MELTING OF A PRIMITIVE MARTIAN MANTLE AT 1-2 GPA: EXPERIMENTAL CONSTRAINTS ON THE ORIGIN OF BASALTS ON MARS.

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Introduction: The surface of Mars is mainly covered by basalts produced by partial melting of the planet interior. Data from Martian meteorites and surface analyses have highlighted compositional diversity among Martian basalts. In parallel, model compositions of the bulk silicate Mars (i.e. the primitive Martian mantle) have been proposed based on physical constraints and correlations between element ratios from Martian meteorites and chondrites [*e.g.* 1, 2]. These models provide the opportunity to study experimentally how melting conditions can affect the composition of deep mantle melts from which surface basalts are derived.

Igneous processes like magma ocean crystallization and continuous melting have likely produced chemical and mineralogical heterogeneities in the mantle. Two evidences for this are the large range of trace element abundances and the various Ca/Al ratios of Martian basalts and meteorites. However, the extend of compositional variations produced by partial melting of an undifferentiated Mars mantle, at various pressure and temperature, remain poorly constrained. Melting experiments on primitive mantle compositions are scarce and melt compositions were only measured at 1.5 [3] and 5 GPa [4]. Therefore, additional experiments are necessary to obtain a consistent dataset in order to discuss the relations between major element contents of Martian basalts and melting conditions in the mantle. Such experiments will support subsequent investigations of more complex scenarios of Martian basalts formation.

Methods: We have performed new melting experiments on a synthetic equivalent of the most largely accepted Martian mantle model (DW) [1]. Other reasonable models give very similar compositions [2], and share key differences with the terrestrial mantle: low Mg# (75-78), and high incompatible (Na, K, P) and compatible (Cr, Mn) volatile elements.

Experiments were performed in a piston-cylinder apparatus at 1.0, 1.5 and 2.0 GPa. This pressure range covers plausible depths of melting (80-170 km) of the Martian mantle [5, 6]. Runs were equilibrated at temperature from 1200 to 1600 °C corresponding to degrees of melting between 3 and 70 %. These conditions were previously investigated by Bertka and Holloway (BH) [3]. However, recent developments of melt extraction techniques have allowed analysis of glasses at each pressure and a better characterization of melts produced by low degrees of partial melting. A layer of vitreous carbon spheres was added to extract the liquid and avoid quench modifications [7]. At 2.0 GPa, graphite spheres were damaged and no longer efficient. Liquids were thus extracted within small cracks in graphite capsules [8].

Experimental run products were analyzed with the Cameca SX100 EPMA of the "Laboratoire Magmas et Volcans". Modal compositions were estimated by mass balance calculations.

Results and discussion: Phase relations in our experiments are similar to those of [3] but present significant differences (fig 1). Notably, the stability field of pigeonite is expanded and solidus temperatures are lowered by 30-40 °C probably due to the addition of K in our starting composition. Close to the solidus, the residual mineralogy comprises olivine, two pyroxenes (orthopyroxene and pigeonite) and spinel. At low temperatures, melting proceed through the peritectic reaction opx + pig + sp = ol + melt (fig 2A). With increasing temperature, the CaO content of pigeonite decreases progressively from 12 to 4%. Pigeonite and spinel disappear simultaneously at around 20% of melting. Then, both olivine and orthopyroxene are consumed by an eutectic melting reaction. Orthopyroxene disappears after about 50% melting at 1.0 GPa but persist longer at higher pressure.

At 1.0 GPa, liquids produced by low to moderate degrees of melting are richer in SiO_2 (51-53%) compared to liquids at 1.5 GPa (47-48%) and 2.0 GPa (46%; fig 3). The high SiO_2 content in anhydrous melts at low pressure results from alkalis enrichment. Alkalis depolymerize silicate melts by increasing the number of non-bridging oxygen in SiO_4 tetrahedra at pressure <1.5 GPa [9]. This decreases the activity coefficient of silica, compensated by an increase of the SiO_2 concentration in the melt. No influence of alkalis was detected at 1.5 GPa (fig 3). The maximum CaO content in liquids ($\approx$ 9%) coincides with the disappearance of pigeonite (fig 2B). The FeO content increases with temperature and MgO and reaches a maximum of 19-21%.

Comparison of experimental melts with the pMELTS model [10] indicates an overall good agreement. However, Si and Ca are strongly underestimated by the thermodynamic model while Fe is overestimat-

ed. This could be a consequence of inadequate pyroxene solid-solution models and overestimation of pyroxene stability at the expanse of olivine.

