

**EVIDENCES OF MIXING PROCESSES ON MARS BY STUDYING ISM DATA;**  
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Infrared reflectance spectra of a planetary surface contain important mineralogic and compositional information. Telescopic observations of Mars have been used effectively in the past (1,2), but spot sizes are limited to several hundred kilometers in diameter. The ISM instrument on the Phobos spacecraft provided high quality spectra between 0.76 and 3.16  $\mu\text{m}$  with pixel sizes of about 20  $\text{km}^2$  (3). Also the data were acquired in an imaging mode permitting the analysis of heterogeneities in surface composition. However, these pixels are mixtures of many different surface components and it is necessary to deconvolve the relative contributions of these components to address science issues. There are three main types of spectral mixing : linear, intimate (non-linear), and thin layer or surface coatings. Linear and intimate mixing approaches have been used effectively in geologic analyses (4,5) but depend on the existence of spectral libraries or ground truth measurements that match the remotely obtained data. An alternative method is presented here which expands on the methods presented in (5). Simple statistics are calculated from the spectral data which can be used to select spectral endmembers. These statistics can also be used to explore the nature of the spectral features which define the axes of variation.

In this analysis, we have focused on the 32 even channels between 0.76 and 1.51  $\mu\text{m}$ , but this approach can be easily generalized to any number of channels. The arithmetic mean ( $\underline{S}$ ), and the related standard deviation ( $\sigma$ ) are computed for each spectrum  $S(\lambda)$  which is then transformed into a residual spectrum  $R(\lambda)$ . All these quantities are defined by :

$$\underline{S} = \frac{1}{32} \sum_{\lambda=1}^{32} S(\lambda) ; \quad \sigma = \frac{1}{32} \sqrt{\sum_{\lambda=1}^{32} [S(\lambda) - \underline{S}]^2} = \frac{1}{32} \sqrt{\sum_{\lambda=1}^{32} [R(\lambda)]^2} ; \quad R(\lambda) = S(\lambda) - \underline{S}$$

All spectra are plotted in a ( $\sigma, \underline{S}$ ) diagram (about 3500 per image). In figure 1 is represented such a diagram for the Syrtis-Isidis image. The first and important observation is that the points are not randomly scattered, but define domains that are very strongly correlated with the geological areas defined from the Viking images (5). In addition, the cloud of points define trends that are more or less linear. From these trends, we can derive endmembers and their spectra.

Assuming that each pixel is composed of two endmembers A and B (A and B can be rocks ore mineral), and that the spectrum is a linear combination of endmember spectra  $S_A$  and  $S_B$ , then the observed spectrum is :  $S_X(\lambda) = x \cdot S_A(\lambda) + (1-x) \cdot S_B(\lambda)$ . For each spectrum  $S_X$  we calculate  $\underline{S}_X$  and  $\sigma_X$ . If all the corresponding points are represented in a diagram ( $\sigma, \underline{S}$ ), the curve is given parametrically by the system :

$$\underline{S}_X = x \cdot \underline{S}_A + (1-x) \cdot \underline{S}_B$$

$$\sigma_X = \sqrt{x^2 \cdot (\sigma_A^2 + \sigma_B^2 - 2 \cdot \sum_{\lambda=1}^{32} R_A(\lambda) \cdot R_B(\lambda)) + 2 \cdot x \cdot (\sum_{\lambda=1}^{32} R_A(\lambda) \cdot R_B(\lambda) - \sigma_B^2) + \sigma_B^2}$$

This method has been applied for binary mixtures of olivine, anorthite, magnetite, and enstatite (Fig 2A). All spectra were recorded using the RELAB facilities (6). Although the previous equations do not define a straight line (7), the trend is almost linear for the En-An, Ol-En, and Ol-An mixtures. However, the Ol-Mg trend approximates a parabolic curve. These trends can be linearized by plotting the residual at a given wavelength against the mean  $\underline{S}$  (Figure 2B). For remotely acquired data, it is unlikely that any pure endmember will be measured. However, the spectral properties of the endmembers can be predicted by extrapolating linear trends in the ( $R, \underline{S}$ )

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plots and converting back to reflectance. This is one of the most powerful applications of this new approach.

