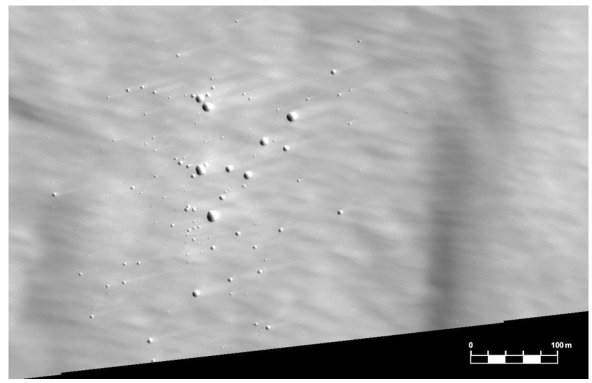
FROM ALMAHATA SITTA TO CRATER CLUSTERS ON MARS. W. K. Hartmann[1], O. Popova[2], and E. C. S. Joseph[1]. [1]Planetary Science Institute, 1700 E Ft Lowell Rd Ste 106, Tucson AZ 85719-2395 USA; [2]Institute for Dynamics of Geospheres, Moscow, Russia.

The 2008 Almahata Sitta meteorite showered a desert area of Sudan with fragments of asteroid 2008 TC3 (diameter 4.1 ± 0.3 m). About 90% of the mass was lost in the form of dust during entry, and the remaining fragments were a mixture of ureilites, enstitite chondrites and other ordinary chondrites [1]. In 2011, Popova et al. examined the 13 then-known cases where terrestrial fireball breakup had been well observed, and where "ground truth" fragments had been collected. In all cases, they found initial breakup at very altitudes, corresponding to a bulk strength much weaker than the strength of the intact fragments on the ground. They suggested that many or most small asteroidal fragments are laced with fractures, or full-fledged rubble piles [2]. The 200 m ×500 m asteroid 25143 Itokawa, for example, appears to be more like a rubble pile than coherent rock fragment [3].

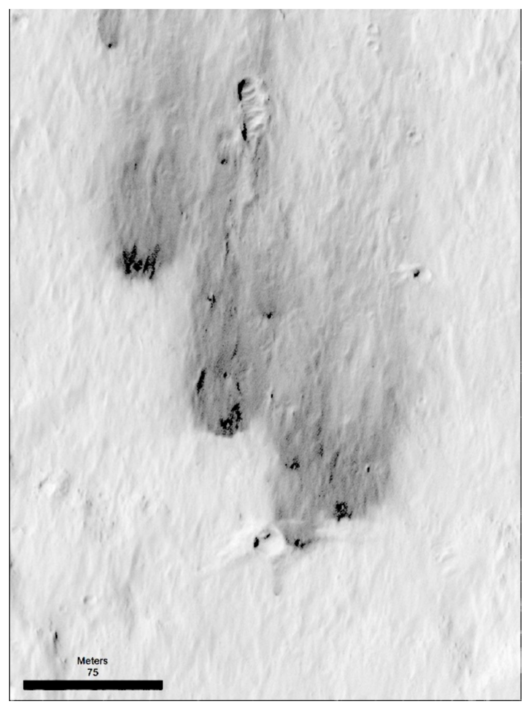
Such data suggest that many asteroidal fragments in diameter range ~1 m to ~500 m are masses of loosely consolidated regolith, some capturing multiple, intact meteorite impactors of different types, at relatively slow velocity. This concept, in turn, raises some questions about whether we fully understand the collision history of asteroids and the forces that hold small objects together [4, 5].

We investigate these issues by analyzing small, "primary crater clusters" on Mars. In 2003, Popova et al. [6] estimated that meteoroids of common strengths would fragment at heights around 10-20 km above the mean surface of Mars, producing clusters of ~5 m to 20 m craters ~100 m to ~300 m wide. They confirmed existence of such clusters [6, 7]. Popova used the 2011 data to estimate that weak meteoroids would fragment at elevations all the way from 45 km above the mean surface down to the mean elevation level, or lower. Both sets of calculations suggest at least some meteoroid breakups on Mars between the highest (+24 km) and lowest (-8 km) surface elevations. By measuring frequencies of such clusters at different elevations, we should be able to obtain the first direct statistics on strength distributions of interplanetary meteoroids from a large sample of breakup events.

