GAMMA-RAY DATA OF THE THARSIS REGION, MARS: A SIGNATURE OF PARTIAL MELTING OF THE MARTIAN MANTLE?

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Introduction: The data obtained by the Gamma-Ray Spectrometer (GRS) onboard the Mars Odyssey spacecraft have been used to provide global maps of the distribution of Si, Fe, Cl, K, Th, Ca, and H_2O at the Martian surface [e.g. 1, 2]. As data for more elements become available, it becomes increasingly possible to constrain the processes which have led to the present day composition of the Martian surface. Within the framework of this idea, we have focused on GRS data from the volcanic Tharsis rise, with the aim of assessing to what extent the geochemical signature of this region is the consequence of magmatic processes (e.g. partial melting of the mantle) or whether other processes such as alteration are required to explain the data.

The Tharsis rise: The Tharsis region harbors most of the major volcanic mega structures on Mars (Fig. 1) and is particularly suitable for analysis of GRS data as it is well away from the H-rich polar regions, of high average elevation, and of large spatial extent. On the other hand, this region has a low thermal inertia, implying that it is mantled by fine, bright dust [3]. However, recent work shows that the mantled region at Tharsis is chemically distinct from other mantled regions such as Arabia and Amazonis [4], leading to the conclusion that surface materials are at least partly representative of the underlying bedrock.

GRS data: Consideration of the GRS data in the range 40°S to 40°N in latitude and 90°W to 170°W in longitude shows the presence of a prominent area of low silica content (Fig. 1). This low silica zone overlaps the region of Olympus Mons to the north and two of the Tharsis Mons volcanoes to the south-east. For the present purposes the region contoured by a white line in Fig. 1 has been considered. The average surface composition of this area has been calculated using arithmetic means of values for each element analyzed in 5° bins. GRS data have been converted to wt% oxides (assuming stoichiometries of SiO_2, FeO, CaO, and K_2O) subsequently normalized to a water-free basis (i.e. multiplied by 100/[100-wt%H_2O]). The composition measured (Table 1) is significantly poorer in SiO_2 and richer in FeO than primary melts produced by partial melting of the Earth's mantle. The aim of this work is to assess to what extent these characteristics may be produced by simple partial melting of the Martian mantle.

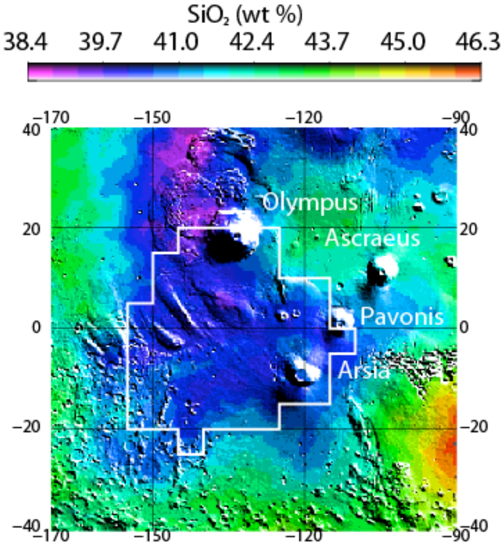

Figure 1. Silica abundance in the Tharsis region. The white line encloses the area used for the calculation of composition.

wt %	SiO_2	CaO	FeO	ThO_2	K_2O
Minimum	40.6	7.2	14.4	0.60	0.346
Mean	42.1	8.5	16.7	0.81	0.411
Maximum	43.4	10.0	19.2	0.99	0.486
Belly-band average	45.9	8.5	19.3	0.76	0.401
Belly-band std error	0.7	0.5	1.2	0.03	0.002

Table 1. Composition of the region outlined in Fig. 1. Belly-band values are for all longitudes from 40°S to 40°N. Cumulative GRS spectra from 8 Jun '02 to 2 Apr '05 were used.

