Cratering on Mars with Almost No Atmosphere or Volatiles: Pangboche Crater.

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Introduction: Pangboche crater (17.2°N, 226.7°E; 10.4 km dia.; Fig. 1) lies close to the summit of Olympus Mons volcano, Mars, at an elevation of 20.9 km above the datum. Given a scale height of 11.1 km for the atmosphere, this relatively large fresh crater most likely formed at an atmospheric pressure < 1 mbar in essentially volatile-free young lava flows. As such, the morphology of Pangboche crater provides unique insights into the cratering process on Mars without the influence of an atmosphere or target volatiles, and allows the testing of the ideas on ejecta-volatile interactions proposed by Kieffer and Simonds [1]. These interactions could involve the mixing of hot ejecta with vaporized volatiles derived from ice or water that existed within the target rocks at the time of impact. The result of these interactions might also include destruction of impact melt prior to emplacement, the formation of pitted material within the crater interior, and the fluidization of ejecta blankets.

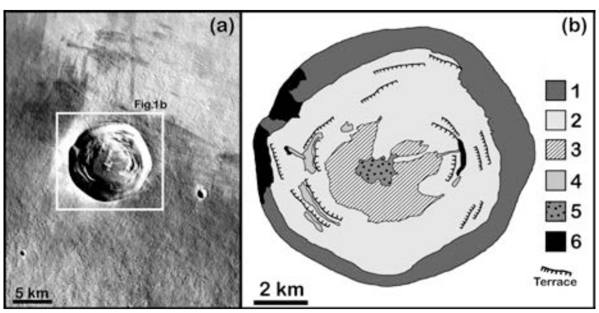

Figure 1: (a) Pangboche crater lacks fluidized ejecta and has a complex interior with a central pit and multiple terraces. Box illustrates area of Fig. 1b. CTX image P07_003621_1980. (b) Geomorphic map of Pangboche crater showing the wall units ("1"), scalloped terraces ("2"), floor material ("3"), flows and ponds of material on terraces ("4"), the central pit ("5"), and areas obscured by shadows ("6"). Steep scarps associated with terraces blocks are also shown.

Topography: Topographic data from the Mars Orbiter Laser Altimeter (MOLA) and a stereo-pair of CTX images reveal that the target material was non-horizontal (Fig. 2). The floor of Pangboche crater lies at an elevation of ~2 km above the floor of the Olympus Mons caldera. Pre-impact topography (the crater formed on a regional slope of ~2°) most likely influenced the final crater geometry; the up-slope rim is ~250 m higher than the downslope rim.

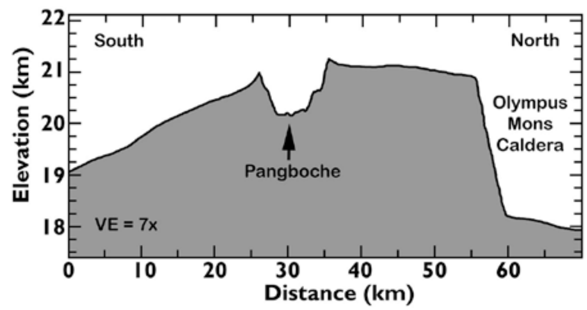

Figure 2: South-north cross-section through Pangboche crater, derived from CTX DEM. Elevation is referenced to the MOLA datum for Mars.

Central Pit: Pangboche crater displays a prominent cluster of three pit craters near the center of its floor (Fig. 3). The largest of these pits is ~1,150 m in diameter, has a rim ~30 m high, and is ~150 m deep. The origin of these central pits remains enigmatic. Central pits are seen in over 1,500 Martian impact craters [2] all of which formed at lower elevations. However, in these cases the origin is believed to be associated with the release of target volatiles [3, 4]. The raised rims of the central pits within Pangboche indicate that these are not simply volatile-related, nor are they collapse features equivalent to the pits seen on Mercury [5] because the rims are constructional features.

Impact Melt: Evidence for extensive impact melt can also be found on the terraces (Fig. 4). The clearest example of potential flow of impact melt is perched at an elevation of ~190 m above the crater floor. This flow is ~1 km wide and 6 km long, and displays festoon ridges that point in the down-slope direction. In addition to this flow, a second smaller flow over-rides part of the large flow, indicating that drainage of material was multi-phased.

Ejecta Blanket: Mouginis-Mark [6] predicted that ejecta blankets of craters formed at high elevations on Mars should be similar to those seen around craters on the Moon or Mercury, and that appears to be the case for Pangboche crater. Detailed mapping of the southern summit area of Olympus Mons from CTX images has revealed many hundreds of secondary craters. These secondary craters have the elliptical outline and herring-bone patterns commonly identified at lunar craters [7]. These secondary craters extend to a maximum range from the crater rim of ~37 km (~7.2 crater radii) for Pangboche crater.

