CENTRAL PIT CRATERS ON MARS AND GANYMEDE: CHARACTERISTICS, DISTRIBUTIONS, AND IMPLICATIONS FOR FORMATION MODELS. N. G. Barlow and N. Alzate, Dept. Physics and Astronomy, Northern Arizona University, Flagstaff, AZ 86011-6010. Nadine.Barlow@nau.edu; na84@nau.edu.

Introduction: Central pit craters display a central depression either directly on the crater floor (in place of a central peak) or atop a central rise/peak. They are common on Mars, Ganymede, and Callisto but have not been identified on volatile-poor bodies such as the Moon and Mercury. Their presence on bodies with ice-rich crusts suggests that target volatiles are necessary for central pit formation. Several formation models have been proposed for central pits: release of impact-generated gases during crater formation [1], excavation into subsurface liquid layers [2], collapse of central peak [3], and coalescence of pits formed by impact melt-target ice interactions [4]. Analysis of the sizes, distributions, and general characteristics of central pit craters on Ganymede and Mars can provide constraints on these formation models [e.g., 5,6].

Martian Central Pit Craters: Martian central pits are classified as floor pits (pit occurs directly on crater floor) and summit pits (pit occurs on central peak or other central rise). Floor pits are further subdivided into symmetric or asymmetric pits, depending on pit shape. Using Viking, MOC, and THEMIS imagery, we have identified 1522 central pit craters, although our analysis is continuing. Half of all central pit craters are symmetric floor pit (SY) craters while 41% are summit pit (sP) craters and 9% are asymmetric floor pit (AP) craters. While pit craters are seen on all terrains within the ±70° latitude range, strong concentrations are seen in the Xanthe, Margaritifer, and Arabia Terrae regions. No strong regional variations in distribution are seen between floor and summit pit craters. There is similarly no difference in occurrence of floor pits versus summit pits as a function of crater size—pit craters have diameters between 5 and 60 km (frequency peak near 13 km), suggesting excavation depths between ~1 km and 4.5 km based on standard depth-diameter relationships [7]. Central pit craters display a wide range of preservational states, from 2.0 (degraded) to 7.0 (pristine) [8, 9], indicating that the conditions favoring central pit formation have existed for most of the planet's history including up to the present. Those central pit craters fresh enough to display an ejecta blanket are typically associated with a multiple-layer ejecta morphology rather than single layer or double layer.

Comparison of the pit diameter (D_p) to the crater diameter (D_c) reveals that floor pits tend to be larger compared to their parent crater than summit pits. SY craters have D_p/D_c ranging between 0.07 and 0.28 with a median of 0.15. Summit pit D_p/D_c ranges between 0.05 and 0.19 with a median of 0.11.

On Ganymede, most central pits are superposed on an updomed crater floor. This updoming is believed to result from relaxation of the ice-rich crust after crater formation. We have used MOLA topography to investigate whether martian floor pits are similarly located on updomed floors. Based on analysis of 485 floor pit craters in the northern hemisphere of Mars, we find no indication of floor updoming [10]. This suggests that high crustal ice concentrations, such as seen on Ganymede and Callisto, are not necessary to produce central pits. The ~20% crustal ice concentration estimated from martian layered ejecta blanket studies [11, 12] is consistent with the lack of crater floor updoming.

Ganymede Central Pit Craters: We have identified 432 central pit craters on Ganymede using Galileo and Voyager imagery. Ganymede central pit craters range from 5 to ~100 km in diameter (frequency peak ~40 km), suggesting excavation depths of ~1 km to 8 km. The diameter of the frequency peak is almost 3 times greater than the corresponding diameter for martian central pit craters. Since Mars' gravitational acceleration is 2.6 times greater than that of Ganymede, the difference in crater size is likely due to the difference in gravity between the two bodies.

Our study reveals that craters in the 5 to ~100 km diameter range can show either a central pit or a central peak. This is contrary to Voyager results which reported no central peak craters in the diameter range where central pits were seen [3, 13]. However, Ganymede central pits occur as floor pits on updomed crater floors. No examples of pits atop central peaks, comparable to the martian summit pits, have been identified on Ganymede.

Ganymede central pit craters have D_p/D_c values ranging from 0.11 to 0.38 with a median value of 0.19. The median value is larger than that of either the floor pits or summit pits on Mars indicating that central pits on Ganymede are larger relative to their parent crater than central pits on Mars.

Comparison: Comparison of our current results for central pit craters on Mars and Ganymede reveal both similarities and differences between the two bodies:

- Central pits are common over all terrains on both bodies. No statistically significant latitudinal variation is seen on either body although some regional concentrations are suggested for Mars.

- Central pit craters can be small (~5 km diameter) up to large (~60 km on Mars, ~100 km on Ganymede). The diameter at which the frequency of central pits peaks is about 3 times larger on Ganymede than on Mars, probably due to the 2.6x difference in gravity between the two bodies.
- Central pit craters display a large range in preservational state on both Mars and Ganymede, suggesting that the conditions favoring central pit formation have existed over most if not all of the history of these two bodies. Fresh central pit craters on Mars tend to be associated with the multiple layer ejecta morphology.
- Central pits tend to be larger relative to their parent crater on Ganymede than on Mars. The difference in median D_p/D_c is less than 2.6 so gravity alone does not explain the difference. The higher ice concentration in the target on Ganymede or possibly higher impact velocities of the crater-forming projectiles could be responsible.
- Central pit craters on Ganymede are floor pits while those on Mars are both floor pits and summit pits. The greater strength of the target material may explain the occurrence of summit pits on Mars.
- Central pit craters on Ganymede typically occur on a updomed crater floor. Floors of floor pit craters on Mars do not show this updoming. Updomed floors on Ganymede are believed to result from rebound of the ice-rich target material [13]. The lack of updoming of the martian central pit crater floors indicates a much smaller concentration of ice is present. This indicates that central pits can form in targets with a large range in ice concentration (from ~20% to 100%).
- Central peak craters are seen in the same diameter range as central pit craters on both bodies.

Implications for Pit Formation Models: By comparing the distributions and characteristics of central pits on Mars and Ganymede, we get a better understanding of the range of environmental conditions producing these features and can better constrain the various formation models proposed for these features.

We can reject the model that central pits form by the collapse of central peaks in weak target material [3]. The presence of summit pits on Mars and the occurrence of central peaks within the same diameter range and regions as central pit craters argues against this mechanism.

The model proposing layered targets with liquid layers at depth [2, 5] may have some support. The Xanthe, Margaritifer, and Arabia Terrae regions of Mars, where an abundance of central pit craters is seen, also display other geologic features (i.e., outflow channels, chaotic terrain) indicative of subsurface water and Arabia Terra has been proposed to be the site of a long-term subsurface aquifer [14]. The association of fresh central pit craters with multiple layer ejecta morphologies is consistent with subsurface liquid layers since multiple layer ejecta have been proposed to result from excavation into liquid water reservoirs [15, 16]. Ganymede is expected to have harbored subsurface liquid layers/oceans throughout its history. The greatest problem with this model is the fact that central pit craters are seen practically everywhere on both Mars and Ganymede. This would suggest that subsurface liquid water layers exist within the upper 5 km on Mars and the upper 8 km on Ganymede everywhere on these bodies.

Vaporization of subsurface volatiles during crater formation [1], supported by high temperature gradients under the transient cavity in numerical simulations [17], remains a viable mechanism for central pit formation. More investigation of coalescence of impact melt-generated pits on craters floors as a mechanism of central pit formation [4] is needed as additional HiRISE imagery becomes available.

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