SMALL CRATER MORPHOLOGY WITHIN GUSEV CRATER AND ISIDIS PLANITIA:EVIDENCE FOR WIDESPREAD SECONDARIES ON MARS. M. Hurst[1], M. P. Golombek[2], and R. Kirk[3], [1]Department of Geology, Brigham Young University, Provo, UT 84602, [2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, [3]US Geological Survey, Flagstaff, AZ 86004.

Introduction: Large (>2 km diameter) impact craters on the martian surface have been extensively studied and modeled [1,2,3]. Craters smaller than this were known to exist but the lack of high-resolution images prevented detailed measurements and descriptions. Images obtained by the Mars Orbiter Camera (MOC) on Mars Global Surveyor are of sufficient resolution to perform detailed studies on the morphology of small (<1 km diameter) craters. Previous workers have suggested that many of these small craters are secondary craters [4,5]; while others maintain that they represent primary impacts [6]. The difference is significant, however, because of implications for surface age, climate change, impact generated regolith, provenance of surface rocks, engineering considerations (landing safety and rover trafficability), and the origin of martian meteorites [3,7,8].

For this study, two areas were chosen that had extensive MOC (including stereo) coverage that allowed for the creation of high-resolution digital elevation models (DEMs): Gusev crater and Isidis Planitia. Gusev crater is of particular interest because it is the landing site that the Spirit, Mars Exploration Rover has landed [9]. The data can therefore be used to better understand the landing site. The purpose of this study is to examine small craters within Gusev crater and Isidis Planitia in order to characterize their general shapes and morphologies. These small craters are then compared to large craters in order to determine whether the impact structures have a primary or secondary origin.

Methods: Data used for this study were obtained from the Astrogeology Team of the U.S. Geological Survey in Flagstaff, Arizona [10]. High resolution digital elevation models (DEMs) were created using photogrammetric analysis and photoclinometry. The DEMs created using photogrammetric analysis yield a 3-pixel (typically 10 m) horizontal resolution, vertical precision of a few meters, and slope error of 1-3°. Photoclinometry resulted in DEMs with 1-pixel (typically ~3 m) horizontal resolution and sub-meter vertical precision [10]. These data were then imported into ArcMap 8.1 in order to make measurements describing crater morphology by creating multiple profiles across individual craters. Using these profiles, average diameter, depth, and rim height were measured for each crater.

We measured the depth/diameter (d/D) ratios of small craters in two 10 m DEMs of Isidis (95 craters in 65 km^2 in Isidis 1 and 58 craters in 15 km^2 in Isidis 2), five 10 m DEMs of Gusev (58 craters in 75 km^2 in Gusev 1, 26 craters in 56 km^2 in Gusev 2, 67 craters in 33 km^2 in Gusev 3, 68 craters in 44 km^2 in Gusev 4/5, and 105 craters in 36 km^2 in Gusev 6), one 6 m DEM of Gusev (195 craters in 5 km^2 in Gusev 3) and one 3 m DEM of Gusev (525 craters in 17 km^2 in Gusev 6), where the numbered regions refer to the DEMs of Kirk et al. [10]. A total of 1300 craters were measured in both the 10 m and higher-resolution DEMs with 580 measured in the 10 m DEMs and 720 in the 3 and 6 m DEMs. We also examined the crater rim height versus diameter for the craters in the highest resolution (3 m) DEM.

Results and Discussion: The d/D ratio for all craters measured, both in Isidis and Gusev, is 0.08 with a least squares correlation coefficient of 0.8 which is slightly less that the d/D ratio of 0.11 for the 150 lunar secondary craters measured by Pike and Wilhelms [11] and substantially less than the d/D ratio of 0.2 for primary craters on the Moon and Mars [1,2]. Examining the craters (10-475 m diameter) in the highest resolution (3 m) DEM in more detail showed that craters in different degradation states had different d/D ratios (Figure 1). The freshest craters (class 1) with bowl shapes, sharp rims and little evidence for modification have d/D of 0.11 with an excellent regression fit of 0.9. Class 2 craters with rounded rims, less of a fresh bowl shape, and evidence for sediment deposited on their floors have d/D ratios of 0.045 with a least squares fit of 0.9. Class 3 craters appear most degraded with muted low-relief rims, fairly flat floors and distinctly non-round planform have d/D ratios of 0.03 with a fit of 0.8.

The fact that the d/D ratio for fresh craters is indistinguishable from the d/D ratio for lunar secondaries argues that they too are secondaries. The observation that more degraded craters have lower d/D suggests that with time the secondaries are modified by erosion of their rims and/or deposition on their floors.

