IMPACT GARDENING OF ANCIENT ICE ON THE MOON. E. S. Costello[1,2], R. R. Ghent[3], M. Hirabayashi[4], P. G. Lucey[1] [1]Hawaii Institute of Geophysics and Planetology, University of Hawaii, Honolulu, HI, USA , ecostello@higp.hawaii.edu; [2]Dept. of Geology and Geophysics, University of Hawaii, Honolulu, HI, USA; [3]Planetary Science Institute, Tucson, AZ, USA. [4]Auburn University, Auburn, AL, USA.

Introduction: Impacts are the dominant geologic force acting on the surfaces of solid bodies in the solar system and control all aspects of surface evolution, from generation of the blanket of fine-grained heterogenous regolith to large-scale cratered terrains. "Impact gardening" is the process by which impacts remove material from depth and emplace it on or relatively nearer to the surface. Gardening is also called "mixing" or "overturn" [e.g. 1] because it complicates what might be an otherwise distinct stratigraphy with depth by repeatedly and stochastically inverting the depth-distribution of materials. We have previously developed an analytic impact gardening model that quantifies the degree to which surfaces are pulverized and mixed by impacts in depth and time [2]. In a recent publication [3] we presented a quantitative investigation the surface evolution of ice at the poles of the the Moon and concluded that if the Moon ever had Mercury-like water ice deposits they must have been ancient [e.g., 4, 5], and therefore subject to the orders of magnitude higher impact environment before the Copernican era or buried.

The Model: Our model describes the frequency a with which point at depth is in the overturned volume of an impact crater as a function of time. The word 'overturn' in the context of this model means that material at a sample point has been a component of the ejected volume of a crater, taken from depth and placed on or relatively nearer to the surface than its location pre-impact. The model is based on a concept first presented by Gault et al. [1], and in Costello et al. [2, 3], we reworked the model and included several vital updates: the ability to calculate overturn using a crater production function method that can inform investigations of overturn over longer timescales and to deeper depths and, most importantly, the inclusion of a treatment of secondary impacts.

Results: To investigate the effects of gardening on ice deposits that may be older than the Copernican era, we assume that the thickness of mare regolith of known surface age can constrain 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 about 3 m thick [e.g. 6,7,8,9]. We extend our model for gardening beyond the Copernican era and explore how thick an ancient pure ice deposit must have been to have been completely penetrated by impacts.We assume that a model for $n \geq 10$ overturns at 99% probability, represents the relatively uniform production of 3 m of mare regolith. We then assume that $n \geq 1$ overturns have also affected polar ice deposits to a greater depth proportional to the greater efficiency of cratering in ice (Figure 1).

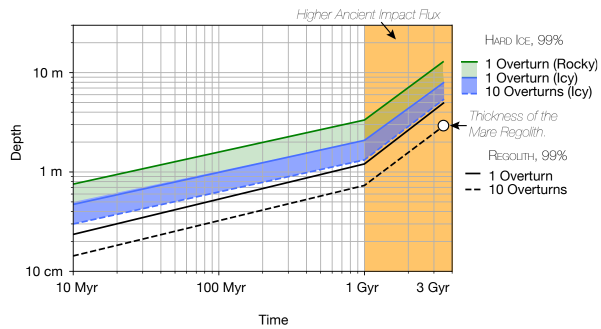

Figure 1: The higher ancient impact flux simulated using the depth of mare regolith. We model impact gardening in regolith and ice for $n \geq 1$ and $n \geq 10$ overturns at 99%. If we assume that between 1 and 10 overturn events in the model transforms mare basalt into regolith, then we can assume that between 1 and 10 overturns have also affected polar ice deposits to a greater depth proportional to the greater efficiency of cratering in ice.

Discussion: The minimum thickness a surface deposit must have been to have been gardened to its interface with the regolith: 4–15 m (Figure 1). The Moon may well have had ancient Mercury-like deposits which have since been so thoroughly mixed with regolith that they are invisible to radar [10]. If instead of extensive Mercury-like surface deposits, ancient lunar ice was buried under meters of regolith [12], and if cohesive ice deposits exist at depths between 1 and 10 m, the surface ice we observe may be the result of secondary impact gardening up-sampling that ice during the Copernican era. We calculate that gardening could efficiently up-sample ice between 1 cm and 3 m deep.

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