NEW INSIGHTS INTO THE CHARACTERISTICS AND FORMATION OF CENTRAL PIT CRATERS ON MARS.

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Introduction: Craters with central depressions, called central pit craters, have been reported on Mars, Ganymede, and Callisto since the 1970's explorations by the Viking and Voyager spacecraft, respectively. The discovery of central pit craters on bodies with volatile-rich crusts led to the hypothesis that target volatiles are required for pit formation. Detailed study of other solar system bodies now reveals that central pits are found on many objects, including "drier" bodies such as Mercury and the Moon. My team has conducted morphologic and morphometric studies of central pit craters on Mercury, the Moon, Mars, Ceres, Ganymede, Callisto, Dione, Rhea, Tethys, and Pluto. The results of this comparative analysis combined with detailed geologic and structural mapping of well-preserved central pit craters on Mars, allow us to reconsider the proposed formation models for these pits.

Formation Models: Central pit craters are characterized by a pit either directly on the crater floor ("floor pit") or atop a central peak ("summit pit") [1, 2] (Fig. 1). Several models have been proposed, mostly to explain the formation solely of floor pits. The formation models include (1) explosive release of impact-produced vapor [3, 4], (2) collapse of a central peak [5, 6], (3) excavation through layered targets [7], (4) melting and drainage of target materials [6, 8, 9], and (5) impacts of low-velocity projectiles [10]. Some have suggested that central pits are erosional features similar to the central structure in Gosses Bluff, Australia [11].

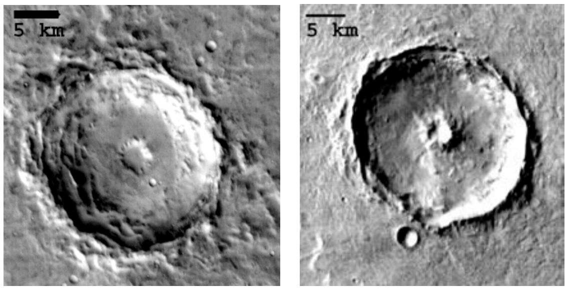

Figure 1: Example images of a floor pit crater (left; crater is 20.7-km-D; 22.46°N 340.41°E) and summit pit crater (right; crater is 22.2-km-D; 5.73°N 304.64°E)

Methodology and Observations: We have used the best-resolution global images for each body to identify central pit craters and classify them as floor or summit pits. We utilize GIS capabilities to measure crater and pit diameters, determine location, measure basal diameter of peaks on which summit pits are found, and compare distributions with geologic units, topography, etc. In each case, the ratio of pit-to-crater diameter (D_p/D_c) and peak basal diameter to crater diameter (D_{pk}/D_c) were calculated. In the case of Martian central pit craters, we used THEMIS daytime IR images (100 m/px resolution) to identify central pit craters and used THEMIS VIS (18 m/px), CTX (6 m/pixel) and HiRISE (up to 0.3 m/px) to characterize all central pit craters and conduct detailed geologic and/or structural mapping of selected well-preserved central pit craters. Topographic information was obtained from MOLA profiles and DEMs created from CTX and HiRISE.

Central pit craters comprise less than 10% of all craters on the bodies studied. On Mars, they account for 7.7% of all craters analyzed to date (approximately ¾ of the planet's surface). Of the 2083 currently-identified Martian central pit craters, 1310 (63%) are classified as floor pits and 773 (37%) are summit pits.

The median D_p/D_c value for floor pits is 0.16 whereas that for summit pits is 0.12. This indicates that floor pits are larger relative to their parent crater than summit pits. D_{pk}/D_c for the peaks on which summit pits are found is 0.32, which is statistically identical to the value found for unpitted Martian central peaks ($D_{pk}/D_c = 0.30$). This indicates that there is no difference in the formation of pitted versus unpitted central peaks.

The distribution of both floor and summit pit craters on Mars is random, with no preference shown for specific latitude zones or geologic units. This is similar to what we have observed on the other bodies where we have conducted central pit crater studies.

Floor pits were initially subdivided into rimmed, partially rimmed, and non-rimmed, based on the presence/absence and extent of uplifted material surrounding the edge of the pit as seen in THEMIS daytime IR images [12]. Upon further investigation with higher resolution THEMIS VIS and CTX images, we find that pits originally classified as unrimmed are either heavily covered with dust or have undergone degradation to remove or cover the pit rim. Thus all floor pits are rimmed or partially-rimmed upon formation. Thermal inertia analysis of the partially rimmed floor pit in 16.3-km-diameter Esira crater (8.95°N 313.40°E) suggests that even in places where no rim is exposed at the surface that uplifted bedrock exists immediately below the surface [13]. We find no evidence for post-pit-formation uplift of the pit floor on Mars [14], unlike the case with some of the icier bodies such as Ganymede, Callisto, and Pluto where domes possibly caused by diapiric activity are common.

Our detailed structural and geomorphologic mapping of several fresh central pit craters on Mars reveals insights into the timing and process of central pit formation. Pitted material indicative of impact melt [15, 16] is seen on the floors of very fresh floor pits and summit pits, indicating that pit formation is contemporaneous with crater formation. Mapping of structural features in the pit rim reveal evidence of uplifted bedrock from beneath the crater floor. This suggests a sequence of uplift followed by collapse to form the pit.

Implications for Formation: Utilizing the information from the studies of central pit craters on Mars and other solar system bodies, we have produced the table below showing how the proposed formation models agree or disagree with the predictions of the current central pit formation models. None of the current models are entirely consistent with our observations. This has led us to propose a new formation model which includes aspects of the central peak collapse and layered targets models. In this scenario, craters excavate through layered targets which have a strong layer overlying a weak layer. The weak layer may consist of volatile-rich material but could be volatile-poor brecciated material as well. A central peak is formed during crater formation—if the overlying layer is relatively weak, the central peak largely collapses to form a floor pit with only the outer edge of the central peak remaining as the pit rim. If the overlying layer is relatively strong, the central peak remains and only the central core partially collapses to form a summit pit. We are working on resolving questions about diameter range and small central pit crater percentages.

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Formation Model	**Observations consistent with Model Predictions**	**Observations inconsistent with Model Predictions**
Central Peak Collapse [5, 6]	Structural analysis in pit rim reveals evidence of uplift followed by collapse to form the pit.	Only see a transition from central peaks in smaller craters to central pits in larger craters for icy bodies.
	Central pits are more common in weaker crustal materials and pit D_p/D_c is smaller than a peak D_{pk}/D_c for floor pits.	
Vapor Release [3]		Gas produced during excavation stage has to be retained until modification stage
		Do not see "ejecta" blocks exterior to pit. There is impact melt inside pit which would be destroyed by this mechanism
Layered Targets [7]	Does not require subsurface volatiles but their presence would enhance layer weakness	Expect to see a terrain dependence in distribution of central pit craters
	Both floor pits and summit pits can be produced in same locations	
Melt Drainage [6, 8, 9]	Only craters in certain size range will have central pits due to impact energy considerations	Only works for bodies with volatiles and cannot explain central pit craters on bodies with volatile-poor crusts. Does not explain presence and structure of pit rim.
Melt Contact [4]		Do not see "ejecta" blocks exterior to pit. There is impact melt inside pit which would be destroyed by this mechanism