Martian volcanic rocks: a signature of planetary evolution

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The recent accumulation of mineralogical, chemical and morphological observations of the surface of Mars allows us to take a fresh look at the evolution of magmatism and volcanism through the ages. There are three types of volcanic landforms on Mars. (1) Low and large shield volcanoes are found in the southern hemisphere (e.g., Syrtis Major, Tyrrhena Patera). In the northern hemisphere, typical shield volcanoes (2) are characterized by elevations above the plain up to 20-30 km, and are considered to be a different class of volcanic landforms. The third kind of volcanic provinces is typical of plains volcanism with long lava flows and clusters of small shield volcanoes analogous to the terrestrial situation at the Snake river plain. The elementary composition of these volcanic landforms has been recently documented from GRS (Mars Odyssey). We will show here that the chemical composition of volcanic landforms evolves with time. These compositions have been compared to the primary liquids that can be derived from the primitive mantle of Mars using Pmelt for the thermodynamic modeling of liquid and solid phases equilibriums. The decrease of Si abundance with time in the Martian volcanic rocks is interpreted as a progressive deepening of the source of the magma and a decrease of the degree of partial melting, a case consistent with the progressive cooling of the planet.

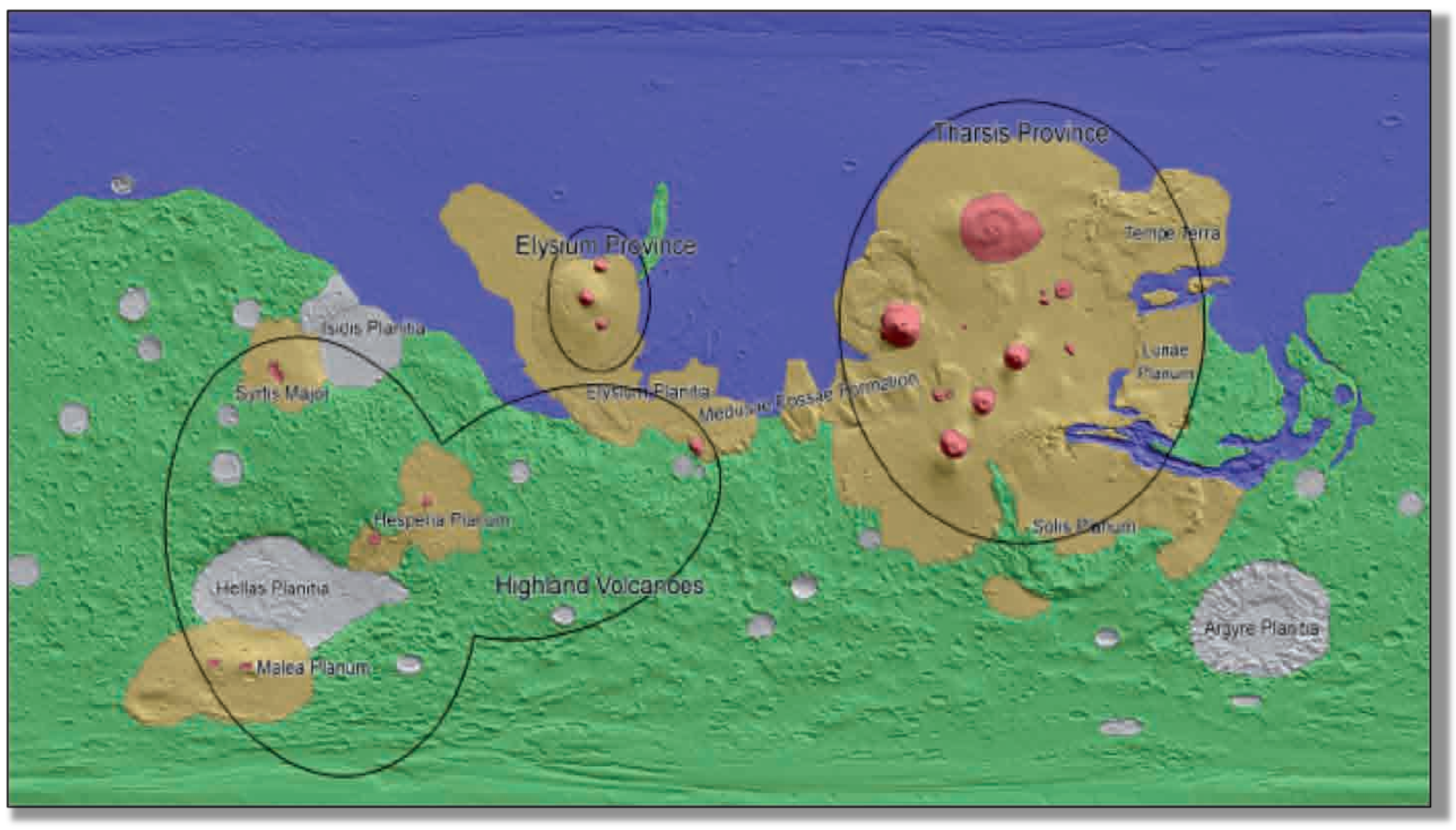

Fig. 2. Map of the main volcanic provinces on Mars (Werner, 2007)

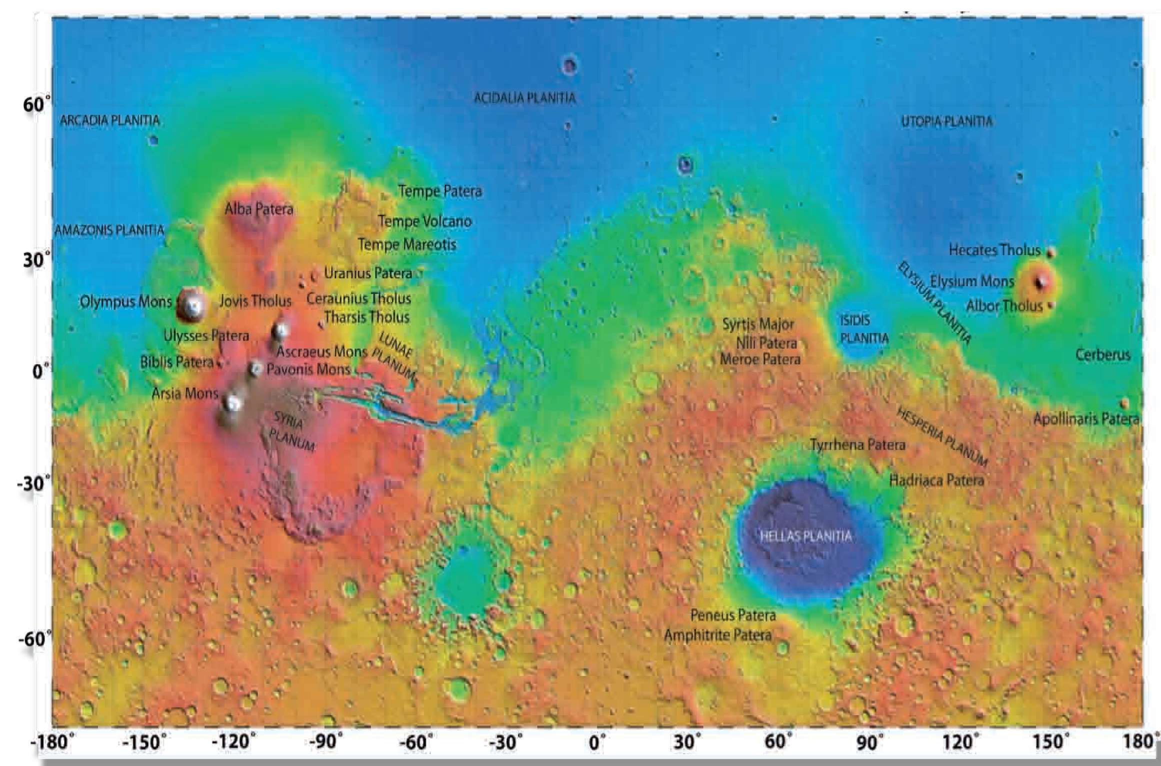

Fig.1. Martian topography - low shield volcanoes at the southern hemisphere, giant shield volcanoes at the northen hemisphere

