# 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 mound formation [2,3]
- Provide input to 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 shallow 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 on 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 andCraterTools.

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.

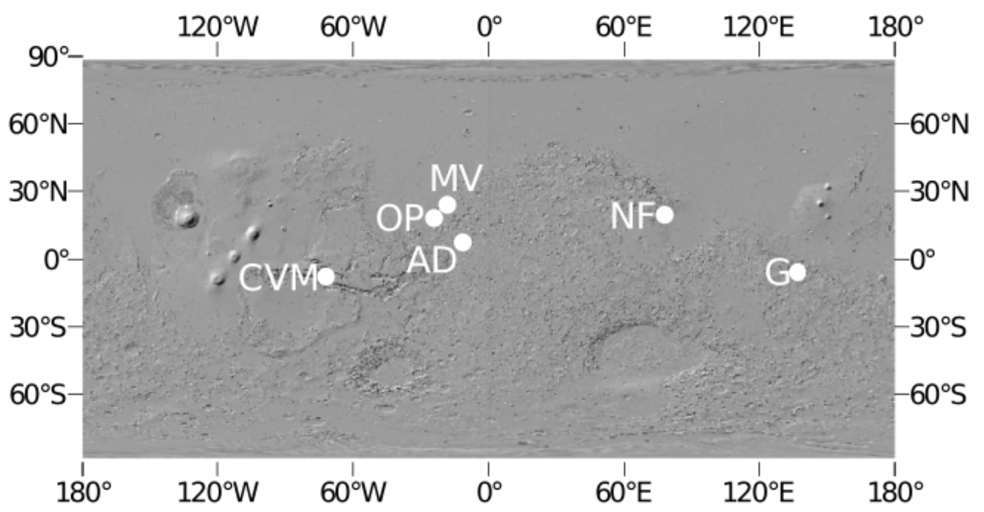


***Figure 1:*** *Map highlighting regions where craters were counted. AD = Aram Dorsum, CVM = Central Valles Marineris, G =Gale Crater, NF = Nili Fossae, MV = Mawrth Vallis, OP =Oxia Planum. 10 of 18 images mapped by ≥3 analysts are located in CVM or G.*

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).

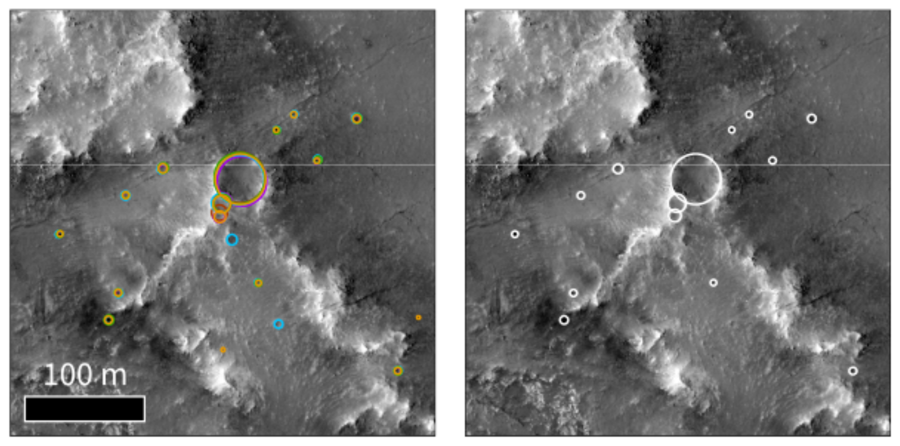


***Figure 2:*** ***(a)*** *Example of mapped craters before aggregation. Colored circles represent craters mapped by different analysts.* ***(b)*** *Final aggregated craters (white circles) based on agreement by ≥2 analysts. HiRISE image ESP_015942_1980.*

### Obliteration Rate Estimation

We estimated crater obliteration rates, $\dot{z}_i$ for each size bin $i$ using the following equation:

$$\dot{z}_i = \frac{f H_i}{N_i}$$

where $H$ is the expected flux of craters onto a unit surface per 1 Ga (Table 1 in Ref. 10), $N$ is the observed density of craters in the size bin and $f$ 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.

