COMPARISON OF CENTRAL PIT CRATERS ACROSS THE SOLAR SYSTEM AND IMPLICATIONS FOR PIT FORMATION MODELS.

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Introduction: Craters containing central depressions, called central pit craters, were first reported in the 1970's from Mariner 9 and Viking Orbiter images of Mars and Voyager imagery of Ganymede and Callisto [1-3]. Several formation hypotheses were proposed involving impact into volatile-rich crusts, including collapse of a central peak in weakened target material (central peak collapse model) [3, 4], explosive release of vaporized subsurface volatiles (vapor release model) [5], excavation through layered target materials (layered target model) [6], and melting of subsurface volatiles followed by drainage of the liquid (melt drainage model) [7-9]. A recent model invokes explosive interaction between impact melt and subsurface volatiles in the creation of central pits (melt contact model) [10]. Although central pit craters are seen in abundance on Mars, Ganymede, and Callisto, a few also have been reported on the Moon and Mercury [11-15], leading to questions of whether target volatiles are required for central pit formation. With the advent of recent image, composition, and topographic datasets, we have initiated a new investigation of central pit craters across the solar system which includes detailed geologic mapping and interbody comparisons of morphometric characteristics. Insights gained from these studies are helping us to refine the conditions of central pit formation.

Central Pit Crater Characteristics: We have investigated the morphologic and morphometric characteristics of central pit craters on Mercury, Mars, Ganymede, Tethys, Dione, Rhea, and Ceres--studies of central pit craters on the Moon and Callisto are nearing completion. Results from this comparison study [15, 16] include:

- The frequency of central pit craters is highest on Mars and Ganymede and low on Mercury, Ceres, Tethys, Dione, and Rhea.
- Floor pit craters tend to be more common on bodies with crusts that are inferred to have higher volatile contents (Ganymede followed by Mars) while the frequency of summit pit craters increases as crustal volatile content decreases.
- Pit-to-crater diameter ratios (D_p/D_c) are typically larger for bodies with crusts richer in volatiles.
- Floor pits are larger relative to the parent crater than summit pits.
- Craters containing central pits occur in the same diameter ranges as craters containing central peaks on all bodies except Ganymede.
- Central peaks on which summit pits occur have the same basal peak-to-crater diameter ratios (D_{pk}/D_c) as unpitted central peaks.
- The D_p/D_c values for floor pits are smaller than the D_{pk}/D_c values for central peaks on both Mars and Ganymede.
- There is no correlation of the locations of Mercury's central pits with hollows or polar ice deposits.

Detailed Mapping of Martian Central Pit Craters: Our most detailed studies involve central pit craters on Mars, where we have conducted geomorphic and structural mapping of the following well-preserved central pit craters: 16.3-km-D Esira (floor pit) (8.95°N 313.40°E), a 33.8-km-D unnamed summit pit crater (35.83°N 319.21°E), and 50.9-km-diameter Negril (floor pit) (20.18°N 69.39°E). Results from the detailed mapping include:

- Where exposed, crater-related pitted materials, interpreted as impact melt which has interacted with target volatiles [17, 18], is seen on the floors of the central pits, indicating that pit formation is contemporaneous with crater formation.
- Earlier studies subdivided floor pits into rimmed, partially rimmed, and non-rimmed [19]. Our studies find that all floor pits display evidence of at least partial rim uplift. In the case of the partial rim of Esira's central pit, thermal inertia data suggest blocky material just below the surface in areas where no exposed rim uplift is seen.
- Structural mapping of the pit rims indicate initial uplift followed by collapse of the core of the uplift, consistent with [20].

Implications for Central Pit Formation: Our comparison study and detailed mapping of central pit craters provide observations which constrain the mechanisms involved in pit formation. For example, the presence of crater-related pitted material (impact melt) on the floors of both floor and summit pits indicates that central pit formation is essentially contemporaneous with crater formation—central pits are not subsequent erosional features. Table 1 divides the predictions of the various central pit formation models into those supported and not supported by this study's results. The vapor release [5] and melt contact [10] models are not consistent with our observations since they predict blocks ejected by the explosion would occur around the pit, which are not seen even for the freshest craters. An explosion event creating summit pits also would remove the pitted material (impact melt), which is observed on pit floors. Some aspects of the central peak collapse, layered target, and melt drainage models are supported by our observations. Our results are leading us to a hybrid formation model which involves a specific range of impact energies combined with a subsurface weak layer (that may or may not contain volatiles) which enhances collapse following uplift of the central region. Some component of collapse is required to explain the topographic depression of the pit.

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Table 1: Comparison of observations from this study with central pit formation model predictions.

Formation Model	**Predictions consistent with Observations**	**Predictions not consistent with Observations**
Central Peak Collapse	Uplift and collapse revealed by structural analysis in pit rim	Transition from central peaks in smaller craters to central pits in larger craters
	Central pits more common in weaker or finely layered crustal materials	D_p/D_c for floor pit craters should be larger than D_{pk}/D_c for central peak craters
Vapor Release		Gas produced during excavation stage retained until modification stage
		"Ejecta" blocks exterior to pit and no impact melt inside pit
Layered Targets	Does not require subsurface volatiles but the presence of such volatiles would enhance layer weakness	Terrain dependence in distribution of central pit craters
	Mechanism can produce both floor pits and summit pits in same locations	
Melt Drainage	Only craters in certain size range will have central pits due to impact energy considerations	Only bodies with volatile-rich crusts will have central pit craters
Melt Contact		"Ejecta" blocks exterior to pit and no impact melt inside pit