The mixing approach is applied to the Syrtis Major-Isidis window obtained by the ISM instrument (3). We can define two linear trends for Syrtis Major (A, B) and four for Isidis and the cratered highlands (C, D, E, F). We defined two different lines A and B since A points on Eastern Syrtis have larger standard deviations than those on Western Syrtis. This might be due to the difference in topographic slope between these two areas. When extrapolating the residuals to lower values of ( $S$ ), the residual spectrum presents similarities with spectra of ultramafic rocks. When the extrapolation is done to higher ( $S$ ) values, the residual spectrum corresponds to a straight line with a slope that could be due to a coating effect or the presence of atmospheric dust. The western part (beginning of Arabia) of the image has residuals that look similar to those on the cratered highlands, suggesting a very close mineralogy. The further from the central part of Isidis, the larger the standard deviation, suggesting that the influence of Isidis dust becomes smaller. The mixing lines E and F correspond to the substratum of Isidis fossae whose mineralogy seems to differ from that of the surrounding cratered highlands. The study of Viking frames suggest a volcanic substratum.

**References :** (1) Mc Cord, T.B. et al, J. Geophys. Res., 87, 3021-3032, 1982. (2) Singer, R.B., et al, Proceedings of the 10th LPSC, 1835-1848, 1980. (3) Bibring, J-P., et al, Proceedings of the 20th LPSC, 461-471, 1990. (4) Adams, J.B. et al, J. Geophys. Res., 91, 8098-8112, 1986. (5) Erard, S. et al, Proceedings of the 21th Lunar and Planetary Science Conference, 1991. (6) Mustard, J.F., and C.M. Pieters, Proceedings of the 17th LPSC, 1987. (7) Singer, R.B., J. Geophys. Res., 86, 7967-7982, 1981.

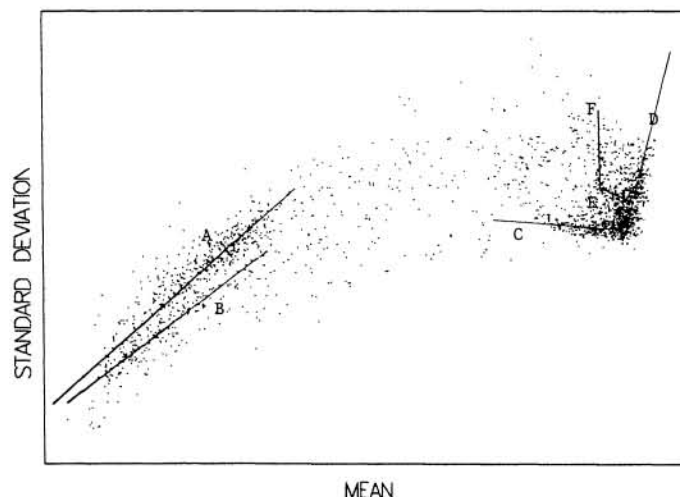


Fig 1 : Standard deviation against arithmetic mean of the 3500 spectra of Syrtis-Isidis window on Mars. Low and high values of the mean correspond to pixels in Syrtis Major, and in Isidis Planitia and cratered highlands, respectively. Lines A, B, C, D, E, and F are linear trends (see text for more details)

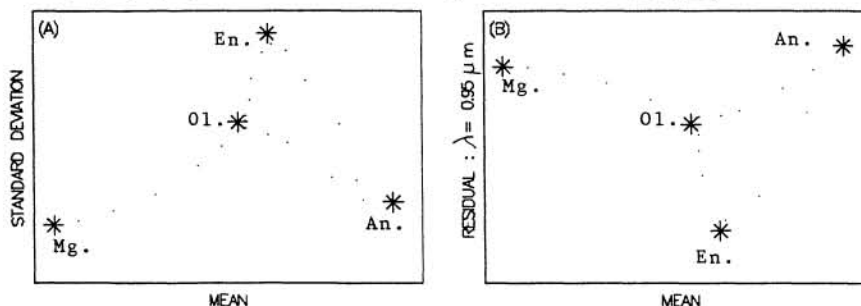


Fig 2 : A- Same type of plot than that of Fig 1 for spectra recorded in a laboratory. Asterix are pure endmembers (Olivine, Anorthite, Magnetite, Enstatite) and dots are binary mixtures between these endmembers. B- Residual at  $\lambda = 0.95 \mu\text{m}$  is plotted against the mean. This plot provides more linear trends between pure endmembers