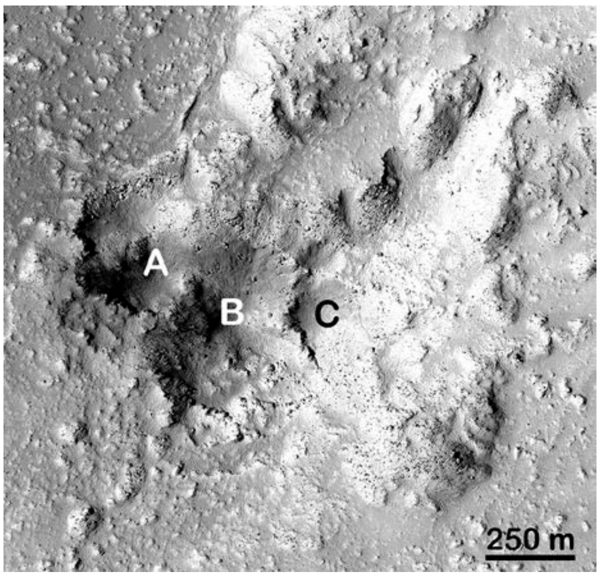

Figure 3: A large central pit occurs on the floor of Pangboche crater. The large pit "A" is ~1,150 m in diameter, has a raised rim ~30 m high, and is ~150 m deep. Other pits are denoted by "B" and "C". Note the many boulders a few meters in diameter that cover the entire area. Part of HiRISE image PSP_001643_1975.

Conclusions: Pangboche crater displays several morphologic units that are rare or unique on Mars. With the exception of a cluster of central pits with raised rims, none of the landforms typically linked to target volatiles can be found at Pangboche. The ejecta blanket shows no signs of fluidization, there is abundant evidence for impact melt production, and the pitted terrain attributed elsewhere to volatile/melt interactions are absent. Given the fact that the target material comprised a sequence of layered lava flows, Pangboche crater may well represent the best crater on Mars for direct comparison with craters formed on the Moon (permitting variations in gravitational effects to be investigated) or on Mercury (allowing the role of the atmosphere to be studied). Future research could, therefore focus on the detailed distribution and morphology of secondary craters at Pangboche, or on the estimation of the volume of the impact melt at this crater.

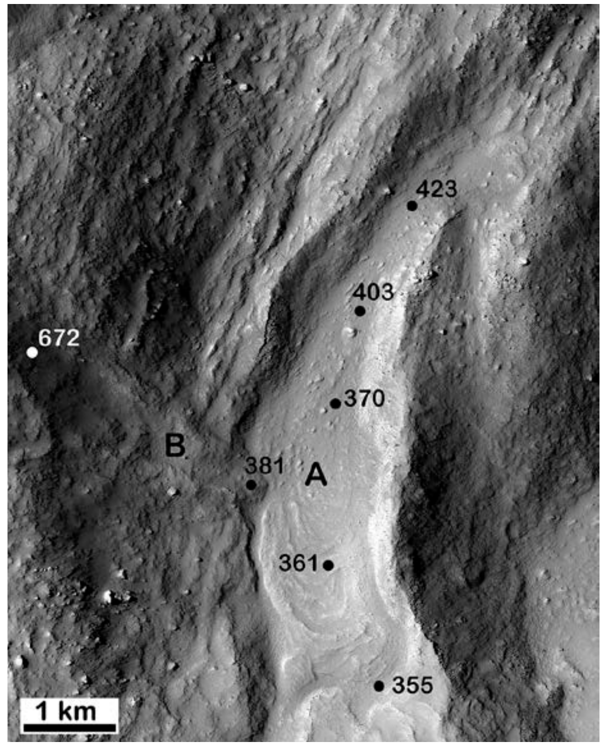

Figure 4: Lobate flow ("A") perched on the western inner wall of Pangboche crater. This flow, interpreted to be solidified impact melt, is ~190 m above the crater floor (at lower right). Direction of flow was from top to bottom. Note also the subsequent flow ("B") that post-dates this larger flow. Black circles give elevations in meters above an elevation of 20 km above datum. Part of HiRISE image ESP_027646_1975.

References: [1] Kieffer, S. W. & Simonds, C. H. (1980). *Revs. Geophys. Space Phys*. 18: 143 – 181. [2] Barlow, N. G. & Alzate, N. (2008). In: *Large Meteorite Impacts and Planetary Evolution IV*, abst. 3071. [3] Wood, C.A., Head, J. W. & Cintala, M. J. (1978). *Proc. 9th Lunar Planet. Sci. Conf.*, 3691 – 3709. [4] Barlow, N. G. (2006). *Meteoritics & Planetary Sci*ence 41: 1425 – 1436. [5] Gillis-Davis, J. J., et al. (2009). *Earth Planet. Sci. Lttrs.* 285: 243 – 250. [6] Mouginis-Mark, P. J. (1979). *J. Geophys. Res.* 84: 8011 – 8022. [7] Oberbeck, V. R. & Morrison, R. H. (1973). *Lunar Sci. Conf. Proc.* 4, 107 – 123.