MANTLE SOURCES OF MARTIAN BASALTS AS CONSTRAINED BY MAGMARS, A NEW MELTING MODEL FOR FEO-RICH PERIDOTITE. M. Collinet[1], A. -C. Plesa[1], T. Ruedas[2,1], S. Schwinger[1] and D. Breuer[1], [1]German Aerospace Center (DLR), Institute of Planetary Research, Berlin, Germany (max.collinet@dlr.de), [2]Museum für Naturkunde Berlin, Impact and Meteorite Research, Berlin, Germany.

Introduction: Understanding how the crust of Mars was formed first requires to constrain the composition of the primary melts extracted from the mantle. We have recently developed a melting model [1], MAGMARS, specifically designed to simulate the melting of the Martian mantle. We have previously applied the model to the Adirondack-class basalts analyzed at Gusev crater by Spirit, the most widely accepted example of a Martian primitive basalt [1]. Here, we review some other candidates of primitive Martian basalts that could have largely escaped igneous differentiation and therefore represent snapshots of the melting conditions in the mantle. While the number of possible primitive basalts sampled by meteorites and analyzed by rovers is still limited, they are characterized by contrasting crystallization ages and have the potential to highlight how the mantle composition and thermal state evolved through time.

Methods: The MAGMARS melting model follows the same overall approach as the Kinzler and Grove (1992) [2] family of models. Melting equations and partition coefficients are used to calculate the concentration of minor and/or incompatible elements (Al_2O_3, Na_2O, K_2O, TiO_2, P_2O_5) that are then used to lower the variance of the system and determine the concentration of major elements (FeO, MgO, CaO, SiO_2) with polynomial regressions.

Here we use MAGMARS in near-fractional polybaric mode to constrain the source composition and P-T conditions of Martian primitive basalts as melt extraction is believed to be highly efficient during decompression melting. The solidus temperature of each mantle source is calculated from the composition of the first 0.1 % melt produced at the pressure of interest using an empirical liquid-thermometer. The pressure is then progressively lowered until the mantle adiabat intersects the solidus (Fig. 1). Once melting has started, the melt is continuously extracted and the mantle composition updated. The final melt composition is calculated by adding all the melt increments produced at different depth in one "pooled" aggregate melt composition. The resulting composition is then compared to possible primary Martian melts. A large number of calculations are performed by varying the source composition until melts with a composition identical to Martian melts are found.

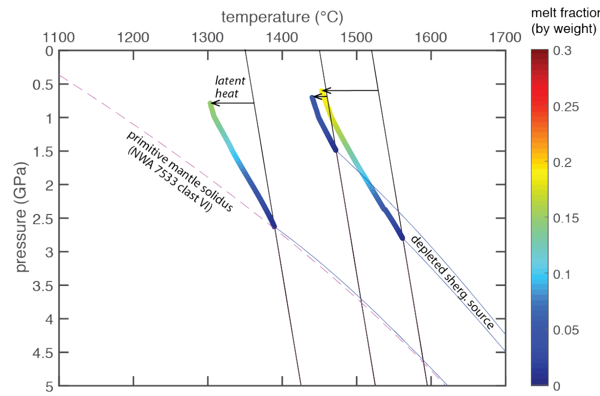

Figure 1: Near-fractional polybaric melting paths for three different mantle sources (primitive mantle and possible sources of the depleted shergottites). The solid blue lines represent the MAGMARS solidi. The dashed magenta line is the parametrized solidus of [3]. The color map indicates the total amount of melting. The composition of the aggregate melts corresponds to the composition of clast VI in NWA 7034 [4] or the depleted shergottite Yamato 980459 [5] after minor olivine fractionation (0-10 %).

Results: Reconstructing a mantle source with MAGMARS can lead to non-unique results. Even in such cases, the mantle sources share important characteristics. For depleted shergottites, a highly depleted (i.e., refractory) mantle that melts to a small extent can produce liquids nearly identical to the ones produced by a slightly more fertile mantle that melts to a greater extent. Both sources are more depleted than the possible sources of all other samples (Fig. 2) and both have a high solidus temperature (Fig. 1).

The source of the Adirondack basalts could be equivalent to a depleted DW85 [6] or YM20 [7] mantle affected by prior melting events (solutions exist for both associated Mg#, 75 vs. 79 [1]). The mantle source from which the basaltic clasts in NWA 7034/7533 were derived [4, 8] could be nearly identical to the primitive DW85 mantle. All other mantle sources are enriched in alkalis compared to DW85 and YM20 residual mantles (Fig. 2).

The mantle potential temperature (T_P) associated with most studied samples falls in the range 1400-1500 ºC with no clear temporal evolution (Fig. 3).

Discussion: All but the oldest sampled mantle sources (NWA 7034/7533) are depleted (i.e. refractory). This is consistent with the early and rapid formation of the crust during the Pre-Noachian. All mantle sources sampled afterwards could have been altered by the early crust-mantle differentiation event.

