

IMPACT GARDENING ON EUROPA: THE DEPTH TO ORGANIC MOLECULES. E. S. Costello^{1,2}, R. R. Ghent^{3,4}, P. G. Lucey¹ ¹Hawaii Institute of Geophysics and Planetology, University of Hawaii, Honolulu, HI, USA, ecostello@higp.hawaii.edu; ²Dept. of Geology and Geophysics, University of Hawaii, Honolulu, HI, USA; ³University of Toronto Dept. of Earth Science, Toronto, ON, Canada; ⁴Planetary Science Institute, Tucson, AZ, USA.

Introduction: Impacts are the dominant geologic force acting on the surfaces of solid bodies in the solar system. "Impact gardening" is the process by which impacts till surface material to depth and scoop up material previously at depth and emplace it on or relatively nearer to the surface. Gardening is also called "mixing" or "overturn" [e.g. 1, 2] because it complicates what might be an otherwise distinct stratigraphy with depth by repeatedly and stochastically inverting the depth-distribution of materials. Our impact gardening model [3] successfully describes the rate at which space weathering products have been shuffled into the top meter of Lunar regolith as observed in the Apollo cores ([4, 5]; Figure 1). The model quantifies the degree to which surfaces are pulverized and mixed by impacts in depth and time and enables a quantitative investigation of the surface evolution of bodies across the solar system.

Europa is an icy moon of Jupiter. Its surface is dominated by water ice and may be astrobiologically significant. Whether we land on or remotely observe Europa it is important that we explore how impact gardening has played a role in shaping the surface and the distribution of organic molecules.

On Europa, a critical constraint on the abundance of biomolecules is radiation. Radiolytic destruction of biomolecules on Europa is essentially surficial, with most energetic particles penetrating only the first few microns of regolith [e.g. 6]. Thermal segregation and sublimation upsets the top microns to millimeters depending on ice albedo [7]; however, impacts interact with ice and organics buried much deeper, exposing previously buried pristine material to the surface and gardening surface-exposed materials to depth. If we wish to discover organic molecules on Europa, the impact gardening rate can tell us how deep we will have to dig, or, if we can not drill, identify craters that are sufficiently large and fresh that they may have exposed pristine material that we can explore remotely.

Approach: In previous work we showed that our analytic model of impact gardening on the Moon calculates a mixing rate consistent with the rate inferred from lunar surface features and the reworking rate calculated from observations of the depth distribution of space weathering products in Apollo cores. Here, we apply the same approach to

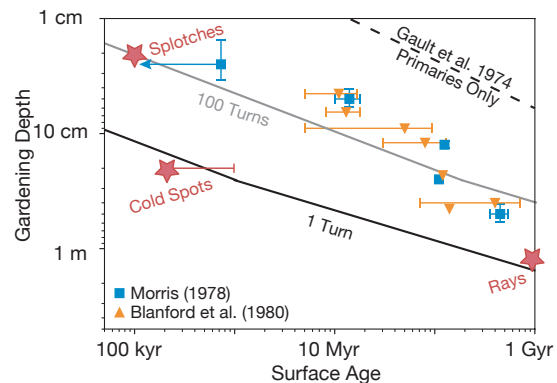


Figure 1: Reworking rates with secondary impacts included are in good agreement with the rate calculated from Apollo cores [4,5]. It is further validated by the reworking rate inferred from splotches [8], cold spots [e.g. 9], and crater rays [e.g. 10]. The Apollo core data represent the depths contaminated by space weathering products over a time interval and show that the model can predict the depth to pristine material. Figure from [3].

understanding the depth-distribution of surface material on Europa.

Space weathering is the set of physical and chemical changes that occur when a material is exposed to space. On the Moon, solar wind, micrometeoroids and cosmic rays alter regolith grains on the surface, giving rise to observable changes in spectral reflectance and other properties. If we are concerned about surface residence time - like we are in the case of Europa, where organics would be destroyed by exposure to the destructive radiation of Jupiter's ionosphere, then the gardening of surface-corollated space weathering products on the Moon is a good conceptual analogy for the fate of organic molecules on Europa.

