EPSC Abstracts
Vol. 11, EPSC2017-158, 2017
European Planetary Science Congress 2017

The role of sesquinary impacts on the Moon

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Abstract

Sesquinary impacts are impacts of projectiles ejected by primary impacts into geocentric orbits. The total number of sesquinary impacts is negligible in comparison to secondary impacts. The majority of sesquinary impacts occur during a few years after their primaries. Sesquinary impacts into their primaries leave craters of identifiable morphology. Sesquinary craters can form tight clusters.

1. Introduction

Sesquinary ("1.5-ary") impact craters on the Moon are created by projectiles previously ejected from the Moon into geocentric orbits by larger impacts. In a sense, they are transitional between primary and secondary craters. Here I extend the classic analysis [1] of lunar impact ejecta dynamics to assess sesquinary crater significance.

2. Sesquinary inventory

I performed massive calculations of trajectories of projectiles launched from different places on the Moon in different directions using MERCURY code [2]. The calculations traced massless projectiles launched from different locations on the Moon in different directions with different velocities on different dates in the gravitational field of the Earth, the Moon, and the Sun on their present-day orbits. The fate of individual projectiles depended on the launch date, while the global statistics of sesquinary impacts do not. The effect of the launch zenith angle on launch-azimuth-integrated number of sesquinary impacts is minor. Sesquinary production depends strongly on location of the primary impact (=launch point), as discussed in detail in [1]. Primaries within ~60° around the lunar apex (the center part of the western hemisphere) produced almost no sesquinaries. The highest sesquinary production efficiency is for impacts in a wide band at ~40°-80° distance from the antapex.

More than 50% of sesquinaries are produced during the first year after the primary impact with prominent production peaks at 1, 2, 3, 4, 5, and 6 lunar orbital periods; ~35% of all sesquinaries are produced within these peaks. Only ~11% of all sesquinaries are formed more than 10 years after the primary impact.

The majority of sesquinaries are formed by projectiles ejected just above the escape velocity v_{esc} = 2.38 km/s [1]. launched at 2.40 and 2.45 km/s. Among all projectiles launched at 2.40 km/s, only 3.0% hit the Moon, much less than in limited and therefore less accurate calculations in [1]. Almost all (98%) traced projectiles that hit the Moon were slower than 3.00 km/s at their launch.

To calculate the average sesquinary formation efficiency I assumed that the mass ejected faster than v is proportional to $v^{-4/3}$ [3] and that the primary impacts are distributed uniformly. Under these assumptions, the mass of material that re-hit the Moon is 0.50% of the total mass ejected from the Moon above v_{esc}. The latter mass is 2 – 4 impactor masses [4], therefore the total mass of sesquinary impactors is 1% – 2% of the total mass of primary impactors. An unknown part of this mass is finely fragmented and does not produce observable craters. The total number of sesquinaries is ~1% of the total number of distal secondaries, assuming similar size-frequency distributions. Thus, *the bulk contribution of sesquinaries into the cratering record is negligible*. However, the largest primary impacts may produce a noticeable number of sesquinaries.

3. Cluster formation

Surprisingly, my trajectory calculations show that some of those *sesquinary impacts* that occur during the showers 1, 2, and 3 months after the primary impact, *cluster on the lunar surface*. This occurs due to combination of three focusing mechanisms. (1) All geocentric orbits of lunar ejecta go close to the ejection point in the non-rotating geocentric reference frame. This trajectory convergence is responsible for the monthly spikes in sesquinary arrivals and contributes to projectile focusing. (2) All such sesquinary impactors approach the lunar Hill sphere with very low velocities with respect to the Moon, therefore trajectory focusing by lunar gravity is very strong. (3) In some cases, there is caustic-like concentration of impact sites. From secondary craters we know that the ejecta tend to cluster at launch. This clustering at launch combined with the strong focusing gives a possibility for formation of tight sesquinary clusters.

4. Possible sesquinaries

Fig. 1 shows an example of a crater-like feature on an impact melt pool on the rim of young large crater Tycho. Morphology of this feature suggests the following sequence of events: Tycho-forming impact, segregation of impact melt and formation of the melt pool, impact into melt pool excavating from the pool floor and forming an impact crater with elevated rim, fill of the crater cavity with still (partly) liquid melt from the pool, melt solidification, formation of thermal contraction cracks. This scenario means that the small impact occurred within a few months after Tycho formation. Formation of a single primary crater of such size on all Tycho's melt pools during a few months is highly improbable. Such features have been explained as self-secondaries [5], however, sesquinary seems a better explanation.

Fig. 2 shows an example of a tight long linear cluster of relatively fresh impact craters (<~300 Ma age according to morphology, roughness signature and superposition relationships). This cluster is not a part of any rays related to large young craters, and there are no large young craters on a continuation of the cluster axis. The crater density within the cluster is higher than in distal secondary clusters. These characteristics suggest that this cluster is not a cluster of secondary raters. Sesquinary origin of this and several similar features seems likely.

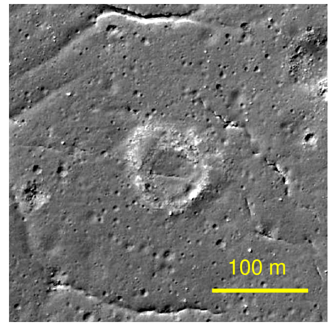

Figure 1: Crater-like feature on a melt pool on Tycho rim (43.68°S 9.04°W); from LROC NAC image.

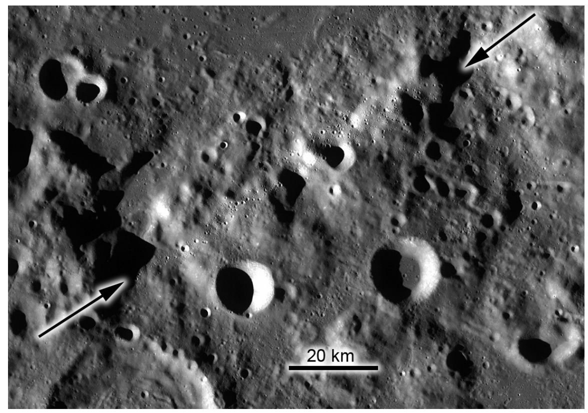

Figure 2: Dense elongated cluster of relatively sharp craters (between long arrows). The scene is centered at 52.5°N 84.5°E; from LROC WAC mosaic.

Acknowledgements

Discussions with Erik Asphaug were very helpful. The work was funded by NASA grant NNX13AJ51G.

References

[1] Gladman B. et al.: The dynamical evolution of lunar impact ejecta, Icarus, Vol 118, pp. 302 – 321, 1995.

[2] Chambers J.: A hybrid symplectic integrator that permits close encounters between massive bodies, Mon. Not. Royal Astron. Soc., Vol. 304, pp. 793 – 799, 1999.

[3] Housen K. and Holsapple K.: Ejecta from impact craters, Icarus, Vol. 211, pp. 856 – 875, 2011.

[4] Artemieva N. and Shuvalov V.: Numerical simulation of high-velocity impact ejecta following falls of comets and asteroids onto the Moon, Solar System Res., Vol. 42, pp. 329 – 334, 2008.

[5] Plescia J.: Lunar Crater Forms on Melt Sheets – Origins and Implications for Self-Secondary Cratering and Chronology, Lunar Planetary Sci. Conf. 46, #2054, 2015.