THE ROLE OF UPLIFT IN THE FORMATION OF CENTRAL PITS IN MARTIAN IMPACT CRATERS.
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Introduction: Central pit craters are characterized by having a depression near the center of the crater floor. Pits are subdivided into floor pits and summit pits [1, 2] (Fig. 1). A floor pit occurs directly on the crater floor, with the elevation of the pit’s floor below the elevation of the crater floor. A summit pit occurs at the top of a central rise such as a central peak, with the elevation of the pit’s floor lying above the elevation of the crater floor. Central pits more frequently occur on bodies with ice-rich crusts than on volatile-poor bodies. Central pits have been reported on Mars, Ganymede, Callisto, Rhea, Tethys, Dione, and Ceres [2-5], leading to suggestions that volatiles in the crusts of these bodies are a primary contributor to pit formation. However, a small number of central pits also have been reported for the volatile-poor bodies of the Moon and Mercury [6-9], indicating that volatiles are not necessarily a requirement for pit formation.

Methodology: Our research group has been focused on studies of central pit craters in various locations across the solar system [2, 4, 15, 16]. This has involved global studies of central pit craters on a single world [15, 16], global comparison studies between worlds [2, 4], and detailed mapping of individual well-preserved central pit craters [17]. This report is focused on recent results of Martian central pit craters.

We have used THEMIS daytime IR, THEMIS VIS, and CTX images to identify, classify, and measure central pit craters on Mars. Our survey currently covers the entire northern hemisphere and the region between 0-30°S latitude and stretching from 180°E eastward to 90°E longitude. We have identified 1200 floor pit craters and 655 summit pit craters within this study region. Floor pits are further divided into rimmed, partially rimmed, and non-rimmed pits (Fig. 2). The study also notes the location of each central pit crater, measures the diameters of both the crater and the central pit, measures the basal diameter of the peak on which summit pit craters are found, and calculates the ratio of the pit-to-crater diameter (Dp/Dc) and peak basal diameter to crater diameter (Dpk/Dc) for summit pit and central peak craters.

Collapse is certainly required for central pit formation and many proposed formation models focus primarily on the collapse mechanism, whether that is collapse of weak material [3, 10, 11], melting of ice and subsequent drainage of the liquid through subsurface fractures [12], or vapor-initiated removal of material [13, 14]. However, in this study we are finding evidence that uplift is involved prior to the collapse which forms the pit.

Figure 1: Examples of central pit craters on Mars. Left: This 20.7-km-diameter crater (22.46°N 340.41°E) displays a floor pit. (THEMIS image I01199005) Right: A summit pit is seen atop the central peak of this 22.2-km-D crater (5.73°N 304.64°E). (THEMIS image I03218002)

Summit Pit Craters: Summit pits form by collapse after uplift of the central peak on which they are found. This study finds that the peak on which the summit pits form have similar morphometric characteristics to normal central peaks in the study region. For example, the Dpk/Dc values for summit pit peaks range from 0.13 to 0.65 with a median value of 0.32. The Dpk/Dc values for normal (non-pitted) central peaks in the same region (N = 1770) have a range from 0.04 to 0.89 with a median of 0.30. The distribution of summit pit and central peak craters overlap as well, with both having their highest frequencies in the heavily cratered regions of the study area. A similar overlap is observed in the characteristics of Mercury’s summit pit and central peak craters [16]. Therefore the peaks on which summit pits occur appear to form in the same manner as...
normal central peaks. Weakened material (through brecciation and/or presence of volatiles) can cause the central core of the peak to undergo partial collapse, creating the summit pit. This mechanism was first proposed by Croft to explain lunar summit pit craters [18] and remains consistent with current studies of these features on Mars and Mercury.

**Floor Pit Craters:** This investigation finds that 78% of all floor pits in the study area display a complete or partial rim which is upraised above the edge of the pit. Detailed mapping of the 16.3-km-diameter partially-rimmed central pit crater Esira (8.9°N 313.4°E) reveals structural evidence of uplifted megablocks in the rim [17]. A thermal inertia map of Esira reveals that the complete or partial rim which is upraised above the edge of the pit. Detailed mapping of the 16.3-km-diameter partially-rimmed central pit crater Esira (8.9°N 313.4°E) reveals structural evidence of uplifted megablocks in the rim [17]. A thermal inertia map of Esira reveals that the pit is completely surrounded by high thermal inertia material (Fig. 3), corresponding both to regions where the rim in uplifted above the surface and in areas where the no pit rim is seen. This suggests that material is uplifted completely around the pit edge, but does not always break the surface of the crater floor.

This study finds no major morphometric differences among craters with rimmed, partially rimmed, or non-rimmed floor pits. The ranges of $D_p/D_c$ for all three types (0.02-0.32 for rimmed, 0.07-0.26 for partially rimmed, and 0.07-0.48 for non-rimmed) and the median $D_p/D_c$ values (0.16 for rimmed and 0.15 for partially-rimmed and non-rimmed) are all statistically identical. We do see a slight preference for rimmed and partially rimmed pits to occur in craters on heavily cratered terrain compared to non-rimmed pits which tend to be found in craters on younger volcanic lava flows.

**Conclusions:** This study of central pit craters on Mars reveals that uplift followed by collapse is associated not only with summit pits but also most, if not all, floor pits. The discovery of impact melt flowing from the floor of Esira crater into the floor of its central pit [17] indicates that pit formation occurs essentially contemporaneous with crater formation, at least for floor pit craters. Future work will investigate the timing of summit pit formation relative to crater and central peak formation. The peaks on which summit pits are found are morphometrically similar to normal central peaks, indicating that summit pits form by typical central peak uplift followed by partial collapse of core material weakened by brecciation and/or presence of volatiles. The prevalence of summit pit and central peak craters in heavily cratered regions of Mars suggests that the impact-fragmented upper crust, further weakened by ancient fluvial and glacial activity, enhances central peak formation. The occurrence of complete or partial raised rims around the majority of floor pit craters, also showing concentrations in heavily cratered regions, suggests a similar mechanism of uplift and collapse. However, the $D_p/D_c$ values of floor pits are approximately half of the $D_p/D_c$ values of central peak and summit pit craters, so it is not simply a case where floor pits represent full collapse of a central peak. Continued study of the remaining Martian central pit craters is likely to provide further insights into the formation mechanism of these interesting morphologies, both on Mars and elsewhere in the solar system.

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**References:**