Candidate source regions for SNC Meteorites on Mars.

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Introduction: Martian meteorites are the only samples of Mars that we have. However, their exact source region at the Martian surface is still unknown, which prevents fully exploiting information they give us about the composition and evolution of the surface and mantle of Mars. Several studies have tried to identify the source region of these meteorites using their age as well as our understanding of the dynamics of impacts to constrain geologically and chronologically appropriate regions and/or Martian craters [e.g. 1,2,3]. Alternatively, [4] tried to identify some possible source regions of Martian meteorites by comparing their spectral properties with those of the Martian surface in the thermal infrared using TES data. The present study proposes a similar approach, but based on near-infrared data from the hyperspectral imaging spectrometer MEx/OMEGA. This dataset provides global coverage of the Martian surface at a km-scale resolution making possible the identification and mapping at a global scale of regions with spectral properties similar to Martian meteorites. Without the ambition to find the exact source region of Martian meteorites, this study can give us hints about the types of geological settings in which rocks similar to the martian meteorites could have formed, as well as their apparent age and their representativeness which are still debated topics [5, 6].

Method: This analysis is based on 11 martian meteorite spectra extracted from [7,8,9] and presented in Figure 1: four spectra of basaltic shergottites (Los Angeles, Shergotty and NWA6963 (enriched in REE elements) and QUE94201 (depleted)), four spectra of olivine phyric shergottites (NWA1068 (enriched), NWA6234 (intermediate) and NWA2626 and Tissint (depleted), two spectra of lherzolitic shergottite (ALH77005 and NWA7397), one of Nakhlite (Nakhla), one of Chassignite (Chassigny) and one of the orthopyroxenite ALH84001. These meteorite spectra are fitted to each OMEGA C-channel (1.0–2.5 µm) spectrum exhibiting pyroxene and olivine signatures, over the full dataset (7700 data-cubes), following the method described in [9, 10]. The quality of the fit is evaluated using an RMS value calculated between 1 and 2.5 µm for each OMEGA pixel. Given the SNR of OMEGA spectra, the fit can be considered as nearly satisfactory for RMS values lower than 0.2% [11]. Larger values are not considered in this study. Moreover, since RMS values are affected by many factors, an additional visual inspection is performed for each meteorite to select satisfactory fits.

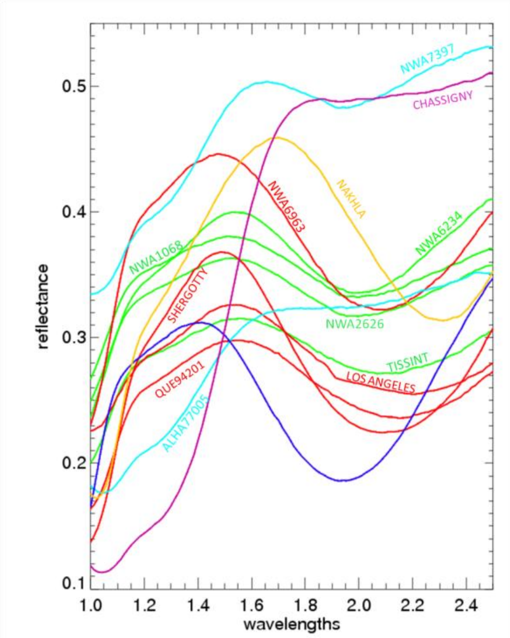

Figure 1. *Spectra of studied Martian meteorites. Their sources are from [7,8,9].*

Results: Analyses of RMS global maps have shown that shergottites have NIR spectral characteristics that are the most representative of the Martian surface (Figure 2). Conversely, all other studied Martian meteorites (Nakhla, ALH84001 and Chassigny) have spectral properties that seem less common in the OMEGA measurements of the Martian surface. A few acceptable fits are found for the Nakhla meteorite associated with olivine-enriched units, which is in agreement with Nakhla composition (15% olivine). However, the OMEGA spectra are noisy, leading to relatively high RMS values compared to other meteorites (> 0.0012). The absence of convincing spectral analogue of the Nakhla meteorite in the observable part of the Martian surface suggest that the Nakhla spectral properties (olivine and HCP) could be representative of those of the Amazonian terrains buried under dust, which is in agreement with its Amazonian age (1.3 Ga). Spectral signatures similar to those of ALH84001 are found in tens of localized spots (Figure 2). Most of them are small (a few tens of OMEGA pixels) and mainly associated with crater rims or small outcrops, but spectral matches are found over large areas within the North of Hellas and in northeast Syrtis Major. All these regions were previously identified as Noachian LCP-enriched terrains [12], which is in good agreement with the Noachian age of this meterorite (4.1 Ga [6]) and its low-calcium pyroxene-rich composition (Figure 1).

The spectral properties of Chassigny are dominated by the strong 1 µm absorption band of the olivine (Figure 1) and satisfactory fits are not surprisingly observed in the region of Nili Fossae, well known to exhibit the strongest olivine signatures on Mars. Other satisfactory fits are found in large crater ejecta of the northern plains and in outcrops around Argyre and Hellas basins. These olivine-bearing units were interpreted to be early Noachian or primitive material in [13] which is not consistent with the estimated Amazonian age (1.3Ga) of Chassigny [6,14]. An alternative hypothesis would be that the chassigny-like olivine-bearing material found on large crater ejecta was excavated from Amazonian-aged deep cumulate.

