ANDESITES IN THE PRIMITIVE MARTIAN CRUST: PRODUCTS OF HYDROUS MELTING?

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Introduction: Deconvolution of thermal emission spectra from Mars orbiting spacecraft, in-situ analysis of martian rocks by Mars Pathfinder, Spirit and Opportunity rovers, as well as investigation of martian meteorites, all point towards a wide magmatic diversity at the surface of the planet. Compositions varying from olivine-rich basalt to high-silica granite / rhyolite through basaltic andesites, andesites and dacites have all been identified [1].

Primitive olivine-rich basalts (45-46 wt% SiO_2) have been analyzed by the Spirit rover inside Gusev Crater [2]. Similar olivine-rich rocks have also been identified by infrared spectrometry in different places on Mars [1,3]. These basaltic rocks have been interpreted as partial melts of an undepleted martian mantle [4], and might form part of the primitive martian crust.

Infrared and thermal emission spectroscopy, however, show that most of the martian surface is not covered by primitive basalts [5], but by more silica-rich basaltic andesites (52-55 wt% SiO_2, surface type 1) or andesites (56-59 wt% SiO_2, surface type 2). Andesitic rocks have also been analyzed by the Mars Pathfinder mission [6]. Andesites are common rocks on Earth that can be formed through two main processes: fractional crystallization of basaltic rocks and partial melting in the presence of water. In this abstract, we discuss the potential role of water in the generation of basaltic andesites and andesites, through an experimental study of hydrous peridotite melting and comparison with magmatic processes that occur on Earth. We argue that if magmatic rocks of basaltic-andesitic or andesitic composition are present in large amounts in the Martian crust, their genesis is highly likely to have involved the presence of water.

Water in the Martian mantle: There is compelling evidence that Mars was quite wet, at least through part of its history. Well-developed valley networks suggest that there has been running water during early Martian history [7]. Extensive hydrous alteration of the Martian surface [8], evaporite deposits [9] and polar water ice deposits [10], confirm the presence of surface water throughout the planet's history. Although controversial, analytical and experimental evidence from Martian meteorites suggests magmatic water contents as high as 1.8 wt% [11].

Experimental study of hydrous melting: Water-saturated experiments have been performed in a piston-cylinder apparatus, at 1.0-1.5 GPa and temperatures between 975 °C and 1025 °C on a primitive (mantle + crust) Martian composition [12]. Glasses from three experiments, saturated with olivine, orthopyroxene, clinopyroxene, spinel, and, for one experiment, amphibole, have been analysed by electron microprobe. They have very similar andesitic compositions, with SiO_2 = 57-60 wt%, Al_2O_3 = 18-21 wt%, FeO = 2-6 wt%, MgO = 1-3 wt% and CaO = 8-10 wt%. Melt fractions have been calculated by mass-balance, and are between 9 and 10 wt%.

Generation of the Martian crust: Olivine-rich basaltic rocks, like those observed at Gusev crater, are very similar to dry partial melts of the Martian mantle [4]. Dry fractional crystallization of such "tholeiitic" basalts is characterized by an important iron enrichment [13] that is not observed in surface types 1 or 2 (Fig. 1). Furthermore, dry crystallization leads to almost constant silica content until very high amounts of crystallization are reached. Any basaltic-andesitic or andesitic composition like surface types 1 or 2 is thus unlikely to be derived by dry crystallization of primitive Martian mantle melts.

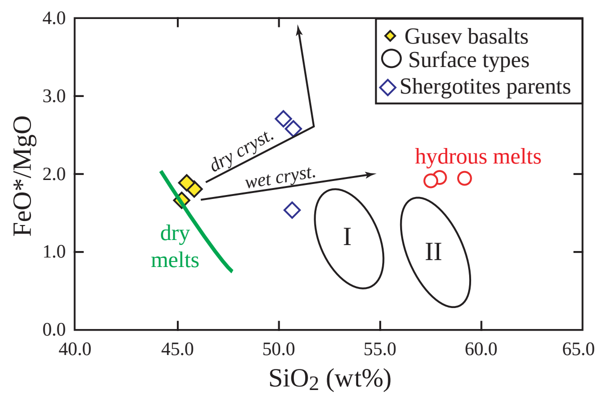

Fig. 1 Comparison of spectral surface types 1 and 2 with dry [14] and hydrous melts of the Martian mantle, and their evolution by fractional crystallization [13,15].