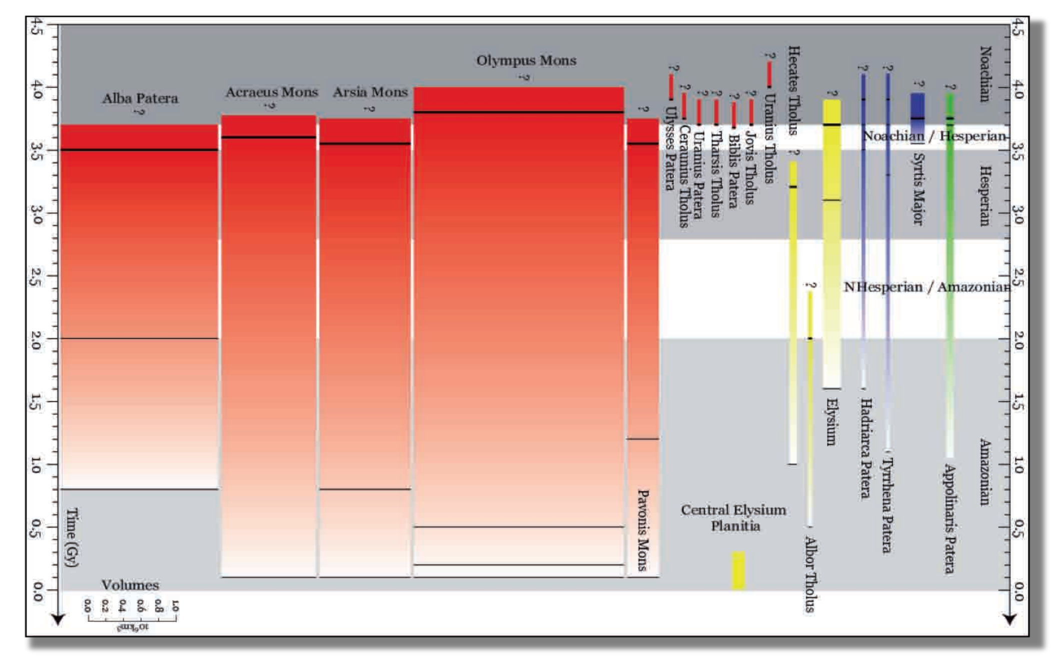

Fig. 3. Mars volcanic history (Vaucher et al., 2009)

Maps of abundances of SiO2, FeO and Thorium

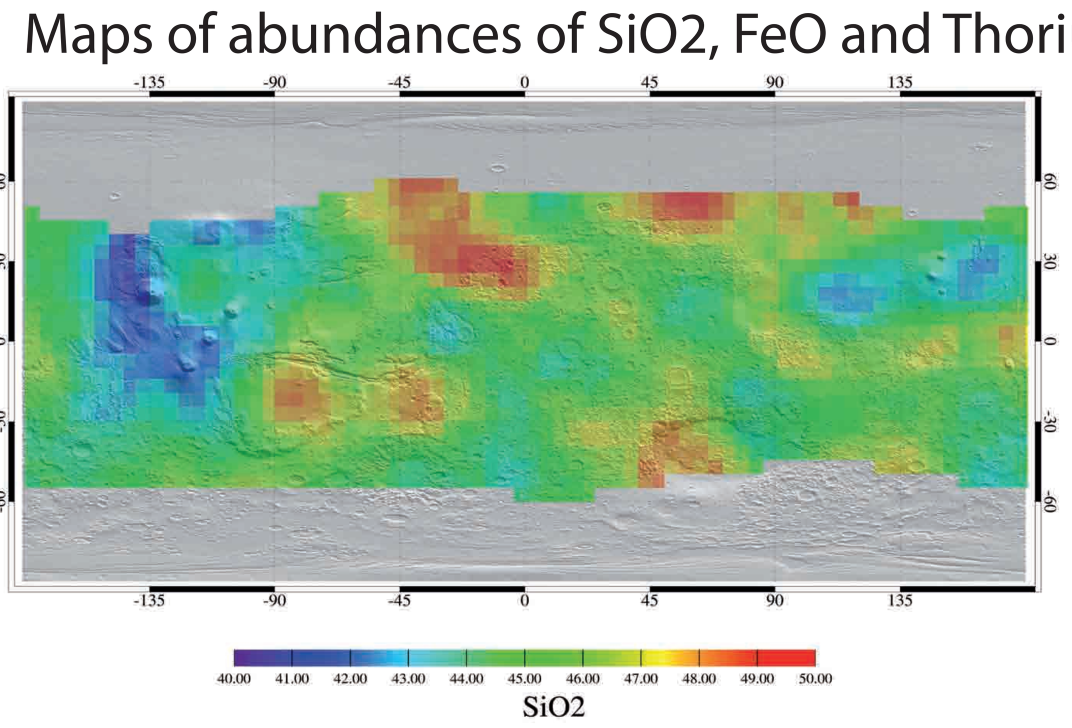

Fig. 4. Map of SiO2 abundance (water-free normalized). Adapted from Boynton, 2007.

