Calculated Thicknesses of Volcanically Derived Water Ice Deposits at the Lunar Poles. D. H. Needham[1], M. Siegler[2], S. Li[3], and D. A. Kring[4], [1]Marshall Space Flight Center (MSFC), 320 Sparkman Drive, Huntsville, AL 35805, debra.m.hurwitz@nasa.gov, [2]Southern Methodist University, Dallas, TX, and Planetary Science Institute, [3]University of Hawaii at Manoa, Honolulu, HI, [4]SSERVI Center for Lunar Science and Exploration, LPI, Houston, TX.

Introduction: The lunar polar regions are known to preserve hydrogen-bearing materials [e.g., 1-6], but the lateral and vertical distribution of these materials remains unclear. The distribution of these materials is dependent on the age and mechanism of delivery of volatiles to the Moon, as well as the migration process of the volatiles to the lunar poles. The primary sources for these H-bearing materials include the solar wind [7], asteroids and/or comets [8], and ancient volcanic eruptions [9]. Recent work investigated the mass of volatiles released during ancient lunar volcanic activity, and results indicate that if only 0.1% of the released volatiles migrated to the lunar poles, volcanic sources could account for all H-bearing materials currently observed at the lunar poles [9]. If these volatiles, which were released primarily during peak lunar volcanic activity ~3.5 Ga, migrated to the lunar poles in a single pulse, their distribution would be expected to form a distinct horizon deep in the lunar substrate (~6-10 m deep if regolith generation is similar to that on the mare [10,11]). This would be in contrast with volatiles delivered in sporadic pulses associated with asteroid or comet impacts, which may form discrete patches of volatile-rich materials, and with volatiles delivered by the solar wind, which would be evenly distributed throughout the regolith (Fig. 1). The current work aims to gain further insight into the vertical distribution of lunar polar volatiles by calculating the deposit thicknesses expected for volcanically derived H_2O upon initial delivery to the lunar polar regions ~3.5 Ga.

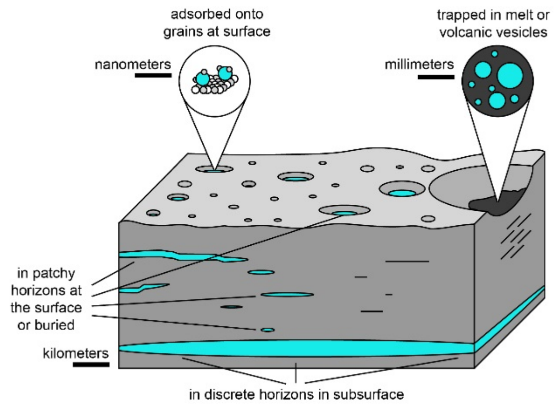

Fig. 1: Schematic of volatile distributions in the lunar subsurface. Volatiles delivered at constant, low rates would be expected to be distributed more diffusely and homogeneously than volatiles delivered in sporadic pulses or in one significant pulse early in lunar history.

Methodology: To estimate the initial thickness of H_2O, we take the previously reported mass of volatiles released during volcanic eruptions [9], convert to volume, and divide by the area of the deposition region. We perform this calculation for three separate regions (Fig. 2), including (1) current permanently shadowed regions (PSRs) identified in Lunar Orbiter Laser Altimetry data [12], (2) regions with current exposures of surface water ice identified in Moon Mineralogy Mapper

