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Regolith mixing by impacts: Lateral diffusion of basin melt

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1. Introduction

Impact cratering has been the primary process to alter the distribution of lunar highland materials since the formation of a crust. The impact history is recorded in the radiogenic clocks of produced impact melt which are accessible to study in lunar samples. However, emplaced impact melt is exposed to a long-time gardening process (i.e. re-melting, excavation, burial, and re-excavation) by the subsequent impacts resulting in a complex spatial distribution. To investigate the diffusion behavior of impact melt, a model tracing the evolving distribution of melt laterally and by depth within a narrow band is built by means of a Monte Carlo approach. The lateral melt diffusion for three mid- to late-forming basins (Serenitatis, Crisium, and Imbrium) are obtained based on the model.

2. Method

A band passing along the great circle is chosen for modelling. By dividing the band into cells, the ejecta volume and the portion of unheated and melted materials are recorded laterally and by depth, tracking the age of the newly-generated impact melt with progressing model time, t. There are three key aspects when modelling:

Distribution of impact events: A minimum (D_{min}) and maximum (D_{max}) crater diameter, is chosen as 5 and 300 km, respectively. By using the Monte Carlo method, the diameter of craters, D, is generated, the size-frequency distribution of which statistically conforms to the standard production function (PF) larger than D_{min} [1]. The corresponding impact centre of each event is randomly distributed along the great circle. The average time to the next impact event larger than D_{min} in diameter, that is impact rate, is calculated from the chronology function (CF) [2], PF, and t [3].

Excavating and melting processes: The excavation depth for each simulated crater, d_{exc}, is $D_t/10$, where D_t is the diameter of the transient crater [4]. D_t is related to D as follows: for simple craters, $D_t = 0.8D$ [4]; for complex craters, $D_t = (DD_Q^{0.13}/1.17)^{1/1.13}$ [5], where D_Q is the simple-complex transition diameter, and taken as 21 km [6]. The corresponding volume of the excavated materials, V_{exc}, having a torus-like shape is estimated to be 1/3 of a disc with d_{exc} in thickness and D_t in diameter. For the conservation of mass, the excavation unit is assumed to be a cuboid with 1/3 D_t in length and d_{exc} in thickness located at the crater centre. The volume of each penetrated layer is diminished. The total volume of the generated impact melt with a reset age as t is: $V_{melt} = cD_t^d$, where c and d are taken as 1.4×10^{-4} and 3.85, respectively [7].

Distribution of melt materials: The distribution of impact melt has not been well quantified [8, 9]. Recently, the relationship between the melt proportion in ejecta and the distance from crater center was found by the means of numerical modelling using the iSALE shock-physics code [10]. It was found that ~75% of the generated impact melt stays within the crater and the remainder is ejected. About 85% of the ejected materials are deposited within five radii from crater centre (consists of an ejecta blanket and a transition to a patchy ejecta zone). We assume that ejecta material in patchy transition zones is also continually distributed with thin thickness. Only the melt within five radii from the crater center is therefore traced. In addition, it showed that melt fraction is linearly increasing with distance from impact center. By assuming a continual distribution of melt in ejecta as a layer, the thickness of impact melt, δ_m, was obtained: $\delta_m(r) = A_m r^{-2}$. A_m is recalculated for craters with different size. To conserve V_{melt}, the integrated melt volume within five radii is taken to be exactly 25% of V_{exc}. The thickness of ejecta layer decreases with distance from crater centre, r: $\delta(r) = Ar^{-3}$ [4], where A is varied for the craters with different D to conserve mass similar as A_m described above.

To conserve the mass, we take instead that all the excavated materials on the band are transported along the great circle instead of spread radially. It may be considered as compensating the ejecta produced by craters outside the band that the model does not record.

3. Results

The generated impact melt is depleted by re-melting, spread to more distant locations by excavation, and buried by the overlaying ejecta of subsequent impacts.

The great circle through the mid- to late-forming Imbrium, Crisium, and Serenitatis basin is chosen to investigate the lateral diffusion of melt from the giant basin-forming events. The plausible ages for the three basins are calculated to be 4.13, 4.09, and 3.88 Ga, respectively, based on N20 [11]. The present-day distribution of impact melt by depth for three basins (Figure 1) shows that the initially generated melt is destroyed and redistributed by the subsequent impact events: the older the basin, the less the remaining melt. In addition, the ejecta materials from both Crisium and Imbrium basin cover the Serenitatis melt burying it to the greater depth. Some of the buried melt was re-excavated to shallow layers subjecting to the further gardening. Furthermore, it shows that the local gardening by the lesser-scaled impact events after the formation of basins strongly mixed the basin melt in the near-surface resulting in an irregular distribution which has significant consequence for scooped samples at the landing sites

The quantitative abundance of basin melt at Apollo-Luna sampling sites is estimated and compared with the radiometric datings (Figure 2). For the relatively young Imbrium and Crisium melt, the simulated results are consistent with the radiometric datings. The older Serenitatis melt at the near-surface is strongly dependent on the subsequent impact events. Its content is only statistically predictable at specific sites.

