DEEP MARTIAN "CRATERS" (OR COLLAPSE FEATURES) WITH HIGH DEPTH/DIAMETER RATIOS: OUTSTANDING QUESTIONS RELATED TO PROCESSES AND TIMING. J. R. Michalski[1,2], [1]Planetary Science Institute, Tucson, Arizona, USA. [2]Natural History Museum, London, UK. J. E. Bleacher[3], [3]NASA Goddard Spaceflight Center, Greenbelt, MD, USA.

Introduction: Malin and Dzurisin [1] showed that Martian impact craters "exhibit considerable depth variation and are generally shallower than their lunar or mercurian counterparts." Craters are generally shallower on Mars because, compared to the Moon or Mercury, Mars has had higher erosion rates that serve to infill craters over time [2]. But yet, Mars contains many craters that are anomalously deep for their diameters [1-3]. There are a number of possible explanations for such features on Mars; one of them is that some of the depressions interpreted as impact craters are actually not impact craters at all. Indeed some ancient, deep depressions exhibit characteristics similar to those of calderas [4] and may have formed by magmatic processes. Other collapse features, including some Hesperian-Amazonian features, may have formed by groundwater release [5]. But yet, the volumes of collapse involved, timing, and contact relationships in various settings suggest that there is more to the story.

A database of Martian impact crater properties created by Robbins and Hynek [3] is inclusive of all candidate impact features and provides a powerful tool for evaluating impact crater characteristics on Mars, and for identifying features that potentially formed by other processes. This work is focused on using morphometric characteristics of that dataset to identify interesting craters or other depressions on Mars.

Methods: Robbins and Hynek [3] (and references within) describe how the transition from simple to complex crater on Mars is affected by several parameters, including latitude and poorly constrained aspects of target properties. However, in a plot of global crater morphologies versus diameter, they showed that the transition from simple to complex crater morphology occurs at ~7 km [2]. Therefore, in our analyses, we binned simple craters at (diameter =) 1-7 km and complex craters at >7 km. We focus primarily on complex craters.

Using the craters in their [3] database that have MOLA rim-floor depth measurements (N>76,000), we plotted crater depth versus depth/diameter ratio for each crater (Figure 1). The "diameter" used in this case is the length of a major axis of an ellipse fit to each crater. A number of authors have quantified the relationship between depth (d) and diameter (D) for Martian impact craters [3, 6-7]. Robbins and Hynek [3] report a global average of d-D relations for complex

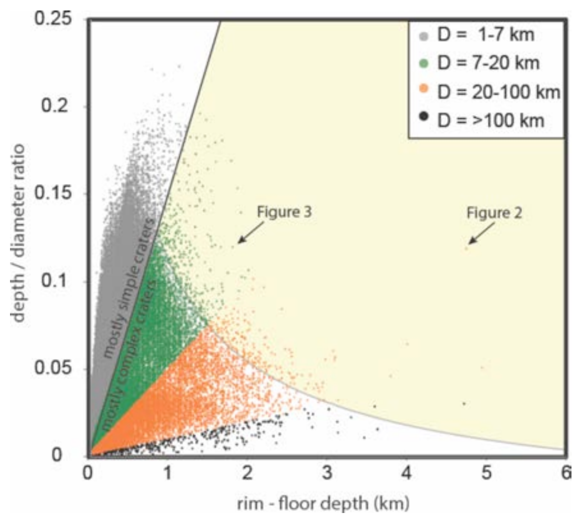

Figure 1: Plot of Martian crater MOLA rim-floor depth versus depth/diameter ratios. (from [3]). Craters are grouped according to their diameters (D). The transition from simple to complex craters is taken to occur at ~7 km-diameter on average (see text). The yellow region corresponds to features with high depth/diameter relationships.

craters of: $d = 0.107D^{0.559}$. We empirically fit the exponential shape of this relationship to the data in our Figure 1 to highlight in yellow a field of relatively extreme depth and depth/diameter relationships among Martian impact craters.

