Incorporation of nebular water into the Earth's mantle

JIBAMITRA GANGULY[1], ABU ASADUZZAMAN[2], KRISHNA MURALIDHARAN[3]

[1]Department of Geosciences, University of Arizona, USA, ganguly@email.arizona.edu
[2]Department of Life and Physical Sciences, Lincoln University, USA, asaduzzaman@email.arizona.edu
[3]Department of Materials Science and Engineering, University of Arizona, USA, krishna@email.arizona.edu

The D/H ratio of melt inclusions in mantle derived olivine, δD as low -218 ‰, suggests a primordial source of terrestrial mantle water (1). However, the protosolar nebula was much more depleted in D (δD = -870 ‰). A popular model to explain the D/H of earth is the delivery of water by 2 ± 1 wt% carbonaceous chondritic materials (CCs) (2) that have D/H comparable to the earth. However, this model suffers from several problems (3, 4, 5). Furthermore, it is unclear how the CCs attained its isotopic signature. Using quantum chemical and thermodynamic calculations, we show that a considerable amount of water could have accreted from the solar nebula via chemisorption mediated hydroxylation of olivine surfaces and near surface domains. We have also calculated D-H fractionation between the solar nebula and the chemisorbed hydroxyls as f(T). The results show that the observed D enrichment in the earth could have been achived by equilibration with the solar nebula at ~300 K during the accretion process. The inverse correlation of D/H ratio of hydrocarbons in CCs with the H-C bond strength (6) strongly suggests isotopic fractionation. Our calculations show that the observed D/H ratios could have been attained by equilibration with the nebula at 175-200 K. Overall, the D/H ratio vs. T relation for H-Cs is quite similar to that calculated for chemisorbed hydroxyls and structural water in nominally anhydrous minerals, thus explaining the similarity between the D/H ratio of earth, CCs and the asteroid Vesta. Our results do not preclude partial contribution by CCs and other sources/mechanisms to the water budget of the earth (2). However, it substantially reduces the required amount of CCs and thus resolves the problem with the overestimation of highly siderophile element budget resulting from mixing with the CCs (4). Since the D-H fractionation is a f(T), we predict variability in the D/H ratio of the earth's mantle resulting from variation of temperature during accretion.

(1) Hallis L. J et al. (2015) Science 350, 795-797; (2) Marty B. (2012) EPSL, 313-314, 56-66; (3) Halliday A. N. (2013) GCA 105, 146-171; (4) Sharp Z. (2016) Chem Geol 448,137-150; (5) Fischer-Gödde M & Kleine T (2017) Nature 541, 525-528; (6) Remusat et al. (2006) EPSL 243, 15-25