Figure 2 shows the distribution of satisfactory fits obtained with the shergottites spectra. All fits are observed in old terrains of the southern highlands. Best fits ($\chi^2<0.0011$) are obtained for the basaltic shergottites in the three Hesperian volcanic provinces of Syrtis Major, Hesperia Planum and Thaumasia Planum (Figure 2). Some acceptable fits are found in these regions for the olivine-phyric shergottites but they are isolated and it is thus difficult to draw conclusions about their representativness. Best fits for olivine-phyric shergottites are found in Terra Tyrrhena, and to a lesser extent in Terra Cimmeria and in the northern Argyre rim associated with previously detected olivine signatures [13]. In the region of Terra Tyrrhena good fits are associated with early-Hesperian olivine-bearing unit (plains and crater floors [13]), and are mainly found in the edge of the unit where the olivine signature is weaker. Basaltic shergottites show also good fits in this region but are likely associated with the adjacent olivine-poor Noachian terrains rather than with the olivine-enriched unit. The lherzolitic shergottite NWA7397 spectrum is also well fitted in this region associated with stronger olivine signatures, but not with the spectrum of ALHA77005. Good fits for these two lherzolitic shergottites are also found in other olivine-bearing Noachian to early Hesperian terrains like Nili Fossae, the Nili Patera caldera, some craters dunes or ejecta in the northern plains, and in the Argyre and Hellas rims.

These results shows that the diversity of spectral signatures found in the old southern highlands of the Martian surface, including Noachian to early-Hesperian terrains, is well representative of that observed in reflectance spectra of shergottite Martian meteorites. In contrast, the spectral properties of the Amazonian Nakhla meteorite differs significantly from those of old terrains and could be typical of Amazonian-aged terrains. Based on these results, NIR spectroscopic observations are more consistent with an old age (>4 Ga, [6]) for the shergottite meteorites rather than a young age [14]. However, we cannot exclude that the Amazonian terrains composition was more diversified and include some shergottite-like compositions buried under dust.

References: [1] Mouginis-Mark et al .,(1992), *JGR*, 97:10213–10225. [2] Treiman (1995), *JGR*, 100:5329–5340. [3] Barlow (1997), *LPSC 28*. [4] Hamilton et al., (2003), *Meteor. & Planet. Sc. 38*, Nr 6, 871-885. [5] McSween et al., (2009), *Science*, 324, 5928. [6] Bouvier et al., (2009), *Earth and Planet. Sc. Lett.*, 280, 285-295. [7] McFadden and Cline, (2005), *Meteor. & Planet. Sc.*, 40,151. [8] RELAB spectra, QUE94201 (DD-MDD-024/C1DD24) and ALHA77005 (DD-MDD-026/C1CC26). [9] Ody et al., (2014), LPSC 45. [10] Ody et al., (2013), LPSC 44. [11] Poulet et al., (2009), Icarus 201 84–101. [12] Poulet et al., (2009), *LPSC 40* [13] Ody et al., (2013), *JGR*, 118, 1–29. [14] Nyquist et al., (2001), *Chronology and Evolution of Mars*, Kluwer, Dordrecht, pp. 105–164.

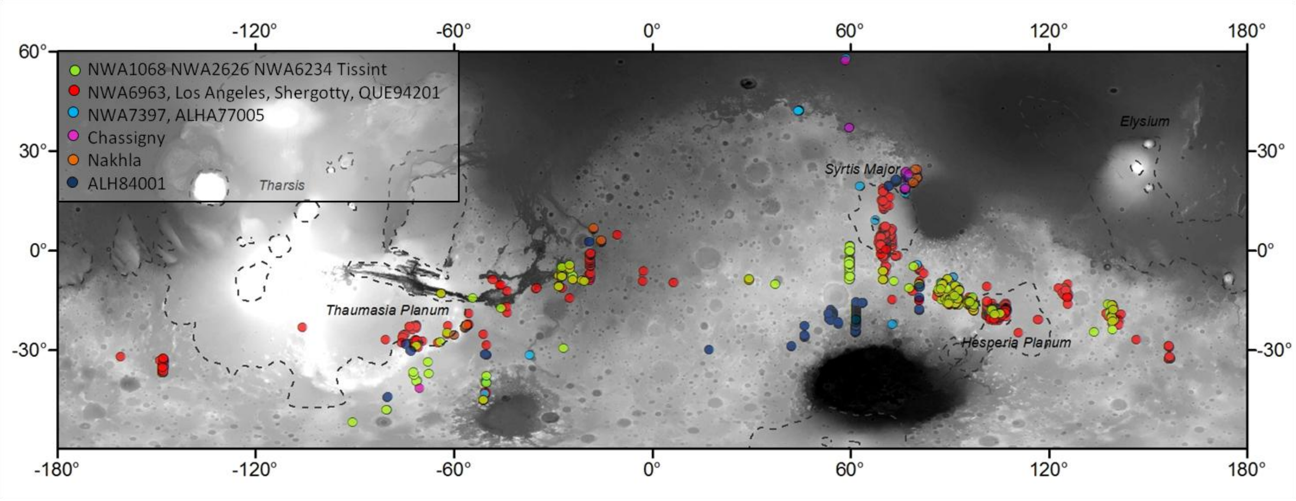

Figure 2. *Global map of satisfactory fits for all studied Martian meteorites including basaltic shergottites in red, olivine phyric shergottites in green, lherzolitic shergottites in light blue, Chassigny in pink, Nakhla in orange and ALH84001 in dark blue.*