NEW MARTIAN IMPACT EVENTS: EFFECTS OF ATMOSPHERIC BREAKUP ON STATISTICS.

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Introduction: For the past five years, new Martian craters have been discovered using repeat imagery bracketing impact events [1-4]. As of June 2010, 164 new impacts have been discovered, confirmed, and dated. About 60% of those consist of clusters of craters as opposed to single-crater sites. As we build up decent statistics on these events, it's important to examine the observational biases that are affecting those statistics. One process that is certainly affecting the detection and detailed distributions of new impact sites is fragmentation in the atmosphere.

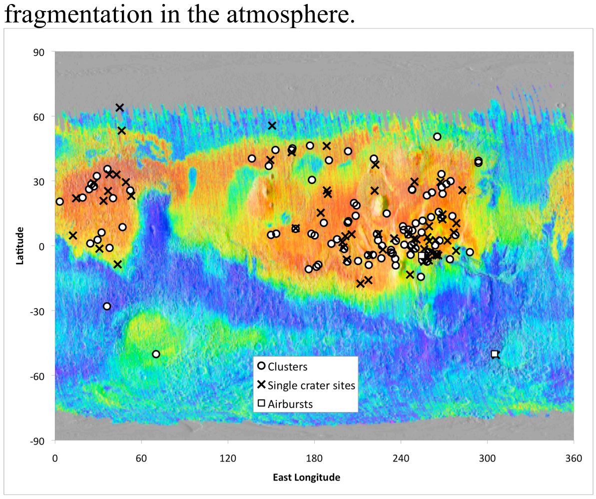

***Fig. 1:** Locations of 164 new confirmed impact sites plotted on a map of the TES dust cover index [10]. Almost all are in areas of high dust cover.*

Detection biases due to halos: Dark "halos" surround the majority of new impact sites (Fig. 2), allowing them to be detected using lower-resolution data. These are areas where a thin layer of bright dust has been removed. In addition to the obvious spatial bias this produces (Fig. 1), we might also expect a bias toward detecting certain types of impacts.

Halos range in size from ~10-100 times the diameter of the central crater [5]. They are complicated in detail, and their formation mechanism is still being investigated (possibilities include hemispheric shock wave interactions, ballistic waves [5], and in a few cases, thousands of slope-streak-like features triggered by the impact airblast [6]). Regardless of how they are generated, some simple geometric considerations can be made. For example, clusters in general will have a larger visual footprint than single craters. We therefore expect that the true ratio of current impactors breaking up in the atmosphere to those remaining intact is somewhat less than the measured ratio of 3:2.

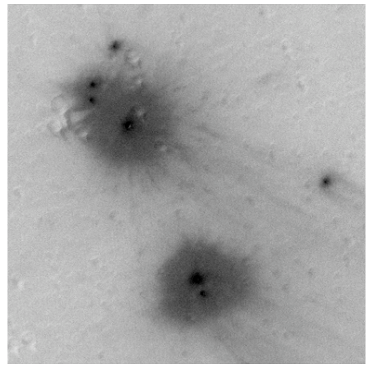

***Fig. 2:** Cluster with dark halos around individual craters. Several craters exhibit overlapping halos.*

Scene is 90 meters across. North is up. Observation ID: PSP_007496_1735 Image credit: NASA/JPL/University of Arizona

Clusters with dispersion (distance between craters) larger than the halo diameters will have more darkened surface area visible, since there will be no overlap of halos. Thus weaker bolides, which break up at a higher elevation, resulting in more dispersed final clusters, will be preferentially detected. There should be a falloff in this effect for very weak/small impactors, which would be entirely obliterated in the atmosphere. Those might create craters below our detection limits, or possibly only a dark spot where dust is disturbed on the surface. We have found several sites with dark spots but undetectable central craters where this might have occurred.

Ablation effects: The amount of ablation is proportional to the cross-sectional area of the body [7]. Thus fragmentation should increase the total amount of ablation relative to the original mass of the impactor, decreasing the effective diameter of the resulting cluster. Effective diameters for clusters are calculated as $D_{eff} = (\Sigma D^3)^{1/3}$ [5]. This approximates the diameter of the crater that would form if fragmentation had not occurred, discounting the increased ablation expected for fragmented impactors. This estimate also does not take into account the reduction in the vertical velocity of individual fragments [8], which would further decrease the final crater sizes.

Despite these two reasons we would expect clusters' effective diameters to be smaller, we do not find a significant difference in the size distributions for the effective diameters of clusters versus single-crater sites (Fig. 3). This may indicate that ablation is not a significant factor in these cases. Another explanation may be that the effects of increased ablation and deceleration of fragments are balanced by the increase in number of clusters detected due to their halos, as previously discussed. In this case that effect should not be significant, however, since Fig. 3 represents nearly equal numbers of clusters and single-crater sites.

