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Pre-Noachian における水の散逸：火星隕石中の水素同位体による制約
Significant Water Loss during pre-Noachian era: Constraints from Hydrogen Isotopes in Martian Meteorites

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Martian surface morphology implies that Mars was once warm enough to maintain liquid water on its surface (Jakosky and Philips, 2001). Although the high D/H ratio (~ 4500 per mil) of the current Martian atmosphere and hydrosphere (Owen et al., 1981; Jakosky and Philips, 2001) suggests that significant water should have been lost from the surface by the atmospheric escape during the Martian history, the timing and amount of the water loss have been poorly constrained. Whereas previous studies have focused on the water loss after the cessation of Martian dynamo (Lammer et al., 2003), studies for the pre-Noachian period (4.5 - 4.1 Ga) and the Noachian period (4.1 - 3.7 Ga) are limited.

Recent technical developments of ion-microprobe analysis have provided more accurate estimation of hydrogen isotope compositions (D/H) in Martian meteorites which inform the evolution of Martian water reservoirs (Usui et al., 2012; Boctor et al., 2003; Greenwood et al., 2008). Based on the D/H data from the meteorites, this study determines the amount of water loss during each period.

The water losses are estimated with a one-box model. The model is similar to Lammer et al. (2003). We assume that surficial water is lost in two stages: Stage-1 (4.5 - 4.1 Ga) and Stage-2 (4.1 Ga - present). Stage-1 corresponds to pre-Noachian era. The boundary (4.1 Ga) is derived from the crystallization age of ALH 84001, the only Martian meteorite formed in Noachian (Lapen et al., 2010). The D/H ratio at 4.1 Ga is 1200-3000 per mil. The values are derived from analyses of magmatic phosphate and secondary carbonate minerals in ALH 84001 (Boctor et al., 2008; Greenwood et al., 2008). The D/H ratio at 4.5 Ga is $<$ 275 per mil which is the value of melt inclusion in Yamato 980459 (Usui et al., 2012) and thought to represent the primitive D/H ratio of Mars. We use present water amount as an input parameter. The water losses in both stages are obtained as outputs.

Our results show that the water loss was more significant in Stage-1 (4.5 - 4.1 Ga) than in Stage-2 (4.1 Ga - present), indicating significant water loss during pre-Noachian era. This result is independent from the estimation of present water amount. Present water reservoirs exist mainly as polar layered deposits (PLD), which corresponds to 2-3x10^6 km^3 (Zuber et al., 1998; Plaut et al., 2007). The amount is 20-30 m of global equivalent layer (GEL). Using this value and assuming an efficient fractionation, minimum values of water losses are obtained as 35 - 85 m and 5.7-41 m (GEL) in Stage-1 and Stage-2, respectively. The sum of these values yields 82-120 m GEL for the total water reservoir at 4.5 Ga.

Our minimum estimate of the initial water reservoir are consistent with the amount of ocean (~150 m) provided by Vastitas Borealis Formation (VBF) (Carr and Head, 2003). Also, minimum estimates of the water losses in Stage-1 and Stage-2 are close to the values obtained by simulations of oxygen escape (Lammer et al., 2003; Terada et al., 2009). The significant water loss during pre-Noachian ($>$ 4.1 Ga) might have been caused by the intense atmospheric escape due to the solar wind without magnetic protection at the first ~150 Myr of the Mars history (Terada et al., 2009) before the time when Mars obtained ancient magnetic field.

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