Fluid-deposited fracture-margin ridges in Margaritifer Terra, Mars

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1. Introduction: Astrobiological potential of fracture-margin mineralization
Sites where mineral deposition occurred in association with fluid flow from the subsurface are excellent targets as which to seek evidence for past life on Mars because:
1. aequous environments are favorable to life, and
2. precipitated minerals can encase biosignatures, protecting them from degradation in the oxidizing environment at the Martian surface [20,23].

We report 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 the two ridge types are best explained by low temperature mineralization in the subsurface and surface deposition from a hydrothermal system, respectively, both of which have the potential to preserve astrobiological evidence.

2. Approach to Analysis
Using Mars Reconnaissance Orbiter (MRO) CTX [11], HiRISE [14] and Mars Global Surveyor MOC [16] images, we identified 12 candidate sites of fracture-margin mineralization in Margaritifer Terra, a Noachian highland region just south of the global dichotomy boundary that is extensively cross-cut by Late Hesperian-Amazonian chaos (Fig. 2) and associated fractures and hosts many floor-fractured impact craters [39]. In all but one case, ridges occur at crater floor fractures, indicating that this is a characteristic setting for them. For the best-imaged examples of two morphologically-distinct ridge types, we:
- Created morphostratigraphic maps using image and thermal inertia [15,16,18,44] data.
- Investigated topography with gridded Mars Laser Altimeter (MOLA) data [7], Mars Express HRSC DTM [12], and CTX DTM derived from stereo images using Ames Stereo Pipeline software [15,16].
- Explored spectral variation in THEMIS decorrelation stretch images (DCS875) [12].

3. Ubud-type ridges
Observations: Resistant regions of the existing substrate
Fracture-margin ridges with a broad, rounded morphology and composed of material consistent with the rest of the crater floor (Fig. 3) are seen in two impact craters in eastern Margaritifer.

They are best-imaged and most substantial in Ubud (Fig. 4), a 28 km-diameter impact crater south of Margaritifer chaos (-18.3°E, 10.6°N). Isolated outcrops of dark-toned capping material and morphological degradation of superposed impact craters indicate that the rugged crater floor has experienced erosion, and channels at the crater rim consistent with overspill suggest some erosion may have been accomplished by fluid upwelling from the fractures.

Interpretation: Subsurface mineral precipitation
The similarity of ridges to surrounding material and their rugged, rounded morphology indicate that they are erosion-resistant zones in crater floor material. Their occurrence along fractures suggests that they result from structurally-controlled subsurface induration by a mineral cement, as seen at Spencer Flat, Grand Staircase-Escalante, Utah. Here, iron (oxy)hydroxide cementation occurred in the subsurface when oxidizing meteoric fluids channeled by joints met a reducing, Fe³⁺-saturated subsurface reservoir [16]. The cemented zones now form ridges due to their superior resistance to erosion versus surrounding sandstones (Fig. 5).

Chemical precipitation can occur due to changes in pressure and temperature as well as by redox reactions; all of these factors would be expected to come into play in fluid flow as fluid rose from the deep, warm, reducing Martian subsurface to the oxidizing surface. Thus, subsurface precipitation at a geochronal boundary is a good explanation for cementation in Ubud’s fracture wall-rock, as it is for cementation and chemical alteration along other structural lineaments on Mars [14,17].

4. Type II ridges
Observations: Steep-sided ridges overlying pre-existing substrate
Steeply-dipping ridges with flatter distal regions (Fig. 6) flank fractures in the floors of two unnamed craters in northern Margaritifer. The best imaged is 50 km south of Hydaspia Chaos (0.3°N, -25.1°E; Fig. 7). Though a lack of HiRISE imaging precludes determination of whether the texture of the ridge material differs from the surrounding crater floor, ridge material superposes pre-existing impact craters, indicating that the ridges considerably post-date floor formation and that they were emplaced at the surface.

There is evidence for both fracture-associated fluid flow (shallow channelization adjacent to fractures) and volcanism (a spectrally-different deposit around a northwest crater floor fracture) within this crater. Crater-count evidence suggests erosion by fluid and volcanism occurred contemporaneously.

5. Conclusion: Good potential for astrobiological preservation
Chemical precipitates have the potential to encase any organisms living at the site of precipitation or entrained in the mineralizing fluid. Though conditions at the Martian surface in the Hesperian-Amazonian era of chaos and fracture-formation [20] are not expected to have been favorable to life, potential habitability in the source regions of the upwelling fluid is good. Even shallower groundwater on Mars comes from a zone that is shielded from inhospitable surface conditions, retains porosity and is minimally-altered [20,21]. Further, if fluids at Type II examples derived from a hydrothermal system, this will have been an especially warm, nutrient-rich source environment, potentially reaching to great depths if associated with a regional magmatic intrusion.

After mineral entombment, the potential for long-term preservation of biosignatures is good. Though syndepositional environmental fluctuations and diagenesis may have destroyed organic material [20,23], other biosignatures such as microbial fossils [20,23], biologically-mediated structures [21], and body molds [20] are found preserved in precipitates from both hot and cold settings on Earth. As silica is the most stable of the potential mineral precipitates mentioned here [20], and the best able to preserve biosignatures [21], Type II ridges, if high-temperature siliceous precipitates, have the best biosignature preservation potential of the two types.

References


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