EVOLUTION OF THE WATER CONCENTRATION IN THE MARTIAN MANTLE AND ITS THERMAL HISTORY: IMPACTS ON MAGMA GENESIS.

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Introduction: The abundance of water in the martian mantle is ambiguous due to the lack of diverse samples from Mars [1]. Although martian meteorites currently provide the unique collection of rocks we have on Earth from Mars and reveal crucial information regarding Mars' interior and magmatic processes, most of them are < 2.4 Ga and sampled less than 10 regions of Mars [1]. As of now, it is estimated that between 14 and 321 ppm of water was present in Mars' mantle according to analyses of hydrous minerals like apatite within martian meteorites, with most measurements agreeing with tens of ppm [2-3]. Such large range of H_2O concentration is problematic since water is known to have significant effects on magmas chemical and physical properties. For instance, the presence of water delays the crystallization of plagioclase in cooling magmas enhancing the Al_2O_3 concentration in the melt [4] and favors the production of Fe-bearing minerals [5]. Constraining the amount of water in the martian mantle is thus crucial to understand the composition and mineralogy of Mars' magmas and interior.

This work aims to constrain the water evolution through time in Mars' mantle based on its thermal history constraints, and deduce the effects of these two variables on mantle-derived melts and crustal composition using thermodynamical modeling.

Methods: Both water and temperature affect mantle viscosity, hence influencing mantle dynamics. Flexure studies [6] and estimates of mantle potential temperatures from chemical analyses of igneous rocks and volcanic terrains measured by rovers and orbiters, respectively [7], provide constraints for Mars' thermal evolution. We modified the method of [8] for a stagnant lid planet. The model relies on thermal history constraints and balances a state equation for mantle viscosity with a parameterized thermal history model, in light of uncertainties, to estimate the historical mantle water content.

Water Abundance in Mars' Mantle: In agreement with martian meteorite studies, the models suggest water loss throughout Mars' history (Fig. 1). The absence of efficient water recycling characteristic of stagnant lid planets explains the monotonic water loss.

The water estimations from ~600 ppm 4.5 Ga ago to ~350 ppm today correspond to the upper range of water abundances deduced from martian meteorite analyses. Analyses of martian meteorites demonstrate the heterogeneity of Mars' mantle with the presence of several reservoirs, some being more hydrated than others [e.g., 3]. Our model illustrates that overall, Mars' mantle water abundance is of the same order of magnitude of that of Earth's.

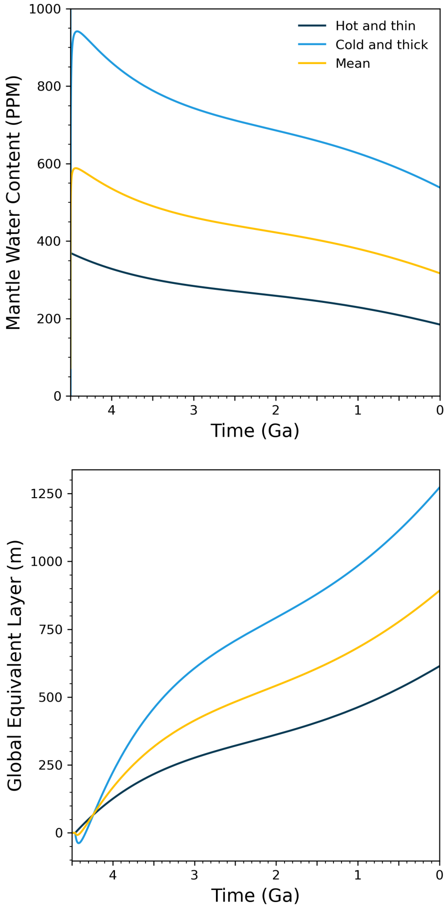

Figure 1. (Up) Evolution of the water content in Mars' mantle over time (yellow line) considering the uncertainties of the thermal history and effective elastic thickness evolution (dark and light blue lines). (Down) Accumulation plot showing the Global Equivalent Layer (GEL) of water considering that all the water in the mantle is homogeneously distributed at the surface of Mars. Same legend as upper figure.

