Boulder source formation model on lunar crater inner walls

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Recent observations by lunar orbiters have found fresh topographic features such as boulder sources consisting of meter-size boulders on inner crater walls (e.g. Xiao et al., 2013). Basilevski et al. (2013) estimated the time ($T_{1/2}$) when 50 % of the original boulder population was destroyed to be 50 Ma. However, boulder sources have been found on inner walls of old craters up to 4 Ga, and their formation processes are still unknown. To investigate how boulders are supplied to crater walls and how boulders affect slope topography, we analyzed inner walls at Flamsteed crater (315.7-315.9E, 4.14-4.83S), where boulder sources are widely distributed. This crater was formed in Eratosthenian period (1.1–3.2 Ga). We analyzed distributions of boulder sources, small craters ($D > 5$ m), rock abundance (RA; Bandfield et al., 2011; 2017), slope angle, and topography on the inner walls.

We found that boulder sources, which consist of boulders up to 10 m in size, were distributed mainly in the middle of the inner walls. They spread downward with lobate shape, and cliffs of rock layers were located above the boulder sources. This feature suggests that boulders were supplied from the rock layers, which may have been formed by past magmatic activity. From these observations, we developed a boulder source formation model. We hypothesized that the volume (V) of a boulder source changes due to the boulder supply from the rock layers and fragmentation of supplied boulders in the boulder source at the same time. When the rock layers of volume V_0 are fractured at a rate of α and V decreases at a rate of β, time evolution of V is expressed by the following equation:

$\mathrm{d}V(t)/\mathrm{d}t = \alpha V_0 - \beta V(t)$,

where αV_0 and βV are the boulder generation rate from the rock layers and the disappearance rate in the boulder source, respectively. For $t >> 1/\beta$, $e^{-\beta t}$ converges to 0, and V becomes in a steady state and reaches a constant value ($V_c = \alpha V_0/\beta$). β is determined from $T_{1/2}$, and then αV_0 can be estimated from V_c and β. We estimated V_c by measuring the areal distributions of the boulder sources and assuming their thickness of 10 m. Using $T_{1/2} = 50$ Ma, we obtained the time to reach the steady state as about 250 Ma. To fracture the rock layers, there are two possible processes: one is by impacts and the other is by thermal fatigue. We estimated the time required to fracture the rock layers by impacts as follows. First, we estimated the impactor size (d_{proj}) to generate a half-size fragment from a 10 m-size basalt block in the rock layers. Then, we calculated the crater diameter (D_c) due to the impact of d_{proj} on lunar regolith using a scaling law (Melosh, 1989). The areal density of craters larger than D_c (d_N) was derived by the crater size-frequency distribution (CSFD; Neukum et al., 2001), in which we extrapolated the CSFD to small crater diameters. Our estimates indicate that the time to fracture a 10 m-size block in the rock layers by a single impact requires approximately 1 Ga. This estimate indicates that the number of boulders fractured by impacts is so small that boulder sources cannot be formed. Therefore, thermal fatigue rather than impacts is the main cause of the fracturing process of the rock layers. Thermal fatigue is more effective to fracture rocks down to the skin depth (z_s), which is about 1 m on the lunar surface. Using z_s and αV_0, the time to fracture the rock layers was estimated to be 1–10 Ma, indicating that rapid fragmentation by thermal fatigue is required to form the boulder sources.

Our results suggest that boulder sources can be formed by thermal fatigue when rock layers are exposed on crater slopes. These processes occur regardless of crater formation ages, and therefore fresh boulders are commonly found even in old craters.