DEPTH TO DIAMETER RATIOS OF RECENT PRIMARY IMPACT CRATERS ON MARS. I. J. Daubar[1] and A. S. McEwen[1], [1]Lunar & Planetary Lab, Univ. of Arizona, Tucson, AZ, 85721 (ingrid@pirl.lpl.arizona.edu)

Introduction: Since confirming as new impacts 19 of the 20 dark spots on Mars detected by [1], ~50 additional new impact sites have been confirmed by the High Resolution Imaging Science Experiment (HiRISE) following their discovery by the Context camera, both on the Mars Reconnaissance Orbiter. These impact events have probably occurred within the last decade or so, as indicated by the absence of associated dark spots in previous images. Several of these sites have been described elsewhere [2, 3, 4, 5].

Primary Impact Sites: New small craters are most likely to be primaries [1] because they formed at different times, in widespread locations across the planet. No new large craters have been found that could be the potential primary or primaries if these were secondaries; such a new crater would almost certainly have been detected by at least one of the eight cameras orbiting Mars on four spacecraft over the past decade. In addition, the statistical probablility of enough new large impact events within the last decade to explain these as secondaries is extremely low [2].

Statistics of small primary impact events constrain modification rates and have important implications for the broader field of planetary chronology [e.g., 8, 9]. The difficulty has been in distinguishing small primaries from the huge number of secondaries produced episodically by larger primaries. It has been suggested that most of the small craters in many regions of Mars are secondaries because nearly all of the freshest craters have depth/Diameter (d/D) ratios like those of secondaries [7]. However, we now know that small primaries are forming at a high rate, perhaps comparable to the long-term rate of secondary production. One solution to this enigma would be if small primaries on Mars are generally shallower than on the Moon, due to different surface properties, atmospheric interactions, and impact velocities. This does not seem to be the case, however, at least not for this subset of new small primaries.

Depth/Diameter: The ratio d/D has long been used as a criterion for distinguishing primary from secondary craters [e.g., 6]. Now we have a data set of small craters that we know are extremely fresh primaries. Their d/D ratios can be used as a standard for studies of craters whose origin is not as clear, for example spatially random craters that could be either primaries or very distant secondaries [e.g. 7].

Other criteria used for identifying secondaries [e.g. 10,11] are not always present or reliable. Non-circularity, for example - distant secondaries can be circular if ejection velocities are high enough [7, 8]. Clustering alone cannot be used to recognize secondaries. Even if it wasn't previously known that meteroids break up in the martian atmosphere creating clusters of primary craters [13], these new impacts, 60% of which are clusters, would verify it. Optical or infrared rays are also used in identifing secondaries contained within them, but such rays are not always present or preserved [7, 8].

Method: In this work, the new craters were examined in HiRISE images, and rim-to-rim diameter and rim-to-floor depth were calculated using shadow measurement techniques of [14]. Features that were too small to be confidently measured (<4 pixels across), observations taken with solar incidence angle <45° (and thus inadequate shadows), and those with indistinct or uneven rims or shadows were excluded from the study. HiRISE's three-band color coverage was useful for distinguishing shadows from dark material exposed in the interiors of craters. Groups of craters in clusters clearly associated with the same event were measured individually; measurements were combined to get a site average for each impact event.

The resulting list is concentrated in areas of high dust cover (Fig. 1) like Tharsis and Arabia because new impacts are more easily recognized in these areas.

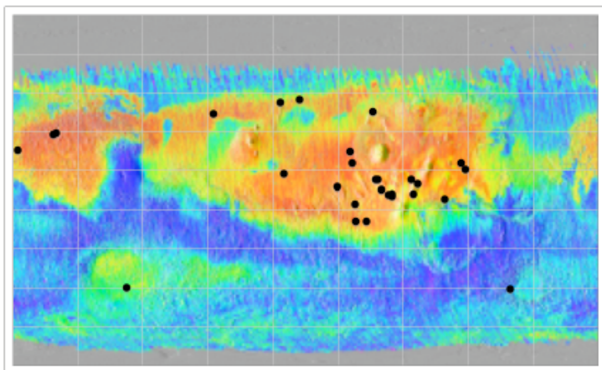

Figure 1. Recent impact sites in this study (black dots) correlate with areas of higher dust coverage (red) as measured by the TES dust cover index [15]).

