EVIDENCE FOR A NEBULAR CONTRIBUTION TO THE EARTH'S WATER INVENTORY Z.D. Sharp[1] [1]Dept. of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM, 87131, zsharp@unm.edu, and Center for Stable Isotopes, University of New Mexico, Albuquerque, NM 87131

Introduction: The formation of our solar system is a fairly well understood process. It is thought that a dense interstellar molecular cloud collapsed to form the protoplanetary disk ([e.g.,1] at 4.568 Ga [2]. In the next 10^5 years, dust accreted in the presence of a thick nebular gas to form kilometer-sized planetesimals, [3]. These then coalesced into larger 'planetary embryos' (10^{25}-10^{26} g) over the next 10^5-10^6 years [4], ultimately merging to form the terrestrial planets in 10^7 to 10^8 years [5]. The culminating large impact, known as the 'Giant Impact' [6], was the collision between a Mars-sized body and Earth which resulted in the Earth-Moon system at ~60-100 Ma after the beginning of the solar system [7, 8]. Additional smaller impact events continued for close to 10^9 years [9]. Two 'identified' events include a 'late veneer' at about 100 Ma after solar system formation [10, 11] and a later series of impacts known as the 'Late Heavy Bombardment' occurring at ~3.85 to 4.0 Ga [12, 13].

A solar nebular source of 'water' for Earth. The above scenario is consistent with astronomical observations, numerical simulations, and geochemical constraints from meteorites and Earth. Outstanding to our understanding of planetary formation is the crucial question regarding the source and timing of delivery of volatiles to Earth and other differentiated bodies. While straightforward models for condensation from the planetary nebula describe the concentrations of lithophile elements, the most volatile elements, including hydrogen, cannot be modeled in this way. The source(s) and quantity of hydrogen on Earth are not well known, with a number of competing mechanisms having been suggested.

The terrestrial planets are thought to have formed inward of the 'ice line', eliminating the possibility of incorporation of solid H_2O into the growing planetesimals. A number of possibilities for the sources of water have been proposed including the following: 1) Adsorption of water on early dust particles [14]; 2) incorporation of wet planetessimals [15] 3) incorporation of late cometary material or 4) addition of carbonaceous chondrite-like material during the 'late veneer' bombardment [11]. Here, I propose that a siginficant proportion of Earth's hydrogen may have been added directly from the solar nebula. Such a source would have a D/H ratio different from the present value. This discrepancy can be resolved by the process of H_2 loss due to later hydrodynamic escape [16, 17].

The following scenario is envisioned: 1) During early planetary formation, a thick nebular atmopshere exists around Earth-sized bodies [18]. The atmosphere consists mostly of H_2, although some H_2O would be present. 2) The blanketing effect of the atmosphere results in formation of a magma ocean [19]. 3) H_2 and H_2O gas dissolve into the magma ocean. The low D/H ratios of the solar nebula gas would result in a D/H ratio of the proto Earth that is not consistent with measured D/H ratio of the Earth, Moon and Vesta. However, as the magma ocean crystallizes, and degassing occurs, 4) loss of H to space during intense EUV radiation not only raises the D/H ratio of the remaining volatiles to the 'normal' measured values of differentiated bodies, but it also raises the $f(O_2)$ value of the Earth to its present value of *FMQ* [17].

We have measured the solubility of H_2 gas in haplobasalt at 1 bar. Hydrogen gas was passed over a graphite crucible filled with synthetic basalt (courtesy of A. Bell, UNM) heated with an induction furnace to ~1350°C. Our 1 bar solubility measurement of 4 ppm wt H_2 is slightly less than the extrapolation of the higher pressure results of Hirschmann et al. [20]. The α value for H_2 (g) - H dissolved in basalt glass (at 1350°C) is 0.75. The quantity of dissolved H_2 into a magma is a direct function of a $f(H_2)$ of the atmosphere. A 10 bar H_2 atmosphere would add one ocean equivalent H_2O to the Earth. An atmosphere of 1000 bars [a likely upper limit –18] would add 100 ocean equivalents to the Earth.

The D/H ratio of Earth has been modified from its initial value by loss of H to space by hydrodynamic escape [21]. We have considered loss of H_2 to at atmosphere using the α value determined in this study between basalt and H_2 gas, the loss of H to space assuming Graham's law diffusion, oxidation of H_2 to H_2O in the planetary atmosphere and then redissolution back into the magma and incorporation of H_2 into the core ($\Delta D_{H2\ -\ FeH}$ = 60‰ from [22]). Depending on the amount of material lost to space, the δD value of the mantle could be raised by well over 100‰ by loss of 20-40% H_2 to space. Such a loss of H_2 also explains the high $f(O_2)$ value of the Earth's mantle.

If the above scenario is correct, then samples of differentiated bodies that have not undergone significant H_2 loss should retain their eary low δD values. In fact, samples from Vesta [23], Moon [24] and most recently Earth [25] all have δD values as low as -250‰, less than the range of typical carbonaceous chondrites [26]. These low D/H ratios are consistent with at least part of the differentiated bodies' water having come from a solar nebular reservoir. They also explain the high $f(O_2)$ of Earth. A loss of 1/4 ocean-equivalent water as H_2 is sufficient to raise the $f(O_2)$ to the present day *FMQ* buffer. In contrast, addition of water from late accretion will have no appreciable effect on $f(O_2)$ *unless* it is followed by significant H_2 loss to space, which would, in turn, raise the δD value significantly above those of carbonaceous chondrites. Given these strong fractionation effects, it is possible that the initial D/H ratio of Earth was far lower than today and nebular water needs to be considered as an possible component.

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