WIDE-SPREAD OCCURRENCE OF CRATER-RELATED PITTED MATERIALS ON MARS: IMPLICATIONS FOR THE ROLE OF TARGET VOLATILES DURING THE IMPACT PROCESS.

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Introduction: Ongoing observations from the Mars Reconnaissance Orbiter (MRO) are providing new insights into the aqueous history of Mars and the role volatiles may play during the impact process. The High Resolution Imaging Science Experiment (HiRISE) and supporting images from the Context Imager (CTX), continue to reveal pitted materials (PM) within well-preserved impact craters, that may be similar to suevites (i.e., impact-melt bearing breccias) in terrestrial craters [1–4] (Fig. 1). Here we give an update on the study of crater-related PM that was last presented during the 7th Mars conference in 2007 [1,4].

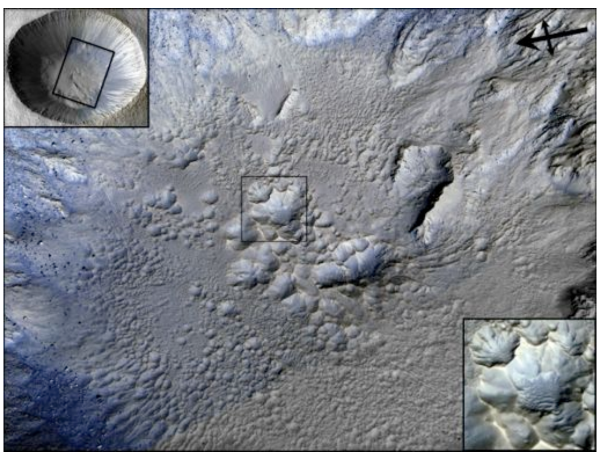

Figure 1. Pitted deposits observed on the floor (i.e., the crater-fill) of the "thermal" rayed crater Zumba in Daedalia Planum, Mars. The perspective here is 1:1 with no vertical exaggeration. This is a full resolution (25.2 cm/pixel) composite of an orthorectified HiRISE RED/IRB image and a 1-m/post HiRISE stereo pair-derived DTM (derived from PSP_002118_1510 & PSP_003608_1510). Image/data credits: NASA/JPL/UA.

Approach: Both systematic and non-systematic targeting of craters with HiRISE and CTX were utilized to specifically target craters that were likely to contain PM. The systematic survey was based on our preliminary observations [1], while the non-systematic (random targeting of crater interiors) was utilized to ensure that our observations were not biased (e.g., geographically, or preservation-wise), respectively. A combination of Thermal Emission Imaging System (THEMIS) day- and night-time thermal infrared brightness temperature, and the Mars Orbiter Laser Altimeter (MOLA) shaded relief, global mosaics were used to assess the relative crater freshness and preservation. Both PM occurrence and preservation correlate with crater preservation [1–5], thus the best-preserved craters were targeted with HiRISE (CTX requested for coordination) to map the occurrence of crater-related PM.

Crater-fill pit size measurements were collected for the best-preserved examples to determine if a relationship exists between this parameter and crater diameter. Variations in pit size were also measured within the ~30-km diameter Tooting crater progressing from the crater-fill, terraces and ejecta PM. Four Digital Terrain Models (DTMs) have been processed from HiRISE stereo observations [6,7] of PM-bearing craters since the onset of the Primary Science Phase (PSP) of the MRO mission [8]. Three of these were used to determine some of the morphometric properties of the pits and the materials that contain them (e.g., Fig. 1).

Observations and Results: *Geographic distribution*: A global view of the occurrence and geographical distribution of pitted material-bearing craters has begun to materialize over the last 5 years of ongoing MRO observations. Of the 1061 impact craters examined, ~28% (764 craters) had insufficient visible image coverage and/or resolution to determine if PM are present. PM were observed in 198 (~26% of the aforementioned 764) with possible detections in an additional 171 craters, which require additional data to confirm or dismiss. Together these comprise almost half the craters with good image coverage. Overall, the 198 craters with positive identifications of PM range in diameter from ~1 to 150 km and do not show a strong preference for the northern hemisphere versus the south (94 vs. 104). However, a histogram of the number of pitted craters with respect to 10-degree latitude

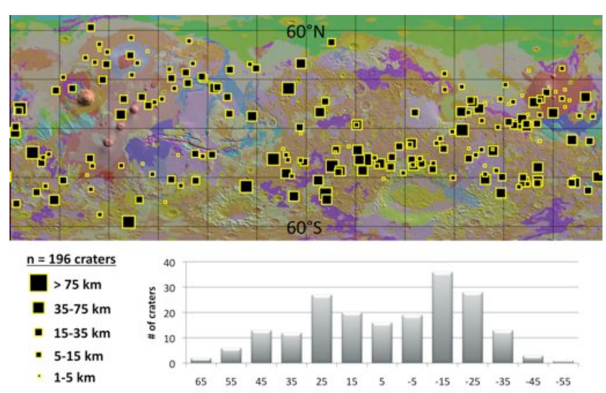

Figure 2. Observed distribution of pitted material bearing crater on Mars on a geologic map [9] of Mars. And a raw frequency (not normalized to area) histogram of the distribution of PM craters as a function of latitude [see 4 for further details].

