EPSC Abstracts
Vol. 13, EPSC-DPS2019-890-1, 2019
EPSC-DPS Joint Meeting 2019

EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

Impact Gardening Ice on Mercury and the Moon

Emily Costello (1,2), Rebecca Ghent (3) and Paul Lucey (2)
(1) University of Hawaii, Honolulu, HI, USA (ecostello@higp.hawaii.edu), (2) Hawaii institute of Geophysics and Planetology, Honolulu, HI, USA (3) Planetary Science Institute, Tuscon, AZ, USA

Abstract

Impact gardening exposes ice to catastrophic loss and our model results can be used to investigate the age and source of ice deposits on the Moon and Mercury. We interpret model results to conclude that the most recent deposition of ice on Mercury must have occurred no more than 100 Myr ago and that it must have been from a catastrophic source such as a comet impact to outlast intense near-surface gardening. In our investigation of the Moon we find that a deposit emplaced 3.5 Gyrs ago must have been about 10 m thick and that the Moon has never had much greater than 10 m thick ice deposits in the last 3.5 Gyr.

1.Introduction

The Moon and Mercury have regions shielded by topography that are in permanent shadow (PSR). Temperatures in these PSRs are low enough to preserve water ice for geologic time [e.g. 1, 2]. Over time, ice in PSRs is gardened by meteoritic impacts and their secondary fragments. These impacts expose ice to loss. Impacts vaporize ice and mechanical overturn exposes ice that was previously secure at depth to a relatively hostile surface environment. Ice at the surface or near-surface is vulnerable to impact vaporization [3], sublimation [e.g. 1], photolysis [3] and sputtering [e.g. 4]. In this work, we explore the effects of impact gardening on lunar and hermian polar ice deposits in an effort to use impact gardening as a constraint on the source, age and, in the case of the Moon, the initial thickness of polar ice deposits.

1.1 Model

The Costello et al [5] overturn model is analytic and describes the frequency a point at depth is in the overturned volume of an impact crater as a function of time. The model predicts that gardening proceeds to depth following a power law function of time controlled by a Poisson-derived average number of events per interval that controls the number of turns and percent probability, and material parameters that control the size and shape of a crater given an impactor [6] and the magnitude and size distribution of the incoming flux. We include the flux of secondary impacts, which have recently been shown to be important in shaping the surfaces of planetary bodies across the solar system [e.g. 7, 8, 9].

2.Mercury

We model gardening on Mercury using the flux of 1 cm - 100 m objects from Marchi et al. [10] and the secondary impacts they produce in both ice and regolith. Model results show: 1) Hard ice is more efficiently gardened than rocky regolith; 2) Thick or buried deposits are exponentially more durable against gardening than thin or surface deposits, as gardening loses efficiency with depth following a power law; and 3) Over 1 Gyr, gardening does not thoroughly rework the entirety of a 2 m thick ice deposit on Mercury, let alone > 10 m thick deposits.

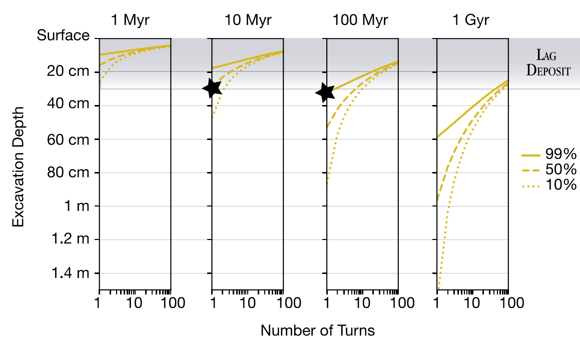

Figure 1: Lag deposits that are 30 cm thick are reworked by impacts over about 10 to 100 Myr on Mercury (stars).

We constrain the age of Mercury's polar ice by calculating the maximum age of thermal lag deposits. Locations exist on Mercury where the surface is darkened but is not radar-bright. It is thought that these locations once harbored ice deposits that has sublimated, leaving behind an albedo-dark thermal lag deposit [11]. If the lag deposits are 10-30 cm thick [11, 12], then we calculate that it would take 10 to 100 Myr of gardening to remove them (Figure 1);

however, these lag deposits are still observable today and have clearly not yet been reworked into background regolith. By virtue of the observable presence of lag deposits today, the ice that sublimed to produce the lag must have been emplaced no longer than 100 Myr ago.

