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The fate of early Mars' lost water: the role of serpentinization

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Abstract

The fate of water which was present on early Mars remains enigmatic. We propose a simple model based on serpentinization, a hydrothermal alteration process which may produce magnetite and store water. Our model invokes serpentinization during about 500 to 800 Myr, while a dynamo is active, which may have continued after the formation of the crustal dichotomy. We show that the present magnetic field measured by MGS in the Southern hemisphere is consistent with a ~500 m thick Global Equivalent Layer of water trapped in serpentine. Serpentinization results in the release of H_2. The released H atoms are lost to space through thermal escape, increasing the D/H ratio in water reservoirs exchanging with atmosphere. We show that the value of the D/H ratio in the present atmosphere (~5) is consistent with the serpentinization of a ~500 m thick water GEL. We reassess the role of non-thermal escape in removing water from the planet. By considering an updated solar wind-ionosphere interaction representation, we show that the contribution of oxygen escape to H isotopic fractionation is negligible. Our results suggest that significant amounts of water (up to a ~330-1030 m thick GEL) present at the surface during the Noachian, similar to the quantity inferred from the morphological analysis of valley networks, could be stored today in subsurface serpentine.

1. The study

Like Earth, Mars has been endowed with large amounts of water during accretion, equivalent to the content of several terrestrial oceans, corresponding to a several 10 km thick Global Equivalent Layer. The present inventory of observable water on Mars, mainly within the polar caps, is quite smaller, in the range from ~20-30 m. The mega-regolith capacity is large, with up to ~500 GEL m potentially trapped in the cryosphere, and hypothetically several additional hundreds of meters (up to ~500 m) of ground water surviving at depth below the cryosphere [1]. A ~500 m thick GEL is generally assumed to be required to explain the formation of outflow channels [2], and most of this water could be trapped today as water ice, and possibly deep liquid water, in the subsurface, and also possibly under the form of hydrated minerals.

The presence of hydrated minerals at the surface of Mars [3] suggests that hydration processes have been active. Such minerals may have been formed, either at the surface of Mars during the Noachian, when liquid water was flowing at the surface of the planet, or in the subsurface by aqueous alteration of subsurface rocks, and possibly by impacts able to provide subsurface water to the impacted material. A particular hydration process occurring in Earth's crust is serpentinization, which generates H_2 from the reaction of water with ferrous iron derived from minerals, primarily ultramafic rocks [4]. In the reaction, ferrous iron is oxidized by the water to ferric iron, which typically precipitates as magnetite, while hydrogen from water is reduced to H_2. Iron oxidation is accompanied by the storage of a large number of water molecules in serpentine, an hydrated mineral which has been recently observed on Mars [5]. Based on an analysis of the present Mars' D/H ratio, a water GEL of up to ~300-400 m thickness may have been stored in crustal serpentine on early Mars [6]. Serpentinization of the southern crust has been suggested to be at the origin of both the crustal dichotomy and the strong remanent magnetic field of old southern terrains [7].

The main goal of this talk will be to present the results of a study [8] reassessing the hypothesis that serpentinization may have played a major role in removing a several hundred meters thick GEL of water, by using the magnetization of ancient Martian terrains as an additional constraint on the serpentinization rate.

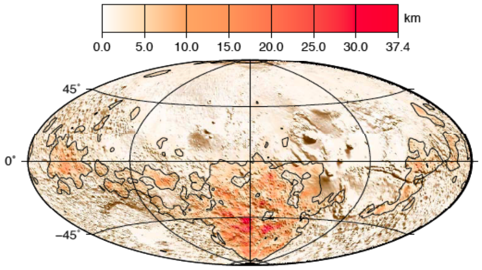

Figure 1: Thickness of the magnetized layer required to explain the magnetic field of Mars, assuming a chemical remanent magnetization due to a 90% serpentinization rate. Contour denotes the 3.05-km thickness conservative limit (from [8]).

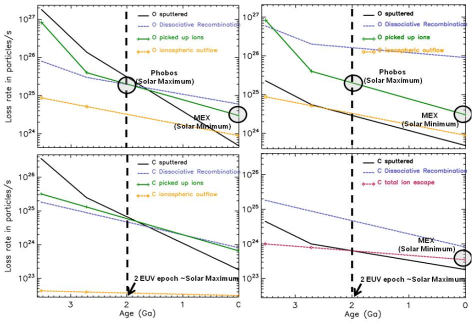

Figure 2 : Time evolution of the loss rate of the O (upper panel) and C (lower panel) atmospheric Martian atoms along Mars' history following the different processes thought to act on Mars' atmosphere. Dark solid line: O atoms sputtered from Mars' atmosphere. Green solid line: picked up ion rates. Dashed blue line: O atoms ejected from Mars' atmosphere by photo-dissociative recombination. Orange dashed line: ionospheric outflows (from [8]).

First, assuming that the magnetization of the southern crust is due to serpentinization, we provide an estimate of the thickness of the magnetized layer, and the corresponding amount of water required to have been trapped in serpentine, to explain remanent magnetic field observations (Figure 1).

We describe how recent models of Mars-solar wind interactions show that an increased solar activity might result in a higher planetopause inducing non-thermal escape rates lower than previously estimated [9] (Figure 2). Such low escape rates are unable to explain the removal of significant amounts of H_2O (and CO_2) through O (and C) escape, since the late Noachian/Hesperian transition.

Then, we provide an estimate of the expected D/H ratio induced by serpentinization, non-thermal escape and sulfur oxidation. We examine if consistent solutions, in terms of both crustal magnetization and hydrogen isotopic fractionation, exist and propose a plausible estimate of the amount of water trapped in serpentine. The implications of our results for the early history of Mars, as summarized in the abstract above, are discussed.

Acknowledgements

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