieters et al. (2011) *JGR,* Submitted. [4] Dhingra D. et al. (2011) *LPSC XXXXII,* this vol.. [5] Goswami J. N. and Annadurai M. (2009) *Curr. Sci., 96, 4,* 486-491 [6] Pieters C.M. et al. (2009) *Curr. Sci., 96, 4,* 500-505 [7] Hapke B. (1993) p291 [8] Denevi et al. (2008) *JGR, 113, E02003,* doi:10.1029/ 2007JE0029 29 [9] Carrier W.D. (1973) *The Moon, 6,* 250-263

Endmember	RELAB ID	Origin	Grain size	Viewing Geometry
Crystalline Plag	LS-CMP-086	Lunar	0-25 µm	i = 30°; e =0°
Spinel -1	SP-EAC-017	Terrestrial	0-45 µm	i = 30°; e =0°
Spinel - 2	PS-TXH-083	Terrestrial	0-45 µm	i = 30°; e = 0°
Shocked Plag (M3 Spectrum)	-	Lunar	Unknown	i = 50°; e = 4°

Table 1: Details of the endmembers used for the initial analysis.

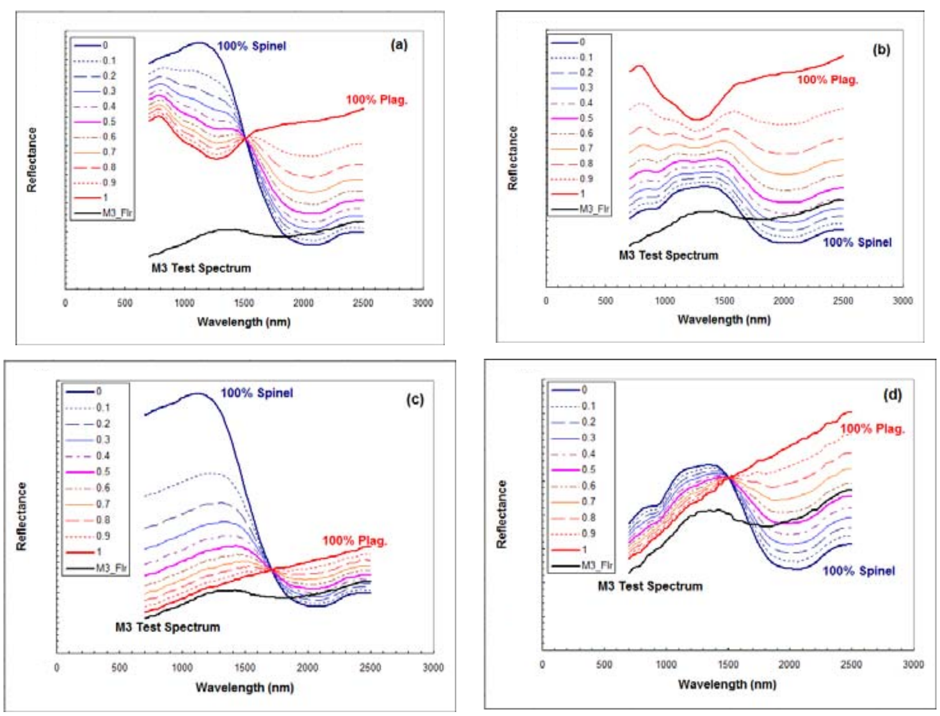

Fig. 1 Initial comparison of a target spectrum with four different combinations of endmembers: (a) Crystalline plagioclase and Spinel 1 (b) Crystalline plagioclase and Spinel 2 (c) Shocked plagioclase and Spinel 1 (d) Shocked plagioclase and Spinel 2. The black spectrum is the M3 test spectrum.