COMPARISON OF CENTRAL PIT CRATERS ACROSS THE SOLAR SYSTEM AND IMPLICATIONS FOR THEIR FORMATION. N. G. Barlow, Dept. Astronomy & Planetary Science, Northern Arizona University, Flagstaff, AZ 86011-6010 Nadine.Barlow@nau.edu.

Introduction: Impact craters with central depressions are called central pit craters. Initially reported on Mars, Ganymede, and Callisto and attributed to crustal volatiles, central pit craters are now seen on many bodies throughout the solar system with varying crustal compositions. This investigation is the first to compare central pit craters across multiple solar system bodies. We have completed the analysis for Mercury, Ganymede, Ceres, Dione, Rhea, and Tethys, are largely complete for Mars, and are finishing the analysis for the Moon, Callisto, and Pluto.

The goal of this investigation is to determine the role of crustal characteristics and surface gravity on the morphologic and morphometric properties of central pit craters. We also compare the resulting observations with predictions from the various formation models which have been proposed for these features: (1) ***Vapor Release***: Crustal volatiles are vaporized during crater formation and subsequent release of this vapor produces the pit [1]. (2) ***Central Peak Collapse***: A central peak forms but the crustal material is too weak and the peak collapses to form a pit [2, 3]. (3) ***Layered Target:*** The crater excavates through a stronger surface layer into an underlying weaker layer, which creates the pit [4]. (4) ***Melt Drainage***: Impacts with a certain range of energy melt the crustal ice, producing liquid at the center which eventually drains away to leave the pit [5-7]. (5) ***Melt Contact***: Volatiles interact with impact melt, producing an explosion which creates the pit [8].

Methodology: We have utilized the best global mosaics for each of the bodies to survey craters for central pits. These include: MESSENGER MDIS mosaic (250 m/px) for Mercury, Mars Odyssey THEMIS daytime global mosaic (100 m/px) for Mars, Dawn HAMO global mosaic (140 m/px) for Ceres, global mosaic from best Galileo SSI and Voyager ISS images (400 to 20 m/px) for Ganymede, and the LPI global color mosaics from the best Voyager ISS and Cassini images (250-400 m/px) for Rhea, Dione, and Tethys. We are using the LRO WAC global mosaic (100 m/px) for the Moon, the best combined Voyager ISS and Galileo SSI images (400 m/px to 60 km/px) for Callisto, and the New Horizons LORRI-MVIC mosaic (300 m/px) for Pluto. Central pit craters are subdivided into floor pits (pit on crater floor) or summit pit (pit atop central peak) based on careful image analysis and use of topography when available. In the case of Mars where higher resolution datasets are available (MRO CTX (6 m/px) and HiRISE (up to 0.3 m/px)), we have conducted geomorphic and structural mapping of selected fresh central pit craters.

For each body, we have looked at the following characteristics of the central pit craters: location and relationship to geologic units, pit type as a function of distribution, crater diameter (D_c), pit diameter (D_p), pit-to-crater diameter ratio (D_p/D_c), central peak basal diameter for summit pit craters (D_{pk}), and peak-to-crater diameter ratio (D_{pk}/D_c) for summit pits. We compare the results across solar system bodies, looking specifically at how crustal composition (rocky vs icy) and surface gravity affect the results.

Results: Central pit craters comprise less than 10% of all craters on each of the studied bodies. Table 1 shows the details for the bodies where the analysis is largely or totally complete. General results include: (1) The frequency of central pits is highest on bodies with higher surface gravities and volatile-rich crusts (Mars and Ganymede). (2) Floor pit craters are more common on bodies with volatile-rich crusts and summit pits become more numerous on bodies with low crustal volatile contents. (3) D_p/D_c is typically larger for volatile-rich bodies. Floor pits are larger relative to the parent crater than summit pits. (4) Craters with central pits occur in the same diameter ranges and locations as craters containing central peaks on all bodies except Ganymede. (5) Central peaks with summit pits have the same basal D_{pk}/D_c as central peaks without summit pits. (6) The D_p/D_c values for floor pits are smaller than D_{pk}/D_c values for central peaks on Mars and Ganymede. (7) There is no correlation of the location of Mercury's central pits with hollows or polar ice deposits. (8) We see no strong correlation of central pit crater distribution with terrain or latitude except for Ceres where all floor pits are in the northern hemisphere [9]. (9) Where exposed, crater-related pitted materials (interpreted as impact melt [10-11]) are seen on the floors of central pits, indicating the pits form with the crater. (10) All floor pits display evidence of at least partial rim uplift. Structural mapping of pit rims indicate initial uplift followed by collapse of the core of the uplift.

