Young Crater Clusters on Mars.

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Introduction: Fresh craters formed by new impact events on Mars have been identified in before and after high-resolution orbital images of the Martian surface (Figure 1) [1-3]; impact events with approximate formation dates are now known in ~700 sites. High-resolution views have revealed that roughly half of these dated impacts occur as clusters, most likely due to impactors fragmenting in the atmosphere [2,4]. Understanding the characteristics of these clusters can constrain: 1) fragmentation processes in the martian atmosphere, 2) the properties of the impactors [4,5], 3) the characteristics of the impact-produced seismic activity [6] (e.g. InSight investigations [7,8]), and 4) crater chronology [9].

Data and Methods: Images from the High Resolution Imaging Science Experiment (HiRISE) [10] on Mars Reconnaissance Orbiter (MRO), with pixel scales of 0.25 m/pixel, are used to investigate new, dated impact sites. Here we focus on 77 recently formed crater clusters (Figures 1 and 2) [3].

For each crater in each cluster, the diameter was measured, along with the crater's center latitude and longitude [3]. A lower size limit of 1 m diameter (four pixels in the highest resolution HiRISE images) was used. For clusters containing more than five craters, we determined a best fit ellipse to each distribution of craters using a solver based upon the Khachiyan algorithm [11] to find the ellipsoid with a minimum volume encasing the location of craters in the cluster. A bootstrap method [12] was then used to derive uncertainties for the ellipsoid fit and form a bootstrap distribution (N=300) of potential ellipse azimuths and radii that could be used to construct the mean and standard deviation of our crater cluster parameters (azimuth (Figure 3), radii, ellipticity (e)). We then estimated the angle and direction of the impact from the best-fit ellipses; low ellipticity (e=0) was assumed to represent near-vertical impacts, while elogated ellipses (e>0) were assumed to occur from impactors with off-vertical impact angles. The ratio of the two axes of the best-fit ellipse was used to estimate the angle of the impact from vertical (Figure 4) [3].

To disambiguate impact direction, we identified the position of the largest crater relative to the best-fit ellipse center, and used the assumption that the largest fragment should have the least deceleration due to gravity, and should be located farthest downrange [13-15].

We calculated the dispersion, D, for all clusters containing more than three craters as the standard deviation of distances between each possible combination of pairs of craters in the cluster.

Fig	Lat (°N)	Lon (°E)	Description
1A	4.28	135.25	Single crater; diameter: 5.4 m
1B	-1.34	141.57	3 craters; diameters: ~1 to 4.6 m
1C	-6.63	156.45	6 craters; diameters: ~1 to 6 m
1D	25.85	247.62	>100 craters; diameters up to ~4.5 m

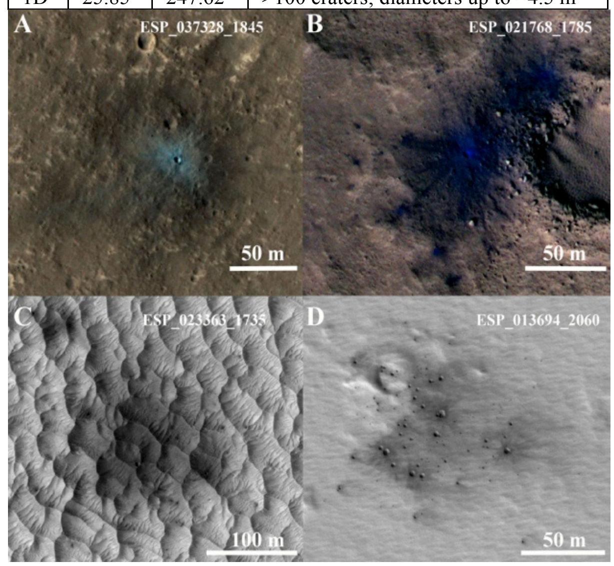

Figure 1. New dated impact sites showing a variety of types of impacts from a single crater (A) to clusters with different numbers of craters (B, C, and D). HiRISE observation IDs are indicated. For all: North is up; sun is roughly to the west. A and B are enhanced false color RDRs; C and D are red RDRs. Image credit: NASA/JPL/University of Arizona.

Results: Roughly half of recent dated impacts on Mars form clusters of craters that impact the surface nearly simultaneously. Although some clusters can consist of hundreds of craters, most clusters in this study comprise small numbers of craters (<10) with diameters ranging from below HiRISE resolution up to tens of meters (Figures 1 and 2) [2,3]. Clusters may be dispersed over a few meters to a few kilometers, with most dispersions on the order of tens of meters. This dispersion of clusters generally does not appear to correlate with topographic elevation which cannot be adequately explained with current fragmentation models of atmospheric breakup [3]. The azimuths of cluster strewn fields are randomly distributed (Figure 3) suggesting a wide distribution of incoming meteoroid directionality. This cannot be connected in a simple way to the pre-impact orbital inclination of impactors [3].

We also find impact angles to be in the range 40-80º (Figure 4) which is shallower, or closer to horizontal, than expected based on the most likely impact angle of 45º found by [16]. This may be the result of observational biases [3].