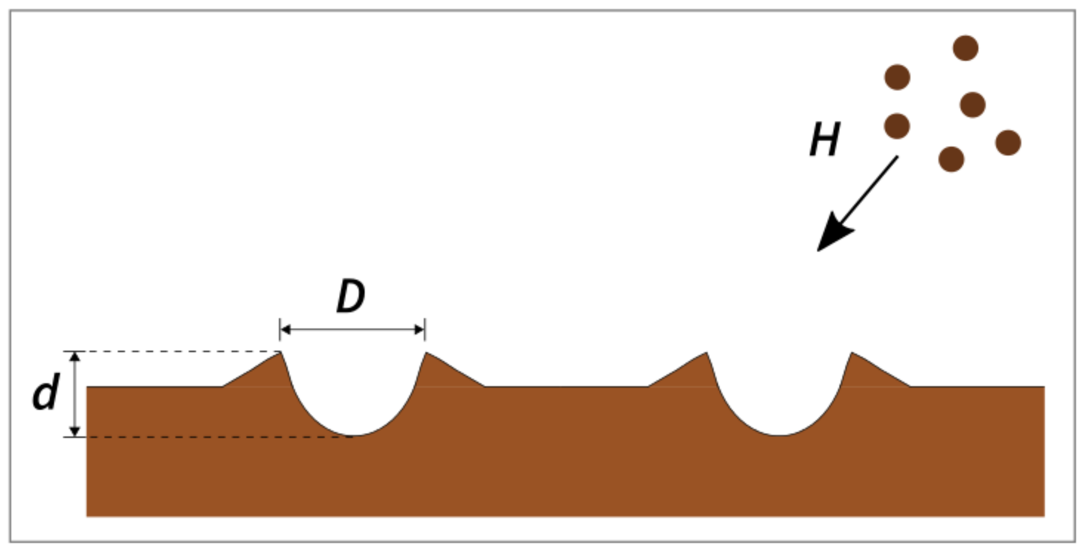


***Figure 3:*** *Schematic of a surface containing craters belonging to the same size bin. For a given size bin, the obliteration rate is a function of crater diameter* D *(which is empirically related to crater depth* d*), impactor flux* H *and the density of craters. Not to scale.*

## 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.

The mean crater obliteration rates derived from the crater counts are 0.1-0.2 μm/yr if craters counted by ≥2 analysts are included (Figure 5). Individual images showed crater-obliteration rates varied from 0.02-1 μm/yr, with an interquartile range ~0.2μm/yr, consistent with [8,9].

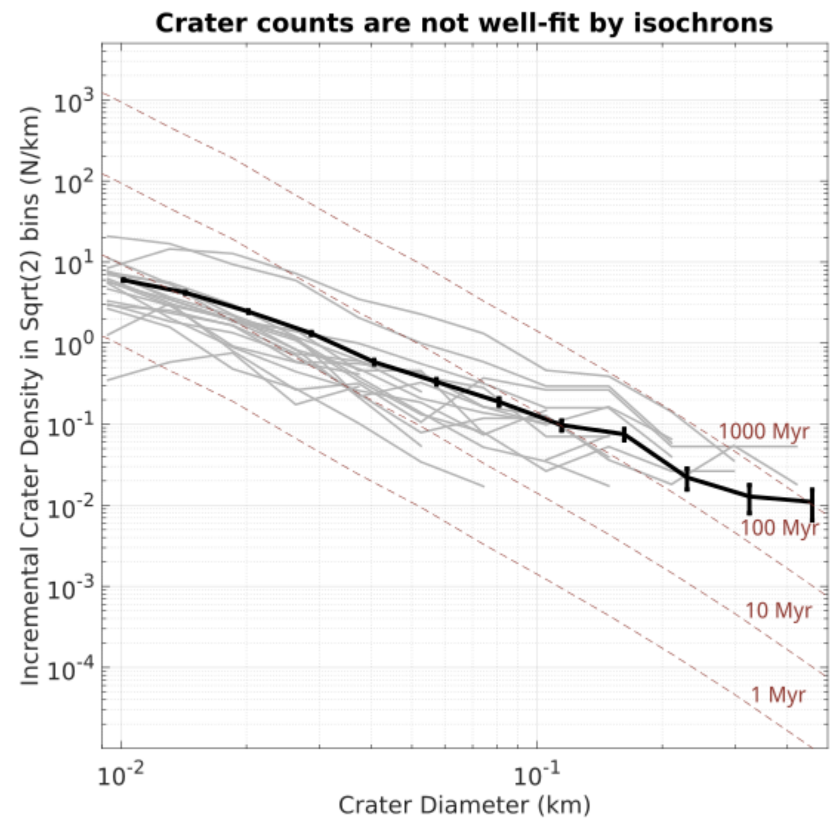


***Figure 4:*** *Incremental crater density plot . Gray lines correspond to individual HiRISE images based on craters agreed upon by ≥2 analysts. Bold black line is average over all images. Dashed red lines are isochrons after [10]. Incompleteness in crater identification at D <10m.*

