EXPLORING IMPACT CRATERING ON THE MOON AND ITS IMPLICATIONS FOR THE BIOLOGIC EVOLUTION OF, AND HABITABLE CONDITIONS ON, THE EARTH.

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Introduction: The Apollo era revealed that the Earth and Moon have been the target of impacting asteroids and comets far more frequently than that suggested by the small number of surviving impact craters on Earth. Because the missions returned samples to Earth, an absolute chronology of the impact flux began to grow. When combined with a relative impact chronology provided by extensive ejecta blankets (strata) and crater densities on different lunar terrains, the data indicate most impact craters on the Moon were produced during an early period of bombardment and that the last of the great basin-forming impacts occurred ~3.85 Ga. We now understand that similar impact cratering events on the Earth had the potential to affect the origin and evolution of life on our planet. Because impact cratering is 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 [1-3], which is consistent with more recent analyses of lunar meteorites [4,5]. Although the source of debris remains controversial, chemical fingerprints in lunar impact melts suggest an asteroid source [6], which was recently confirmed with an analysis of the size distribution of projectiles needed to produce ancient lunar craters [7]. This is also a process that appears to have affected the entire inner solar system [6,8] and, thus, potentially habitable conditions on early Mars too [6,9].

The volume of data is still insufficient, however, and the hypothesis of a brief period of bombardment needs to be tested with additional sample analyses. 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 geophraphic locations.

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 [9-11]. If the bombardment did not begin until ~4.1 Ga or later, then these results will also have dramatic implications for the accretion and orbital evolution of outer system planets [7,12]. Furthermore, the collisional evolution of the early solar system may help guide our interpretation of the geologic evolution and potential biologic viability of other planetary systems [e.g., 13].

Post-Bombardment Impact Flux: The Chicxulub impact crater and its link to the K/T (K/P) mass extinction event demonstrates that the post-bombardment impact flux was still sufficient to cause dramatic biological upheaval. 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 impact melts 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 (both in terms of mass extinctions and evolutionary radiations), how impact cratering has perturbed the climate, and the hazards other impactors pose for Earth today and in the future.

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