4. Discussions and Conclusions

In spite of the high impact flux, the lateral transportation efficiency of impact melt by impact gardening is not high as expected. The great volume of melt generated by the giant basin-forming events survives until the present day, which is consistent with the radiometric datings from highland samples. If the estimated basin age is close to the true value, it thus supports the nearby basin origin explanation for the grouped isotopic datings around 3.9–4.0 Ga of Apollo-Luna highlands samples rather than the cataclysm scenario. Understanding the diffusion of impact melt is helpful for interpretation of radiometric dating of lunar samples and may predict likely findings of differently-aged melt in future sampling work like the Chinese Change'E-4 (CE-4).

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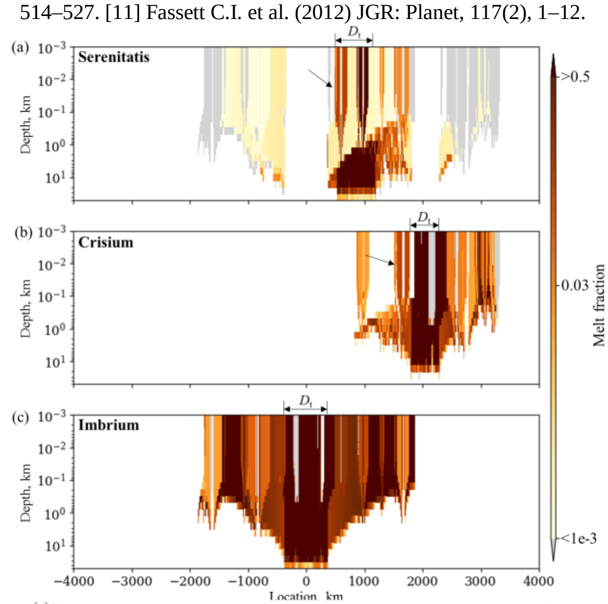
References:

[1] Michael G. et al. (2016) Icarus, 277, 279–285. [2] Neukum G. (1983) Univ. of Munich, 1–186. [3] Michael G. et al. (2017) Icarus, 302, 80–103. [4] Melosh H. (1989) Oxford Univ. [5] McKinnon W. et al. (1997) Venus II: Geology, Geophysics, Atmosphere, and Solar Wind Environment, 969. [6] Pike R. (1977) LPSC, 8, 3427–3436. [7] Cintala M. and Grieve R. (1998) MPS, 33(4), 889–912. [8] Stöffler D. et al. (1975) JGR, 80(29), 4062–4077. [9] Wünnemann K. et al. (2016) MPS, 51(10), 1762–1794. [10] Wünnemann K. et al. (2006), Icarus, 180(2), 514–527. [11] Fassett C.I. et al. (2012) JGR: Planet, 117(2), 1–12.



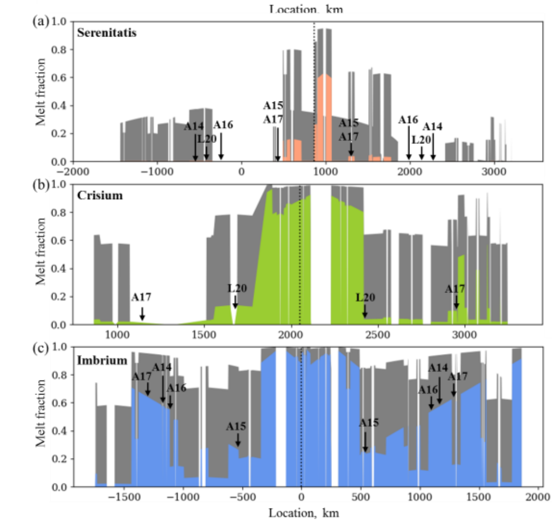


Figure 1 (up). Present-day distribution of the melt from Serenitatis (a), Crisium (b), and Imbrium (c) basin. Figure 2 (down) Average fraction of melt from Serenitatis (a), Crisium (b), and Imbrium (c) basin in the top 0.1 m.