# Origin of Pits in the Pitted Materials of Fresh Martian Impact Craters:

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**Introduction**: A mantle of pitted material is commonly found on the floors, and pooled on interior terraces blocks and ejecta blankets near rims of fresh Martian craters (Fig. 1) [1, 2]. While there are places in this unit that lack pits, typically it is heavily pitted. The closely-packed pits commonly share rims, producing a pattern that resembles foam. The individual pits range from a few meters to ~ 3 km diameter. Previous workers [3 -8] have suggested that this unit is composed of water-rich impact melt (or melt-breccias), or impact-generated, fine-grain sediment and that the pits are collapse or sublimation do not adequately explain the pit morphology or morphometry. However, the foam-like geometry and the presence of rims suggest that a collapse or sublimation origin is unlikely. Most other geologic mechanisms such as secondary cratering, sinkhole, or alas production also seem unlikely because features that only superficially resemble the Martian crater pits [see e.g., 9-13].

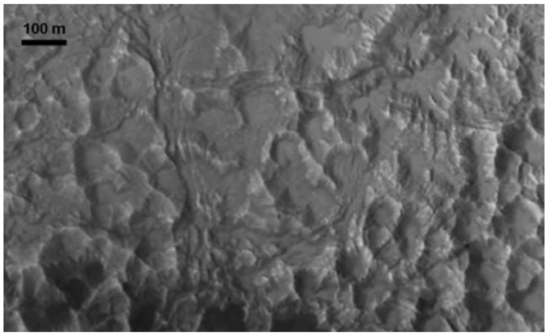

Fig. 1 Pits in the floor of Mojave crater showing low-rims and foam-like geometry (HiRISE image PSP_002101_1875_RED). Sun is from on the left.

**Methodology**: The foam-like geometry of the closely-packed pits provides information about the process that produced them. With this in mind, we have tested the similarity of the geometry of the outline of the Martian crater pits with that of foams [e.g., 14, 15], and other types of natural pits using the centroid locations of individual features in these different populations for nearest neighbor (NN) analyses [16-20]. Our analysis of the resultant geospatial distribution of the centroids suggests that relative to Poisson nearest neighbor (PNN) distributions, they all exhibit significant departures from the null hypothesis. Moreover, the value of R (i.e. ratio of the actual mean NN distance relative to the mean NN distance predicted by a Poisson model) suggests that self-organization processes have affected their formation (Fig 2, left) by generating the random NN separations within the pits networks. We took and additional step and tested the $k$ = 1 Scavenged PNN model [16, 20] to determine whether the greater than random NN distances can be explained by a resource scavenging process involving NN. This is of particular importance because of the likelihood that the resource is water (or ice) in the pitted materials. The results of this test (Fig. 2, right) indicate that, while other types of pits exhibit significant departures from the $k$ = 1 Scavenged PNN model, foams and Martian crater pits do not. This suggests that a resource scavenging model generally provides a reasonable description of the spatial organization of the Martian crater pits, although it also implies that the strength of the resource scavenging process for the Martian pits is weaker than predicted by the model. This suggest that the formation of a Martian crater pit does not completely consume the resources required to form the next nearest pit, but that competition for limited resources does tend to drive NN pits apart (similar to the self-organization processes that occur within foam networks, i.e., see Fig 2, right). This adds a valuable constraint to models of pit formation.

**Proposed Pit Formation Mechanism:** Although we agree with previous workers [1-4] that the pitted unit initially may have been water-bearing and that the escape of the water is the ultimate cause of the pits, the raised rims of the pits and their foam-like pattern do not support the proposals that the pits are mainly due to collapse or sublimation [3-8]. Instead, we propose that the pits are more akin to mud pots, formed when water bearing host pitted material came in contact with the hot basement rock of the newly-formed crater resulting in boiling of the water in the pitted material (most likely starting at the bottom), and produces steam bubbles and bubble trains. The ascending steam bubbles developed pathways (i.e., vent pipes) that drove hot water and carried solid particles through the pitted materials to the surface, in much the same way as in devolatilizatation pipes form in pyroclastic deposits [21, 22] and the suevite at the Reis crater [e.g., 23]. Once upward flow has started in the vent pipes, the venturi effect should draw water from the surrounding deposit to feed the upward flow [24, 25]. Because multiple vent pipes should form in the deposit competition for water between the vent pipes should develop and as a result influences the characteristic of flow in each pipe. This is consistent with the data shown in Fig. 2. We suggest that the erupting steam, water, and solid particles from the vent pipes should build broad, shallow, low-rimmed pits, similar to terrestrial mud pots, air discharge pits, or spring pits [e.g., 26-28]. The observed low-relief suggests that water and steam were the dominantly components that emerged from the pipes, with only a relatively small proportion of solid particles. In addition, the pitted material must be relatively indurated because it has survived in some parent craters for as much as a few hundred million years old [1, 3] consistent with cementation and induration associated with hydrothermal environments [29, 30].