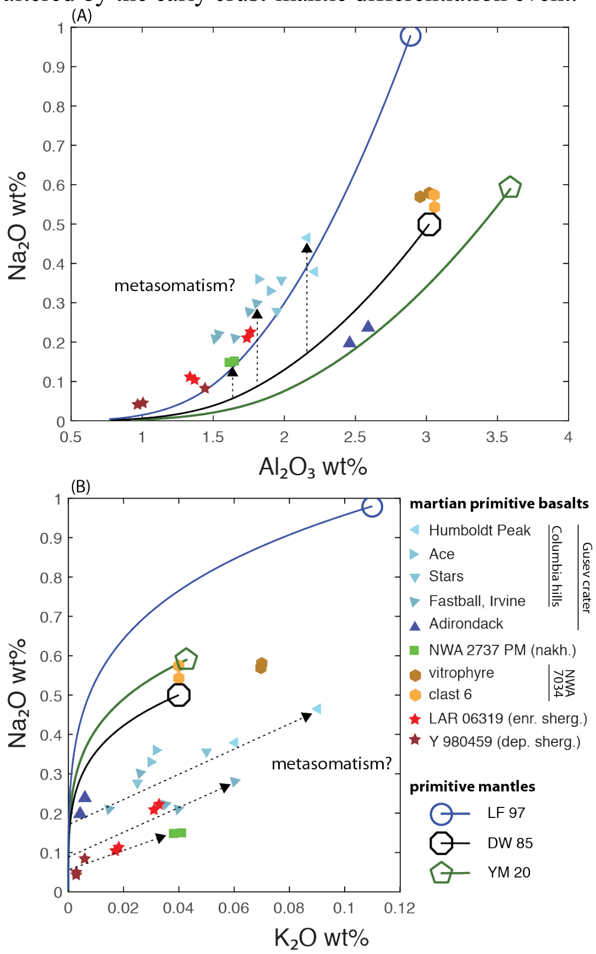

Figure 2: Concentration of incompatible elements in different mantle sources. The solid lines represent the trajectory of residual mantle compositions when melting the model Martian mantles of [6, 7, 9]. The primitive mantle compositions are represented by the corresponding open symbol.

While the sources of the Columbia Hills basalts were relatively rich in Na_2O, their high K_2O/Na_2O ratio suggests that they were not primitive, nor derived from a primitive mantle with elevated alkali concentrations (e.g., similar to LF97 [9], Fig. 2). Instead, the high K_2O/Na_2O and high Na_2O/Al_2O_3 of these mantle sources suggest that they represent regions of a refractory mantle re-fertilized by fluids (metasomatism; dotted arrows in Fig. 2). The sources of the nakhlite parental melt [10] and enriched shergottites [11] could have been affected by a similar but less extensive process.

The fact that the T_p of sampled primitive basalts seem to have remained relatively stable could seem surprising considering that the planet is believed to have cooled since accretion [12]. However, several biases should be considered. First, melts produced at very high temperature in the interior of Mars would have been extremely FeO rich (~ 25 wt.%) and dense. It is therefore possible that the hottest and oldest primary melts were not sampled because they never reached the surface, at least not until substantial igneous differentiation could take place. Second, the mantle affected by partial melting in recent history is not representative of the bulk mantle. Melting is believed to have been extremely localized over the past billion years (e.g. Tharsis, Elysium) and the mantle at those locations (the possible source of shergottites) undeniably represents the hottest regions of the Martian mantle. Overall, the sampled primary melts, while not fully representative, seem to be in line with global thermal evolution models (Fig. 3).

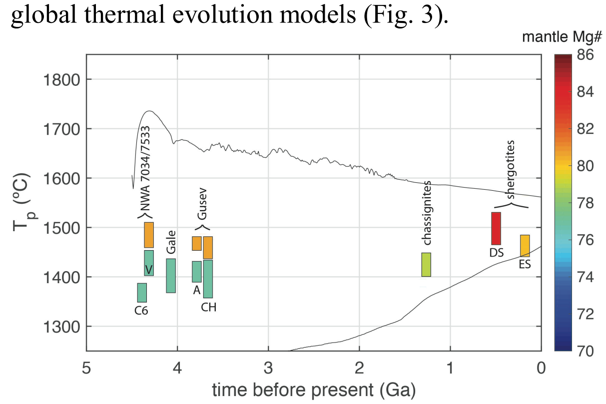

Figure 3: Mantle potential temperature required to produce primary parental melts as a function of the crystallization age of Martian rocks. C6: clast VI [4]. V: vitrophyre [8], A: Adirondack-class basalts, CH: Columbia Hills basalts, DS: depleted shergottites [5], ES: enriched shergottites [11]. The solid lines represent the minimum and maximum T_p of the melting zone in a global thermo-chemical evolution model of Mars (thick crust model of ~60 km on average) [12].

References: [1] Collinet M. et al. (2021) *JGR:P, 126,* e2021JE006985. [2] Grove T. L. and Kinzler R. J. (1992) *JGR, 97,* 6885-6906. [3] Collinet M. et al. (2015) *EPSL, 427,* 83-94. [4] Santos A. R. et al. (2015) *GCA, 157,* 56-85. [5] Musselwhite D. S. et al. (2006) *MAPS, 41,* 1271-1290. [6] Dreibus G. and Wanke H. (1985) *Meteoritics, 20,* 367-381. [7] Yoshizaki T. and McDonough W. F. (2020) *GCA, 273,* 137-162. [8] Udry A. et al. (2014), *GCA, 141,* 281-293. [9] Lodders K. and Fegley B. (1997) *Icarus, 126,* 373-394. [10] He Q. et al. (2013) *MAPS, 48,* 474-492. [11] Basu Sarbadhikari A. et al. (2009) *GCA, 73,* 2190-2214. [12] Knapmeyer-Endrun B. et al. (2021) *Science, 373,* 438-443.