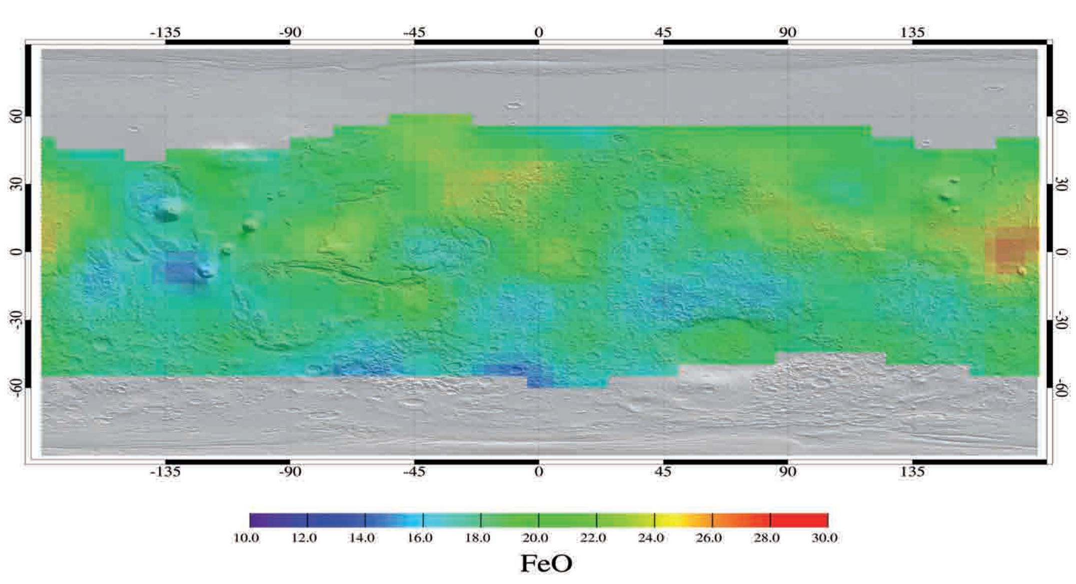

Fig. 5. Map of FeO abundance (water-free normalized). Adapted from Boynton, 2007.

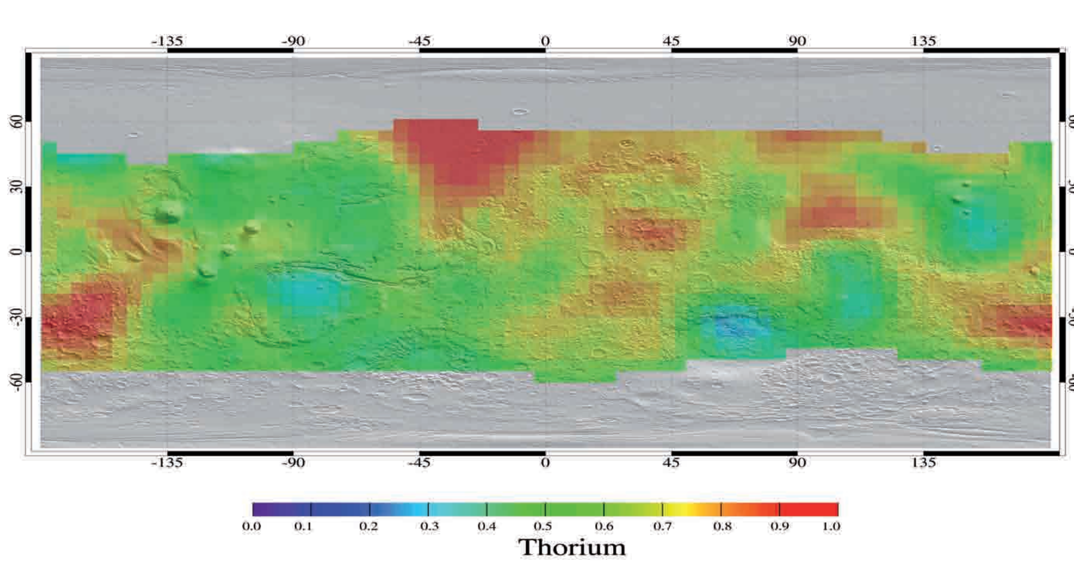

Fig. 6. Map of Th abundance (water-free normalized). Adapted from Boynton, 2007.

