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chemistry of Martian meteorites (Dreibus and Wanke 1987) and from dynamical modeling of planet formation and isotopic studies (e.g., Lunine et al., 2003). Estimates of the amount of water originally accreted range up to an amount equivalent to a global layer of many tens of kilometers deep. But we just saw that the core formed very early, within no more than 20 million years of the start of accretion. During global differentiation to form the core water would have outgassed, possibly forming a steam atmosphere (Matsui and Abe, 1987), and would have reacted with metallic iron in the originally accreted material to form FeO and H, which would have outgassed (Dreibus and Waenke, 1987). The early atmosphere probably suffered a massive loss of hydrogen by hydrodynamic escape driven by extreme ultraviolet radiation from the early Sun (e.g., Pepin, 1994; Zahnle et al., 1988). The outflow of hydrogen to space would have carried other atmospheric gases with it, including CO_2, N_2, and most of the noble gases lighter than xenon (Pepin, 1994). The hydrodynamic phase was over within 200 MY of the start of accretion at which time the Sun's output of extreme ultraviolet was no longer sufficient to drive the flow. A major uncertainty is the extent to which water incorporated into the planet during accretion was retained after these massive degassing and atmospheric losses. It has been argued that most of the early water was lost and that most of the present inventory of water on both Earth and Mars was delivered mainly by comets and carbonaceous chondrites late during heavy bombardment after the hydrodynamic phase was over (Chyba, 1990; Owen and Bar-Nun, 2000). Dreibus and Waenke (1987) argued against addition of such a late volatile-rich veneer for Mars because of the lack of excess siderophiles in Martian meteorites. However, there are other plausible explanations for the lack of a siderophile anomaly, such as a poorly mixed Martian mantle due to a lack of plate tectonics (Carr and Waenke, 1992). D/H enrichment of water in Martian meteorites provides some support for late cometary additions since comets have a higher D/H ratio than asteroids, the source of most of the original accreted materials (Baker et al., 2005); however, high D/H ratios also result from preferential loss of H from the upper atmosphere.

After the hydrodynamic phase was over, the atmosphere would have been supplemented by further outgassing from the interior and depleted by various processes including erosion by large impacts (Melosh and Vickery, 1989) and losses by weathering to form carbonates and other minerals. Losses from the upper atmosphere would have been largely restricted to hydrogen until the magnetic field turned off, which is estimated to have been around 4 Gyr ago (Connerny et al., 1999). After this time, impingement of the solar wind on the upper atmosphere would have resulted in enhanced losses of heavier species such as O and N as a result of ion pickup and sputtering. These losses continued for the rest of the planet's history (Jakosky and Jones, 1997).

Preferential loss of hydrogen over deuterium from the upper atmosphere can, in principle, be used to estimate the size of the water reservoir that was originally present in the Noachian and exchanging with the atmosphere ever since. Lammer et al. (2005), for example, estimate that 3.5 Ga ago this reservoir was the equivalent of 35–115 m spread over the entire planet. Unfortunately we have no way of estimating the size of the reservoir, such as deep ice and groundwater, which is not