The petrological expression of the thermal evolution of Mars

D. Baratoux[1], M. Toplis[1], M. Monneau[1]

[1]University Paul Sabatier, Toulouse – Observatory Midi-Pyrénées, Institut de Recherche en Astrophysique et Planétologie (IRAP), UMR CNRS 5277

Reconstruction of the geological history of Mars has been the focus of considerable attention, with important discoveries being made concerning variations in surface conditions. On the other hand, despite a significant increase in the amount of data related to the morphology, mineralogy and chemistry of the Martian surface, there was no clear global picture of how magmatism has evolved over time and how these changes relate to the thermal evolution of the planet. With this in mind we have used Silica, Iron, and Thorium global maps from the data Gamma Ray Spectrometer (GRS) onboard the Mars Odyssey spacecraft, focusing on 12 major volcanic provinces of variable age. This analysis reveals trends in chemical composition which are consistent with varying degrees of melting of the Martian mantle. In detail, there is evidence for thickening of the lithosphere (17–25 km/Gy) associated with a decrease of mantle potential temperature over time (30–40 K/Gy) [1]. This thermal scenario for the mantle of Mars may be now used to predict the composition of primary melts as a function of time. Then, the characteristics of mineralogical assemblages after crystallization of these primary melts may be calculated and directly compared to the variable proportions and compositions of pyroxene, olivine and plagioclase in igneous rocks as revealed by spectroscopic observations. In particular, a trend in the composition of pyroxene was revealed by OMEGA (Mars Express) and CRISM (Mars Reconnaissance Orbiter) data. This trend is characterized by a decrease of the ratio between low-calcium-pyroxene and rich-calcium pyroxene end-members at the Noachian/Hesperian boundary (3.7 Gy ago). Our thermodynamic calculations indicate that this change results from a higher degree of partial melting in the Noachian associated with a hotter mantle and/or a higher geothermal gradient. The thermal scenario inferred from GRS data [1] may be thus extended back to early Mars. This study of the igneous mineralogy and alterations phases of rocks and soils formed during this period of time is a major objective of the Mars Science Laboratory mission launched in November 2011. We thus hope to provide useful constrains (such as a range of possible geothermal gradients) to discuss the surface and sub-surface conditions at the landing site (Gale crater).

Taken together, these petrologic analyses are consistent with simple models of mantle convection and with the reconstruction of the thermal evolution of the mantle from paleo-heat flows inferred from the evolving elastic thickness of the lithosphere. They also argue for the existence of a period of active volcanism in the Noachian, which had participated to a large extent to the construction of the crust after the crystallization of a magma ocean. This scenario provides also non-geochronological arguments to the debate surrounding the age of a group of martian meteorite, and supports an old age for the basaltic shergottites.

[1] Baratoux, D., Toplis, M., Monnereau, M., Gasnault, O. Thermal history of Mars inferred from orbital geochemistry of volcanic provinces, Nature, doi:10.1038/nature09903 (2011).