



Redistribution of lunar polar water to mid-latitudes and its role in forming an OH veneer



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ABSTRACT

We suggest that energization processes like ion sputtering and impact vaporization can eject/release polar water molecules residing within cold trapped regions with sufficient velocity to allow their redistribution to mid-latitudes. We consider the possibility that these polar-ejected molecules can contribute to the water/OH veneer observed as a 3 μm IR absorption feature at mid-latitudes by Chandrayaan-1, Cassini, and EPOXI. We find this source cannot fully account for the observed IR feature, but could be a low intensity additional source.

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1. Introduction

Chandrayaan-1's M-cubed instrument discovered the presence of surficial OH and water veneer on the Moon (via the 2.8–3 μm IR absorption feature) that progressively intensified from ~ 60 – 70° latitude to extreme poleward locations in both the northern and southern hemispheres (Pieters et al., 2009; McCord et al., 2011). A similar signature was also detected in IR instruments onboard Deep Impact and Cassini (Sunshine et al., 2009; Clark et al., 2009), and all three observational sets were reported simultaneously in late 2009, presenting a convincing cross-correlated case for the water veneer. A number of ideas have been put forth to account for the surficial water, including manufacturing of water via the solar wind and possibly the presence of water in nominally anhydrous mineralogy (Housley et al., 1974; Pieters et al., 2009; Dyar et al., 2010; McCord et al., 2011). However, the source of the mid-latitude water and OH veneer is still unknown.

In contrast, some of the sunlight-sheltered cold polar craters are confirmed to have accumulations of water. Recent LCROSS findings (Colaprete et al., 2010; Schultz et al., 2010) suggest that Cabeus crater contains large amounts of water ice (~ 5 – 10% by weight). However, Lunar Reconnaissance Orbiter neutron spectrometry indicates that not every substantial polar crater appears to have significant H-bearing mineralogy (Mitrofanov et al., 2010). FUV albedo also suggests that surficial water frost may also be present in some of the polar craters (Gladstone et al., 2012). Any polar icy regolith is exposed to harsh space environment that includes micro-meteoroid impacts and solar wind sputtering; processes that can energize and transport molecules in an extended region about the pole.

Given the proximity of the known polar water source to the locations of the mid-latitude veneer, an obvious question is whether the icy regolith regions within polar craters can be a source for the thin water/OH veneer at lower latitudes (~ 70 – 85°); polar crater water being released by space environmental erosion processes (impact vaporization, sputtering, etc.). In essence, we revisit the idea that lunar ices are eroded (Arnold, 1979; Lanzerotti et al., 1981) to contribute to the exosphere (Morgan and Shemansky, 1991) and adjacent surface. We thus will test the

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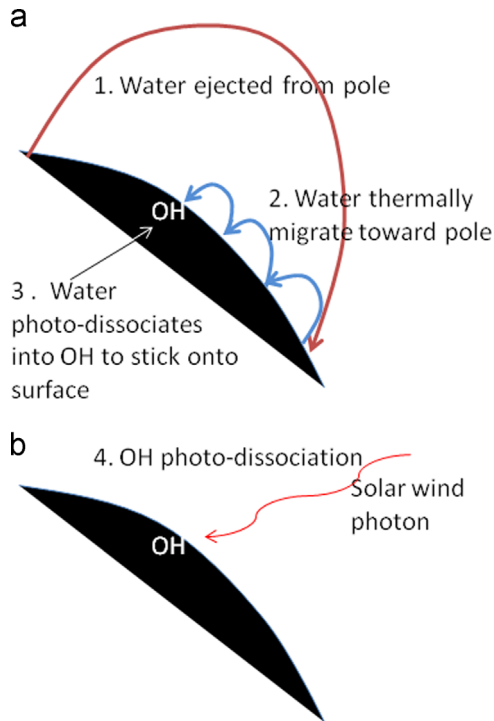


Fig. 1. An illustration of the process in creating the OH and water veneer.

hypothesis that regions containing icy-regolith at the poles are a water ‘fountain’ source ejecting water molecules over an extended latitude range.

Fig. 1 illustrates the concept. In the polar region, environmental processes like impact vaporization and sputtering release water molecules from the cold trap. The water molecules have sufficient kinetic energy to be transported to mid-latitudes, where they land on a warm surface and thus have a very short residency time. They undergo thermal migration back toward the pole in ballistic ‘hopping’ trajectories, as illustrated in Fig. 1a (Crider and Vondrak, 2000). However, the photo-dissociation time for water is less than the polar migration time and thus over 90% of these molecules should be destroyed before their migration to the pole is complete (Crider and Vondrak, 2000). The resulting photo-dissociated product OH then resides or ‘sticks’ on the surface for an extended period due to its high desorption temperature of > 400 °K (Hibbitts et al., 2011). We thus have the creation of a longer-lived OH surface veneer in tandem with an active water transport cycle. In this concept, we are not creating water, but only considering the redistribution of pre-existing water from the poles to a more extended region in latitude.

