WATER IN THE MOON: IMPLICATIONS FOR LUNAR FORMATION AND GEOCHEMICAL EVOLUTION.
G. Jeffrey Taylor, Hawaii Inst. of Geophys. and Planetology, UH NASA Astrobiology Program, 1680 East-West Rd., Honolulu, HI 96822; gjtaylor@higp.hawaii.edu

Introduction: Recent lunar sample analyses of pyroclastic glasses and apatite crystals in igneous rocks and breccias [1–5] have demonstrated the presence of water in the lunar interior. This overturned a four-decades-old conclusion that the Moon was anhydrous. This important discovery has implications for lunar origin and differentiation, and the ultimate sources of water to Earth and Moon. I summarize key issues here.

What is the water content of the bulk Moon? Although the Moon clearly has vastly more water than thought previously, its bulk water content is not known. Estimates range from tens of ppm based on pyroclastic magmas [1] to as low as 0.1 ppb determined on from fractionation of Cl isotopes [6]. The data imply that water is heterogeneously distributed in the Moon.

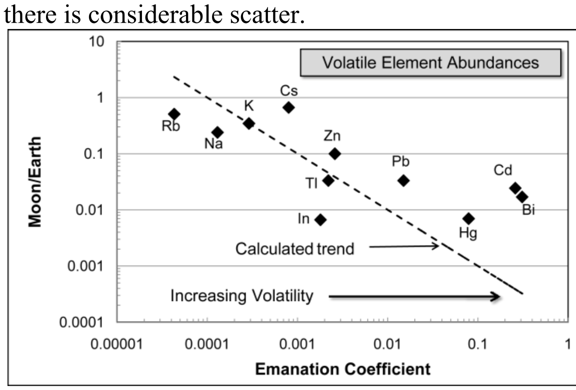
Water does not appear to be correlated with REE: Water behaves as an incompatible element during igneous processes, until low pressure allows it to escape from magma, so it ought to correlate with REE [7]. No such correlation is evident.

How did picritic glasses acquire water? The hundreds of ppm of water apparently present in the picritic magmas that produced pyroclastic eruptions [1] either came from source regions containing sufficient water (tens of ppm) or acquired it from hydrous regions as the magmas ascended to the surface. Magma ocean models [7] indicate that initial cumulates in the depth range (300-500 km) of picritic source regions contained only a few ppm or less if the initial lunar water content was ≤100 ppm. This has implications for lunar differentiation (nature of magma ocean turnover), magma interaction with rocks rich in incompatible-elements and/or water, and whether water was added to the Moon after it formed.

Does the Moon have inherently high D/H? Greenwood et al. [5] show that δD in lunar apatite crystals ranges from about -200 to 1000, with most values being clearly elevated compared to terrestrial D/H. It is critically important to determine if the high D/H in the lunar samples represents fractionation during loss of water from magmas or from the protolunar disk, or whether it represents the isotopic composition of bulk lunar water. If the latter, it could be a fingerprint of the objects that delivered water to the Moon [5].

Did the Earth and impactor have water when the moon-forming giant impact happened? A fundamental issue in planetary science is how and when Earth and the other terrestrial planets obtained their water [e.g., 8]. It is feasible to add water to both Moon and Earth after they formed, but it is also likely that Earth contained at least some water by chemisorption onto dust grains that ultimately accreted to form the Earth, and probably the moon-forming impactor [8].

How much water and other volatiles were lost from the protolunar disk? Desch and Taylor [9] suggest that the Moon retains about 2% of the water initially in the Earth and impactor. If the Earth and impactor had 500 ppm to begin with [10], lunar bulk water would be 10 ppm. Other volatiles would also be lost, in proportion to their solubility in the molten region of the protolunar disk. Loss of volatiles during volcanic eruptions can be quantified by an "emanation coefficient" [11]. Using this as a guide, lunar/terrestrial bulk abundances of volatile elements [12-13] can be compared to their emanation coefficients and to predicted abundances based on those coefficients. Abundances show a broad correlation with volatility, but there is considerable scatter.



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