TERMINAL CATACLYSM EPISTEMOLOGY: A CATACLYSM THAT NEVER HAPPENED?

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The "terminal cataclysm" or "late heavy bombardment," LHB) concept of the last 40 years exhibits curious epistemology, with changing definitions and inconsistent evidence.

Pre-Apollo evidence indicate an impact rate prior to ~3.5 Ga ago *averaging* ≥~150x the post-mare rate [1]. In 1973-4, Tera et al. [2, 3] introduced the term “terminal cataclysm” (TC) for widespread metamorphism ~3.9 Ga ago --- caused either by the Imbrium impact [3, p.15], or by formation of many basins in < 200 Ma [3, p.18]. In 1990, Ryder [4] reported a strong spike in Apollo *impact melt* ages at ~3.85-4.0 Ga ago, and Moon-wide TC bombardment at that time. He asserted what I have called “Ryder’s rule:” lack of earlier impact melts equates with lack of earlier cratering. His work was widely adopted as proof of TC.

Three inconsistencies soon appeared. (1) Starting in 2000, Cohen et al. [5] found *no* 3.9 Ga spike in KREEP-poor (non-Imbrium?) lunar meteorite impact melt clasts. Still, they "support(ed)…lunar cataclysm," citing Ryder’s principle.) (2) The Nice model predicted sudden scattering of objects from the outer to the inner Solar System [6], with a spike plausibly at ~3.9 Ga; yet asteroidal meteorite impact melt clasts show no sharp spike at ~3.9 Ga. (3) In recent years, reports of pre-4.0 impact melts have increased among upland breccia clasts, violating Ryder’s rule.

Dynamicists then re-introduced earlier ideas of "sawteeth" spikes before 4.0, and gradual declines after 3.8, thus “melting down” the cataclysmic spike into a mere bulge. In 2014 Marchi et al. [7] modeled a declining impact flux, 4.4 to 3.5 Ga, with no spike or bulge at 3.9 Ga. At the 2015 Houston conference on Early Bombardment, several speakers excluded a 3.9 impact-spike “TC.” Others supported the asteroidal bulge as showing “LHB” though only the decline after 3.9 is visible in lunar data. The 3.9 “TC” appears to be collapsing; we should be concerned that it is still being utilized in models for the formation of life on Earth.

A high, rather than low, pre-4.0 flux [1] can explain the data [8, 9]. In this quantitative model, 3.9-4.0 Ga marks the transition to probable survival of early impact melts. Pre-4.1 *lunar* impact melt lenses in the upper kilometers were pulverized into dust and upland megaregolith breccia clasts, recently being dated. Most *asteroidal* impact melts from >4.1 were ejected into heliocentric orbits from violent collisions, and removed by YORP forces --- others were buried during reassembly after catastrophic fragmentations. Deep-seated 4.4-era igneous “genesis” rocks, however, are constantly replaced as ejecta from 10^2-km lunar and asteroidal craters, and by recent asteroidal fragmentation events.

References. [1] Hartmann W.K. 1966. Icarus **5:** 406-418. [2] Tera F. et al. 1973. LPSC absts. p. 723. [3] Tera F. et al. 1974. EPSL **22:** 1-21. [4] Ryder G. 1990. EOS **71**: 313. [5] Cohen B., et al. 2000. Science **290**: 1754-1756. [6] Gomes, R., et al (2005) Nature, **435:** 466-469. [7] Marchi S. et al. 2014. Nature **511**: 578–582. [8] Hartmann, W. K. 1975. *Icarus*, **24:** 181-187. [9] Hartmann 2003. Meteoritics and Planet. Sci. **38,** 579-593.