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Exploring Lunar Impact Craters and Their Implications for the Origin and Early Evolution of Life on Earth

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Introduction: The Apollo program demonstrated that the Earth-Moon system was targeted by impacting asteroids and comets far more frequently than that suggested by the small number of surviving craters on Earth. Because Apollo missions returned samples to Earth, a quantitative chronology of that impact flux began to emerge, indicating most impact craters on the Moon were produced during an early period of bombardment that ended ~3.85 Ga. These ages suggested that similar impact cratering events on the Earth affected the origin and early evolution of life. Because impact cratering is a continuing process, we also realize that the processes, even at scales far smaller than basin-forming events, pose a hazard for modern life. However, the details of the impact flux remain murky, because so few samples have been analyzed and many of those analyzed are without geologic context. Consequently, one of the most important scientific goals of renewed lunar exploration, both robotic and human, will be to collect appropriate samples to deduce impact cratering's effect on the fabric of life on Earth.

Early Earth Bombardment: Ar-Ar, U-Pb, and Rb-Sr analyses of Apollo-era samples suggest early bombardment may have been particularly intense in a <200 Ma interval that ended ~3.85 Ga [Turner et al., 1973; Tera et al., 1974; Dalrymple and Ryder, 1996], which is consistent with more recent analyses of lunar meteorites [Cohen et al., 2000, 2005]. Although the source of debris remains controversial, geochemical [Kring and Cohen, 2002] and geological [Strom et al., 2005] fingerprints suggest an asteroid source. This bombardment is a process that appears to have also affected the entire inner solar system [Bogard, 1995; Kring and Cohen, 2002] and, thus, potentially habitable conditions on early Mars too [Abramov and Kring, 2004].

The volume of data is still insufficient, however, to confidently assess the temporal extent or magnitude of any brief period of bombardment. Additional samples are needed to test the hypothesis further. Specifically, a collection of impact melts unambiguously tied to large craters and basins are needed for detailed petrologic, geochemical, and radiometric age analyses. These should be selected to represent the entire distribution of relative ages among large basin-forming events, and of lunar geographic locations. The highest priority sample is an impact melt sample from the South Pole-Aitken basin-forming event.

These same samples can also be used to test the source of projectiles. This will, in turn, permit an analysis of the delivery of biogenic elements during, and environmental consequences of, the bombardment. Some of the consequences were detrimental, but these same impact events may have generated vast hydrothermal systems that were critical for the origin and early evolution of life.

Post-Bombardment Impact Flux: The Chicxulub impact crater and its link to the K/Pg mass extinction event demonstrates that the post-bombardment impact flux was still sufficient to cause dramatic biological upheaval on Earth. In addition to the flux of sporadic impact events, it will be important to determine if there were particularly intense storms of impact activity, hints of which occur in the Archean, at 800 Ma, and 500 Ma. This requires precise analyses of lunar impact melt ages from a moderate number of post-3.8 Ga impact craters and an accurate determination of the relative number of impact events that occur between those absolute benchmark ages. These analyses will allow us to determine the role impact cratering has had in the biologic evolution of Earth, how impact cratering has perturbed the climate, and the hazards other impactors pose for Earth in the future.