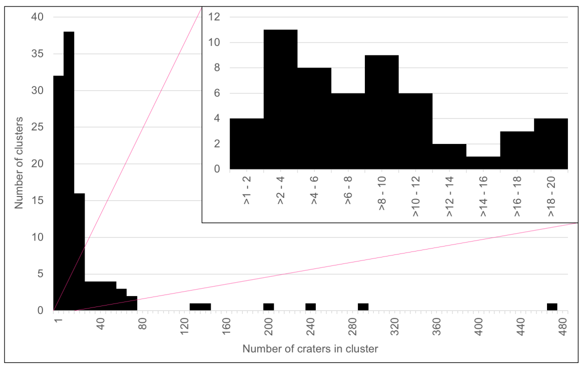

Figure 2: Histogram of number of craters in clusters. Figure from [3].

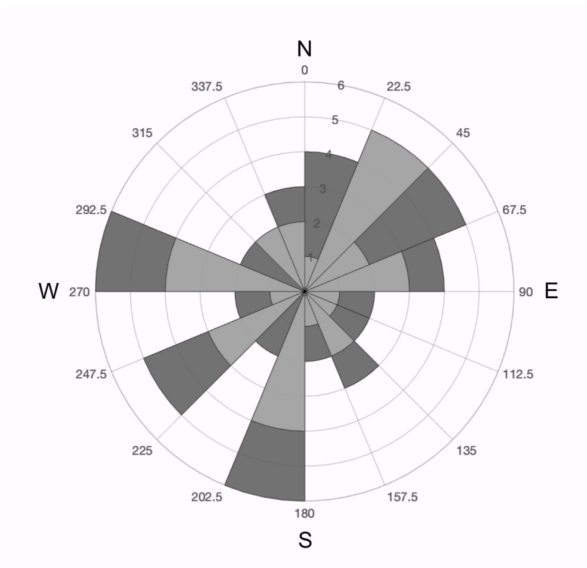

Figure 3. Rose diagram of azimuths of the best-fit ellipses of impact clusters (*N*=55; dark gray). Clusters with more well-constrained azimuths (*N*=32) are in light gray. Figure from [3].

Measured crater parameters and properties from this study, and a range of target material constraints are being used to inform elastic wave propagation simulations for assessing the detectability of impact seismic energy [6]. The results reported here can also be used as constraints to inform fragmentation processes in the martian atmosphere [17] and properties (strength and density) of the impactors themselves.

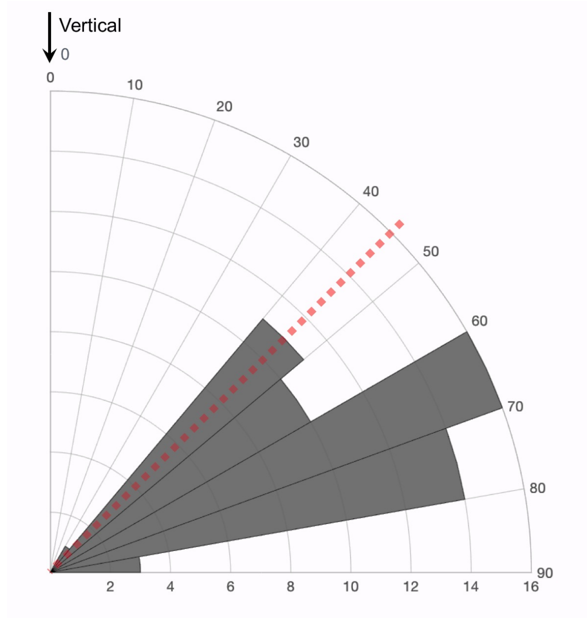

Figure 4. Histogram of estimated impact angle for 55 new dated impact clusters. The red dashed line marks the most likely impact angle of 45º found by [*Shoemaker,* 1961]. Figure from [3].

References:

[1] Malin M.C. et al. (2006) *Science, 314*, 1573-1577. [2] Daubar I.J. et al. (2013) *Icarus, 225*, 506-516. [3] Daubar et al., (2018) submitted *to Journal of Geophysical Research, Planets.* [4] Ivanov, B. *et al.* (2009) *LPSC,* 1410. [5] Ivanov, B. *et al.* (2014) *LPSC 45,* 1812. [6] Schmerr, N.C. *et al.* (2016) *LPSC 47*, 1320. [7] Daubar et al. (2018) SSR, in review. [8] Banerdt, W. *et al.* (2013) *LPSC 44*, 1915. [9] Hartmann W. K. and Daubar I. J. (2017) *MAPS 52*:493–510. [10] McEwen A.S. et al. (2007) *JGR*, doi:10.1029/2005JE002605*112*. [11] Todd, M.J., and Yildirim, E.A. (2007) *Discret. Appl. Math. 155*, 1731–1744. doi:10.1016/j.dam.2007.02.013 [12] Efron, B., and Tibshirani R. (1986) *Statistical Science, 1(1)*, 54-75. [13] Ivanov, B., Melosh, H.J., McEwen, A.S. (2008) *Lunar Planet. Sci. Conf. 39*, 1221. [14] Ivanov, B., et al. (2009) *Lunar Planet. Sci. Conf. 40*, 1410. [15] Golombek, M. et al. (2010) *Journal of Geophysical Research, Planets, v. 115*, E00F08, doi:10.1029/2010JE003628. [16] Shoemaker, E.M. (1961)in: Kopal, Z. (Ed.), Physics and Astronomy of the Moon. Academic Press Inc., London, UK, pp. 283–359. doi:http://doi.org/10.1016/B978-1-4832-3240-9.50012-2. [17] Daubar et al. (2017) *LPSC 48,* 2544.