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Why there is water on the Moon but apparently none on main-belt basaltic asteroids

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Abstract

Implantation of solar wind particles on the Moon may produce hydroxyl through combining with the oxygen in the silicate minerals, which then may evolve into water through a combinative process that is highly temperature-dependent, occurring exponentially quicker with increasing temperature, and preferentially accumulating in anorthositic terrain versus basaltic mare terrain. In contrast, the surfaces of silicate asteroids in the main belt are significantly cooler than the Moon reducing, and possibly preventing, water formation through this combinative process. Additionally, any resulting water would likely be less stable on basaltic silicate asteroids than a comparable lunar highland surface.

1. Introduction

Water and hydroxyl have been discovered on the Moon through the presence of their fundamental infrared bands near 3 μm [1,2,3]. Various origins including internal, cometary, and solar wind H^+ implantation have been proposed as possible sources [e.g. 4, 5], with a solar wind origin being investigated by many researchers and experiments both supporting and casting doubt on a solar wind process [e.g. 6, 7]. If solar wind implantation does result in hydroxyl and subsequently water on the Moon, then it may be expected that solar wind generated water would be produced on airless bodies throughout the solar system, such as main belt silicate-rich asteroids. However, main belt asteroids have been observed at high signal-to-noise in the infrared with no 3-μm band indicative of water being detected [e.g. 8 and Figure 1].

Thus, if solar wind bombardment is creating hydroxyl on these main belt silicate bodies, the abundance is sufficiently small to not induce a large 2.8-μm band and very little if any water subsequently forms, resulting in no detectable absorption band at 3 microns. The lower temperature of main belt asteroids and basaltic composition may offer at least a partial explanation for this difference between silicate main belt asteroids and the Moon.

1.1 Formation process of OH and H_2O

Hydroxyl formation. Solar wind proton bombardment would form hydroxyl by breaking mineral bonds and scavenging oxygen from the surface [e.g. 9]. The characteristics of lunar surface materials strongly influence the abundances of the resulting hydroxyl and subsequent water that may be stored there. For instance, soil maturity (especially the accumulation of glass) may inhibit the adsorption of hydroxyl and water because of the naturally-passivated nature of glass [e.g. 10]. Fresh polar highland soil adsorbs water whereas mature highland soil primarily retains the more stable hydroxyl [11]. Mineral composition may also be a factor; more hydroxyl is adsorbed onto highland soil than on mare soil, possibly because of the crystal structure of the feldspars (tectosilicates) in the highlands. By way of comparison, Vesta is dominated by basaltic flows analogous to those in the lunar maria (Ca-rich feldspar, pigeonite pyroxene, and glass), though the compositions of other asteroids vary widely. If composition and mineralogy significantly control hydrogen adsorption, then basaltic regions on Vesta, too, would be predicted to have only a shallow 2.8-μm band as seen in lunar mare – assuming that other factors (temperature and turnover rate) are equal. However, there are also large regions of Vesta where the surface is likely dominated by coarse-grained pyroxene-rich rocks, probably representing exposed plutonic rocks. If water adsorptivity relates to the amount of crystals (vs. glass) in the regolith, then

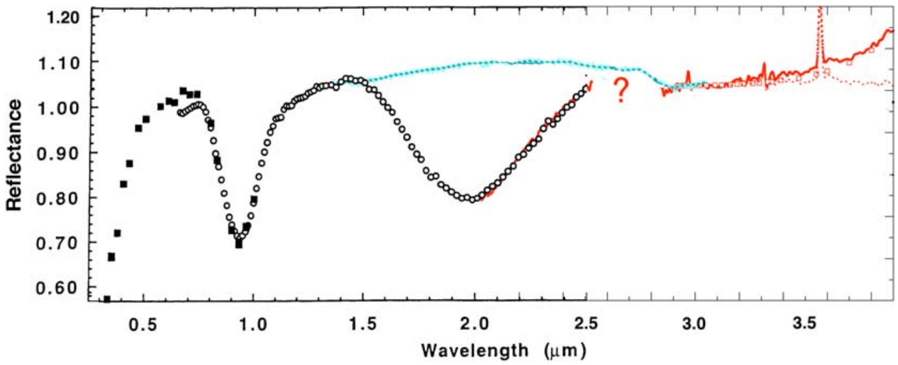

Figure 1. Telescopic spectra of Vesta in the 2 – 4-μm region shown in red (mod. [8], Fig 1) are not sensitive to a shallow 2.8-μm band such as occurs in mature polar highland soils on the Moon as shown for the continuum removed spectrum from M3 in blue (adapted from [1], Fig. S2). Vis-SWIR spectrum of Vesta (mod [14]) in black provides context and overlap with the 2-4-μm data.

deeper hydroxyl bands could be found in such mineral-dominated regions.

Water formation. Water (H_2O) does not necessarily follow from the presence of hydroxyl (OH). The production of water from hydroxyl most likely occurs as the result of multiple hydroxyls combining or hydroxyls combining with adjacent implanted protons [9,12-14] in a highly temperature-dependent reaction as described by the Polanyi-Wigner equation:

$$\frac{d\theta}{dt} = -\nu \cdot \exp\left(-\frac{\Delta E_{des}}{RT}\right) \cdot \theta^n ,$$

with θ as the adsorbate coverage at time = t, ν the frequency factor, ΔE_{des} the energy of desorption, R the ideal gas constant, T the temperature at time = t, and n the order of desorption. Because two molecules are required for this reaction, it would be a second order reaction with a rate dependent on the amount of adsorbate (hydroxyl) squared. We term the formation of water by this process as 'combinative desorption' because the hydroxyl was supplied by implantation of solar wind hydrogen and not (likely) by the prior adsorption and dissociation of water onto surface, which is the source for adsorbed hydroxyls under terrestrial laboratory conditions. Furthermore, the water that results is less thermally stable than the hydroxyl, and would likely quickly desorb [13].

Conclusions

If solar wind bombardment forms hydroxyl on silicate asteroids, then such accumulation may be similar to that for hydroxyl in lunar mare terrain at high –latitudes, sufficient to induce only a few percent band depth in the infrared. Additionally, the cool surfaces of main belt asteroids will likely reduce and possibly prevent the subsequent formation of water from hydroxyl, potentially explaining the lack of water inferred from the absence of a 3-μm band on asteroids such as Vesta.

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