Modeling the composition of volcanic rocks on Mars

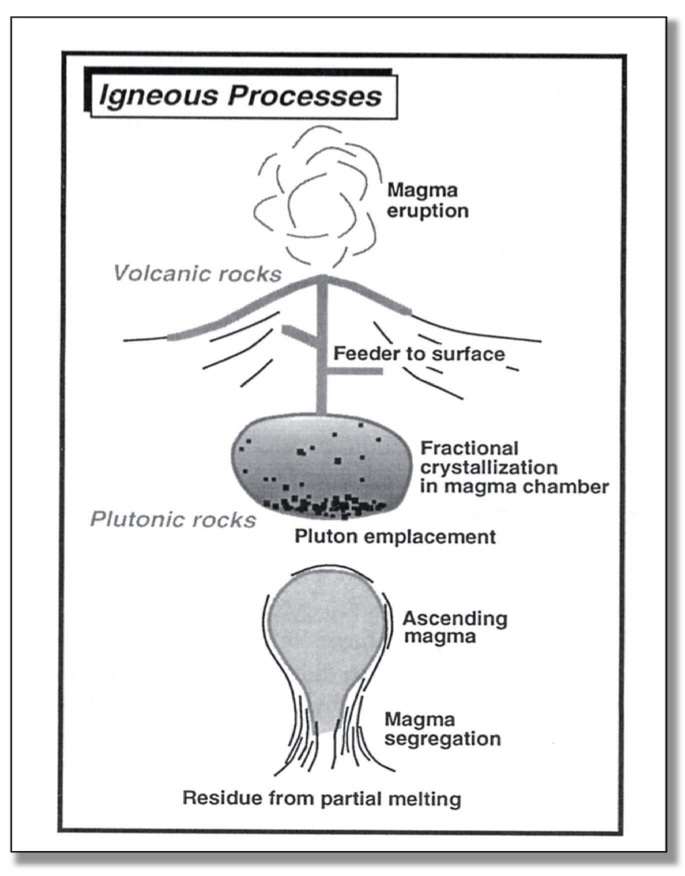

Fig. 7. From partial melting to volcanic eruptions. Basic concepts for the modeling of martian volcanic rocks.

Primitive martian mantle composition (Dreibus and Wanke, 1985). → Thermodynamical modeling Pmelt - Ghiorso et al. (2002) Pressure Degree of partial melting or temperature → Primary melt composition

Composition of martian primitive mantle (Dreibus and Wanke,1985)

SiO_2 : 44.39 %	Al_2O_3 : 3.02 %	Cr_2O_3 : 0.76 %
FeO : 17.9 %	K_2O : 0.03 %	MnO : 0.46 %
MgO : 30.19 %	Na_2O : 0.50 %	P_2O_5 : 0.16 %
Ca0 : 2.45 %	TiO2 : 0.14 %	

