

A Late Heavy Bombardment?

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Disturbances to U-Pb and Rb-Sr lunar ages led to the hypothesis that an intense bolide flux impacted Moon at 3.9 Ga [1]. The Late Heavy Bombardment (LHB; [2]) concept was initially controversial [3], but many researchers came to regard it as confirmed by incremental heating $^{40}\text{Ar}/^{39}\text{Ar}$ dating of lunar impact melt rock samples which were interpreted as yielding ~3.9 Ga “plateau ages”. The LHB concept thus came to be regarded as one of the great successes of Apollo-era exploration. Whole-rock $^{40}\text{Ar}/^{39}\text{Ar}$ dates for lunar impact melt breccias were also used to argue for specific ages of large impact basins, which in turn form the foundation for ‘crater count’ chronologies [4]. Despite the influence that the lunar $^{40}\text{Ar}/^{39}\text{Ar}$ dataset has had on planetary research, and the lack of an LHB-age spike in lunar meteorite (likely a more random spatial sample) $^{40}\text{Ar}/^{39}\text{Ar}$ ages, there has been little in the way of critical examination of the underlying assumptions of these age interpretations over the past 44 years.

We identify three method-specific issues that effectively preclude use of $^{40}\text{Ar}/^{39}\text{Ar}$ data to support the LHB hypothesis: 1) the “plateau age” (an aphysical concept for the thermally disturbed samples typically dated) 2) laboratory artifacts (e.g., recoil, size effects; [5]), and 3) multi-activation energy effects [6]. Even in the absence of these problems, three additional issues greatly complicate the simple interpretations previously drawn: 4) continuous impact reworking of the lunar regolith produces polygenetic breccias [7]; 5) melts that also form during small impacts unrelated to large, basin-forming events [8]; and 6) incremental heating $^{40}\text{Ar}/^{39}\text{Ar}$ dating of polygenetic breccias has an intrinsic tendency to create illusory age spikes [9]. Multiple in situ dating methods using samples from the same sites yield contrasting chronologies [7,10] underscoring point 4) above. Until these accumulating concerns of the classical interpretation of lunar geochronologic data are addressed, the LHB concept should be viewed more as a speculation than proven concept.

[1] Tera et al. (1974) *EPSL* **22**, 1; [2] Wetherill (1975) *Proc. Lunar Sci. Conf.* **6**, 1539; [3] Hartmann (1975) *Icarus* **24**, 181; [4] Norman (2009) *Elements* **5**, 23; [5] Turner (1968) *Origin and Distribution of the Elements*, 387; [6] Boehnke et al. (2016) *EPSL* **453**, 267; [7] Mercer et al. (2015) *Science Advances* **1**, e1400050; [8] Plescia & Cintala (2012) *JGR-P* **117**, E12; [9] Boehnke and Harrison (2016) *PNAS* **113**, 10802; [10] Thiessen et al. (2017) *Meteor. Planet. Sci.* **52**, 584.