FLUID-DEPOSITED FRACTURE-MARGIN RIDGES IN MARGARITIFER TERRA, MARS. Rebecca. J. Thomas[1], Sally Potter-McIntyre[2] and Brian. M. Hynek[1,3] [1] LASP, University of Colorado, Boulder, CO 80309, USA, rebecca.thomas@lasp.colorado.edu, [2] Southern Illinois University, Geology Department, Parkinson Lab Mailcode 4324, Carbondale, IL 62901, [3] Department of Geological Sciences, University of Colorado, 399 UCB, Boulder, CO 80309, USA.

Introduction: Sites where mineral deposition occurred in association with fluid flow emanating from the subsurface are excellent targets at which to seek evidence for past life on Mars. This is because aqueous environments are favorable to life, and precipitated minerals have the potential to encase biosignatures, protecting them from degradation in the oxidizing environment at the martian surface [1,2]. We report the occurrence of ridges at the margins of broad fractures in Margaritifer Terra, and conduct morphological and stratigraphic analysis of two key sites to determine their probable mode of formation. On the basis of this analysis and through analogy with similar structures on Earth, we conclude that ridge-formation at the surface through lower-temperature mineralization and, potentially, in a hydrothermal system are supported at the two different sites. We consider the implications of these formation mechanisms for the preservation of astrobiological evidence.

Means of analysis: At 12 locations across Margaritifer Terra, we have found evidence in Mars Reconnaisance Orbiter CTX [3] and HiRISE [4] images for ridges at the margins of large-scale Late Hesperian to Amazonian fractures. The two best-imaged examples lie within floor-fractured impact craters: Ubud crater SE of Margaritifer Chaos and an unnamed crater in northern Margaritifer Terra. To establish the history of geological activity at these two sites, we investigated unit morphology using imagery, and topography using Mars Express HRSC DTM products [5]. These data were used to construct morphostratigraphic maps. To characterize identified morphostratigraphic units, we assessed the presence of volcanic material through examination of decorrelation stretch images generated by the THEMIS team (DC875), in which basaltic materials can be recognized on the basis of a pink to magenta tone, and assessed physical properties by reference to global THEMIS-IR-derived thermal inertia data [6].

Results:

1. Ubud crater (-18.3°E, -10.6°N) (Fig. 1) is a 25 km-diameter impact crater on Middle Noachian highland plains [7] to the SE of Margaritifer chaos. It lacks a visible central peak and is ~800 m shallower than expected for an impact crater of this size on Mars [8], indicating significant post-formation infilling. The majority of the crater floor has high thermal inertia (maximum 737 $Jm^{-2}K^{-1}s^{-1/2}$), and is light-toned and finely-brecciated. Erosional remnants of darker-toned, lower thermal inertia material are present superposing the light-toned unit, indicating its original presence over a larger proportion of the floor. The floor fill is cross-cut by multiple fractures up to 650 m wide. By analogy with other impact craters in the region, where exposure of light-toned brecciated material (LTBr) from beneath a dark capping unit is clearly associated with crater-floor fractures, we propose that erosion was accomplished by fluid upwelling from these fractures. Channels carved into the crater rim are consistent with overspill of this fluid to the surrounding terrain. At the margin of several fractures, particularly in the crater center, floor materials form topographic highs 500-1000 m wide. Examination of HiRISE images indicates that these ridges have the same tone and brecciation as the wider crater floor. Where one of these ridges is seen in cross-section, it displays horizontal layering.

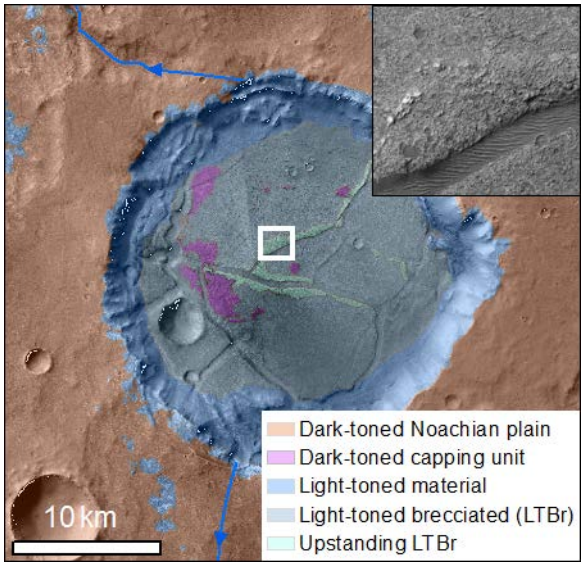

Figure 1 Ubud crater, with upstanding floor material along fractures on the crater floor. Blue lines: channels. Inset: closeup of fracture-margin ridge.

2. Unnamed crater at -25.1°E, 0.3°N (Fig 2.) lies 50 km south of Hydaspis Chaos. It lacks a central peak and is 1.7 km shallower than expected for an impact crater of its size (~44 km diameter), indicating significant infilling. The crater floor is cross-cut by fractures in a polygonal pattern, ~100 m wide in the crater center. Relatively dark-toned material around one of the fractures and across the crater floor shows erosive margins, and impact craters superposed on the remaining floor show evidence for erosion, indicating that

much of the floor has experienced erosion. Shallow channels adjacent to some fractures indicate that these were the source of erosive fluid. The dark-toned material has a purple to violet hue in DCS875 consistent with basaltic lava. Ridges up to 700 m wide and 60 m high occur at the margins of fractures in the center of the crater. These superpose pre-existing impact craters, and lack a distinctive tone in DCS images.