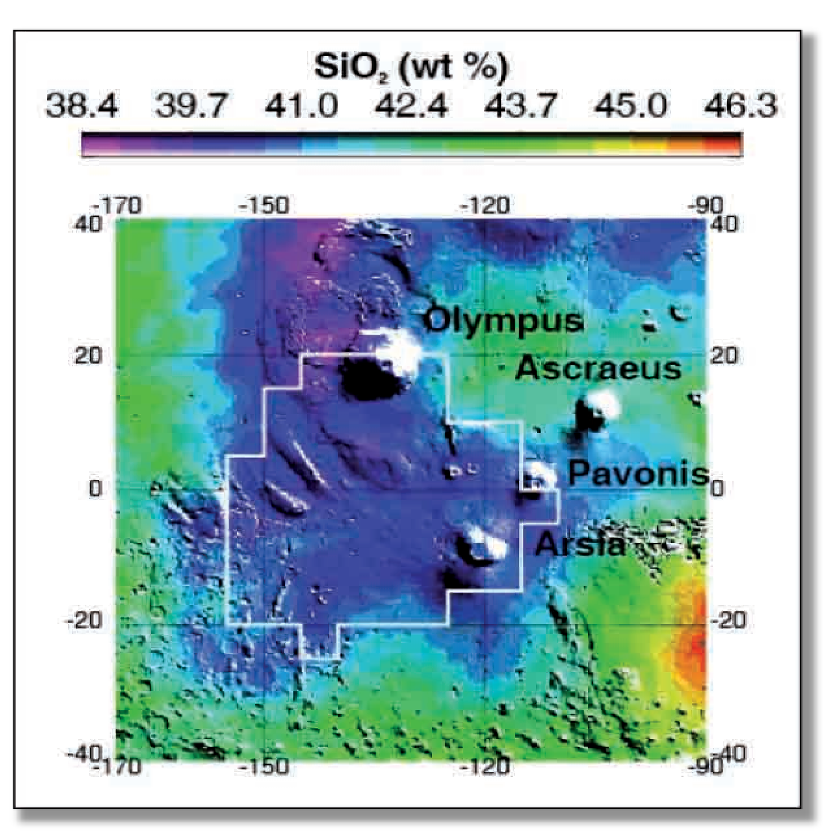

Fig. 8. Tharsis province - The idea place to begin with. A large and recent volcanic province homogeneous in composition.

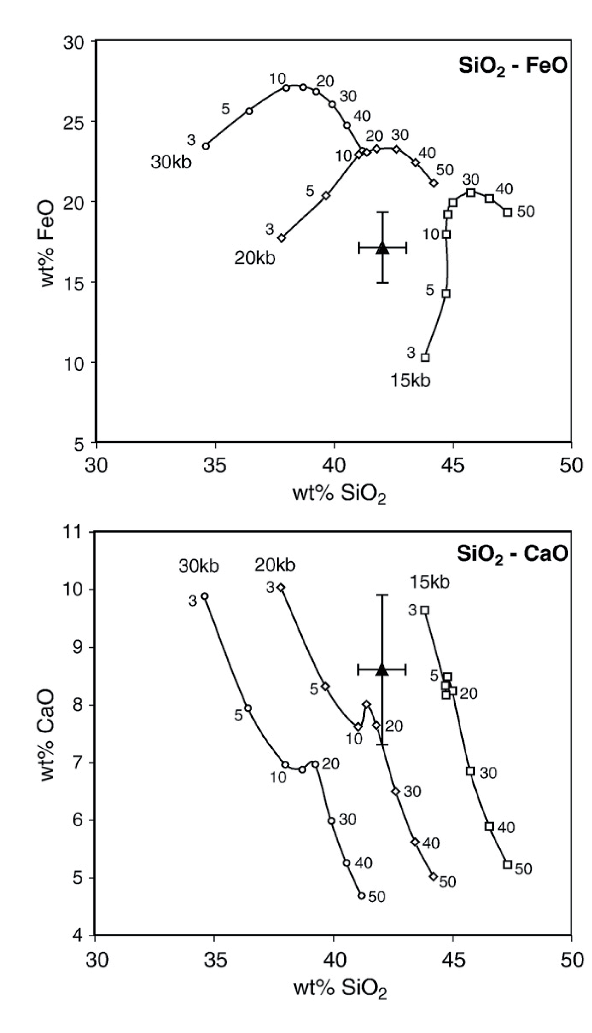

Fig. 9. (El Maary et al. 2009) Comparison with GRS data leads to several important conclusions:

1) Composition at Tharsis can be interpreted as primitive liquids
2) Degree of partial melting is about 5%
3) Pressure of the source of the magma is about 15 - 20 kbars (depth about 200 km). This is consistent with independant estimates of the lithosphere thickness at the time of the formation of the Tharsis dome (Mc Govern et al., 2002).

It is time to look at other volcanic provinces !

