EARLY INTENSE BOMBARDMENT AND ACCRETION TAIL SCENARIO: EFFECTS ON MEGAREGOLITH EVOLUTION AND LUNAR SAMPLES

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Introduction: Pre-Apollo planning led to an expectation that lunar surface samples would reveal the entire history of the moon and solar system, but Apollo and Luna samples showed a paucity of rocks from before 4.0 Gyr ago and a spike in impact melts at ~3.9 Gyr ago. This led to a paradigm in which all major lunar basins formed during a terminal cataclysm at 3.9 Gyr ago (aka late heavy bombardment or LHB), with negligible earlier impact cratering from ~4.4 Gyr ago till ~4.0 Gyr ago, as reviewed in [1]. However, since the impact melt spike is not found in lunar meteorites or asteroidal meteorites, this paradigm appears to have collapsed in recent years [1]. In the same way, dynamical models of planetary evolution, adopting a giant planet instability, were tuned to have the instability happen at ~3.9 Gyr ago, to explain the catastrophic LHB spike proposed for that time. New constraints, however, indicate unlikelihood that the instability occurred at that time [2]. Thus, in 2018, Morbidelli et al. [3] compared earlier dynamical models (~3.9 Gyr LHB and negligible early cratering) with what they called an "accretion tail scenario," (intense early bombardment decreasing more or less monotonically from ~4.5 Gyr ago until 3 Gyr or 2 Gyr ago, when it becomes more nearly constant.) They favored the latter model, noting that it resembled early-1970s, non-cataclysm models, which, in turn, were based on then-current less sophisticated planet accretion models and observed lunar cratering data, but not accepted at that time (see [1] for a review.)

Studying consequences of early intense bombardment and declining accretion tail. We used the "accretion tail" model [3] to provide a quantitative basis for calculations regarding the consequences of early intense bombardment and a declining accretion tail. The "accretion tail" model [3] creates a quite different lunar crustal history than was accepted under the LHB paradigm, as seen in our results, below.

Results. We suggest that: (1) During solidification of the putative magma ocean, it would have been churned to depths of tens of kilometers. Undisturbed crystallization with smooth layering, according to the Bowen reaction series, should not be expected, although anorthosites still dominate the upland surface layers. (2) The early crust would have been pulverized to depths of tens of kilometers, grading into fractured crustal layers, with coherent crustal rock below that. (3) Numerous giant (1000-km scale) impact basins would have been formed before 3.9 Gyr ago, the oldest of which may have been erased by subsequent intense cratering. Rim structures of the earliest basins are severely degraded. (4) The Oceanus Procellarum structure may be an example of such an early impact. GRAIL team arguments that Procellarum is not an impact structure (because of subsurface "ring" structures that are linear instead of circular) are undercut by the fact that multiring basins such as Orientale and Humboldtianum have clear linear segments in some of their rings. (5) The curve of cratering rate decline vs. time predicted in the Morbidelli et al. 2018 model [3] matches remarkably well a curve of cratering rate as a function of time developed from crater count data developed by Neukum in 1983, and discussed by Neukum et al. in 2001 [4]. (6) Megaregolith evolution is an important "filtering" factor in petrology and age distribution of samples collected on the lunar surface. (7) Megaregolith is thinner in some areas than in others due to the stochastic nature of the largest impacts. (8) Our model explains the difference between age distributions of impact melts and primordial crustal samples. (Impact melts were formed in upper kilometers and those from the earliest basins were mostly soon pulverized. Their tiny fragments have been found in a few cases as clasts in upland breccias. Meanwhile, primordial crust is found at the base of the megaregolith, by definition of megaregolith. Sporadic recent, large impacts penetrate it, ejecting a scattered supply of primordial crustal rock samples onto the surface. (9) The 3.9 Gyr spike in Apollo impact melts is due mainly to dominance of Imbrium ejecta at Apollo landing sites.

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