New observational evidence of global seismic effects of basin-forming impacts on the Moon from Lunar Reconnaissance Orbiter Lunar Orbiter Laser Altimeter data

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[1] New maps of kilometer-scale topographic roughness and concavity of the Moon reveal a very distinctive roughness signature of the proximal ejecta deposits of the Orientale basin (the Hevelius Formation). No other lunar impact basin, even the just-preceding Imbrium basin, is characterized by this type of signature although most have similar types of ejecta units and secondary crater structures. The preservation of this distinctive signature, and its lack in basins formed prior to Orientale, is interpreted to be the result of seismically induced smoothing caused by this latest major basin-forming event. Intense seismic waves accompanying the Orientale basin-forming event preceded the emplacement of its ejecta in time and operated to shake and smooth steep and rough topography associated with earlier basin deposits such as Imbrium. Orientale ejecta emplaced immediately following the passage of the seismic waves formed the distinctive roughness signature that has been preserved for almost 4 billion years.

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1. Introduction

[2] Meteoritic impacts have long been understood to generate seismic waves, which can alter the surface of planetary bodies. For example, *Houston et al.* [1973] argued that seismic shaking from impacts contributes to regolith gardening on the Moon. Seismic shaking works more effectively on small bodies [e.g., *Cintala et al.*, 1978] and has been recognized as the primary cause of global resurfacing on them [e.g., *Asphaug and Melosh*, 1993; *Richardson et al.*, 2004, 2005; *Thomas and Robinson*, 2005; *Asphaug*, 2008]. Seismic shaking can trigger global downslope mass movement, if the acceleration of the surface due to seismic waves is comparable to or exceeds gravity. On the basis of this criterion, *Richardson et al.* [2005, equation (7)] obtained a scaling relationship giving a minimum impactor size for the global seismic effects. We applied this scaling relationship to the Moon, assumed 1 Hz seismic frequency, at which the seismic wave attenuation of the Moon is known to be low [*Nakamura and Koyama*, 1982], took a conservative guess of impact seismic efficiency of 10^{-5}, and obtained a 100 km threshold diameter of the projectile. Thus, on the Moon the global seismic effects can be caused only by the largest impacts in its geological history.

[3] The possibility of global seismic effects of large-scale impact events forming multiring basins on the Moon and other planetary bodies has been recognized long ago [e.g., *Schultz and Gault*, 1975; *Hughes et al.*, 1977]. Several modeling studies have aimed to understand the concentration of seismic energy in the regions antipodal to impacts [e.g., *Hughes et al.*, 1977; *Watts et al.*, 1991; *Boslough and Chael*, 1994; *Lü et al.*, 2010]. These studies were inspired by the work by *Schultz and Gault* [1975], who attributed some specific morphologies in a region antipodal to Caloris basin on Mercury and possibly in regions antipodal to Imbrium and Orientale basins on the Moon to seismic effects. At the present state of knowledge, however, the balance between seismic waves and the convergence of basin ejecta [e.g., *Stuart-Alexander*, 1978; *Wieczorek and Zuber*, 2001, and references therein] is not clear in terms of the formation of different morphologies in the antipodal regions. On the other hand, as noted by *Hughes et al.* [1977], even outside the antipodal regions, seismic waves can produce stresses high enough to disrupt rocks and accelerations high enough to exceed gravity, and thus there is a possibility that basin-forming impacts have a global effect on morphology not limited to the antipodal region.

[4] Here we present observational evidence that seismic effects of basing-forming impacts indeed resurface the Moon

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