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## Deciphering Remote Sensing Data from Micro- to Macro-Scale: New Laboratory Investigations on Grain Size and Mineral Mixing in Support of Solar System Exploration

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**DECIPHERING REMOTE SENSING DATA FROM MICRO- TO MACRO-SCALE: NEW LABORATORY INVESTIGATIONS ON GRAIN SIZE AND MINERAL MIXING IN SUPPORT OF SOLAR SYSTEM EXPLORATION.** G. Poggiali<sup>1, 2</sup>, A. Wargnier<sup>1</sup>, L. Fossi<sup>2</sup>, S. Iannini Lelarge<sup>3</sup>, J. Beccarelli<sup>4</sup>, J.R. Brucato<sup>2</sup>, M.A. Barucci<sup>1</sup>, M. Pajola<sup>5</sup>, M. Masotta<sup>3,6</sup>, M. Matsuoka<sup>7</sup>, P. Beck<sup>8</sup>, T. Nakamura<sup>9</sup>, F. Merlin<sup>1</sup>, S. Fornasier<sup>1, 10</sup>, A. Doressoundiram<sup>1</sup>, T. Gautier<sup>11</sup>, and G. David<sup>1</sup>

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**Introduction:** Several Solar System bodies target of past, present and future space missions are characterized by dark surfaces, like C-class asteroids and primitive small bodies. Understanding the spectroscopic behavior of low albedo surfaces represents nowadays one of the most challenging question and our knowledge is still incomplete. Dark surfaces are often linked to the presence of opaque material [1] or surface processes such as space weathering [2] or thermal alteration [3]. The interpretation of remote sensing data could not be disjoint from an intensive laboratory work that provide a powerful tool to unveil the surface physical state and composition.

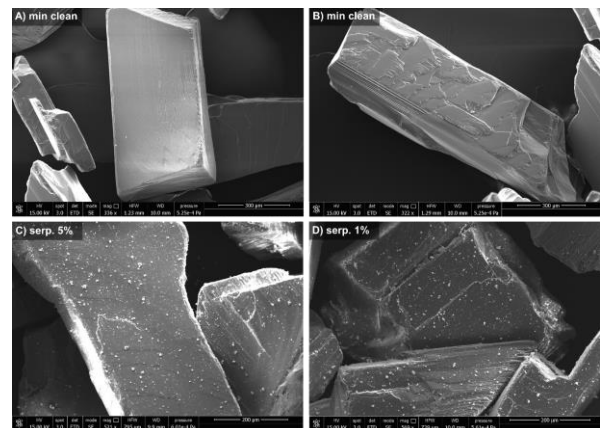
Analyzing complex mixtures of analogous materials remains one of the pivotal laboratory investigations to support remote sensing interpretation, but it also represents one of the most challenging experiments, in particular when multiple components are used in the mixtures. We present in this contribution several results from different works that share the common goal of studying how the mixing of different grain size and dark materials can affect the behavior of infrared spectra in the near- to mid-infrared range (1.25-25  $\mu\text{m}$ ).

**Methods:** Here, two main works will be presented: the first involves the mixing of hydrated and anhydrous minerals components with different grain sizes [4]: the second concerns the mixing of basalts at different grain sizes with dark components [5].

Sample prepared for both works benefit of a new protocol to mix two components with different grain sizes. The method passes through a series of steps including sieving and washing the minerals to separate each grain size and later mixing the selected components. This procedure allows us to produce unique samples with a bigger grain size covered by a selected amount of small grains (Figure 1).

In the first work, we prepared several mixtures using 1 wt% and 5 wt% of hyperfine grain size ( $< 10 \mu\text{m}$ ) of hydrated minerals and 95 wt% and 99 wt% of larger grain size (200–500  $\mu\text{m}$ ) of anhydrous minerals. We measured the IR reflectance spectrum of these mixtures in the range 8000–400  $\text{cm}^{-1}$  (1.25–25  $\mu\text{m}$ ). Analysis of the spectroscopic features was carried out independently in two separated ranges covered by our measurements, in the NIR range we focused on the presence of the hydrated band at 2.7  $\mu\text{m}$  while in the MIR range we carried out an analysis of the most important spectroscopic features present.

The second sample set includes four series of basaltic mix (feldspar and pyroxene), at different grain sizes from  $< 50 \mu\text{m}$  to 500-1000  $\mu\text{m}$ , mixed with amorphous carbon at increasing weight percentages from 1% to 50%. We analyzed several features on the spectrum of each mineral mixture: (i) near infrared slope; (ii) 2.7  $\mu\text{m}$  OH-stretching band; (iii) Christiansen features; (iv) Reststrahlen band and Transparency feature.



**Figure 1.** Secondary electrons SEM image of enstatite sample before (panel A and B) and after mixing with 5% and 1% of serpentine (panel C and D).