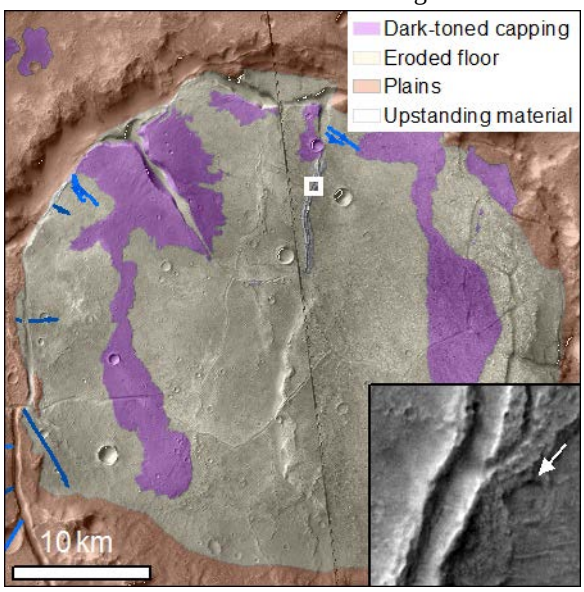

Figure 2 Unnamed crater (-25.1°E, 0.3°N) with fracture-margin ridges and evidence for volcanism. Blue lines indicate channelization. Inset: closeup of ridge, arrow = superposition of impact crater.

Interpretation: The similarity in morphology of Ubud crater fracture-side ridges and surrounding floor material is not consistent with their superposition on the existing surface. Instead, the simplest interpretation of their upstanding topography is that they are well-cemented remnants of the existing surface, similar to ridges reported along other structural lineaments on Mars [9-11]. Cementation would render them more resistant to erosion, and thus lead to a ridge morphology. We have observed a parallel for such a process in Spencer Flat, Grand Staircase-Escalante, Utah, where iron mineralization occurs adjacent to joints, extending kilometers along-strike and up to 100m perpendicular to joints. These mineralized zones form ridges due to their higher resistance to aeolian erosion relative to surrounding sandstones. While in these settings the best explanation for mineral deposition is oxidation of Fe^{2+}-bearing reduced fluids, on Mars one or a combination of changes in pressure, temperature and redox state as fluids approach the surface could have resulted in deposition of cements preferentially in units forming the wall-rock of the fractures. While we cannot be certain of the depth of origin of the fluids emitted at Ubud, deep regions of Mars are expected to have been potentially habitable through much of the planet's history [12]. If organisms from this deep biosphere were entrained in the expelled water, minerals precipitated out of it to form a resistant cement can be expected to have encased evidence for these organisms.

The observation that ridge material in the unnamed crater superposes impact craters indicates that it was deposited at the surface. Evidence for volcanism associated with other fractures in this crater suggests a genesis associated with volcanism. Though these could be purely volcanic (e.g. spatter ridges), their lack of a basaltic spectral signature does not support this, and the evidence for water flow from other fractures in this crater suggests that they may instead be hydrothermal deposits. The most resistant surface-forming deposits in such environments are sinter - minerals, particularly hydrated silica, precipitated from high-temperature groundwater when it cools and evaporates at the surface [13]. These occur along fractures on Earth (for example at Steamboat Springs, NV [14]), though their extent perpendicular to the fractures is not usually on the scale of those observed within this impact crater. Biosignatures, including microfossils, have been identified in sinters on Earth, indicating that those on Mars may also retain evidence for organisms living at or beneath the surface in hydrothermal systems [15].

Conclusions: We find evidence for low-temperature subsurface mineralization and, potentially, surface hydrothermal deposition at the margins of fractures in Margaritifer Terra, Mars. Both of these settings have astrobiological significance and, as such, represent appealing locations at which to conduct further landed investigation.

References: [1] Wattel-Koekkoek E. J. W. et al. (2003) *Eur. J. Soil Sci., 54:2*, 269–278. [2] Farmer J.D. and Des Marais D.J. (1999) *J. Geophys. Res. Planets*, *104*, 26977–26995. [3] Malin M.C. et al. (2007) *J. Geophys. Res. Planets,112*. [4] McEwen A.S. et al. (2007) *J. Geophys. Res., 112*. [5] Neukum G. and Jaumann, R. *ESA Special Publ. 1240*, 17-35. [6] Fergason R. L. et al. (2006) *J. Geophys. Res. Planets*, *111*. [7] Tanaka K.L. et al. (2014) *Planet. Space Sci., 95*, 11–24. [8] Garvin J.B. et al. (2003) *Sixth Int. Conf. Mars*, 3277. [9] Treiman A. H. (2008) *Nat. Geosci., 1:3*, 181–183. [10] Okubo C.H. and McEwen A.S. (2007) *Science*, *315: 5814*, 983–986. [11] Saper, L. and Mustard J. F. (2013) *Geophys. Res. Lett., 40:2*, 245–249. [12] Michalski J. R. et al. (2013) *Nat. Geosci., 6:2*, 133–138. [13] Campbell K.A. et al. (2015) *Earth-Science Rev., 148*. [14] Kruse F.A. (1999) *8th Annu. JPL Airborne Earth Sci. Work.*, 239–245. [15] Ruff, S.W. and Farmer J.D. (2016) *Nat. Commun., 7*.