# EVIDENCE FOR AN EXPLOSIVE ORIGIN OF CENTRAL PIT CRATERS ON MARS.

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**Introduction:** Central pit craters occur in over 1,000 impact structures on Mars in the low- to mid-latitudes and exhibit a crater-in-crater configuration [1-3]. Central pits also occur in impact craters on icy satellites, including Ganymede and Callisto [1], but are seldom observed on other rocky planets, so an icy origin is inferred [4]. Central pit craters thus could provide a unique window into the Martian subsurface and the history of water at depth.

Two principal models are proposed for central pit crater formation: explosive excavation [2,4-6], or drainage and collapse [7,8]. One way to test and distinguish between these hypotheses is to determine whether or not pit ejecta exist around central pits. Under an explosive origin scenario, material should be ejected and distributed around the pit. In the collapse scenario, significant amounts of material should not be ejected outside the rim, as most material travels gravitationally down into a cavity. An ejecta blanket might be manifested in several ways. First, the deposition of ejecta around a crater would build a topographically raised rim. Second, ejected material may have a different grain size and thus a different thermal inertia than material on the parent crater's floor. In this study, we examine the morphology and thermophysical characteristics of central pit craters to test and distinguish between the two origin scenarios.

**Data and Methods:** We conducted a survey to characterize the global population of central pits in impact craters ≥10 km in diameter and within ±60° of the equator using the Mars Odyssey Thermal Emission Imaging System (THEMIS) daytime infrared global mosaic [9]. Morphology of central pit craters in this study was assessed quantitatively using profiles from Mars Global Surveyor Mars Orbiter Laser Altimeter (MOLA) data [10], and qualitatively by shaded relief from THEMIS, Mars Reconnaissance Orbiter Context Camera (CTX) [11], and High Resolution Imaging Science Experiment (HiRISE) [12] images. Variations in thermal properties are observed using relative temperature maps from THEMIS nighttime infrared images [9]. Nighttime temperature differences are used as proxies for thermal inertia and rock abundance [13-15]. MGS Thermal Emission Spectrometer (TES) albedos were used to characterize dust influences on pit thermal signatures [16]. Images and numerical data were viewed and plotted in JMARS [17].

**Results:** Elevation profiles were taken across several large (~50 km) central pit craters in JMARS using MOLA topography. Central pits often have rims slightly raised above the floors of their parent craters (Fig. 1).

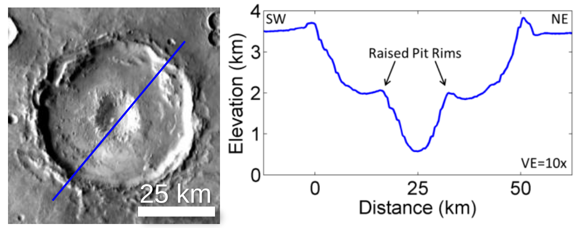



Fig. 1: An impact crater containing a central pit at 63.6°W, 17.6°S, viewed in a THEMIS daytime mosaic (left) and in a topographic profile from MOLA (right).

THEMIS nighttime thermal infrared images typically show warmer temperatures surrounding or directly adjacent to central pits, compared to the surrounding parent crater floor and pit floor (Fig. 2). 60% of central pits globally are surrounded by warm material (Fig. 3), either in an annulus or an off-centered patch. Many of the other pits that do not show warm nighttime temperatures occur in very dusty regions (identified by high TES albedo) and appear mantled in visible images. Sand dunes in the craters often show up as cool patches in THEMIS nighttime images.

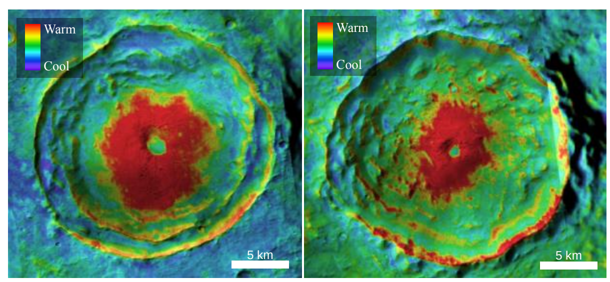
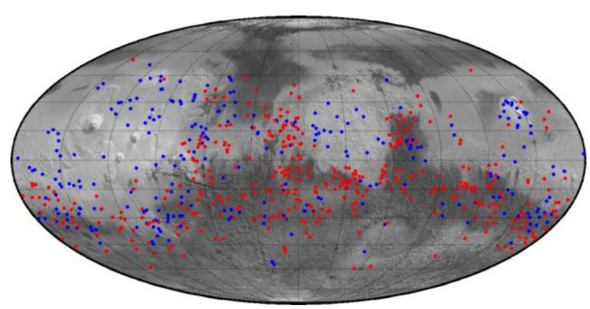



Fig. 2: THEMIS nighttime image mosaic showing examples of central pit craters at 18.4°S, 102.7°E, and 14.7°S, 93.2°E, surrounded by warm (blocky) material.



● Pits w/ Warm Material (n=388)
● Pits w/o Warm Material (n=266)

Fig. 3: Distribution of central pit craters on Mars overlayed on TES albedo. Note pits in dusty (high-albedo) areas tend not to show warm, blocky material.

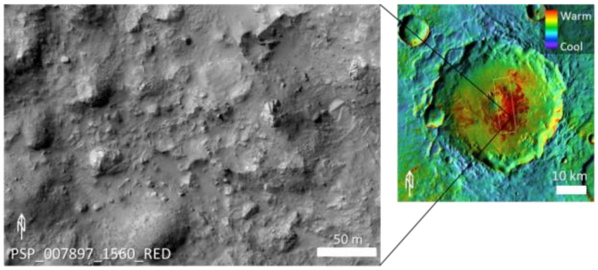



Fig. 4: HiRISE image (left) showing large blocks near a central pit crater at 23.8°S, 126.8°E associated with a warm patch in the THEMIS nighttime mosaic (right).