As shown in Figure 1, on young surfaces such clusters are easy to find among the randomly distributed background craters. Fragments producing such clusters typically have only seconds for lateral spreading, and produce sharp, high-velocity craters of the same age over a narrower cluster width that lower-velocity secondary ejecta.



(a)



(b)

Figure 1. Examples of small Martian crater clusters created by breakup of meteoroids. **(a)** Cluster of ~10 m craters spread over 100-200 m on slopes of Pavonis Mons, elevation 13.0 km above mean surface. **(b)** Cluster of ~5-10 m craters spread over ~200 m in Amazonis Planitia, elevation -3.8 km (below the mean surface). (NASA Mars Reconnaissance Orbiter ESP_012692_1810 and ESP_01770_1990, respectively.)

We have conducted very preliminary investigations of this effect by making crater counts on surfaces of various altitude and crater retention age. Figure 2 shows a comparison of the percentage of primary clusters detected on a high slopes of Alba Patera (altitude +5.8 km), and on a low, eroded surface in the Hellas basin, altitude -7.5 km). The diagram shows some scatter in results but suggests that roughly twice as many clusters may occur in Hellas, relative to Alba Patera, in the diameter range 2 m to 44 m, which is the predicted range for primary clusters.

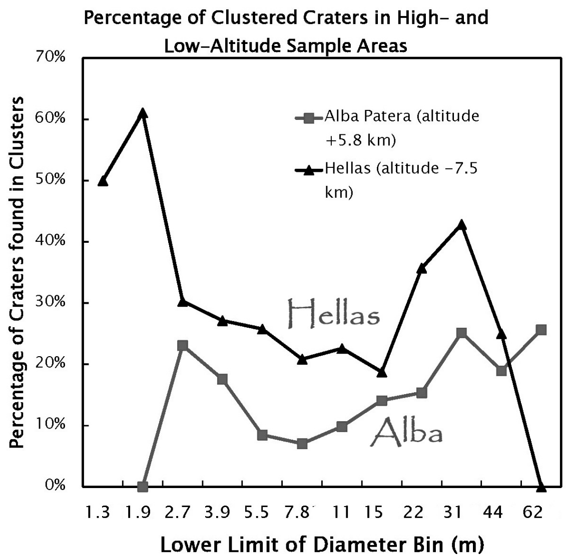


Figure 2. Preliminary test measurements of distribution of percentages of fragmentation events represented among craters as a function of size for two different altitudes on Mars. The data suggest that at crater diameter ~2 m to ~62 m, meteoroids are fragmenting between +6 km and -7 km, causing more "primary clusters" at the lowest elevations.

More work remains to be done. For example, we are concerned that at D >44 m, some of the clusters being picked up in the preliminary survey are secondary clusters. As another example, we began our study be attempting counts on Olympus Mons (to get the highest possible altitude). However, decameter-scale craters on surfaces with crater retention age $\geq 10^8$y tend toward saturation [9], which we suspect increases the chance of spurious cluster detections because of close groupings of independent craters. In general, craters on surfaces that are too old are degraded and the decameter-clusters may be hard to distinguish from the background. On surfaces that are too young, large areas must be studied to get good statistics.

With more counts, a more definitive data set can be established to clarify Martian meteoroid breakup vs. altitude. We believe such counts can be analyzed in terms of existing models of entry and fragmentation [2, 6, 7], and that this will lead to exciting new information on the physical properties and fragmentation mechanics of meteoroids colliding with Mars. We are submitting proposals to continue this work.

References: [1] Jenniskens P. et al. (2009) Nature, 548, 485-488. [2] Popova O. et al. (2011) Meteor. Planet. Sci., 46, 1525-1550. [3] Fujiwara A. et al. (2006) Science, 312, 1330-1334. [4] Michel P. et al. (2013) 44th LPSC, submitted. [5] Scheeres D. and Hartzell C. (2010) 41st LPSC, Abstract #1839. [6] Popova O. et al. (2007) Meteor. Planet. Sci. , 38, 905-925. [7] Popova O. et al. (2007) Icarus, 190, 50-73. [8] Dauber I. et al. (2012) 43rd LPSC, Abstract #1659. [9] Hartmann W.K. (2007) Icarus, 189, 274-278.