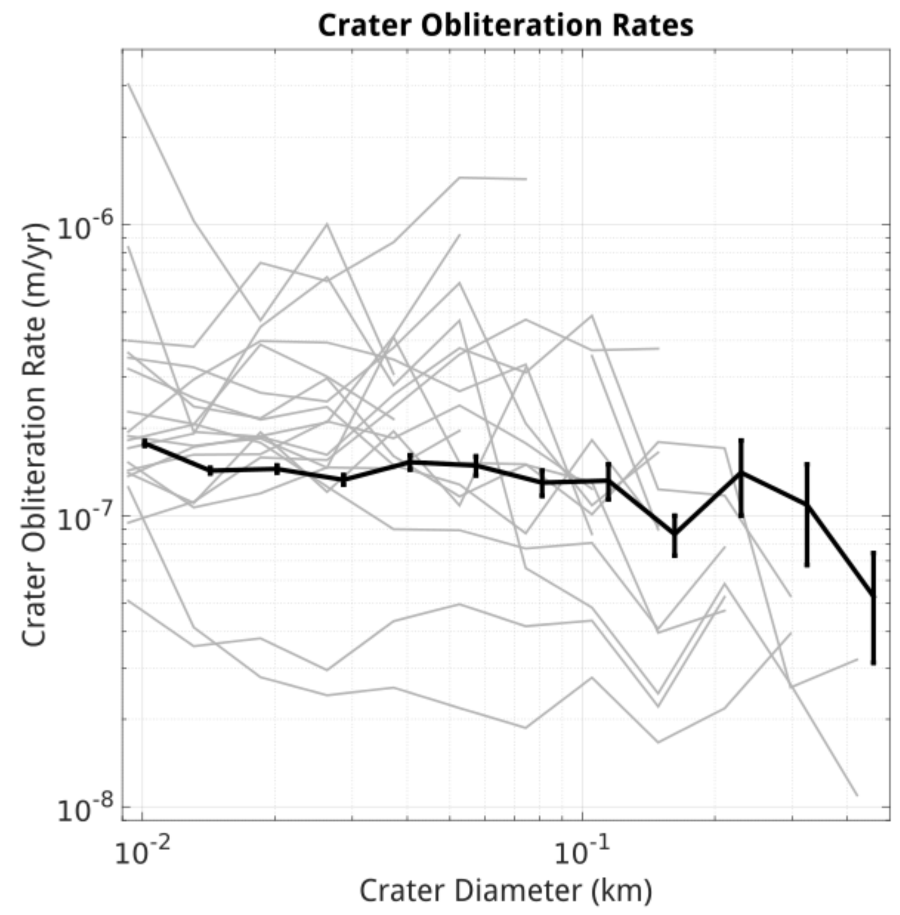


***Figure 5:*** *Crater obliteration rates derived from crater counts on HiRISE images. Bold black line shows results (and statistical error bars). Gray lines show crater obliteration rates for the 18 individual HiRISE images . Incompleteness in crater identification at D <10m.*

Another source of uncertainty in crater obliteration rates is bias in the crater diameters. To assess this, we recalculated obliteration rates based on ≥2-agreed craters after increasing the diameters of a random sample of 25% of them by 50%. This decreased obliteration rates by ~30%.

## 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 ~8 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 the ≥2-agree case because it represents the smallest combined error rate relative to the expert reference.

### Crater Obliteration

The crater obliteration rates we obtain represent upper limits on the rate of landscape-wide exhumation (i.e. landscape lowering). For example, craters can be degraded by diffusive infilling without landscape-lowering (e.g., the Burns Formation [5]). Alternatively, an area may have undergone various periods of erosion-dominated or diffusion-dominated crater obliteration.

Furthermore, the threshold at which craters of a given size become unrecognizable may vary depending on geological setting. Therefore our assumed resurfacing depth fraction could in fact be variable. This could potentially be assessed through a systematic study of crater degradation states over different geological settings. If the resurfacing depth is in fact 100% of the original crater depth, then our calculated rates increase by a factor of 2.

### Implications for Dust Cycle

If craters are destroyed purely by advection, then multiplying our crater obliteration rates by Mars' total sedimentary rock area ($2\times10^{6}$ $km^2$) yields a dust production rate of $10^{-4}$ $km^3$/yr or a ~4 m global equivalent layer over 3 Gyr.

## 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

**[1]** Armstrong et al. (2005) Icarus. **[2]** Day & Kocurek (2016) Icarus. **[3]** Bridges et al. (2012) Nature. **[4]** Farley et al. (2014) Science. **[5]** Golombek et al. (2014) JGR-Planets. **[6]** Öpik (1965) Irish Astro. J. **[7]** Kneissel et al. (2011) Planetary Space Sci. **[8]** Smith et al. (2008) Geophys. Res. Lett. **[9]** Catling et al. (2006) Icarus. **[10]** Michael (2013) Icarus. **[11]** Robbins S. J. et al. (2014) Icarus. **[12]** Kminek & Bada (2006) Icarus.

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