bins show a distinctive bimodal distribution with respect to latitude (Fig. 2) with ~75% of our sample population occurring in the lower mid-latitude regions of Mars (~10–30°N and S) and fewer to a complete lack of these craters at or near the equator and high latitude, respectively. There is no evidence of the occurrence of these materials in craters poleward of 53°S and 62°N. These craters do appear to be restricted in elevation only occurring within the elevation range ± ~5.5 km relative to the MOLA datum. Importantly, the craters in which PM are observed appear to be amongst the most nearly pristine and well-preserved craters. This is supported by quantitative estimates based on crater statistics (e.g., size-frequency or statistics of the largest overprinting impact crater [4].

Morphology & Morphometry: The pits are distinctive negative-relief features with circular to polygonal shaped cavities that are partly in-filled with fine-grained materials (Fig. 1). They also are relatively shallow and possess only subtle topographic rims with no signs of proximal ejecta materials. Isolated pits tend to be more circular, where groups of pits exhibit shared rims that form a polygonal network similar to the cross-sectional geometry of bubble walls within a foam [5,10]. Both pit size and population density are observed to increase locally within an individual crater with respect to the area of the host deposit (e.g., pond size/area). Average (D_{ap}) pit diameters of the ten largest pits within the crater-fill of nine of the best-preserved craters (for D ~1-140 km) correlates with crater diameter, and can be expressed as:

$$D_{ap} = 16.4 D_c^{0.87} \quad (n = 9)\ R^2 = 0.985 \quad \textbf{Eq. 1}$$

DTM profiles indicate that the pit walls exhibit high slopes (>25°) that break to lower slopes (~15–20°) ~0.25 to 0.5 pit radii from the rim.

Stratigraphy, Superpositon and PM Distribution: PM are consistently superimposed by debris flows, talus, and mass wasting features associated with crater modification and post-impact processes. They are also observed primarily as ponded and flow materials located in three specific areas—crater-fill, terraces and ejecta with the ejecta distribution showing a relationship to the inferred impact trajectory for the host crater. Pits are primarily confined to ponded and flow features, which superimpose or embay crater displaced bedrock (e.g., terrace blocks, the central uplift, etc.) and ejecta. Pits have not been observed that cross-cut a geologic boundary (i.e., between the PM and ejecta or displaced bedrock).

Discussion and Conclusions: PM appear to be "primary" crater deposits (i.e., impact-related). This is based on their crater-related distribution and stratigraphic and superposition relationships with bedrock and other less ambiguous post-impact deposits. In addition, the gross morphology of PM (ponds and flows), and distributions, are similar to melt bearing deposits found in and around lunar craters. The lack of observable pits in m-scale images of fresh lunar craters suggests that the Martian pits could be due to volatile interactions with impactites generated during the impact process. This is also corroborated by the observations of the scaling relationship of pit diameter with increasing crater diameter, which may be a function of residual heat generated by an impact event. The possibility that the PM materials represents impactites is corroborated by rare, deposit-free (e.g., dust-free) exposures within pit walls, which exhibit rock fragments that may be breccias [4].

The exact mechanisms involved in pit formation are poorly understood. Unfortunately, terrestrial impact structures, by comparison to Martian craters, are poorly preserved, and terrestrial phreatic craters, craters formed via interactions between water-rich materials and hot magma or lava, are not good matches with these Martian pits [4,5]. We suggest that the pits form from the interaction between hot impact-melt bearing breccias and entrained water derived from the target materials. Volatilization of water within the deposit leads to rapid, and perhaps explosive, degassing of the deposit, with pits corresponding to locations of degassing pipes. An alternative model is collapse following melting and/or sublimation of ground ice.

The lack of PM in polar regions at first may seem puzzling, but we suggest that this may be a preservation issue, but cannot rule out that possibility of target properties (higher volumes of volatile/ice-to-rock ratios influencing the formation of PM. The lack of PM materials in nigh equatorial regions may be due to the greater depths of the cyrosphere/hydrosphere in those regions [11].

Observations and results are consistent with our preferred interpretation of PM as impactite deposits, likely consisting of a mixture of impact melt, and mineral and lithic fragments, and that the pits result from interactions between hot, highly shocked materials with volatile-rich phases. The presence of this deposit in older craters, where preserved, suggests that these potentially volatile-rich materials formed throughout most of Martian geologic history.

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