

ALKALINE PRIMARY MELTS FROM THE PRIMITIVE MANTLE OF MARS. M. Collinet¹, E. Médard², J. Vander Auwera¹, B. Charlier³. ¹Université de Liège–F.R.S.–FNRS, B20 Département de géologie, 4000 Liège, Belgium, mcollinet@ulg.ac.be. ²Laboratoire Magmas et Volcans, Université Blaise Pascal–CNRS–IRD, 63038 Clermont-Ferrand, France. ³Institut für Mineralogie, Leibniz Universität, 30167 Hannover, Germany.

Introduction: The Martian crust seems dominated by iron-rich tholeiitic basalts [1]. Until recently, alkali rocks have only been clearly identified by the Spirit Rover at Columbia Hills [2]. However, recent meteorite discoveries [3, 4] and analysis by the Curiosity Rover [5] indicate that alkaline magmatism is more widespread on Mars than previously thought.

Processes potentially responsible for the formation of alkali rich melts are multiple. Suggestions include differentiation of basalt in the presence of water or at high pressure, under conditions that delay the appearance of plagioclase [5], and low degree of partial melting of a primitive or metasomatised mantle [4]. Because Mars accreted further from the Sun compared to Earth, it incorporated a greater portion of volatile-rich chondritic material. In particular, the primitive Martian mantle is suggested to be 25% richer in Na and 40% richer in K compared to the Bulk Silicate Earth [6]. In this study, we investigated the generation of alkali-rich melts from the primitive martian mantle, specifically by low degree of partial melting (< 10 wt%).

We have performed melting experiments on the most widely accepted composition of the primitive mantle of Mars [6]. Here, we focus on the chemical variability of liquids produced at low degrees of partial melting. Then, we compare our experimental liquids to well-documented alkaline rocks from Mars: the Backstay trachybasalt [2], the Jake_M mugearite [5] and the Northwest Africa NWA 7034 [3] and 7533 [4] impact breccias.

Methods: The starting material is a synthetic analog of the anhydrous primitive Martian mantle [6] prepared by mixing high grade oxides and pre-synthesized silicates. Anhydrous conditions were ensured by drying the Pt-graphite double capsule with 10 to 20 mg of the starting material at 400°C for 12h before welding it shut. Experiments were conducted in a piston-cylinder apparatus for 48 to 96h at pressures and temperatures ranging from 0.5 to 2.2 GPa (45-200 km in depth) and from 1160 to 1400 °C. Redox conditions were buffered close to FMQ-2.5.

From 0.5 to 1.5 GPa, we used a thin layer of graphite spheres to isolate the liquid and prevent quench modifications. Because graphite spheres were damaged at higher pressure, the liquid was extracted and analyzed into micro-cracks inside the capsule's lid.

Glass pockets were analyzed with a Cameca SX-100 EMPA using beam conditions of 15 kV, 8 nA and

defocused beams of 10 µm when possible. Crystalline phases were analyzed with a focused beam and a current of 15 nA. The melt fraction for each experiment was estimated from mass balance calculations.

Composition of experimental melts: The composition of experimental liquids displays a clear dependency on pressure. The silica content continually decreases from 58.7 wt% at 0.5 GPa to 43.3 wt% at 2.2 GPa for melt fractions of 7 and 5 wt%, respectively. In parallel, FeO and MgO contents both increase. For a given melt fraction of 7-8 wt%, they evolve from 7.6 to 16.9 wt% and from 4.1 to 11 wt%, respectively.

Previous experiments on terrestrial compositions [e.g. 7-8] have shown that the stability field of orthopyroxene increases at the expense of olivine with pressure, resulting in a larger normative olivine component in the melt. The melting reaction changes from a peritectic reaction producing olivine ($\text{pig} + \text{opx} + \text{sp} = \text{ol} + \text{liq}$) to another peritectic reaction producing orthopyroxene ($\text{cpx} + \text{ol} + \text{sp} = \text{opx} + \text{liq}$) within the spinel stability field. The negative correlation of SiO₂, FeO and MgO contents mainly result from the addition of an increasing olivine component to the liquid, indicating a similar melting behavior for the martian mantle compared to the terrestrial mantle.

However, at low pressure, the high content of alkalis (5-6 wt%) in the liquid also contribute to its enrichment in silica [9]. High contents of P₂O₅ and TiO₂ are sometimes thought to counteract the effect of alkalis. However, our results indicate that their effect does not seem to be significant at low pressure for primary martian mantle melts. At 2-2.2 GPa, we observe an increase of the SiO₂ content with the degree of partial melting. The effect of alkalis is reduced at high pressure as the liquids are greatly depolymerized by the high content of Mg and Fe [9]. On the contrary, at high pressure, the effect of P and Ti might become noticeable and slightly increase the silica activity coefficient.

The Al₂O₃ content peaks at 1 GPa to 17 wt%, slightly decreases at 0.5 GPa as the stability field of plagioclase is reached and decreases significantly towards the higher pressure.

Comparisons with Martian alkaline rocks: The brecciated nature of meteorites NWA 7034 and 7533 and the heterogeneous distribution of feldspars in Jake_M make the interpretation of their bulk-rock compositions difficult. Jake_M is too enriched in alkalis to be a reasonable melt from the mantle. However,

it could be produced from a primitive melt undergoing limited fractional crystallization. NWA 7034 has the closest composition from our experimental melts (Fig. 1, 3). It could be interpreted as a basalt from the primitive mantle moderately enriched in alkalis and that has fractionated a small quantity of olivine.

