HAS THE IMPACT FLUX OF SMALL AND LARGE ASTEROIDS VARIED THROUGH TIME ON MARS, THE EARTH AND THE MOON?

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Introduction: Mapping and counting impact craters is the most widely used tool to derive qualitative and quantitative temporal information on geological events and processes shaping the surface of terrestrial planets (e.g., [1]). Due to the lack of lunar samples covering recent epochs, i.e., the last ~2 Ga, one of the most important sources of uncertainty of this dating method is the recent (~0 – ~2 Ga) evolution of the impact cratering flux. It is generally assumed a constant flux and a steady size-distribution of impactor [2,3]. In other words, the recent production rate of impact craters on the surface of terrestrial planets and the Moon is considered to be the result of a set of physical processes for delivering impactors in the inner Solar System, that together form a stationary stochastic process. Nevertheless, recent studies argued for the existence of periods of increases in large crater production ("spike"), and/or alternating with quiescent impact cratering ("lull"), assuming the production of small craters remained constant (e.g., [4-7]). In this study we test the hypothesis of the temporal variation of the impact flux of large impactors with respect to the small ones on Mars, the Moon and the Earth, i.e., a decoupling in the cratering rate between impactors of different size. The proximity of Mars to the main belt, as well as the Earth-Moon distance both exclude the possibility that one of these three bodies experienced a cratering spike in their geological history whether the others did not.

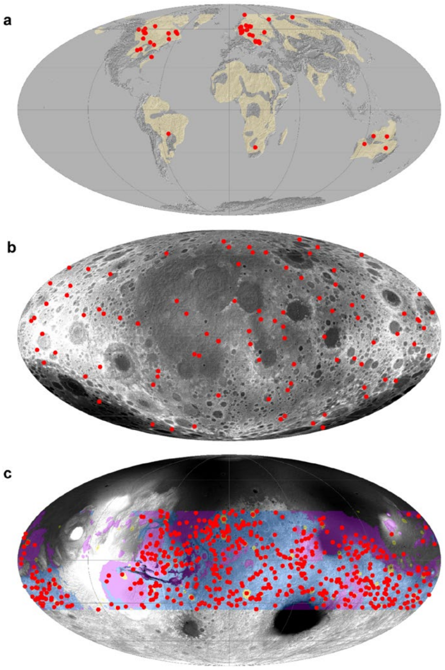

Fig. 1: Location of craters considered in this study on the Earth (a), the Moon (b) and Mars (c).

Methods: We derive the model ages of 521 martian impact craters >20 km in diameter using small craters superposed on their ejecta blanket identified by an image-based object detection algorithm [8-10] on the CTX global mosaic [11], and automatically filter the secondary crater contribution using the method described in [9]. On the Moon, we use the formation age of craters > 10 km and younger than 600 Ma reported in [4] using the rock abundance in lunar impact ejecta [12] (N = 91 craters). On Earth, we restrict our analysis to craters located on stable continental landmasses for a period of time ranging from 23 Ma to 541 Ma, with uncertainties on ages lower than 10 Ma (N = 45 craters, [13]).

Martian craters age distribution: Our Crater Detection Algorithm (CDA) [8-10] returned 1,226,387 detections larger than 100 m superposed on the ejecta blanket of the 521 craters > 20 km considered in this study. Individual crater population are processed to identify cluster of secondary craters [9] and the remaining likely primary craters (835,408) is used to derive their model age. The oldest crater found in this study is 3.8 Ga old. However, the set considered here is not representative of the entire cratering history since 3.8 Ga. We assessed the completeness of the crater set using the method described in [14] and found that the model age threshold from which the crater population dated here can be considered as incomplete is 600 Ma. 49 craters younger than this model age threshold were kept for further analysis.

Results and Discussion: We assessed the randomness of the crater age distribution of the three considered populations on Earth, the Moon and Mars. If the small crater impact rate was strictly proportional, coupled, to the large crater impact rate, then the ages of craters would be a random sample of a uniform distribution.

