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The size-frequency distribution of elliptical craters

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Abstract

Impact craters are asymmetric and elliptical if the impactor's trajectory is below a threshold angle of incidence. Laboratory experiments and 3D numerical simulations demonstrate that this threshold angle is higher if the cratering efficiency is low. As cratering efficiency decreases with increasing crater size, this can explain the increase in the fraction of elliptical craters as a function of crater diameter observed on Mars and other planetary surfaces.

1. Introduction

Impact craters are the dominant landform on almost every solid planetary surface in the solar system. The vast majority of these craters are very nearly circular in plan view; only a few percent of craters show pronounced elongation of the crater in the direction of impact [1, 8]. Although few in number, elliptical craters are an important fraction of any crater population. Many large craters (or suspected craters) in the solar system are elliptical (that is, with an ellipticity = length/width > 1.1), including the South Pole-Aitkin impact basin on the moon, Caloris basin on Mercury and the putative Borealis impact basin on Mars. Moreover, as elliptical craters are the product of highly-oblique impacts, which are far less well understood than their near-vertical counterparts, they provide important insight into the impact process.

In this paper, we use the results of laboratory experiments [e.g., 2, 4] and our own 3D numerical impact simulations to constrain the conditions for elliptical crater formation. We then calculate the predicted elliptical crater population for Mars and compare our model with observations.

2. Elliptical crater formation

The effect of impact angle on crater ellipticity (and other measures of crater asymmetry) has been numerical impact simulations [this work], as well as indirectly by remote sensing [e.g., 1, 8]. Impacts at low angles (measured with respect to the target plane) produce elliptical craters elongated in the direction of the projectile's horizontal movement. Above a certain threshold angle, however, all impacts produce a near-circular crater.

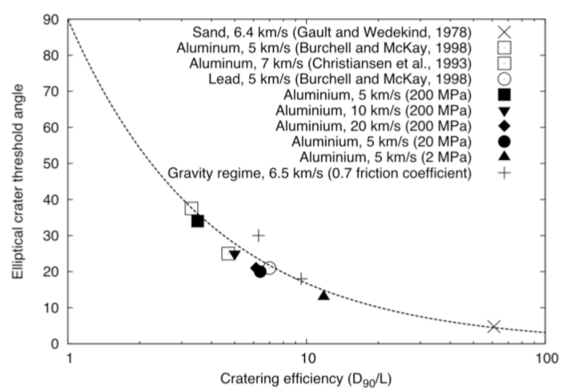

Figure 1: Threshold angle below which all craters are elliptical, for different suites of impact experiments [e.g., 2, 4] and numerical simulations [this work], as a function of cratering efficiency in the vertical impact case.

Laboratory-scale impact experiments [e.g., 2, 4] show that the elliptical crater threshold angle depends on the strength of the target material. Numerical impact simulations, using the iSALE-3D shock physics code [3], reproduce this dependence and demonstrate that the threshold angle is also a function of impact velocity and surface gravity. Importantly, as shown in Figure 1, the elliptical crater threshold angles determined in these suites of experiments follow a single trend when compared in terms of cratering efficiency, defined here as D_{90}/L the ratio of crater diameter (in the vertical impact case) to impactor diameter.

3. Elliptical crater populations

3.1 Model

The trend in Fig. (1), together with crater scaling laws [e.g., 5], can be used to estimate the elliptical crater threshold angle as a function of impactor and target characteristics. The method of [7] for computing the crater size-frequency distribution from a known impactor size-frequency distribution can then be used to estimate the fraction of elliptical craters as a function of size on a given planetary surface. Figure 2 shows two such estimates for Mars: Model A assumes a simple power-law impactor size-frequency distribution (SFD) with an exponent of -2; Model B assumes an impactor SFD inferred from the actual Mars crater SFD [6]. Both models assume an average impact velocity of 10 km/s.

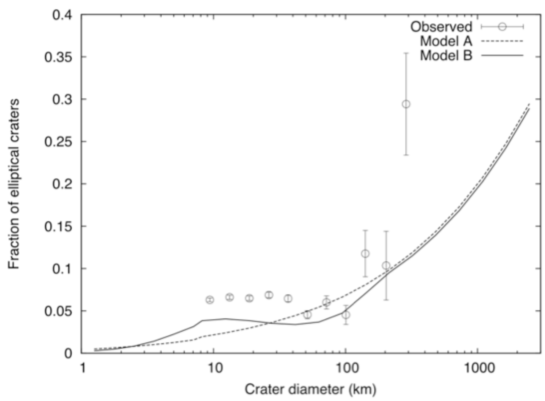

Figure 2: The fraction of elliptical craters on Mars as a function of final crater diameter. Observed data represent the fraction of craters with rim outlines of ellipticity greater than 1.2. Models A and B are the fraction of elliptical craters (e > 1.1) assuming (A) a power-law impactor SFD; (B) an impactor SFD inferred from the martian crater SFD [6].

3.2 Comparison with observation

Previous work [e.g., 1, 8] has shown that ~3-5% of impact craters are elliptical (e > 1.1-1.2) on the moon, Mars and Venus (in the 5-100-km diameter size range). However, no conclusive dependence on crater size was found. Our model predictions are consistent with previous observations (~4-5% of craters between 8 and 100-km diameter are elliptical) and suggest a substantial increase in the number of elliptical craters at large crater sizes.

Figure 2 compares the modeled fraction of elliptical observed population of elliptical craters on Mars. The observed craters were identified and outlined using THEMIS data in ArcGIS. For each crater, non-linear least-squares (NLLS) fitting algorithms that account for the curvature of the globe were used to determine the best-fit circle and ellipse to the rim outline. The resulting crater SFDs were binned in multiplicative D√2 intervals; uncertainties were calculated as the √N where N is the number of craters in each bin. The elliptical crater SFD was then normalized based on the total number of craters in each bin from the global Mars catalog.

Our model predictions of the elliptical crater SFD on Mars are in reasonable agreement with observation, particularly for crater diameters less than 200 km. Both our model and observation suggest that the fraction of elliptical impact craters is much greater among the large basins than among small craters. The discrepancy in the fraction of elliptical craters between model and observation at large crater sizes might be due to small number statistics and/or erosion enhancing crater ellipticity since the data plotted include all degradation states and are not limited to fresh craters. Alternatively, it may suggest that current impact crater scaling laws do not adequately describe large impact crater formation, and, consequently, that the predicted impactor SFD is inaccurate at large sizes.

Acknowledgements

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