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Modelling small impact crater populations on Mars

J.-P. Williams (1), A. Pathare (2) and O. Aharonson (3)
(1) Earth and Space Sciences, University of California, Los Angles, USA, (2) Planetary Sciences Institute, Tucson, USA, (3) Center for Planetary Science, Weizmann Inst. of Science, Rehovot, Israel (jpierre@mars.ucla.edu / Fax: +1-310-825-2779)

Abstract

Size-frequency distributions (SFD) of small primary craters on Mars are modeled. How the SFD is influenced by the fragmentation of meteoroids is explored. We have previously shown modeled SFD based on observed projectiles at the top of the terrestrial atmosphere are comparable with MOC observations of fresh craters down to ~20m [1]. Here we demonstrate an order of magnitude improvement in the model's ability to reproduce martian crater counts that we conducted on the ejecta of Zunil crater using HiRISE observations.

1. Introduction

The technique of dating the martian surface using impact-crater isochrons has been developed over several decades [e.g. 2]. Isochrons are derived from the size-frequency distribution (SFD) of craters observed on the lunar maria, scaled to account for the ratio of meteoroids at the top of the Mars atmosphere relative to the Moon and the differences in gravity and average impact velocity. The resulting isochrons provide an expected crater SFD for a given age surface and provided a means of understanding the absolute timescale of major geological and geophysical processes on Mars (Figure 1).

The SFD can be described by a power-law. Deviations from the power-law occur through various processes which, in general, preferentially alter the smaller diameter crater population making small craters more challenging to use for age-dating surfaces. Because of the frequency at which small craters form however, they provide the ability to discriminate surface ages of geologically young regions and features at a higher spatial resolution where only small craters are available for dating. This level of resolution is required to establish the temporal relation of recent geologic activity on Mars.

We model crater populations using a Monte Carlo simulation assuming a power law distribution of projectiles at the top of the atmosphere and account for fragmentation and the dependence of mass and velocity on deceleration and ablation in the atmosphere [1].

2. Fragmentation

About 50 – 60% of fresh craters observed by the High Resolution Imaging Science Experiment (HiRISE) on the Mars Reconnaissance Orbiter (MRO) are clusters of craters [3] indicating fragmentation of meteoroids in-flight is an important process at these diameters. Fragmentation occurs when the ram pressure, P_{ram}, the product of the atmospheric density and the square of the meteroid velocity, exceeds the bulk meteoroid strength. Assuming single fragmentation events for simplicity, we find a constant meteoroid bulk strength of 0.25 MPa results in a fragmentation rate consistent with observations. This is within the range of bulk strengths inferred from the observed fragmentation altitudes of meteor-fireballs in the terrestrial atmosphere [4].

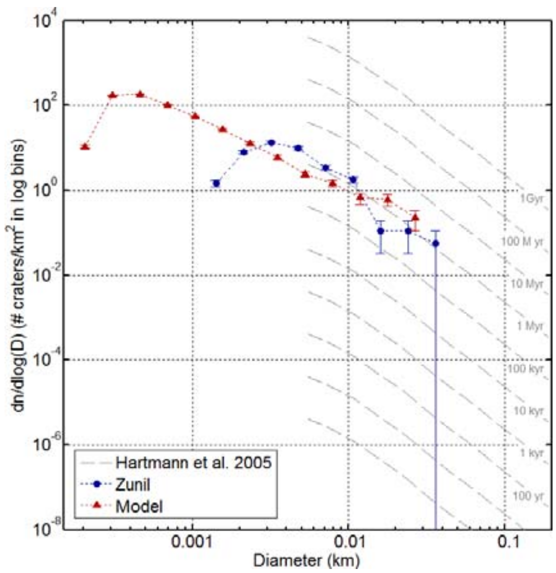

Figure 1: Log differential plot of crater counts for Zunil and a modelled 1 Myr surface. Error bars indicate the statistical uncertainty in the observations, not in model predictions

Observed crater clusters are included in the SFD typically by means of estimating an effective crater diameter, $D_{eff} = (\Sigma_i D_i^3)^{1/3}$, the diameter of an equivalent non-fragmented meteoroid. This does not account for the increase in deceleration and ablation experienced by the smaller individual fragments which can potentially lead to errors at the smallest sizes [5]. We model the ratio D_{eff}/D, where D is the resulting crater diameter of an unfragmented projectile, with initial projectile diameters ≤ 1.5 m, the size range over which atmospheric effects (deceleration and ablation) become significant, assuming a meteoroid density of 2000 kg m^{-3} and entry angle 45°. Figure 2 shows the average D_{eff}/D versus D_{eff} demonstrating the potential errors of D_{eff} as a function of size. Scatter in D_{eff}/D is largely due to variations in meteoroid velocity with lower D_{eff}/D for faster objects. The absence of craters D_{eff} < 20 cm results from the complete atmospheric filtering of objects forming craters at these sizes.

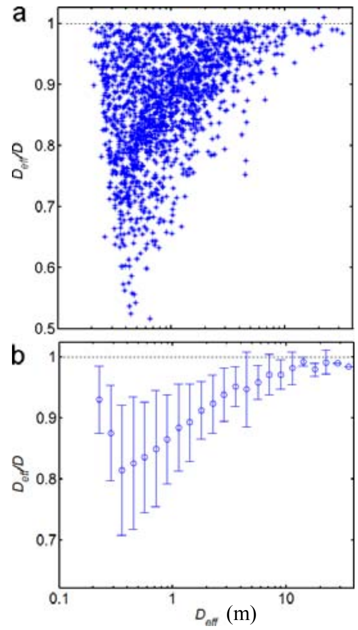

Figure 2: D_{eff}/D versus D_{eff}. a) Scatter plot and (b) mean values. Error bars are standard deviation within each bin, as opposed to uncertainty in the mean.

3. Crater counts

Crater counts were conducted on a portion of the proximal ejecta of Zunil crater, likely the most recent D = 10 km scale crater to form on Mars [6]. The fairly young surface of the proximal ejecta should be relatively uncontaminated by any secondary craters so the crater population is expected to be close to the pure accumulation regime for primary craters. Analysis of a 44.5 km^2 region using HiRISE images is shown on a log-differential plot (figure 1). The crater population has a distribution that falls close to the 1 Myr isochron of [2] consistent with previous age estimates of Zunil of the order a few Myr [6].

We simulate the crater production of a 1 Myr surface with an area of 44.5 km^2 with our model. The power law projectile distribution at the top of the martian atmosphere is assumed to be that of the observed annual flux of small near-Earth objects colliding with the Earth [7] scaled by a factor 2.6, the nominal ratio of the martian and lunar impact rate [2]. This yields a similar result to the observed SFD for D > 2 m. The deficit in observed craters at smaller diameters relative to the model SFD may be a result of observational bias with an increasing fraction of smaller craters remaining unidentified as D approaches the image resolution. Alternately, it could be indicative of erosion and deposition rates. Taking a crater D = 2 m depth to be ~0.2D, implies a resurfacing rate of ~400 nm yr^{-1} to obliterate a crater of this size in 1 Myr on the ejecta blanket of Zunil.

Acknowledgements

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