We test this hypothesis with a peak rate test, sensitive to short-term variation [14]. Applied on the 49 martian craters younger than 600 Ma old, the K-S test yields the p-value 0.11, 0.009 for lunar craters, and 0.09 for terrestrial craters. The peak test gives p-value = 0.002, 0.08, and 0.08 for the Earth (Fig.2.c), the Moon (Fig.2.b) and Mars (Fig.2.a), respectively.

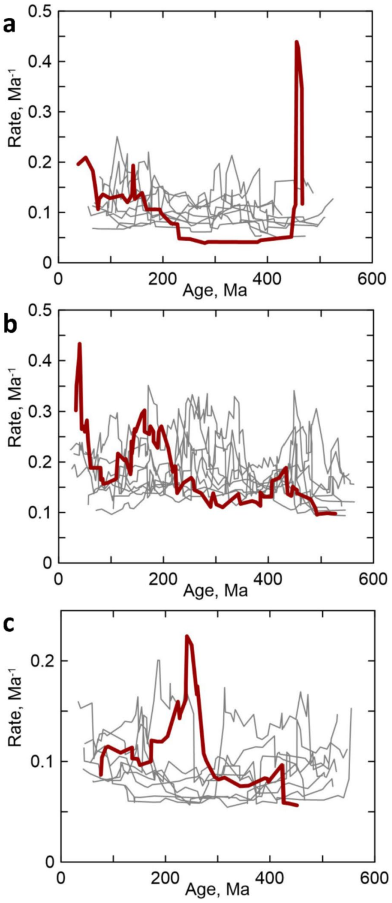

Fig. 2: Impact rate from measured impact crater ages (in red) compared to that of examples with random ages uniformly distributed (in grey curves). (a) the Earth, (b) the Moon, (c) Mars.

Although the lunar cratering rate inferred by rock abundance from [4] presents a significant increase in recent time, its past evolution over older periods of the Phanerozoic is not characterized by either a short or long-term rise. Not any significant spike has been deduced from our measurements on Mars. The absence of such signal in the lunar and martian cratering record raises questions about the qualitative increase observed on the Earth during the Ordovician period. Using plate tectonic reconstruction software and updated model reconstructing paleogeographic features through the Phanerozoic era [15], we inferred the formation location of the 45 craters considered on Earth. While impact craters <200 Ma old considered here were formed at mid-latitudes (~30° of latitude) and beyond, the craters constituting the Ordovician cluster were formed at tropical latitudes (Fig.3). Numerical climate models and carbon isotope measurements suggests that atmospheric levels of carbon dioxide during the Ordovician period were 14–16 times higher than today, mostly driven by widespread volcanic activity [16], thus causing a global greenhouse effect. These environmental conditions, among other factors detailed in [14] favored the preservation of these craters via their rapid burial by sedimentary layers.

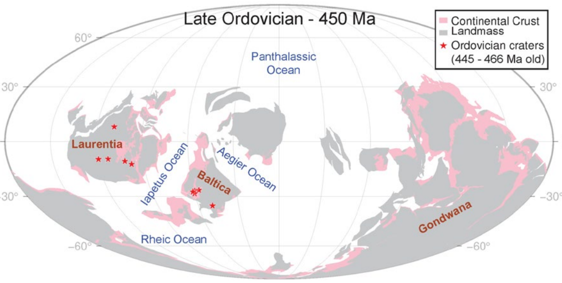

Fig. 3: Configuration of continental landmass 450 Ma ago, showing the approximate formation location of Ordovician craters [14].

Our data and analysis suggest non-statistically significant fluctuation of the martian cratering rate, an apparent increase of the flux on Earth at the Ordovician simply due to a crater preservation bias, and potential issues in age determination method [12] of lunar craters used by [4], as highlighted by [17].

Conclusion: Therefore, we argue that relative temporal fluctuation of the impact flux in the inner Solar System between asteroids >2 km and 5m-100m is relatively limited, statistically insignificant over the last ~600 Ma [14]. This is consistent with the traditional model for delivering asteroids to planet-crossing orbits.

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