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Timing of the early geological evolution on Moon and Mars

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Abstract

We present two different views of the bombardment history of the Moon and Mars. One is based on craters counts on lunar surface units of known radiometric age, which are then extrapolated into the more distant past [e.g., 1]. We call this the “standard chronology”. The other one is based on a dynamical model of the evolution of the Solar System known as the “Nice model” [2]. We refer to it here as the “Nice chronology”.
Here we discuss how these two views have influenced our interpretation of the geological evolution of the planets, as it can be deduced from their cratering records. This abstract focuses on the Moon. Martian surfaces will be discussed at the conference.

1. Cratering Chronologies

The standard chronology reflects the idea that the bombardment of the planets decayed smoothly over time during early Solar System times. This chronology is calibrated on terrains of known radiometric age, younger than ~4.1 Gy. Figure 1 presents our preliminary description of the cratering chronologies described above based on crater counts made by [3] and interpreted through crater size-frequency distributions (SFD) described by [3,4] and [5]. We fitted crater frequencies to the updated size-frequency distribution by [5], which results in a shallower chronology curve (Fig.1, blue) compared to the older curve (Fig. 1, red). These numbers are partially extrapolated, as crater counts have only been made on certain terrains and within varying crater size ranges that go as low as 500 m and as high as 150km. The resultant flux curves differ because (i) we need to extrapolate from the measurements to 1 km or 20 km using the crater SFD (Fig. 2) and (ii) the crater SFD are themselves different. We compare these cratering curves with Nice chronology predictions for crater counts based on crater diameters ≥20km.

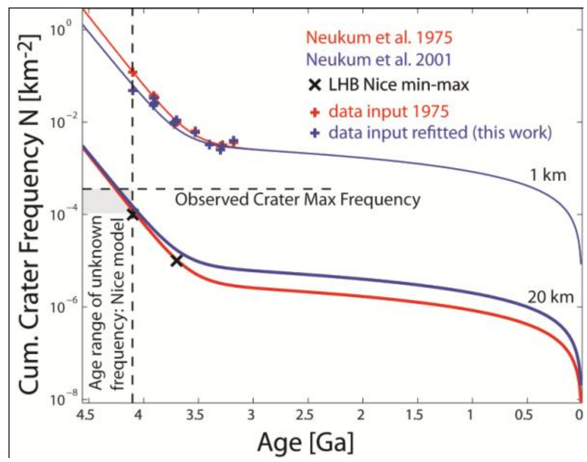

Fig. 1: Two lunar cratering chronology model that, relating crater densities to crater retention ages on the Moon. The upper curve shows the density of craters with diameter D>1km; the lower curve is for D>20km according to the “standard chronology”. In comparison, the cratering densities predicted by the Nice chronology are plotted for craters ≥20km. The horizontal dashed black line indicates the maximum crater frequency observed on the moon. The vertical dashed black line is indicating the maximum time, for which (so far) the crater frequencies are predicted by the Nice model. The width of the band (gray box) indicates the range of crater densities of terrains which, according to the Nice model, predate the LHB and can be as old as ~4.4 Gy.

A key calibration point is the Nectaris Basin. The formation age of Nectaris is debated and radiometric ages are interpreted to be either 4.1 Ga (used in the standard chronology models) and 3.92 Ga [e.g.,6], and remain poorly constrained [e.g., 7]. The density of craters with D>20km is measured on Nectaris. The density of craters with D>1km is then estimated using the crater production SFDs. The crater spatial densities for D>1km and D>20km as a function of time in the standard chronology are illustrated in Fig. 1 as thin (upper) and thick (lower) solid curves, respectively. The color indicates which crater production SFD has been used, making reference to Fig. 2. By construction, the red and blue thick solid curves pass through the same data point at 4.1 Ga (i.e. Nectaris). All these curves are extrapolated to predict the crater densities at t>4.1Ga. The Nice chronology reflects the idea that planetary bombardment evolved in a discontinuous way, due to the existence of an intense spike in the projectile flux that occurred ~4.1-4.2 Ga ago, usually called Late Heavy Bombardment [8,9]. In the Nice model, the origin of the LHB is related to a dramatic change in the orbital configuration of the giant planets. [10].

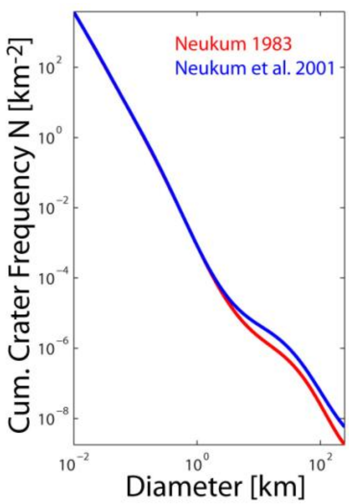

Fig. 2: Two examples of lunar crater size frequency distributions, after [4,5], which are used to estimate the density of craters, see Fig.1.

By assuming the last lunar basin Orientale formed 3.7-3.8 Ga, Nice chronology *predicts* that the age of Nectaris should be near 4.1-4.2 Gy [2]. It also predicts a number of craters with D>20km on Nectaris which is in reasonable agreement with the measured value. Thus, at ~4.1 Gy, the Nice chronology coincides with the standard chronology. The decay rate of the projectile flux since 4.1 Gy ago, computed from the dynamical simulations of the Nice model [2], may also be similar to the one in the standard chronology, though more work is needed. Thus, for < 4.1 Ga, the standard and Nice chronologies may be equivalent, unless the shape of the crater SFDs need revision (compare Fig.1, blue curves).

A likely difference between the standard and the Nice chronologies is for pre-Nectarian times (i.e., terrains with crater densities greater than Nectaris, which may be > 4.1 Ga). In the standard chronology, pre-Nectarian terrains, like the lunar highlands or those in South Pole-Aitken (SPA) basins, are usually only slightly older than 4.1 Ga. We have not yet calculated the lunar impact flux prior to the Nice model/LHB (left of the dashed vertical black line in Fig. 1). We expect, however, that the bombardment rate declined sharply after the formation of the Moon. From that point, it was dominated by impacts from leftover planetesimals and escapees from the primordial main belt/comet disks. The flux during that period is unknown. In Fig. 1 this is schematically represented by the gray area in Fig. 1. Thus, pre-Nectarian terrains may be considerably older than 4.1 Gy, possibly as old as 4.4 or 4.5 Gy. In any case, in the Nice chronology, both the highlands and terrains within SPA basin could be substantially older than in the standard chronology.

2. Future Work

We will apply similar considerations to Mars, whose geological evolution requires us to consider additional variables that may influence our interpretations.

Acknowledgements

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