**Discussion:** The raised rims around central pits observed with MOLA topography are strongly suggestive of explosive excavation, similar to their parent craters which also exhibit raised rims.

The warm patches of material surrounding most central pits are associated with coarse blocks, sometimes visible in CTX and HiRISE images (Fig. 4). For pits in dusty regions, a coating of a few centimeters or more can mask diurnal thermal variations, even if blocks are underneath the veneer of dust. Based on the distribution of warm, blocky material around central pits, we suggest that these blocks represent pit ejecta.

The preponderance of central pits on icy or ice-rich planetary bodies suggests that water greatly enhances central pit formation. On Earth, kilometer-scale craters can form during monogenetic maar volcano eruptions where magma comes into contact with groundwater or ice [18]. Despite small volumes of erupted magma, phreatomagmatic steam explosions can produce large craters. The largest known maar volcanoes on Earth occur on the Seward Peninsula in northwest Alaska and are up to 8 km in diameter [19] – comparable in size to central pits on Mars.

Central pits on Mars would not require endogenic martian sources of heat and volcanism to create a steam explosion, since more than enough impact melt would already be present from the parent impact event. We calculated the available thermal energy for example central pit craters using relations between crater diameter, energy, and estimates of the mass of impact melt. Our calculations show that, if the upper ~kilometer of the surface had >3% permafrost ice by volume, then the impact melt from the parent impacts have more than enough thermal energy to drive steam explosions capable of producing kilometer-sized central pits on Mars. We propose a pit formation model (Fig. 5) in which the central uplift late in the modification phase of crater formation brings water-bearing substrate into contact with impact melt, at which point the water vaporizes and ejects material in a large, central explosion.

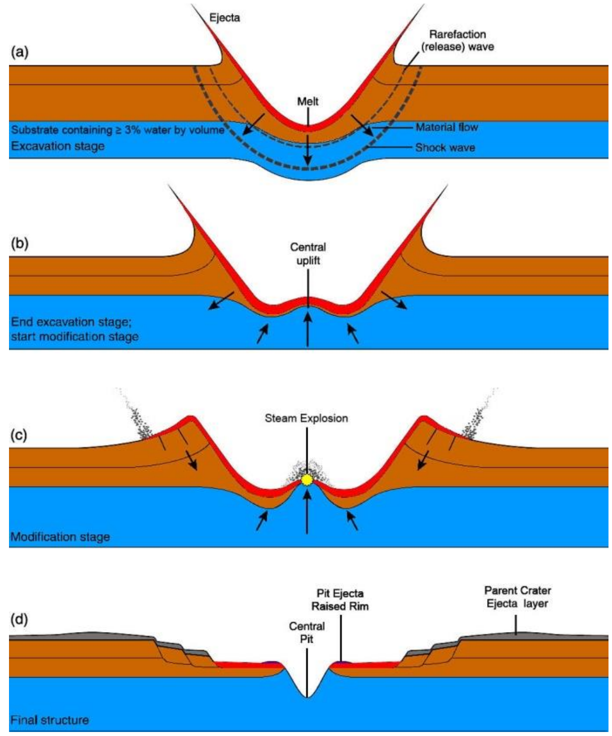



Fig. 5: Schematic cartoons illustrating steps in complex crater formation resulting in our proposed new "uplift contact model" for Martian central pit crater formation.

**Conclusions:** The presence of raised rims and blocky material surrounding pits is consistent with ejecta draped around Martian central pit craters and suggests pit formation by explosive excavation. Drainage and collapse models do not predict an ejecta blanket, as material should predominantly drop down and inwards, instead of being draped around and piled higher than the parent crater floors. An explosive origin would also require much less water – only a few percent by volume – than drainage and collapse scenarios. We therefore support an explosive excavation origin to central pit craters.

**References:** [1] Smith B. A. et al. (1979) Science 206, 927-950. [2] Hodges C. A. (1978) LPS IX, 521-522. [3] Barlow N. G. (2011) LPS XLII, Abstract #1149. [4] Hodges C. A. et al. (1980) LPS XI, 450-452. [5] Wood C. A. et al. (1978) LPS IX, 3691-3709. [6] Barlow N. G. (2006) Meteoritics & Planet. Sci. 41, 1425-1436. [7] Croft S. K. (1981) LPS XII, 196-198. [8] Elder C. M. (2012) Icarus 221, 831-843. [9] Christensen P. R. et al. (2004) Space Sci. Rev. 110, 85-130. [10] Smith D. E. et al. (2001) JGR 106, E10, 23689-23722. [11] Malin M. C. et al. (2007) JGR 112, E05S04, doi:10.1029/2006JE002808. [12] McEwen M. S. (2007) JGR 112, E05S02, doi:10.1029/2005JE002605. [13] Fergason R. L. et al. (2006) JGR 111, E12004. [14] Edwards C. S. et al. (2009) JGR 114, E11001. [15] Edwards C. S. et al. (2011) JGR 116, E10008. [16] Christensen P. R. et al. (2007) JGR 106, E10, 23823–23871. [17] Christensen P. R. et al. (2009) AGU FM, Abstract #IN22A-06. [18] Wohletz K. H. (1986) Bull. Volc. 48, 245-264. [19] Begét J.E. et al. (1996) Arctic 49, 1, 62-69.