Composition of the mantle source region: Interpretation of the composition of volcanic rocks at the Martian surface necessarily requires some understanding of the composition of the source region. In addition to geophysical constraints [e.g. 5], two sources of chemical data have been used to infer the composition of the Martian mantle. The first is the Shergotty-Nahkla-Chassigny (SNC) group of meteorites, while the second is the composition of basalts measured in-situ by the MER rovers [6]. In the first case, simple cosmochemical arguments have been used to estimate the composition of the bulk Martian mantle (e.g. *Dreibus and Wänke,* 1985, [7]). These estimates imply a Martian mantle significantly richer in iron than that of the Earth, with a greater proportion of orthopyroxene relative to olivine, in good first order agreement with geophysical constraints. However, it would appear that liquids inferred to be in equilibrium with the SNC meteorites cannot be produced by one stage melting of the composition proposed by [7] ([8]), while on the other hand, the basalts measured in-situ at Gusev crater can [9]. In light of the fact that at least some Martian volcanic rocks (notably those measured in-situ) can be derived by partial melting of the composition proposed by [7], and in the absence of an alternative, we have chosen to consider liquid compositions produced by partial melting of the composition of Driebus and Wänke.

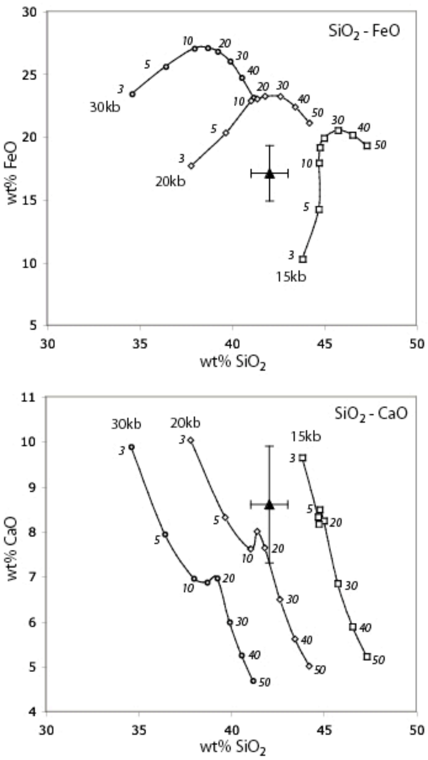

Figure 2. Liquid compositions predicted using pMELTS (solid lines) as a function of pressure (15 to 30 kb) and degree of melting (numbers in italics). Values derived from GRS data are solid triangles with maximum range.

Thermodynamic modeling using p-MELTS: Simulations have been performed using the thermodynamic calculator p-MELTS developed by Ghiorso and co-workers (e.g. [10]). The validity of this approach has been assessed based upon comparison of predicted and experimental results of [11] for an iron-rich bulk composition. Simulations have been performed for pressure in the range 15 to 30 kbar and degrees of partial melting from 3 to 50%. Oxygen fugacity was fixed to be 3 log units below the Fayalite-Magnetite-Quartz (FMQ) buffer. The calculated liquid compositions are represented as a function of calculated silica content in Fig. 2. The results indicate that silica content of liquids generally increases with increasing degree of partial melting, but decreases with increasing pressure. The calcium content of liquids simply decreases as partial melting proceeds, while iron shows a more complicated variation, first increasing then decreasing as the extent of melting increases (Fig. 2).

Discussion: When the GRS data are plotted in the SiO_2-FeO and SiO_2-CaO diagrams, in both cases the GRS data for the Tharsis region systematically plot between the traces for melting at 15 and 20kb and for degrees of partial melting in the range 3 to 10% (Fig. 2). Measured potassium contents are also consistent with such degrees of partial melting. The coherence between the data for these independent oxides implies that the surface compositions in the Tharsis region may indeed represent volcanic liquids derived from partial melting of the Martian mantle. While acknowledging the simplicity of this scenario, we note that it can account for the all the principal geochemical observations available. Furthermore, the inferred pressure of melting (15-20kb) corresponds to a depth range of 125-170 km. In this respect we note that various independent methods have been employed to constrain the depth of the source region for Olympus Mons and other volcanoes in the Tharsis region, including elastic flexure theory, hydrostatic support of volcanic edifices and gravity/topography admittances [e.g. 12]. All of these approaches predict values in the range 140 to 240 km beneath Olympus Mons, values generally decreasing towards the edge of the Tharsis plateau. The depth range inferred from the thermodynamic modeling is thus in excellent agreement with geophysical constraints, providing independent support in favor of the hypothesis that surface chemistry in the Tharsis region is dominated by the signature of primary magmatism. More stringent and detailed tests of this simple model will be possible as more data become available either from the GRS instrument (e.g. Al_2O_3) or future generations of instruments (e.g. MgO, TiO_2).

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