2. Models of the lunar polar icy-regolith

Based on the LCROSS (Colaprete et al., 2010; Schultz et al., 2010), Lunar Prospector Neutron Spectrometer (Feldman et al., 1998), and the evolving LRO/LEND observations (Mitrofanov et al., 2010), water molecules are located in the near-surface of some of the permanently shadowed regions at the poles. Mitrofanov et al. (2010) reported that south polar craters Shoemaker and Cabeus have a statistically significant neutron suppression associated with H-bearing minerals. They also reported that neutron suppressed regions may even extend beyond the shadowed crater regions to topside surface.

We present two possible models of the icy regolith within polar craters. As we demonstrate, results from these models can be scaled for other possible icy-regolith concentrations and

configurations. Model 1 considers that the polar craters have a surficial exposed icy-regolith with a mixed ice content at 0.1 wt% fraction. The total area of this exposed surficial ice is assumed to be $A_s \sim 10^{10}$ m². This area is consistent with the floor of Cabeus and Shoemaker craters in south pole. Model 2 assumes a case where a 5 wt% icy-regolith layer is present in these same craters, but now buried at a depth of 3 cm, at 20 cm, and 50-cm. Comparison of fast and epithermal neutron levels suggest the presence of a water-free/dry top layer over buried icy regolith; this layer being possibly of 10’s of centimeters in thickness (Feldman et al., 1998).

3. Model 1: energization processes and water release at the crater floor

We consider four processes that have the ability to remove water molecules from an icy-regolith: solar wind ion sputtering, electron stimulated desorption (ESD), photon stimulated desorption (PSD) and impact vaporization. All four apply to Model 1 but only the last, impact vaporization, applies to Model 2.

3.1. Sputtering

For surface-incident solar wind ions, the sputtering yield for a 1 keV proton on an ice-substrate is near 0.5 molecules per ions (Johnson, 1990). We now consider the yield for ice mixed with regolith at 0.1%. We apply equation 3.22 of Johnson (1990) to derive a weighted sputtering yield for such a mixture, which is $Y \sim 10^{-3}$ water molecules per incident solar wind ion. The nominal solar wind ion flux incident at the exposed surface above 85° latitude is $< 2 \times 10^{11}$ /m²-s. However, the situation is more complicated for ion inflow into sheltered polar craters like Shoemaker (Farrell et al., 2010; Jackson et al., 2011; Zimmerman et al., 2011). Plasma models suggest that the near-horizontally flowing solar wind ions eventually get diverted into larger polar craters (10’s of km in diameter) via plasma ambipolar E -fields. However, the instantaneous ion inflow varies as a function of location within a crater (Farrell et al., 2010; Jackson et al., 2011). Defining the ratio of ion flux to nominal solar wind ion flux as F/F_{sw} , this ratio is

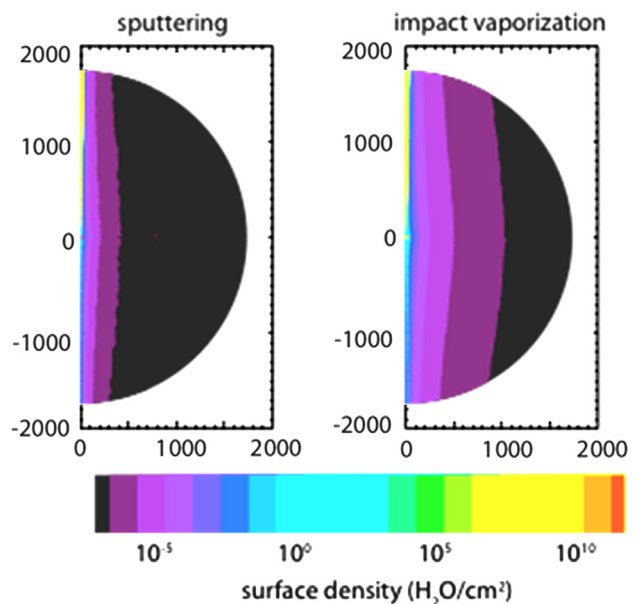


Fig. 2. Monte Carlo simulation of surficial water from a polar source emitting at a flux of $S \sim 10^{19}$ waters/s via sputtering and impact vaporization. Shown is a polar view of the surficial water over the dayside hemisphere. Note that water accumulates near the terminators.

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