The rim height versus diameter ratios show that degraded craters have lower rims than fresh craters. Figure 2 shows that class 1 craters have a rim height/diameter ratio of 0.0325 (r = 0.8) while class 2 craters have a ratio of 0.016 (r = 0.9) and class 3 craters have a ratio of 0.011 (r = 0.6). The rim height/diameter ratio, however, does not give clear insight into the origin of these small impact craters. Primary craters on both the lunar and martian surface exhibit a rim height/diameter ratio of 0.04 [1,2]. Lunar secondaries have a rim height/diameter ratio of 0.02 [11]. The rim height/diameter ratio of 0.0325 found for fresh craters is lower than that expected for primary craters, but is not as low as for lunar secondary craters.. Taking all of the rim height versus diameter data together yield a ratio of 0.026 which is closer to that measured for lunar secondaries.

Another commonly used method for comparison is the size-frequency distribution of craters. The size-frequency distribution is described by a power law of the form $N(D) = kD^{-b}$, where N is the cumulative number of craters, D is the diameter, k is a constant depending on crater density, and b is the power law exponent. For primary craters with diameters from 1 to 100 km on both the Moon and Mars, b is ~2; whereas obvious secondary craters less than 200 m diameter on Mars [8] and the Moon have b ~4 [11]. The size-frequency distribution for the 1300 craters examined in this study has a b ~3.4 However, steep size-frequency distributions (b ~4) for craters less than 1 km in diameter on the asteroid Gaspra may suggest that all small craters have steep size distributions as secondary craters are likely rare on such a small body (although little information exists on craters <200 m) [12,13]. The steep size-frequency distribution for craters may not be indicative of a secondary origin but it is consistent with distributions of craters that are clearly of secondary origin on Mars and the Moon.

Conclusions: Stereo high-resolution images can provide digital elevation models that allow for previously unstudied craters to be measured. The morphology of these small (<1 km diameter) craters is similar to secondary craters on the Moon and Mars. The low depth/diameter and rim height/diameter ratios are consistent with the low-velocity (and kinetic energy) impacts expected for secondary craters. While rim height/diameter ratios and size-frequency distribution do not provide conclusive evidence of a secondary origin when viewed alone, the morphology is comparable with values measured for obvious secondary craters. Assuming the craters measured in this study represent a random sample of Hesperian cratered plains on Mars, these results suggest that most of the small craters seen are secondaries rather than primaries.

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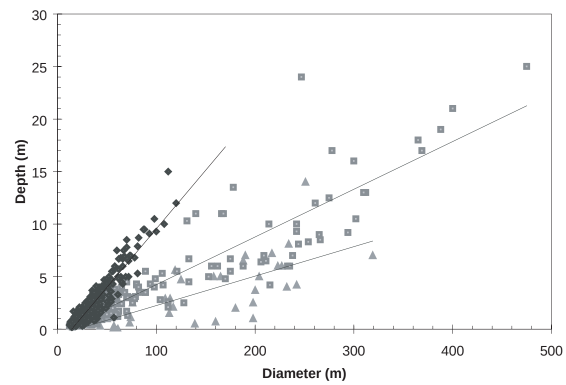

Figure 1. Depth-diameter plot for craters in high-resolution (3 m) DEM within Gusev crater. Craters separated by degradation state: fresh craters (class 1, black diamonds) have a d/D of 0.11, while more degraded class 2 (gray squares) and the most degraded class 3 (light triangles) craters have d/D ratios of 0.045 and 0.03 respectively.

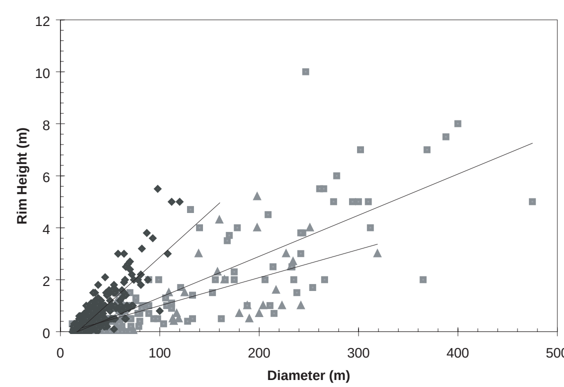

Figure 2. Rim height-diameter plot for high-resolution (3 m) DEM within Gusev crater. Class 1 craters (black diamonds) have a ratio of 0.0325. As expected, more degraded craters have lower rims and lower height/diameter ratios.