Crater Retention Ages of Phobos Based on a Lunar-Like Chronology.

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Introduction: Phobos has been discovered by A. Hall in 1877. Since then, Phobos was investigated by many scientists and many spacecraft. Despite of this afford the geologic history of Phobos is not well understood yet. It is perhaps closely entangled with the early history of Mars and thus, learning about the origins of Phobos may also shed some light to the evolution of Mars. Currently at least three scenarios of Phobos' origin are discussed [1]. I) Phobos is a captured asteroid. II) Phobos formed in-situ from the same material like Mars. III) Phobos formed from ejecta of (a) large impact(s) on Mars. Analysis of Phobos' orbit revealed a shortening of the orbital period, leading to an impact on Mars within the next 30 to 50 Ma [2]. Because of its low density, it is likely that Phobos might be disintegrating by tidal forces much earlier. Spectroscopically Phobos shows similarities to primitive asteroids such as C-, D- or T-type [1]. Furthermore, Phobos is characterized by an unrelaxed topography with a ratio between semi-minor and semi-major axis of about 0.7. Phobos' morphology is further dominated by large craters and it shows various sets of grooves. The origin of the grooves is also uncertain. Determination of surface ages may provide further constrains on the geologic history and evolution of Phobos. For this purpose we developed two crater production functions and two chronologies for two end-member cases of Phobos' evolution. Case A: Phobos has always been in its current orbit since its formation. Case B: Phobos is a recently captured Main Belt asteroid.

Methodology:

Crater Production Function: In order to derive the crater production functions for both cases we calculated the respective impact velocities. In its current orbit the average impact velocity on Phobos should be on the order of 8.5 km/s (Case A). This value is derived from the squared differences of Mars' escape velocity at the Martian surface and at the orbit of Phobos and the impact velocity on Mars (9.4 km/s; [3]). In our Case B scenario Phobos is a recently captured Main Belt asteroid. The related average impact velocity should be on the order of 5 km/s [4]. We scaled the lunar crater production function [5] with these impact velocities and thus derived two lunar-like crater production functions for Phobos. This procedure also takes Phobos' small surface gravity into account. The influence of the surface gravity leads to lager craters on Phobos compared to Mars given the same projectile, even with the higher impact velocity at the surface of Mars. For this crater scaling we used the scaling laws by [6]. The derived crater production functions are very similar to each other. The scaling for our Case B scenario predicts a slightly flatter crater distribution above 1 km crater size compared to Case A.

Chronology Functions: We derive the chronologies for Phobos from the lunar cratering chronology [5]. Our Case A scenario is based on the Martian rate of impacts [6]. As stated in the previous section about crater scaling, the same projectile will form different crater sizes on Mars and Phobos. Thus, the impact rate for Mars was modified to apply to Phobos in a sense that we accounted for different impactor fluxes at variable projectile sizes. The chronology function is valid for the cumulative crater frequency of 1 km large craters on Mars and Phobos. Since projectiles are smaller on Phobos than on Mars forming 1 km craters, their frequency is some-what higher according to the crater production function of Phobos. This ratio was applied to the Martian chronology function, in order to use it for Phobos.

In order to derive a cratering chronology for Phobos for the case B scenario, we used the average impact probability of Main Belt asteroids [4]. Given the average astroidal impact probability, mean radius of Phobos and the number of Main Belt bodies creating ≥1 km craters on Phobos, [7] provide an equation to calculate the current formation rate of such craters, which can be used to adapt the lunar chronology to the case of an asteroidal target.

Software: For the mapping task we used ESRI ArcGIS mapping software together with the CraterTools [8] plug-in. This tool allows for map-projection independent measurements, which increases reliability of measured crater sizes. Crater statistics were generated and analyzed with the craterstats software [9]. In addition, we performed randomness analyses of the spatial crater distribution [10].

Imaging data: In general we used HRSC imaging data. For large scale crater counting we mapped craters on a HRSC basemap [11] and for higher resolution we used a HRSC/SRC image (h3769_0004) for a part of Stickney crater.

Results: We obtained a surface age of 4.3 (+0.03/-0.04) Ga (Case A; 3.66 (+0.03/-0.04) Ga – Case B) for an average surface west of Stickney. The same area shows two sets of grooves perpendicular to each other. Interestingly the cratering data also reveals two resurfacing events possibly connected to these grooves. The respective resurfacing ages are 3.81 (+0.01/-0.02) Ga (2.96 (+0.06/-0.09) Ga; Case B) and 4.04 (+0.02/-0.02) Ga (3.4 (+0.03/-0.03) Ga; Case B).

Inside Stickney crater measurements revealed a comparable image. Crater retention ages suggest a formation of Stickney of 4.18 (+0.07/-0.13) Ga (3.54 (+0.07/-0.15) Ga; Case B). Also two resurfacing events were found inside Stickney. These events could result from down-slope movements of material at the crater walls. It is also possible that the resurfacing is caused by the formation of grooves, which can also be observed inside Stickney. According to our measurements these events happened 3.29 (+0.09/-0.18) Ga (551 (+/-79) Ma; Case B) and 3.84 (+0.03/-0.04) Ga (3.06 (+0.08/-0.16) Ga; Case B) ago. From relative stratigraphy of the groove morphologies and the derived ages, there might be one single event that created a north-south striking set of grooves in two different counting areas around 3.81-3.84 Ga (2.96-3.06 Ga; Case B) ago.

We also did measure global crater frequencies in order to test Phobos' crater distribution for an apex-/antapex asymmetry. We found such an effect with a ratio of about 1.5 +/-0.1. The calculated effect from the current orbit of Phobos however, was expected to be about a factor of 4.1.

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