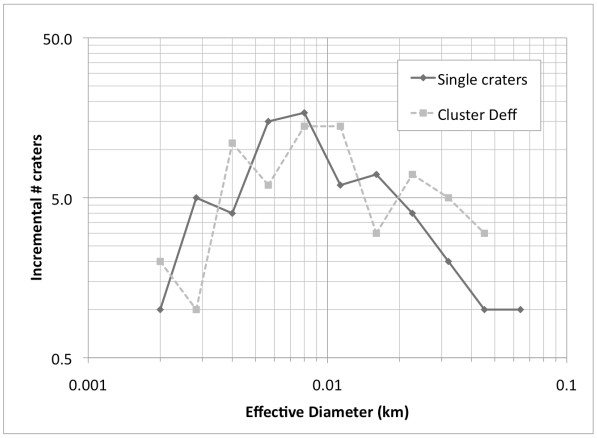

Fig. 3: *No significant difference is seen between the size distributions of 63 single-crater new impacts and 66 new impact clusters (effective diameters).*

SFDs of craters within clusters: The size-frequency distributions of individual craters within most clusters studied so far follow fairly shallow power laws (Fig. 4). This means the mass is not concentrated in the largest fragments, so the resolution limit at the smallest sizes has a non-negligible impact on the effective diameter calculated. To correct for this effect, one could fit a function (a power law or Weibull distribution, for example) to the SFD of the cluster and extrapolate down to smaller sizes than can be resolved in HiRISE's 25 cm/pixel data. This assumes the size distribution remains consistent with that functional shape down to very small diameters, which may not be a good assumption.

Regardless, the distributions show a clear drop-off at sizes below ~2 meters due to resolution effects, and those diameter bins cannot be considered complete.

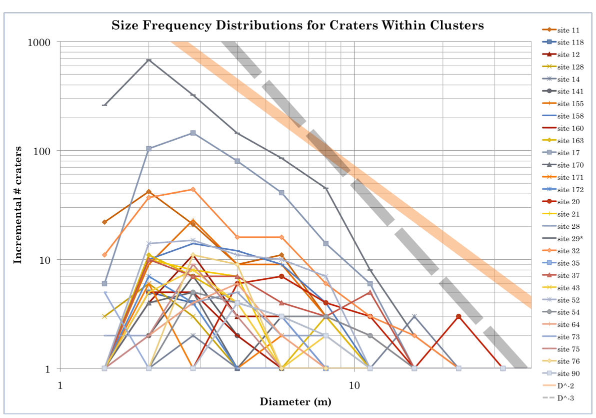

Fig. 4: *Size distributions of individual craters within clusters at 29 different new impact sites with more than 10 individual measureable craters each. Although there is a lot of variation, which may be dependent on the style of fragmentation [11], most seem to follow a shallower power law than D^-3. Many are "unimodal" – somewhat flat with a peak in one diameter bin, which has also been found for other clusters of larger craters [12].* D^{-2} *and* D^{-3} *power law relationships are shown for comparison.*

Mistaking old clusters for individual impacts: For these new dated impact events, we have the advantage of before-and-after imaging, which identifies these as single primary impact events. This is not the case for most craters in this size range. Without other specific evidence for a shared origin, the craters in an older cluster could easily be misinterpreted as multiple individual primaries (or distant secondaries, although most of these have higher depth-to-diameter ratios than secondaries [9]). This kind of misinterpretation can have a substantial effect on the measured size distribution (Fig. 5). The proportion of small craters is artificially inflated, in this case by factors of hundreds at the smallest end, and large craters are underrepresented. The slope of the distribution is also significantly distorted, steepening the overall shape.

Conclusion: A variety of effects due to atmospheric breakup can affect the statistics of small craters. Potential biases include: an over-population of clusters compared to single-crater sites; a higher proportion of sites with large halos (related to dust cover or possibly elevation) or widely dispersed craters (i.e., weaker impactors); underestimation of clusters' effective diameters; and gross misinterpretation of surface ages when compared to chronological models. Careful attention needs to be paid to these potential sources of observational bias.

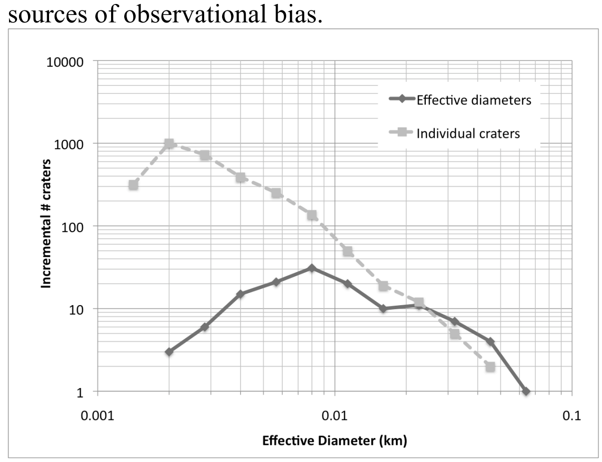

Fig. 5: *Solid line: Size distribution for 129 new impact sites, using effective diameters for cluster sites. Dashed line: Size distribution that would result if individual craters within clusters were mistaken for separate primary impact events.*

References: [1] Malin M.C. *et al.* (2006) *Science, 314*, 1573-1577. [2] McEwen A.S. *et al.* (2007) *LPS 37*, Abs. 2009. [3] Kennedy M.R. & Malin M.C. (2009) *AGU Fall Meeting,* Abs. ID P43D-1455. [4] Daubar I.J. *et al.* (2010) *LPS 41*, Abs. 1978. [5] Ivanov, B.A. *et al.* (2010) *LPS 41*, Abs. 2020. [6] Burleigh K.J. et al. (2009) LPS 40, Abs. 1431.[7] Allen, H.J. & N.A. James (1964) *NASA Tech. Note D-2069*. [8] Artemieva, N. A. & V. V. Shuvalov (2001) *JGR 106*, 3297-3310. [9] Daubar I.J. & McEwen A.S. (2009) *LPS 40*, Abs. 2419. [10] Ruff S.W. & Christensen P.R. (2002) *JGR*, *107*, 5127. [11] Ivanov B.A. *et al.* (2008) *LPS 39*, Abs. 1402. [12] Popova, O.P., *et al.* (2007) *Icarus 190*, 50-73.