Calculation of depth using this method depends on a determination of crater morphology (parabolic, flat-floored, or conical) based on the shadow shape [14]. This parameter has the most uncertainty, since most of the shadows subtend so few pixels that determining a shape is difficult. However, variation in d/D when assuming a different shape was only ~10% on average. The uncertainty on individual measurements is also high, since features such as crater rims are near the limit of resolution; measurements were taken multiple times and averaged to partially address this.

Results: After discarding unsuitable craters, 53 craters in 28 impact sites remained, ranging from <2 to 25 meters across. The average d/D over all sites is 0.26. Site-averaged d/D values vary from 0.12 to 0.46. Fig. 2 shows a plot of log(depth) versus log(Diameter) of each site average. The least-squares power-law fit is $d=0.4D^{0.7}$.

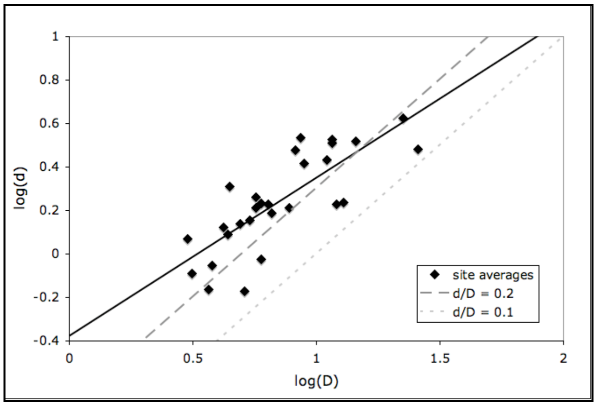

Figure 2. Diameter (D, in meters) vs. depth (d, in meters) from shadow measurements of recent impact sites. Each point is a site average for sites with multiple craters present in a cluster. For comparison, trendlines are shown for d/D = 0.2 (dashed) and 0.1 (dotted).

Discussion: The results for these recent craters are significantly distinct from those reported for secondary craters, which have much lower d/D (e.g., 0.11 for lunar secondaries [12] and for Martian secondaries [7]). Primary craters typically have d/D ~ 0.2 [e.g. 6, 12, 17, 18]. For example, [18] reported $d=0.21D^{0.81}$ for simple Martian primaries overall, although their results varied widely for craters located on different geologic units (e.g., they found $d=0.35D^{0.46}$ on Amazonian volcanic assemblages).

Our d/D of 0.26 is somewhat higher than previous work, although the difference may not be statistically significant. However, these are much more recent craters than have previously been measured, so the possibility that the difference is real should be explored, as crater topography is generally expected to become more subdued over time.

These extremely recent impacts are on average ~0.3 meters deeper than they would be if they followed the expected d/D of older primaries. It's unclear whether average erosion rates are high enough to explain this by erosional infilling of the older craters [16], but erosion and infilling rates of new craters may differ.

Variations in d/D have also been attributed to differences in regional terrain and material properties. Given the spatial clustering in this data set, that is a possibility. Specifically, these recent events all impacted areas with a uniform dust cover and significant mantling in many areas. This selection effect is a result of the detection method, which relies on low-resolution identification of surrounding dark halos where surface dust has been disturbed. Much of the energy of impact into a porous material goes into compaction rather than ejection of material, resulting in relatively smaller, deeper craters [20, 21]. The impactors in these cases are relatively dense [5], especially compared to a thick surface layer of dust that can be identified by the muted morphology surrounding many of the sites. The dust deposits over most of these areas is ~0.1-2 meters thick [22], so much of the excavation of these small craters would be within such a surface layer.

These results also potentially address one of the proposed explanations for lower d/D of secondaries: Clustered impacts have been experimentally shown to result in shallower craters with increasing dispersion [20]. However, the clusters in this study did not have a d/D that was appreciably different from the single craters, within the uncertainties of the measurements. This indicates that lower d/D of secondaries is probably not related to their clustering alone. Lower impact velocities for secondaries or interaction with the primary's remaining ejecta may be better explanations.

How does this inform the low d/D ratios of relatively fresh craters in random plains [7]? One possibility is that secondaries still dominate the statistics, in spite of the current high rate of primary impacts (which could be unusual). Another possibility is that the rate of crater degradation from eolian processes is highly nonlinear over the lifetime of a crater [e.g., 16, 23], such that the d/D of fresh craters is quickly reduced but then remains stable for a significant period of time. Continued monitoring of the new impact sites should provide some insights into these processes [24].

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