3.The Moon

The thickness of mare regolith of known surface age can inform the unknown thickness of polar ice deposits of the same age. Over the last 3.5 Gyr, impacts have pulverized mare basalts into a regolith layer that is, on average, about 3 m thick. If we assume that overturn in the model transforms mare basalt into regolith, then we can assume that overturn has also affected polar ice deposits to a depth proportional to the greater efficiency of cratering in ice. In Figure 2 we explore how thick an initial ice deposit must have been to have been gardened into the 10% patchy surface frost we see today [13, 14, 15]. Model results indicate that a 3.5 Gyr old deposit would have to have been 5 - 10 m thick (Figure 2). We also interpret from these model results that the Moon has never had much greater than 10 m thick Mercury-like ice deposits over the last 3.5 Gyr. If it had, gardening would not have been able to destroy them and they should still be as radar-bright today.

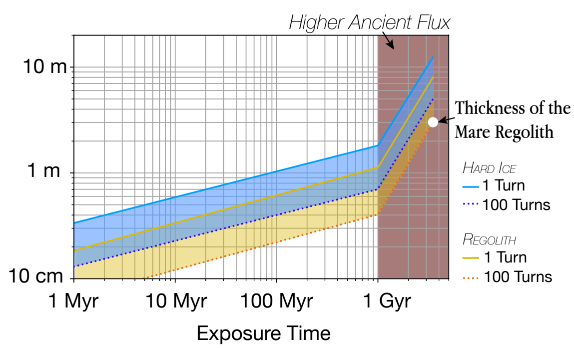

Figure 2: How deep and how old must lunar deposits have been to produce 10% patchiness? The ancient flux simulated using the depth of mare regolith.

4.Summary and Conclusions

Assuming impact gardening exposes ice to catastrophic loss, our model results can be used to investigate the age and source of ice deposits on the Moon and Mercury. We calculate that it takes about 100 Myr to erase lag deposits underlain by regolith; thus, the most recent deposition of ice on Mercury must have occurred no more than 100 Myr ago. In our investigation of the Moon we find that a deposit emplaced 3.5 Gyrs ago must have been about 10 m thick and that the Moon has never had much greater than 10 m thick ice deposits in the last 3.5 Gyr.

References

[1] Vasavada, A.R., et al. (1999). “Near-surface temperatures on Mercury and the Moon and the stability of polar ice deposits.” Icarus, 141(2), 179–193. [2] Paige, D.A., et al. (2010) "Diviner lunar radiometer observations of cold traps in the Moon’s south polar region." *Science.* 330.6003 pp. 479-482. [3] Killen, R. M., et al. (1997) "Mercury's polar caps and the generation of an OH exosphere." *Icarus* 125.1 pp. 195-211. [4] Sarantos, M. (2005), “Ion trajectories in Mercury's magnetosphere”, Ph.D. thesis, Rice Univ., Houston, Tex. [5] Costello, E. S., et al. (2018) "The mixing of lunar regolith: Vital updates to a canonical model." *Icarus,* 314 pp. 327-344. [6] Holsapple, K. A. (1993) "The scaling of impact processes in planetary sciences." *Annu. Rev. Earth Planet. Sci.* 21.1 pp. 333-373. [7] McEwen, A. S., et al. (2005) "The rayed crater Zunil and interpretations of small impact craters on Mars." *Icarus* 176.2 pp. 351-381. [8] McEwen, A. S., & E. B. Bierhaus. (2006) "The importance of secondary cratering to age constraints on planetary surfaces." *Annu. Rev. Earth Planet. Sci.* 34 pp. 535-567. [9] Speyerer, E. J., et al. (2016) "Quantifying crater production and regolith overturn on the Moon with temporal imaging." *Nature,* 538.7624 pp. 215. [10] Marchi, S., et al. (2005) "Flux of meteoroid impacts on Mercury." *Astronomy & Astrophysics,* 431.3 pp. 1123-1127. [11] Paige, D. A., et al. (2013) "Thermal stability of volatiles in the north polar region of Mercury." *Science,* 339.6117 pp. 300-303. [12] Lawrence, D. J., et al. (2013) "Evidence for water ice near Mercury’s north pole from MESSENGER Neutron Spectrometer measurements.” *Science* 339.61 17 pp. 292-296. [13] Hayne, P.O., et al. (2015) "Evidence for exposed water ice in the Moon’s south polar regions from Lunar Reconnaissance Orbiter ultraviolet albedo and temperature measurements." *Icarus* 255 pp. 58-69. [14] Fisher, E. A., et al. (2017) "Evidence for surface water ice in the lunar polar regions using reflectance measurements from the Lunar Orbiter Laser Altimeter and temperature measurements from the Diviner Lunar Radiometer Experiment." *Icarus* 292 pp. 74-85. [15] Li, S., et al. (2018) "Direct evidence of surface exposed water ice in the lunar polar regions." *Proc. of the Nat. Ac. of Sci.*115.36 pp. 8907-8912.