Implications for Formation Models: Table 2 provides a summary of how the observations from this analysis compare with the predictions of the existing pit formation models. No single model completely explains all the observations and the vapor release and melt contact models are inconsistent with our observations. Based on this investigation, we propose a new model which combines features of the central peak collapse and layered target models. In this scenario, a crater excavates through a stronger surface layer into a weaker subsurface layer which may contain volatiles or brecciated dry material. A central peak is uplifted but if composed primarily of the weaker material will partially or completely collapse to form a floor pit with a raised rim or a pit atop a central peak.

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References: [1] Wood C. A. et al. (1978) *Proc. 11th LPSC*, 2221-2341. [2] Passey Q. R. and Shoemaker E. M. (1982) *Satellites of Jupiter*, 379-434. [3] Bray V. J. et al. (2012) *Icarus, 217*, 115-129. [4] Greeley R. et al. (1982) *Satellites of Jupiter*, 340-378. [5] Croft S. K. (1982) LPS XII, 196-198. [6] Senft L. E. and Stewart S. T. (2011) *Icarus, 214*, 67-81. [7] Elder C. M. et al. (2012) *Icarus, 221*, 831-843. [8] Williams N. R. et al. (2015) *Icarus, 252*, 175-185. [9] Zeilnhofer M. F. and N. G. Barlow (2020), this conference. [10] Tornabene L.L. et al. (2012) *Icarus, 220*, 348-368. [11] Boyce J. M. et al. (2012) *Icarus, 221*, 262-275.

Table 1: Central Pit Comparison Data

	Mercury	**Mars**	**Ganymede**	**Ceres**	**Rhea**	**Dione**	**Tethys**
# floor pits	0	1310	471	10	3	1	5
# summit pits	32	773	0	4	0	2	0
D_c range (km) floor	NA	5.0-114.0	12.0-143.8	40.3-155.0	54.0-230.0	72	11.0-450.0
D_c range (km) summit	13.6-47.4	5.1-125.4	NA	30.0-96.1	NA	20.5-47.0	NA
Median D_c (km) floor	NA	13.8	38.1	79.2	46.1	72.0	22.5
Median D_c (km) summit	22.9	14.5	NA	61.6	60.0	33.8	NA
D_p/D_c range floor	NA	0.02-0.48	0.06-0.43	0.06-0.25	0.17-0.26	0.22	0.13-0.42
D_p/D_c range summit	0.04-0.12	0.02-0.29	NA	0.05-0.11	NA	0.15-0.23	NA
Median D_p/D_c floor	NA	0.16	0.20	0.13	0.24	0.22	0.26
Median D_p/D_c summit	0.09	0.12	NA	0.08	NA	0.19	NA
Surface gravity (m/s^2)	3.70	3.71	1.43	0.27	0.26	0.23	0.15

Table 2: Implications for Formation Models

Formation Model	**Predictions consistent with Observations**	**Predictions not Consistent with Observations**
Central Peak Collapse [2,3]	(1) Structural analysis in pit rim reveals uplift followed by collapse; (2) Central pits more common in weaker or finely layered crustal materials	Transition from central peaks in smaller craters to central pits in larger craters only seen for Ganymede.
Vapor Release [1]	None	(1) Gas produced during excavation stage must be retained until modification stage; (2) No "ejecta" blocks exterior to pit. Interior impact melt would be destroyed.
Layered Targets [4]	(1) Does not require subsurface volatiles but their presence would enhance layer weakness; (2) Mechanism can produce both floor and summit pits in same regions.	(1) Expect a terrain dependence in distribution, which is not seen; (2) Experiments were small scale and only produced central pit when weak layer was liquid.
Melt Drainage [5-7]	Only craters in certain size range will have central pits due to energy considerations.	(1) Only bodies with volatile-rich crusts will have central pit craters if due to melting and drainage; (2) Does not explain presence and structure of pit rim.
Melt Contact [8]	None	(1) No "ejecta" blocks exterior to pit and interior impact melt would be destroyed; (2) Requires sufficient amount of underlying liquid to produce steam explosion.