Our model predicts how deep we would have to take a lunar core to reach pristine material that has never been exposed to the surface space weathering environment. If we were to dig a core on Europa, we would observe a gradient of surface-correlated materials (e.g. exogenic sulfur, products of radiolysis), and at some depth there would be more pristine, un-irradiated materials than surface contaminants. In this study we seek to answer the following question: How

deeply is Europa's near-surface contaminated with material that was at one time exposed at the surface?

The Model: The analytic impact gardening model describes the frequency a 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 a given 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], but in Costello et al. [3], we reworked the model and included several vital updates. The most important update is the inclusion of a treatment of secondary impacts, which have recently been shown to be an important actor on the surfaces of planetary bodies across the solar system [e.g. [11,12,13].

To model gardening on Europa we use our statistical and algebraic skeleton of the lunar model with crater scaling parameters such as gravity, yield strength, density, and porosity appropriate for hard ice [14]. We model gardening on Europa using the impact flux from by Hueso et al. [15] (derived from bolide flashes in Jupiter, scaled to the surface area of Europa).

We keep our treatment of secondary impacts the same as we did to model the Moon and adopt the following assumptions: There are 10^5 secondary impacts per primary impact, and the largest secondary impact is 5% its parent primary size, with a resulting size-frequency distribution having a power index of -4 [11].

Results: Our gardening calculations suggest that pristine, un-irradiated, and un-gardened material is 3-5 m deep on the surface of Europa. If the surface is 250 Myr old, the top 5 m will be contaminated with material that has spent time on the surface. If the surface is 50 Myr old, gardening will have worked material to 3 m depth. Younger terrains will have even shallower pristine material.

These depth results have implications for both a landed and remote sensing missions. For a landed mission, they tell us that we need to dig at least 3 m deep before we should expect to find organic molecules. For a remote sensing mission, fresh impacts that are large enough to penetrate the gardened layer will expose buried materials. These gardening results suggest that we may be able to find pristine material in the ejecta or in the interior of fresh craters that are 90 - 150 m in diameter (assuming that craters have ejecta that is from the top third of their depth, and are about a tenth as deep as they are wide [16]).

Discussion & Future Work: Improvement to the model can come in the form of a Europa-specific treatment of secondary impacts. Secondary impacts

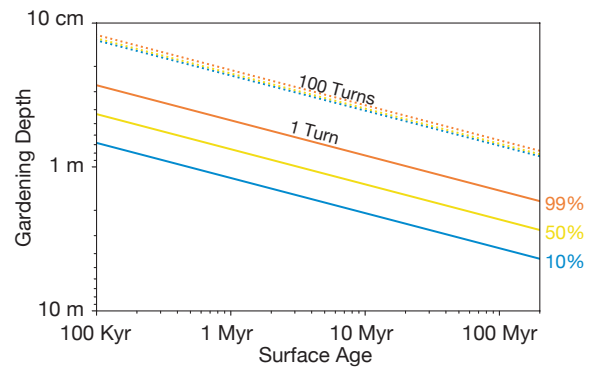


Figure 2: Gardening on Europa tills surface material to ~ 3 m deep in 50 Myr and ~ 5 m in 200 Myr.

have been shown to be abundant and far-flung on Europa [12]. Secondary impacts also dominate impact gardening in the top few meters and thus, any change in the size frequency distribution of secondary impactors or the secondary impact velocity likely have significant effects on the depth of impact gardening and developing a Europa-specific approach to secondary impacts will be an important next step.

The model can also be improved with a investigation of how impacts physically process Europa's near-surface, crunching up ice and evolving material properties such as porosity. Changes in porosity, yield strength and density will also have some impact on the gardening of surface material to depth. Gardening is less efficient in snow than in hard ice. The porosity evolution of Europa's surface may have a growing protective effect as impacts produce a fluffy surface layer.

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