**References:** [1] Mouginis-Mark et al., 2003, Int. Mars Conf. VI, #3004; [2] McEwen et al., 2007, *Science*, 317, 1706-1709; [3] Tornabene et al ,2007, *7th Int. Conf. on Mars.* LPI, 1353; [4], Tornabene et al 2010, Icarus, in prep., [5] Mouginis-Mark & Garbeil, 2007, *MAPS*,42, 1615 – 1625; [6] Morris et al, 2010, Icarus, in press; [7] Mouginis-Mark & Boyce, 2010, *Geology*, submitted; [8] Hartmann et al, 2010, Icarus, doi: 10.1016/2010.03.030 [9] Ritter, et al., 2002, 4th Ed., McGraw-Hill Co. Inc., NY, NY; [10] Burr et al., 2008, *Earth & Planet. Sci.*, 57, 579-596; [11] Soare et al 2008, *Earth & Plant. Sci. Letters*, 272, 382-393; [12] Oberbeck & Morrison, 1973 *Lunar Sci. Conf. Proc.*, 4, v. 1, p 107 -123; [13] Keszthelyi et al 2010 Icarus, 205, 211-229; [14] Vasconcelos et al, 2003 *Physics*, 2, 0303063, 1-34; [15] Glazier & Weaire, 1992, Phys. Condens. Matter, 4, 1867 -1894; [16] Beggan and Hamilton, 2010; [17] Clark & Evans, 1954, Ecology, 35:445-453 [18] Bruno et al, 2004, JGR, doi:10.1029/ 109:E070092004JE0022 73; [19] Bruno et al., 2006 JGR, 111: E06017. doi: 10.1029 /2005 JE002510; [20] Baloga et al, 2007, JGR 112:E03002.doi:10.1029/2005JE002652; [21] Keith., 1991, J. Volcanol. Geotherm,. Res., v. 45, p. 227 – 254; [22] Sparks, & Walker, 1973,Geol. , 1, 115-118. [23] Newsom et al., 1986;*JGR*,*104:*87 17 -8728; [24] Hamilton et al., 2010; *JGR, in press;* [25] *Kokelaar*, 1983 *J. Geol. Soc.*, 140: 939-944; [26] Shipton et al. 2007, *$CO_2$ for Storage in Deep Geol. Form.*,, 2, 699-712; [27] Draganits & Jurda, 2003, *Boreas*, 32, 436-442; [28] Jianhua et al., 2004 *Sed. Geol.*, 170, 1-20.; [29] Newson et al, 1986, JGR 91, B13, E239-E251; [30] Barnhart et al, 2010, Icarus, 0019-1035. doi: 10.1016 /2010 .01.013

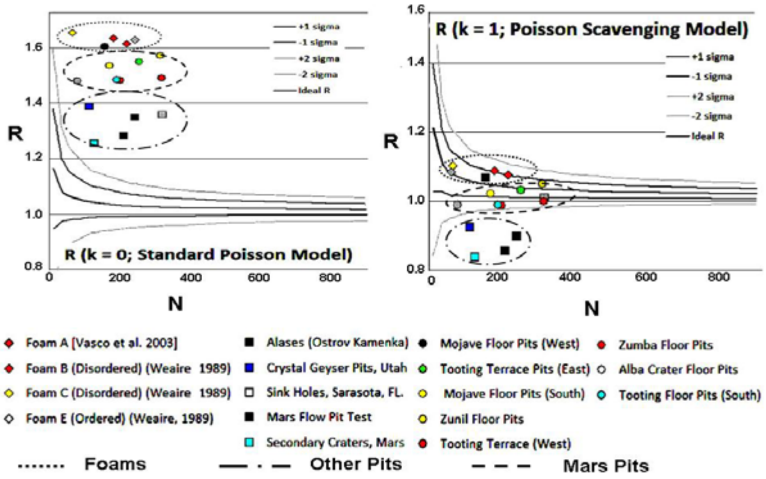

Fig. 2. Nearest Neighbor Results relative to Standard Poisson Model (on left). NN results relative to Poisson Scavenging Model (on the right).