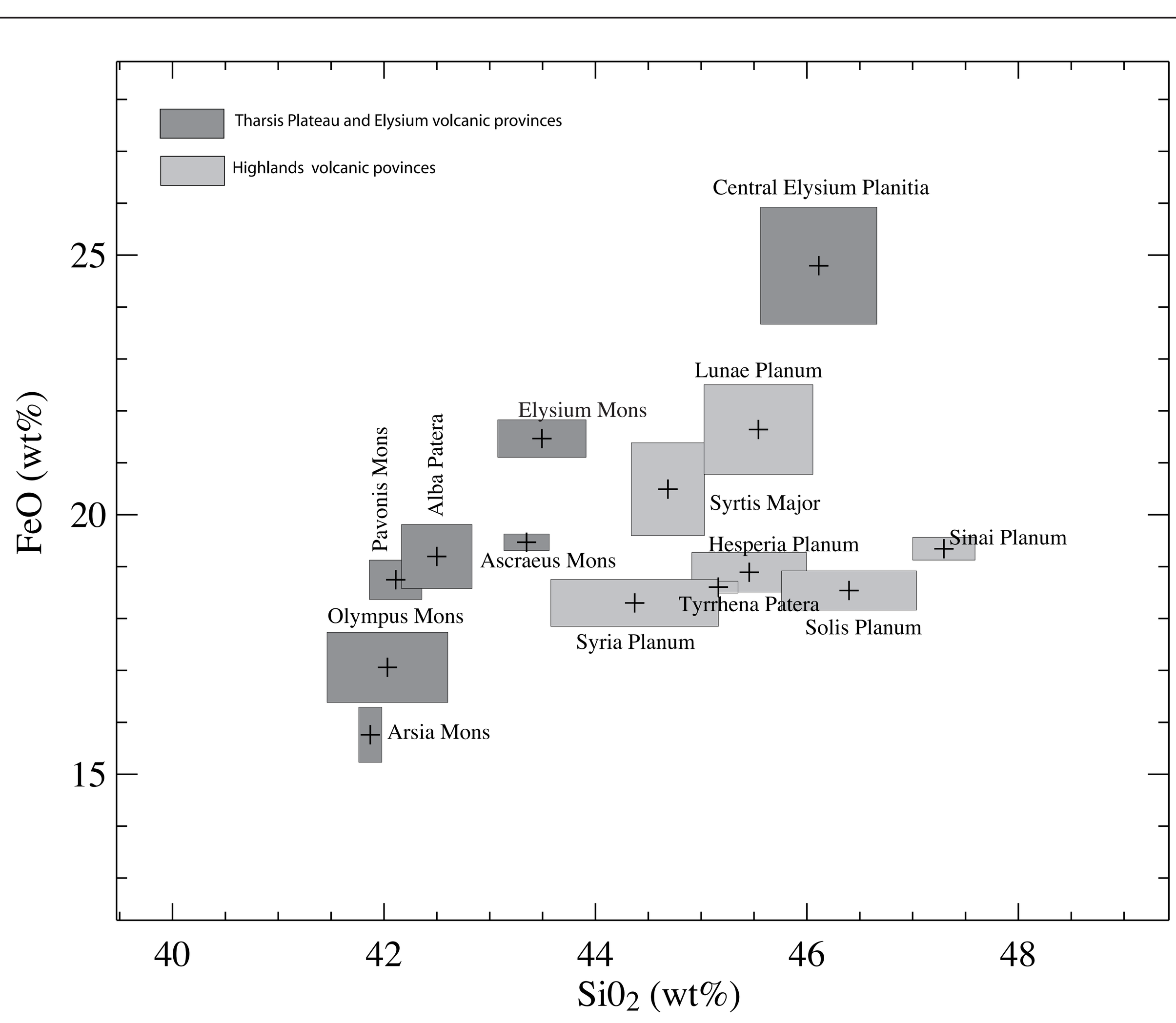

Fig. 10. Abundance of SiO_2 (wt%) versus abundance of FeO (wt%) for each martian volcanic province. Note the decrease the correlation between the Si abundance and the ages of the volcanic provinces.