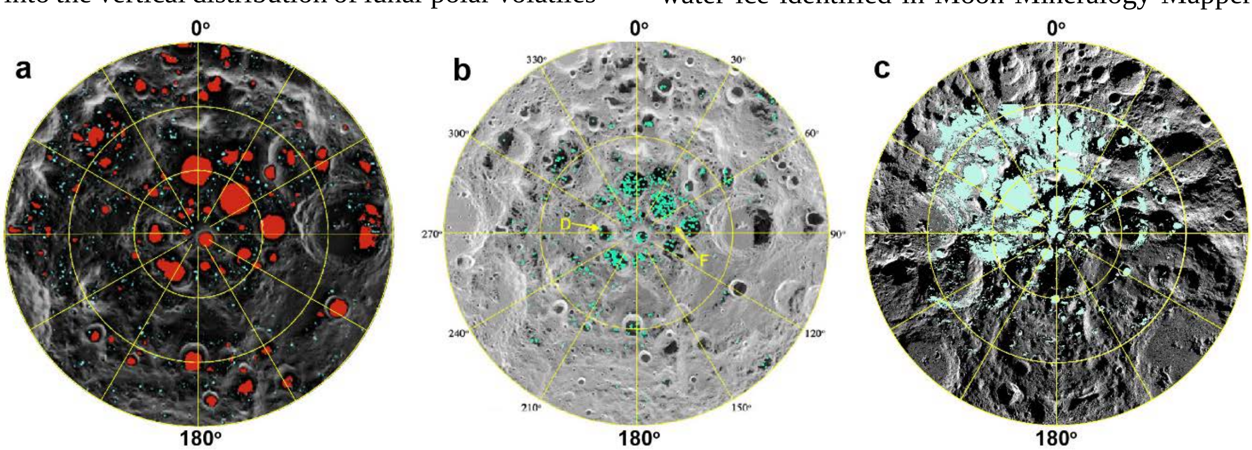

Fig. 2: Regions near the South Pole where (a) permanently shadowed regions have been identified in LOLA data [12], (b) surface water ice has been detected using M^3 spectra [13], and (c) water ice would have been stable in the upper 2.5 m of regolith prior to True Polar Wander [14]. The areas of these regions are used to calculate the maximum deposit thickness of water released during lunar volcanic eruptions [9].

Table 1: Calculated maximum thickness of volcanically derived water in polar regions

Pole	Region	Mass H_2O (kg) [9]	Area (km^2)	Area Reference	Thickness (m)
SP	Current PSRs	2.40E+14	16055	[12]	15
SP	Observed H2O spectra	2.40E+14	115	[13]	2100
SP	Polar Wander Present Stable to 2.5 m	2.40E+14	90884	[14]	2.6
SP	Polar Wander Past Stable to 2.5 m	2.40E+14	82772	[14]	2.9
NP	Current PSRs	2.40E+14	12866	[12]	19
NP	Observed H2O spectra	2.40E+14	35	[13]	6900
NP	Polar Wander Present Stable to 2.5 m	2.40E+14	94565	[14]	2.5
NP	Polar Wander Past Stable to 2.5 m	2.40E+14	86285	[14]	2.8

spectral data [13], and (3) regions where water ice would have been stable to depths of ~2.5 m during a distinct obliquity early in lunar history [14]. We assume the volatiles would be evenly distributed across these regions of interest near the lunar poles.

Results and Discussion: Our calculations (Table 1) indicate that, at the Moon's current orientation, water vapor released during lunar volcanic activity ~3.5 Ga would have formed an initial layer ~15 m thick across the surfaces of the south polar PSRs and ~19 m deep across the north polar PSRs. These regions represent a minimum area where water ice is currently stable at the lunar surface. However, we know from orbiting instruments that H-bearing materials are currently present in some form beneath the surface to at least a depth of 2.5 m [1-6]. This substantially expands the region of water ice stability [14], reducing the thickness of the initial deposits to ~2.6 m in the south polar region and ~2.5 m in the north polar region. These calculations are based on the simplified assumption that there was no volatile loss to space during the eruptions or during migration to the poles; therefore, these reported values represent maximum thickness estimates.

Recent investigations noted that H-bearing deposits at depth are not centered about the lunar poles, potentially indicating the Moon was not always oriented at its current obliquity [14]. If the lunar pole was re-oriented so the H-bearing materials are centered about the poles, the region of water ice stability to depths of 2.5 m is slightly reduced in area and the thickness of the initial deposit would have been ~2.9 m in the south polar region and ~2.8 m in the north.

Although we have known for at least 20 years that H-bearing materials are stable in some form beneath the surface at the lunar poles, recent work has directly confirmed the presence of water ice at the surface of select PSRs [13]. It is highly unlikely that volcanically derived volatiles were preferentially deposited at only these locations, which would have resulted in a deposit ~2 km thick in the south and ~2 km thick in the north. While volcanically derived volatiles may account for some of these deposits, surface water ice deposits appear to be more centered about the lunar poles than the H-bearing deposits located at depth (e.g., Fig. 2b). This may indicate that surface ice deposits are products of recent and ongoing influxes of volatile-bearing materials from the solar wind, asteroid and comet impacts, and internal volatile degassing, whereas the deeper, off-center ice deposits are products of influxes of material from ancient impacts and volcanic eruptions.

Regardless of origin, water ice deposits would have been subjected to removal by impacts, and to burial and mixing during regolith formation, resulting in a thinner deposit with a current depth on the order of 6-10 m [10,11] that is overlain by more diffuse mixtures of H-bearing volatiles and regolith. An exploratory surface mission to the lunar polar regions would verify the depth, composition, and concentration of these volatiles.

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