On the contrary, Backstay is homogenous and displays an aphanitic texture that could indicate that it represents a liquid composition. However, because of its low Ca/(Na+K), it is unlikely that it represents a primitive alkali basalt (Fig. 3). Adding an assembly composed of olivine with clinopyroxene and/or an anorthite-rich plagioclase brings Backstay closer to a primitive melt composition but the resulting liquid is then not significantly enriched in alkalis.

Although none of the three Martian alkaline rocks discussed here are primary alkali basalts, two of them, NWA 7034/7533 and Jake_M, can however be derived from primary alkaline melts by mostly olivine fractionation. They both indicate that primary alkaline melts were likely produced in the Martian mantle. Metasomatism of the mantle with alkali rich fluids or liquids are not necessary to account for the formation of alkaline rocks on Mars

References: [1] McSween et al. (2009) *Science*, 324, 736-739. [2] McSween et al. (2006) *JGR*, 111, E9. [3] Agee C. B. et al. (2013) *Science*, 339, 780-785. [4] Humayun M. et al. (2013) *Nature*, 503, 513-516. [5] Stolper E. M. et al. (2013) *Science*, 339, 6153. [6] Dreibus G. and Wanke H. (1985) *Meteoritics*, 20, 367-381. [7] Kinzler R. J. (1997) *JGR*, 102, 853-874. [8] Walter M. J. and Presnall D. C. (1994) *J. Petrol.*, 35, 329-360. [9] Hirschmann M. M. et al. (1998) *Geochim. Cosmochim. Ac.*, 62, 883-902. [10] O'Hara M. J. (1968) *Earth-Science Reviews*, 44, 39-79.

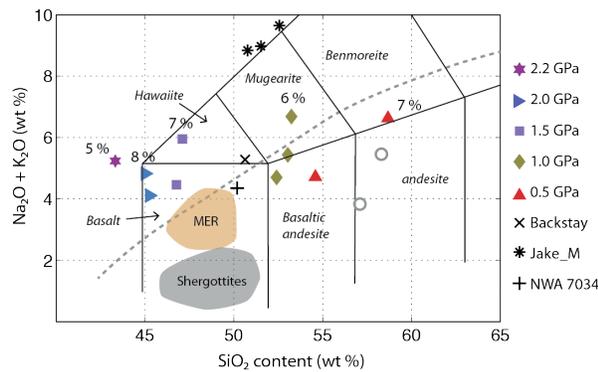


Fig. 1. TAS diagram modified from [5] for comparison with our experimental liquids.

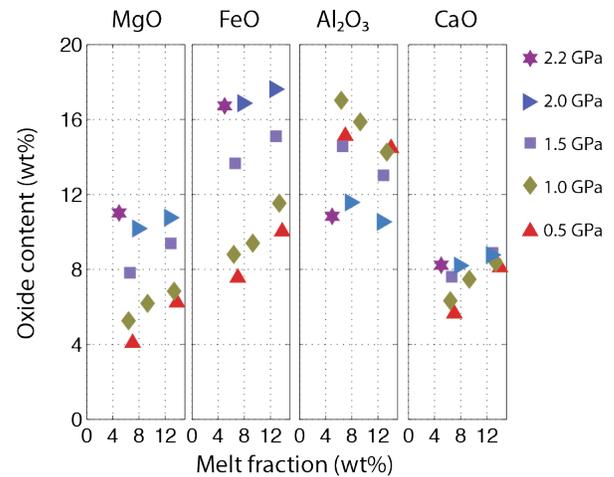


Fig. 2. Major element compositions of experimental liquids.

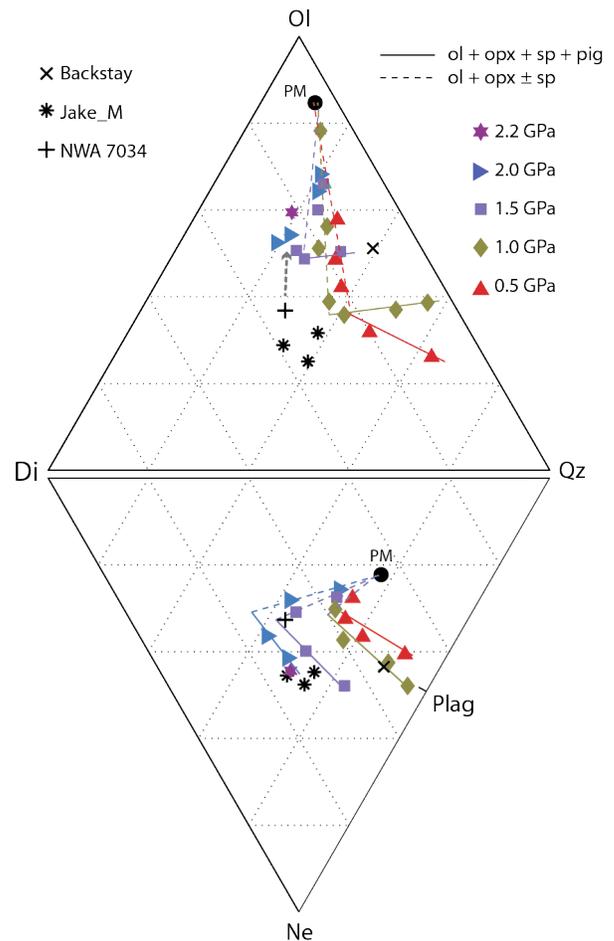


Fig. 3. Projection of experimental liquids and comparison with Martian alkaline rocks. The grey arrow indicate olivine fractionation. PM (primitive mantle) represent the starting composition. Projection schemes inspired from [10].