Observations: Many of the craters with high depth/diameter ratios identified previously [3] are likely impact craters, but here we focus on the anomalous features that likely formed from other processes. For example, Ganges Cavus, located at 308.5E, 10.1S, on the southern rim of Morella Crater, is likely a collapse feature (Figure 2). Ganges Cavus is an elliptical depression >6 km-deep. Estimated conservatively, it has an area >915 km^2 and a collapse volume >2100 km^3. This feature is not only unusual because of its depth/diameter ratio, but also because it is seemingly very young. Based on crater statistics, Ganges Cavus has an age of ~300 Ma.

Ganges Cavus has previously been interpreted as a collapse feature that formed as a consequence of groundwater release that filled and overtopped Morella Crater, ultimately forming Elaver Vallis to the east [8]. However, there are some major problems with this hypothesis as Morella Crater is filled with olivine-rich basalt that, based on crater statistics, likely formed in the Hesperian. In other words, the flooding occurred in

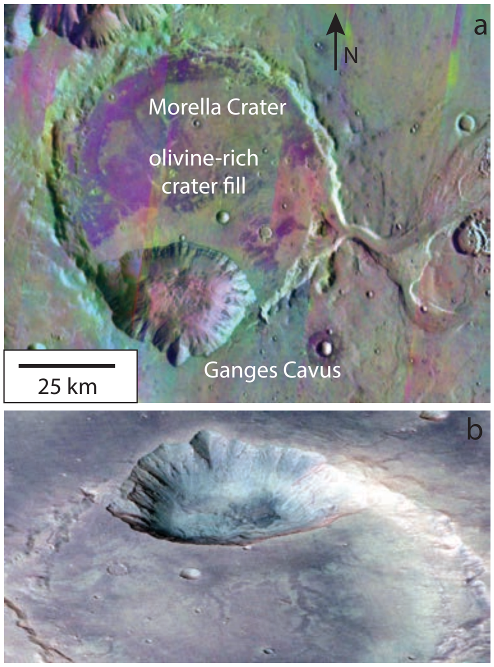

Figure 2: THEMIS 9-6-4 RGB DCS image (a) showing olivine basalt in purple and HRSC color 3D image (b, looking south) of Ganges Cavus.

the Hesperian, and flood deposits were buried by Hesperian lavas. What, then caused the collapse activity in Ganges Cavus in the Late Amazonian?

Another anomalous topographic depression is an apparent collapse feature located at 16.3E, 29.3N (Figure 3). This feature displays circumferential graben suggestive of progressive collapse and radial wrinkle ridges suggestive of compression of the surrounding terrain. The scalloped outer rim is consistent with an interpretation of formation by collapse, as is the terraced southern wall, which could have formed through multiple stages of collapse. This feature might be explained by groundwater escape, but nearest fluvial features that could be potentially related to groundwater release are located >150 km away. Perhaps most importantly, the collapse feature contains very few craters and no craters >500 m-*D*. The feature seemingly formed in (or was active during) the Late Amazonian. Wrinkle ridges surrounding the feature are attributable to volcanism, but it is unlikely that volcanism persisted into the Late Amazonian at this site. This is an enigmatic feature.

Summary and outstanding questions: The global crater database provides a powerful tool for evaluating crater morphometric properties. Some craters with high depth and depth/diameter relationships are likely not impact craters at all, but instead collapse features. Such features might have formed by groundwater release or magmatism, but it is unlikely that huge volumes of groundwater or lava were released form such features in the Late Amazonian. In this presentation, we will describe observations of intriguing collapse features on Mars and discuss multiple working hypotheses for their origins.

References: [1] Malin, M. C. and D. Dzurisin (1977), *JGR*, 82 (2), 376-388. [2] Mangold, N. et al. (2012), *JGR*, 117, E04003. [3] Robbins, S. J. and B. M. Hynek (2012), *JGR*, 117, E06001. [4] Michalski, J. R. and J. E. Bleacher, *Nature*, 502, 47-52. [5] Carr, M. (1996). *Water on Mars*, Oxford U. Press, 229 p. [6] Garvin, J. B., et al. (2003), 6th *Mars Conf.,* Pasadena, #3277. [7] Boyce, J. M. and H. Garbeil (2007), *GRL*, 34, L16201. [8] Coleman, N. M. (2013), *JGR*, 118 (2).

Figure 3: An unnamed collapse feature in Arabia Terra. Top: MOLA data draped over THEMIS daytime IR (north is up). Bottom: HRSC color data over HRSC DTM data (looking east).