Assuming that the DW model is relevant for mantle reservoirs on Mars, comparison of our experimental melts with known Martian rocks allows discussing the conditions of mantle melting. Most known Martian rocks have low SiO_2 contents (< 50%) [e.g. 11]. This would place a lower pressure limit at around 1.5 GPa for the formation of their parental melts. Effects of crystallization-differentiation are believed to be limited to fractionation of olivine and would increase even more the SiO_2 content of liquids reaching the surface. The presence of a significant amount of water in the mantle should also produce melts richer in SiO_2. The new Northwest Africa (NWA) 7034 meteorite could be more representative of the crust than previously known Martian meteorites [12]. Its low average SiO_2 content, despite hydrous and more differentiated (no olivine) characters and high alkalis content, make the formation of its parental melt at pressure < 1.5 GPa from a DW mantle unlikely.

The Adirondack class basalts and the picritic enriched (Larkman Nunatak 06319 and NWA 1068) and depleted (Yamato 980459 and NWA 5789) shergottites represent possible primary Martian basalts [5-6, 13-14]. The composition of enriched shergottites and Adirondack class basalts are close to our 2.0 GPa experimental melts for 35% and 23% of melting, respectively. However, the low FeO/MgO ratio of depleted shergottites and the high CaO/Al_2O_3 ratio of both enriched and depleted shergottites were not reproduced in our experiments. Only the Adirondack class basalts might result from simple melting of a primitive Martian mantle.

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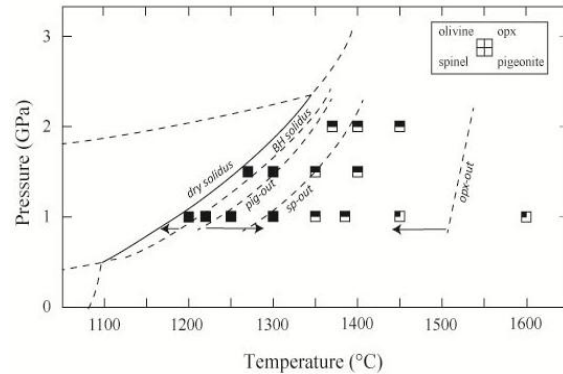

Fig. 1. Phase relations in experiments (squares) and position of the solidus compared to BH [3] phase diagram (dashed lines).
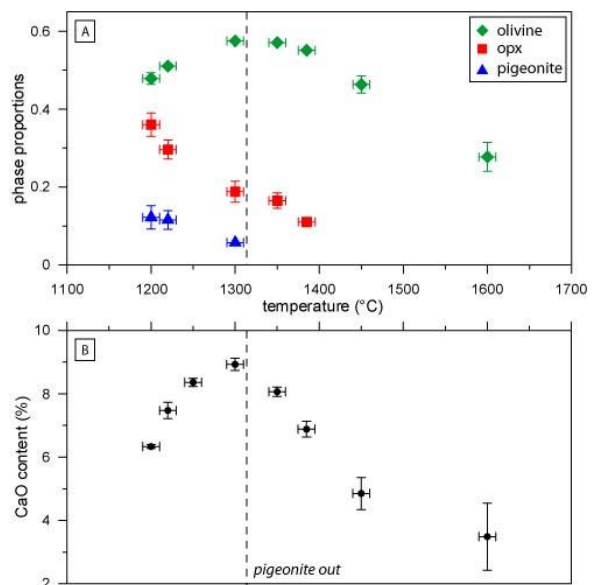

Fig. 2. [A] Phase proportions in 1.0 GPa experiments. [B] CaO content of melts at 1.0 GPa. Error bars are 2σ in Y and ± 10 °C temperature incertitude in X.
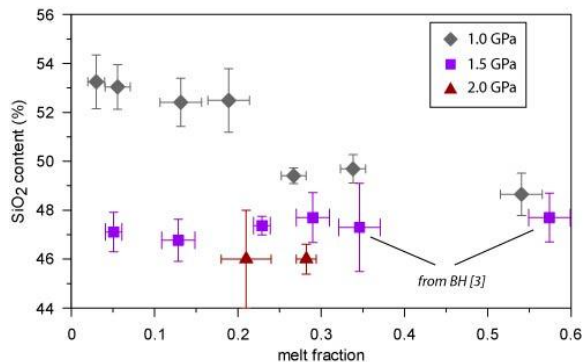

Fig. 3. SiO_2 content of melts at 1.0, 1.5 and 2.0 GPa as a function of the melt fraction. Error bars are 2σ. Alkalis (Na_2O+K_2O) are ≈ 6, 2.5 and 1% at 5, 20 and 50% melting, respectively).