On the other hand, experimentally determined low-degree water-saturated melts of the Martian mantle have andesitic composition similar to the composition of surface type 2. In most major element diagrams, surface type 1 composition plots between dry and water-saturated melts of the Martian mantle (Fig. 1).

We thus suggest that surface type 1 materials could be produced by water-undersaturated melting of the Martian mantle, i.e. with water contents of 0.1-0.4 wt%, which is likely to give melt compositions intermediate between dry and water-saturated melting. Surface type 2 andesites may be partial melts of a more water-rich Martian mantle, as their composition is very similar to experimental water-saturated melts.

An alternative hypothesis is that surface types 1 and 2 are derived by fractional crystallization of primitive basalts that contains some H_2O. The presence of H_2O changes the fractionation trend from tholeiitic to calc-alkaline (Fig. 1), allowing for a rapid enrichment in SiO_2 and suppressing iron enrichment [16]. Andesite can thus be obtained by fractional crystallization of hydrous basalts, as is the case in terrestrial subduction zones.

The silica-rich composition of surface material on Mars thus suggests the presence of H_2O in primitive Martian magmas. Both surface types can be generated by melting of water-bearing Martian mantle, followed by hydrous fractional crystallization. The relative role of hydrous melting and hydrous fractional crystallization is, however, still to be determined.

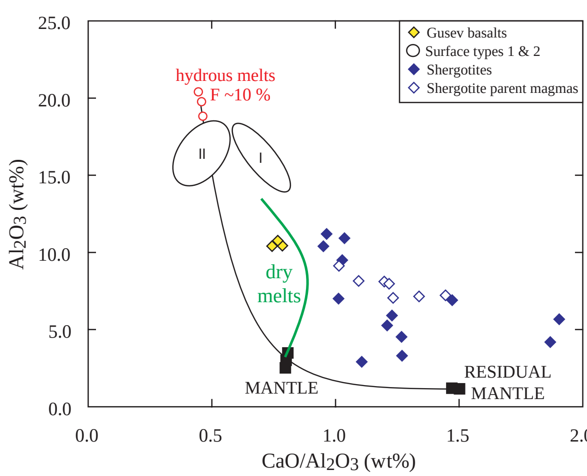

Fig. 2 Generation of high CaO/Al_2O_3 residual mantle by extraction of low-degree hydrous melts.

Origin of SNC meteorites: SNCs (shergottites, nakhlites, and chassignites) are young magmatic meteorites that have been convincingly argued to come from the surface of Mars. Their young crystallization ages support the idea that they have been generated in the long-lived volcanic regions of Tharsis or Elysium. Most, if not all, of this meteorites are actually cumulates, however, their parental magmas can be estimated from mineral / melt equilibrium and analysis of melt inclusions. Major element characteristics of these parental magmas cannot be explained by low-pressure partial melting of the estimated Martian mantle composition, particularly because of their high CaO and low Al_2O_3 contents [17, fig. 2]. However, the occurrence of magmatism in a single place over billions of years is expected to change the composition of the mantle source region. The extraction of ~10 % hydrous melts of the primitive martian mantle composition results in a residue with a high CaO/Al_2O_3 ratio (fig. 2) that could be a potential source for SNC parent magmas. If water was initially present in an upwelling mantle plume below Tharsis region, it is possible that the first melts of the plume were low-degree hydrous melts, leaving a depleted residual mantle that would melt later to form the young SNCs.

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