Pacing Wind-Induced Saltation Abrasion on Mars: Using Crater Counts to Constrain Aeolian Exhumation

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Motivation

Estimates of surface erosion rates and knowledge of how they vary over space are needed in order to better understand various aspects of Mars’ landscape evolution:

- Test models of past wind shear stress[1]
- Test models of sedimentary rock formation [2,3]
- Provide input models of organic matter preservation potential [4]

Relatively small, shallow craters are preferentially obliterated as a landscape undergoes erosion [5], so the size-frequency distribution of impact craters in a landscape undergoing rapid, steady exhumation will develop a shallower power-law slope [6].

Here we present preliminary results from our effort to map impact craters for sedimentary rocks across Mars and estimate their corresponding, obliteration rates.

1. Data and Methods

We used map-projected image data from the HIRISE red channel as the basis for crater mapping. Analysts counted craters in selected areas of HIRISE images using the CraterTools extension for ArcMap [7].

Crater Counting

Six analysts (University of Chicago undergraduates) were given 2 hours of classroom training on Martian impact crater morphology, with examples primarily drawn from HIRISE image data, followed by ~6 hours of hands-on training mapping impact craters on 2 HIRISE images using ArcMap and CraterTools.

Following training, the analysts independently mapped craters in pre-selected areas of ~40 HIRISE images. Portions of the images containing dunes or other apparently unconsolidated material were masked out.

2. Results

Impact craters were mapped by ≥3 analysts in 18 HIRISE images showing sedimentary rocks (Figure 1). The incremental frequency plots of craters agreed upon by ≥2 analysts from each image display a shallower power-law slope than that of an isochron (Figure 4), indicating that these areas have experienced resurfacing.

Figure 1: Map highlighting regions where craters were counted. AD = Aram Dorsum, CVM = Central Valles Marineris, G = Gale Crater, NF = Nili Fossae, MV = Mawrth Vallis, OP = Oxia Planum. 10 of 18 images mapped by ≥3 analysts are located in CVM or G.

Erosion rates were estimated for areas in HIRISE images in which craters were mapped by ≥3 analysts. For each such image, craters mapped by different analysts were aggregated using a clustering algorithm implemented in Matlab.

Final agreed-upon craters were then defined by the mean center location and diameter of the clustered features (Figure 2).

Obliteration Rate Estimation

We estimated crater obliteration rates, $z_i$, for each size bin using the following equation:

$$\frac{z_i}{N_i} = \frac{f_i H_i}{N_i}$$

where $H$ is the expected flux of craters onto a unit surface per 1 Gyr (Table 1 in Ref. 10), $N_i$ is the observed density of craters in the size bin and $f_i$ is an assumed resurfacing depth sufficient to obliterate a crater (i.e., make it unrecognizable as a crater in HIRISE image data) (Figure 3). We set $f = 10\%$ of the crater bin log center.

For small, fresh craters on Mars, the crater depth to diameter ratio, $d/D = 0.2$, therefore our assumed resurfacing depth is 50% of the depth of the original crater.

3. Discussion

Crater Counts

Most studies involving crater counts rely on a single experienced analyst to identify craters. Ref. [11] compared lunar crater counts from 8 expert analysts to those 1000s of non-specialist volunteers and found that, on average, non-specialists are able to identify craters as well as expert analysts are. There can also exist considerable variability between individual analysts’ crater counts, even among experts (review in [11]).

This work took an intermediate approach by providing 6 non-specialists with ~6 hours of intensive training. However, a key remaining uncertainty is the effect of inter-analyst variability on the crater counts.

In an effort to provide an expert reference to the non-specialists’ counts, the authors counted craters on 2 of the HIRISE images (we mapped 42 and 35 craters D≥20 m, respectively, with 32 craters in common).

The false positive rate is ~3% (~1%) for features agreed upon by ≥2 ≥3 analysts (D≥20 m). The false negative rate is 33% (~55%) for features agreed upon by ≥2 ≥3 analysts (D≥20 m).

We chose to calculate obliteration rates based on ≥2-agreed case because it represents the smallest combined error rate relative to the expert reference.

4. Conclusions

- Crater size-frequency distributions in the studied sedimentary rock regions are not well-fit by isochrons.
- We estimate crater obliteration rates of 0.1-0.2 μm/yr based on craters agreed upon by ≥2 analysts.
- These crater obliteration rates represent an upper limit on surface erosion by landscape lowering.
- A key remaining uncertainty on obliteration rate estimates is the effect of crater count variability between non-specialist analysts and between images.
- Future work will involve using estimated erosion rates to assess organic matter preservation potential [4,12].

References


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Implications for Dust Cycle

If craters are destroyed purely by advection, then multiplying our crater obliteration rates by Mars’ total sedimentary rock area (2x10^7 km²) yields a dust production rate of 10^7 km³/yr or ~4 m global equivalent layer over 3 Gyr.