The initial water composition of ~600 ppm agrees with the estimations from accretion models [9], and today water content aligns with those from [10] models and with the potential existence of a present-day plume below Elysium Planitia [11]. Considering the water contained in the mantle as a homogeneous layer overlying the surface of Mars, a total of ~750 meter +/- 200 m GEL is estimated. Despite being an upper estimation as no degassing rate is considered, the modeled GEL matches the range of tens cm to hundreds of meters GEL calculated from the amount of hydrated minerals identified at the surface of Mars and geomorphological studies [12-13].

Effects on Martian Magmas: Both water and thermal history can impact the composition and mineralogy of magmas. Using pMELTS models from the alphaMELTS family software [14], we model an isentropic ascent of a mantle composition [15] integrating the mantle temperature and water concentration estimated by the previous models in order to characterize the evolution in composition of mantle-derived (primary) melts through time (Fig. 2).

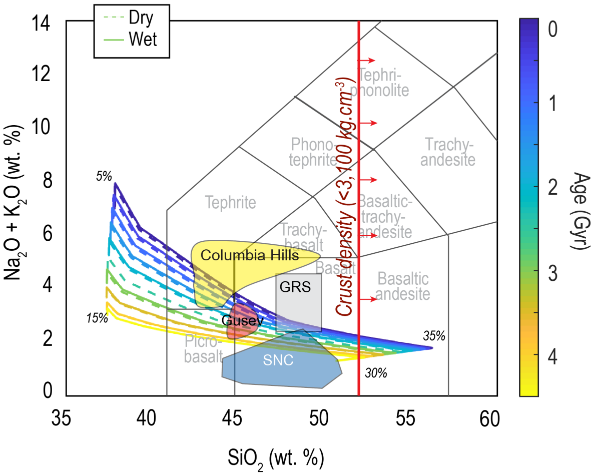

Figure 2. Total alkali silica (TAS) diagram showing the evolution of composition of primary melts deduced from the thermodynamical isentropic models. Solid lines present models considering the water concentrations of the inversion models, and dashed lines shows the exact same models with H_2O = 0 wt.%, showing that the presence of water does not highly affect the composition of primary melts. The red line illustrates the silica composition expected from a crustal density < 3,100 kg.m^{-3} as estimated by [16].

Ancient primary melts would be alkali-poor compared to recent primary melts mainly due to the cooling of the planet (Fig. 2). Because ancient Mars was hotter and the lithosphere thinner than recent Mars, the extent of melting is expected to be higher, ~30 wt.% melt [17]. This suggests that intermediate alkali-poor melts of basaltic-andesitic compositions were likely in ancient Mars, while alkali-rich mafic (SiO_2 < 52 wt.%) primary melts are expected in more recent times (Fig. 2). Slightly silica-rich composition in early Mars might explain light crustal density inferred from seismic, gravity, and topographic data (< 3,100 kg.m^{-3}; [e.g., 16]).

No felsic composition is modeled by the isentropic ascent of a mantle composition. However, crustal crystallization, fractional crystallization, and assimilation following isentropic melting are processes that have been widely suggested on Mars [e.g., 18]. Because water is an incompatible element, it will accumulate in residual liquids, favoring the formation of felsic melts likely alkali-poor as observed on Earth (e.g., from andesitic to dacitic compositions), especially in early Mars. This could explain the felsic rocks identified in Gale crater, with the alkali felsic rocks potentially being younger than the dioritic rocks analyzed by the *Curiosity* rover [18].

Conclusion: Based on the thermal evolution deduced from measurements on martian igneous rocks and volcanic terrains, our models predict a water concentration in the martian mantle decreasing from ~600 ppm at 4.5 Gyr to ~350 ppm today. This agrees with previous numerical studies and accretion models and falls at the upper limit of estimates from martian meteorites. Mars' mantle might be wetter than what is estimated by most martian meteorites highlighting the importance of the Mars Sample Return mission and the necessity of increased sampling from various locations and of different ages. The thermal evolution of Mars directly impacts the composition of mantle-derived melts: generation of alkali-poor and intermediate primary magmas early in Mars' history; whereas alkali-rich and mafic primary melts were generated by more recent magmatic activities. Following magmatic processes such as fractional crystallization of primary melts emphasize the importance of water in residual liquids, additionally impacting both the composition of magmas and its crystallization sequence. Further modeling will illustrate this latter point.

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