EPSC Abstracts
Vol. 6, EPSC-DPS2011-390, 2011
EPSC-DPS Joint Meeting 2011

Determining the modal mineralogy and the chemical composition of planetary surfaces from near-infrared spectroscopy: example of basaltic regions of Mars

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Abstract

Although Near-InfraRed (NIR) spectroscopy has been extensively used in chemistry and physics for many decades, this technique has been applied to the qualitative and quantitative analysis of planetary surfaces only relatively recently. Deconvolving a NIR reflectance spectrum to mineral abundance in an unambiguous way is indeed difficult, because the spectra are complex nonlinear functions of several parameters such as grain size, abundance, and material opacity. Multiple scattering theories using optical constants of minerals can provide approximate solutions to the radiative transfer in a compact medium. The modal mineralogy of a dozen of basaltic regions of Mars is obtained by modeling the OMEGA/MEx NIR reflectance spectra with the Shkuratov radiative transfer model. Modal mineralogies are then converted to bulk chemistries by combining the chemistries of the spectral library end-members used in the best fit in proportion to their modeled abundances. In doing so, a quantitative comparison of the OMEGA-derived chemical composition with chemistries measured in situ, in Martian meteorites and by remote observations is presented and the implications for igneous trends are discussed.

1. Methodology

Modeling of NIR laboratory spectra has been demonstrated to provide an accurate estimate of mineral abundances for basaltic mixtures of granular materials of a wide range of particle sizes [1]. Based on the Shkuratov radiative transfer theory, this modeling technique uses a selected set of optical constants for reproducing spectra of simple and complex laboratory mixtures of mafic minerals as well as powdered and bulk samples of natural basalts. By applying this modeling technique, OMEGA/MEx reflectance spectra are used to derive the modal mineralogy of diverse martian basaltic regions and to identify spatial trends in mineralogical assemblages. Volumetric abundances of each identified phase are converted to weight percent by dividing by the density associated with that phase and normalizing fractions to 100%. Wt % oxides for each phase are multiplied by the modelled weight fraction of that phase and combined to produce the average derived "whole rock" chemistry for each studied region.

2. Results

2.1 Modal mineralogy

The composition of the basaltic studied regions are pretty homogenous: plagioclase (40-60% in Vol.) and high calcium pyroxene (20-40%, HCP) are the dominant minerals, low calcium pyroxene (10-15%, LCP) and minor amounts of olivine are also present. This composition corresponds to evolved basalts rather than ultramafic basalts. Of special interest is the detection of rather strong signatures of LCP and olivine found in localized areas. The LCP outcrops in the ancient cratered terrains have been interpreted to be possible remnants of the early crustal formation. The olivine-bearing terrains are dominated by olivine (40%) plus a certain amount of plagioclase and HCP. They are classified as olivine-bearing basalts and Gusev basalts are good analogues of these terrains. Finally, it is also important to mention that no pyroxene cumulate and no highly anorthositic (Al_2O_3-rich) terrain have been identified at the OMEGA spatial resolution.

It was possible to study the variation of the modal composition of mafic regions with age. Although most of the terrains analyzed are late Noachian and early Hesperian, a few terrains interpreted to be early Noachian terrains and young Amazonian lava flows were also studied. One of the major observations is a decrease of the LCP/HCP ratio from early Noachian-aged outcrops to Amazonian-aged lava flows. This may be indicative of decreasing degree of partial melting as thermal flux decreases with time.

The link between the martian volcanism as seen by OMEGA and Martian meteorites was also investigated. The compositions of basaltic shergottites are more consistent with the composition of the early Noachian-aged outcrops than the compositions of the Amazonian terrains. Shergottites ages of approximately 4.0 Gy determined by [2] could be a good alternative explanation.

2.2 Chemical composition

The igneous chemical composition of the martian crust has been examined through SNC meteorites, remotely sensed data (TES and GRS data), and in situ observations by landers and rovers (see [3] for a review). Some results are consistent with the main conclusions of this review:

- Silica content in weight percent is in the [45,50] interval, which is significantly smaller than the TES-derived content; conversely, these value are in good agreement with the different datasets used in their analysis (Fig. 1A). As stated in [4], this is in favor of a dry basaltic magmatism rather than hydrous melting as suggested by the TES observations.
- The iron content is poorly constrained, but the modelings indicate that the OMEGA average FeO*/MgO ratio is likewise tholeiitic as well (Fig. 1B).
- The Mg/Si (0.22-0.32) ratio closely agrees with the average Mg/Si ratio for Gusev rocks and soils (0.27+/-0.10).
- The Al content is dependent on the composition of the plagioclase used in the OMEGA data modeling. However, the OMEGA-derived Al/Si ratio partly overlaps with those of Gusev samples. Therefore, the OMEGA data also support the higher Al/Si ratio for Mars.

3. Conclusion

The Shkuratov-based spectral model successfully reproduces the NIR OMEGA spectra extracted from various basaltic regions of Mars. The method of analysis presented here allows providing estimates of the modal mineralogy and the chemical composition of these igneous terrains. However, it is important to keep in mind that subtle outcomes exist. The precise identification of HCP (augite versus diopside for instance) cannot be derived uniquely from the method as demonstrated in [5]. The presence of almost NIR neutral components is identified and their abundance quantified, but their specific characterization (e.g., plagioclase) cannot be assessed unambiguously: they could as well be constituted of primary volcanic glass, amorphous silica coatings, and/or poorly crystalline material in weathering rinds. These caveats reinforce the need to use different wavelength regions measured by different instruments, in order to provide complimentary information about the surface composition of any planetary surface.

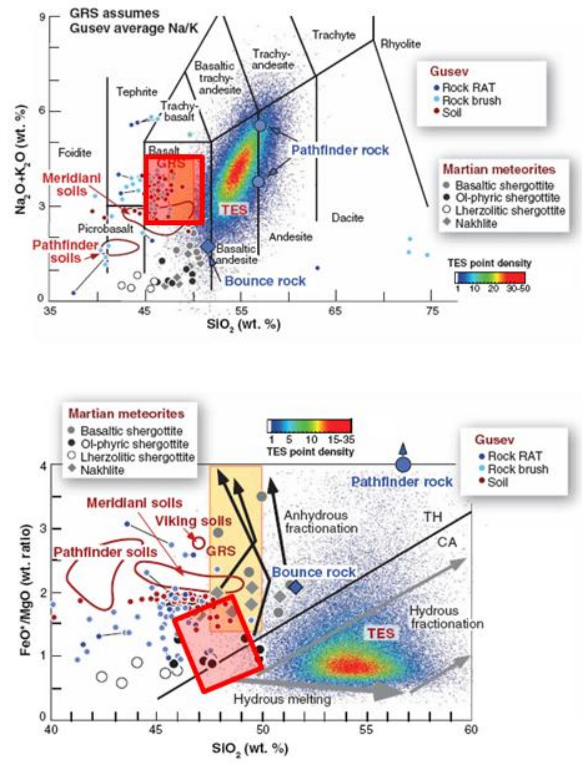

Figure 1. (A) OMEGA data (red box) on the total alkalis-silica diagram used for classification of volcanic rocks shown in [1]. The average Na_2O/K_2O weight ratio for GRS data was assumed. (B) FeO*/MgO vs. SiO_2 diagram with addition of the OMEGA box.

References

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