Volatility, gravitational escape, and abundance of lunar water

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In a series of landmark papers, Hauri and Saal (Nature and Science, 2008-2013) presented data on water concentrations measured in melt inclusions in olivine from the pyroclastic 'orange' and 'green' glasses that compare with contents in terrestrial MORB. A number of moderately volatile elements such as F, Cl, and S have been outgassed from lunar basalts, but this observation is not in itself evidence that water was present. So far no conclusive evidence has been found that other types of lunar basalts ever contained such high water contents. Whether high water contents reflect the processes associated with pyroclastic glass emission rather than being an indication that the lunar mantle is wet is therefore a valid question. Comparing elemental abundances in the Moon and the Earth requires addressing the relative importance of gravitational loss from the disk and intrinsic volatility, which is the topic of the present talk. Gravitational loss should strongly fractionate elements with comparable chemical properties and different atomic masses, typically halogens and alkali elements, among themselves, which is not what current compositional models of the Moon show. The proto-lunar disk lacked hydrogen, which makes significant hydrodynamic entrainment unlikely. Given the very fast accretion of the Moon, Jean's loss from the exobase and up must have remained a minor phenomenon. Hauri's (EPSL, 2015) pattern of lunar abundances based on Lodders' (ApJ, 2003) H-dependent volatility scale is extremely chaotic. In contrast, the pattern based on Albarede *et al.*'s (MAPS, 2014) bond-energy scale is smooth for both the Moon and the Earth. What makes the latter scale useful is the possibility of inter/extrapolating the abundance of a particular element from those of neighboring elements. This plot predicts that the abundance of water in the Moon is in the sub-ppm range. The observed level of depletion of moderately volatile elements in the Moon with respect to BSE such a F and Rb (1/10), Zn and I (1/100), makes the postulated nearly terrestrial H abundance unlikely. This conclusion is consistent with the conclusion reached from Cl isotopes (Sharp *et al.*, Science, 2010). The lingering puzzle is why Earth and Moon received such different volatile endowments. Embedded in this question are the modes and extent of late veneer delivery and the age of the lunar impact.