

The timescales of early silicate reservoir formation on Mars

L. A. E. Meyer^{1*}, P. Morino¹, J. Allaz¹, C. Liebske¹, M. W. Schmidt¹ and M. Schönbächler¹ ¹ ETH Zürich, Institut für Geochemie und Petrologie, Clausiusstrasse 25, 8092 Zürich, Switzerland (* lara.meyer@erdw.ethz.ch)

Introduction: The onset of the Martian silicate differentiation is still a matter of debate. The examination of the short-lived ^{53}Mn - ^{53}Cr system ($T_{1/2} = 3.7$ Ma) in Martian meteorites showed no resolvable variations for the radiogenic ^{53}Cr [1]. A uniform excess in $^{53}\text{Cr}/^{52}\text{Cr}$ with an average of $+20.2 \pm 1.2$ parts-per-million (95% conf.) relative to the terrestrial mantle is observed [1]. This might be explained by an onset of the magma ocean solidification later than 20 Ma after Solar System formation [1]. However, this explanation contradicts models predicting a rapid magma ocean solidification, e.g., [2, 3]. Reliable dating of the magma ocean stage of a planet requires solid-liquid partition coefficients to calculate robust daughter to parent element ratios in minerals that crystallize during the solidification of the magma ocean. Hence, the Mn-Cr model ages depend on suitable partition coefficients for these elements, which are largely absent for Martian conditions. In particular, partition coefficients of Mn and Cr for garnet, clinopyroxene, and spinel are missing. Therefore, the aim of this study is to determine new accurate partition coefficients for Mn and Cr to model Mn/Cr ratios for Martian cumulate piles and to evaluate the ^{53}Cr data in the light of these new values at higher accuracy.

Methods: To determine the solid-liquid partition coefficients, we chose melt experiments that cover 0.5-19 GPa with lunar and Martian bulk composition. These aimed to simulate lunar magma ocean fractionation and the liquidus relations of the deep Martian magma ocean. We obtained new electron microprobe (EMPA) measurements of Mn and Cr concentrations in majorite-, garnet- (with 3 Si pfu), olivine-, spinel-, pigeonitic clinopyroxene- and orthopyroxene-melt pair with extended peak counting times of up to 180 seconds for both elements. The partition coefficients were calculated with $D = c^{\text{mineral}}/c^{\text{melt}}$ (c = concentration of the mineral). They were applied to the Martian cumulate pile crystallization model after [4] and to the crystallization sequence of [5] using fractional crystallization equations to calculate Mn/Cr ratios. In a final step, we calculated Mn/Cr model ages for magma ocean crystallization. In doing so, we assumed core formation at 4 Ma [6] and 10 Ma [7] after Solar System formation without Mn/Cr fractionation during this process. As Martian building blocks, we tested selected building blocks using carbonaceous and ordinary chondrite data [8] as well as the compositions proposed by [9] and [10].

Results and Discussion: We determined new D-values for garnet, clinopyroxene and spinel for a magma ocean-like composition from 0.5 to 3.5 GPa. Applied to different Martian mantle cumulate packages [4, 5] bulk D(Mn) evolves from 0.4 for the deepest cumulates to 1.1 at the top, while bulk D(Cr) evolves from 1.1 to 2.6. Bulk partition coefficients of Cr applied to the mantle mineral composition of [5] vary between 1.2 and 1.8 at a depth of 3.5 to 10 GPa, although the proportions of olivine, garnet, clino- and orthopyroxene remain similar. This might be caused by a gap in melt experiments, which do not cover pressures between 3.5 and 10 GPa and needs further examination. Including the new D-values into the crystallization models, the $^{53}\text{Cr}/^{52}\text{Cr}$ data from [1] matches with models that use all three building block compositions, a crystallization onset at 4 Ma and 10 Ma, and the crystallization sequence of [5]. Crystallization models using the cumulate packages of [4] only match the Cr isotope data with a crystallization onset at 10 Ma and the building block compositions proposed by [9] and [10].

Conclusion and Outlook: We successfully determined new, accurate D-values for Mn and Cr for a range of minerals that are important during magma ocean crystallization. According to our models, the ^{53}Mn - ^{53}Cr radionuclide system allows magma ocean solidification before 20 Ma after Solar System formation on Mars. Additional calculations will be carried out considering mixing lines between (i) isotopically depleted mafic cumulates (low Mn/Cr), which result in small radiogenic ingrowth of ^{53}Cr , and (ii) enriched later stage cumulates (high Mn/Cr ratios and ^{53}Cr values). This might help to further determine the proportion of enriched material in Shergottites.

References: [1] Kruijer T. et al. (2020) *Earth and Planetary Science Letters* 542:116315. [2] Elkins-Tanton L. et al. (2008) *Earth Planet. Sci. Lett.* 271: 181–191. [3] Bouvier L. C. et al. (2018) *Nature* 558: 586–589. [4] Borg L. E. and Draper D. S. (2003) *Meteoritics & Planetary Science* 38: 12. [5] Yoshizaki T. and McDonough W. F. (2020) *Geochimica et Cosmochimica Acta* 273: 137-162. [6] Dauphas N. and Pourmand A. (2011) *Nature*, 473: 489-492. [7] Mezger K. et al. (2013) *Space science reviews*, 174(1): 27-48. [8] Trinquier A. et al. (2008) *Geochimica et Cosmochimica Acta* 72: 5146-5163. [9] Taylor (2013) *Geochemistry*, 73: 401-420. [10] Liebske C. and Khan A. (2019) *Icarus*, 322: 121-134.