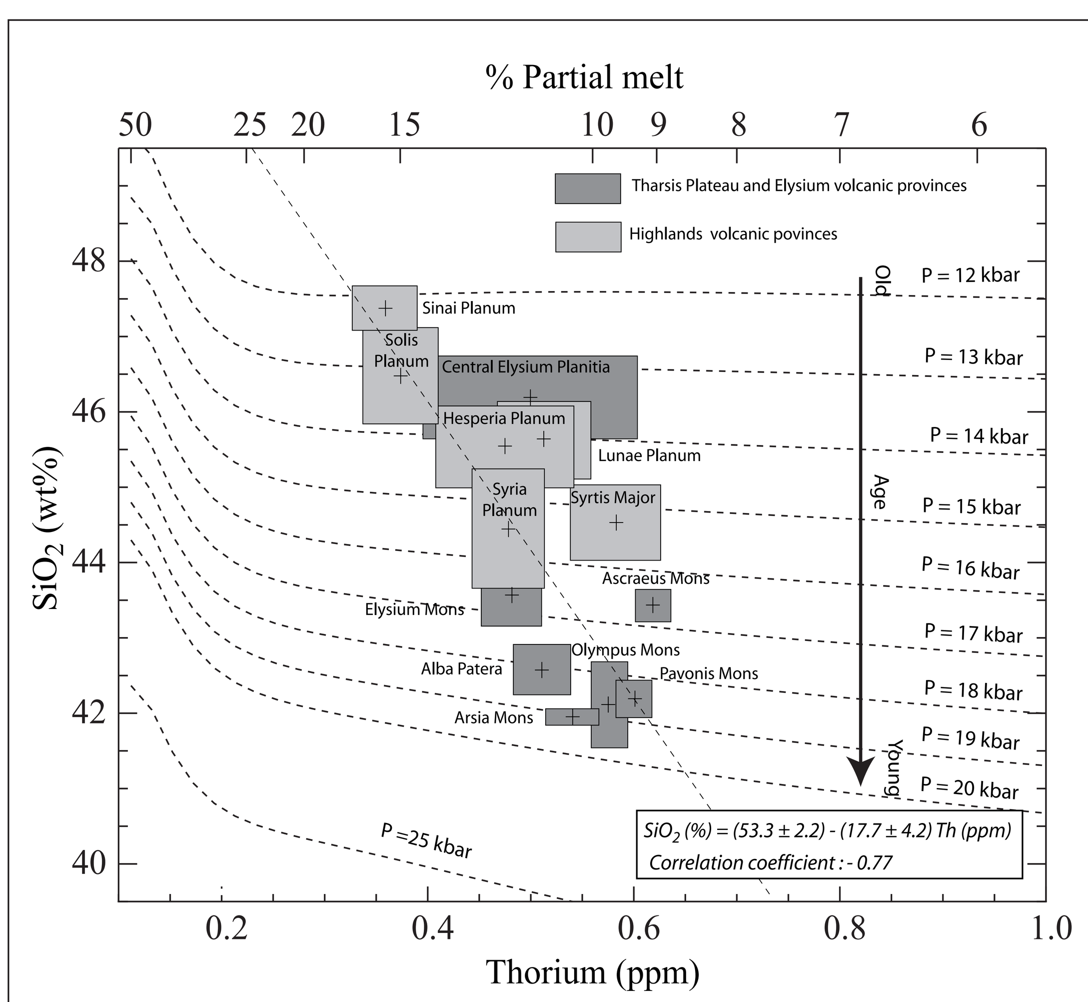

Fig. 11. Abundance of SiO_2 (wt%) versusThorium abundance (with corresponding degree of partial melting on the top x axis), with pressures of source zone overplot.

Conclusions

- Average composition of martian volcanic provinces can be interpreted as signatures of primary melts of the mantle composition given by Dreibus and Wanke (1985) (Mg# 75).
- The low content in SiO2 of martian volcanic rocks is explained by the higer FeO content of the martian mantle compared to the terrestrial one.
- There is a correlation between the age of the volcanic province and its SiO2 content.
- This correlation can be explained by a deepening of the source of the magma which is interpreted as the result of the planetary cooling.
- Other investigations related to this work...
Interpretation of Fe concentration, effect of fractional crystallization, derivation of mantle temperature, investgation on possible effects of mantle depletion (depletion in Thorium, change in Mg#, etc...).

More information about this work in

El Maarry, M. R. et al. Gamma-ray constraints on the chemical composition of the martian surface in the Tharsis region: A signature of partial melting of the mantle? Journal of Volcanology and Geothermal Research 185, 116-122. doi:10.1016/j.jvolgeores.2008.11.027 (2009).