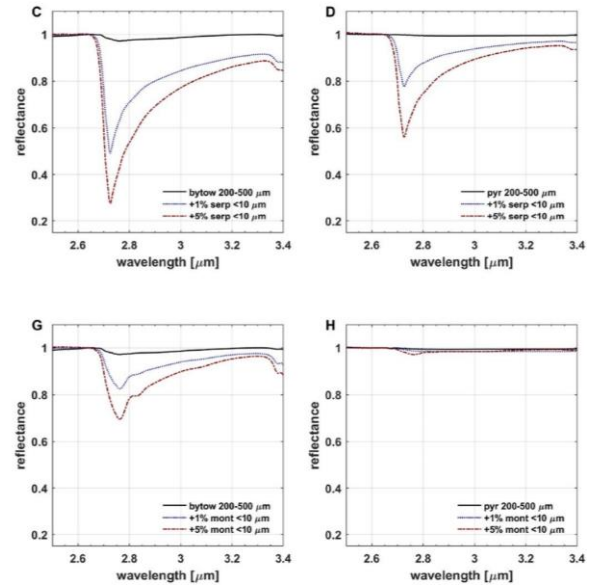
**Results:** *Hyperfine hydrated mineral mixing with coarse anhydrous minerals.* The results of the first paper [4] show how the addition of a hydrated component, which is minor in percentage and has a much smaller grain size, can lead to very remarkable changes in the NIR region especially in increasing the hydrated band depth at 2.7  $\mu\text{m}$  (Figure 2), while slightly affecting the MIR region. The surface of many rocky bodies is covered with regolith, and these new laboratory data show how even a small amount of hydrated mineral in the composition can influence the final spectrum.

*Dark component effect on different grain size bright minerals.* Measurements presented in the second work [5] point towards a critical effect of dark material but with a different outcome for each grain size of the brighter component of the mixture (Figure 3). For the first time we investigate the spectral range from NIR to MIR. Some of the most interesting results involved the slope trend of modification with dark material, in particular we observed an inversion between reddening and bluing depending on the percentage of the mixture and the grain size. Moreover, we investigated also the different behavior of several features such as: hydrated band at 2.7  $\mu\text{m}$ , the Reststrahlen band and Transparency feature.

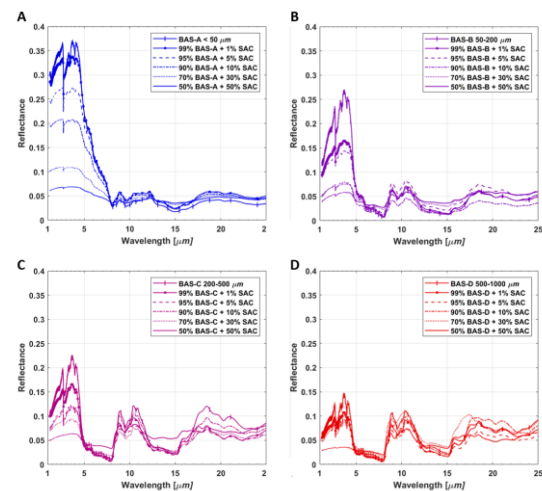
**Conclusion:** Improving our understanding on the spectroscopic changes induced by small variations in the mineral phases is pivotal to a good interpretation of remote sensing data collected on planetary surfaces by space missions. The dataset that we assembled with our experiments presented here and published in two papers will be an essential support in the interpretation of upcoming data from the JAXA Martian Moon eXploration mission, as well as in understanding of previous data from dark surfaces in the Solar System like asteroids (162173) Ryugu and (101955) Bennu.

Still a lot of laboratory work is needed to correctly support the remote sensing data analysis and several other mixtures and combinations will be investigated as follow up of this work. More laboratory measurements will allow, from one side, to increase the database for planetary surface interpretation and, on the other side, to provide reference spectra to improve and validate the actual and future models.

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**Figure 2.** Detail of hydrated band around 2.7  $\mu\text{m}$  for hydrated minerals serpentine (top panels) and montmorillonite (bottom panels) with grain size  $<10 \mu\text{m}$  mixed at 1 wt% (dotted blue line) and 5 wt% concentration (dash-dot red line) with: plagioclase bytownite (panels C, G) and iron sulfide pyrite (panels D, H). (Figure adapted from [4])



**Figure 3.** Infrared spectra of basaltic mixtures [BAS] at different grain sizes,  $<50$ , 50-200, 200-500 and 500-1000  $\mu\text{m}$ , with addition in different proportions, from 1 to 50%, with synthetic amorphous carbon [SAC] (Figure from [5]).

**References:** [1] Cloutis E. et al. (1990) *Icarus*, 84 (2), 315-333 [2] Hasegawa et al. (2022), *ApJ. Let-ter*, 939, L9 [3] Lugassi, R, et al. (2015), *Geoder-ma*, 213, 268-279 [4] Poggiali G. et al. 2023a, *Icarus*, 394, 115449 [5] Poggiali G. et al. 2023b, *A&A* (accepted)