

BIOGENIC IRON MINERALIZATION AT IRON MOUNTAIN, CA, WITH IMPLICATIONS FOR DETECTION WITH THE MARS CURIOSITY ROVER. A.J. Williams¹, D.Y. Sumner¹, C.N. Alpers², K.M. Campbell³, D.K. Nordstrom³; ¹University of California, Davis, One Shields Avenue, Davis, CA, 95616 (amywill@ucdavis.edu); ² U.S. Geological Survey, 6000 J St, Placer Hall, Sacramento, CA 95819; ³ U.S. Geological Survey, 3215 Marine Street, Boulder, CO 80303.

Introduction: Microbe-mineral interactions and biosignature preservation in oxidized sulfidic ore bodies (gossans) are prime candidates for astrobiological study. Such oxidized iron systems have been proposed as analogs for some Martian environments [1]. Recent studies identified microbial fossils preserved as mineral-coated filaments [2,3,4,5,6,7,8,9]. This study documents microbially-mediated mineral biosignatures in hydrous ferric oxide (HFO) and ferric oxyhydroxy-sulfates (FOHS) in three environments at Iron Mountain, CA. We investigated microbial community preservation via HFO and FOHS precipitation and the formation of filamentous mineral biosignatures. These environments included 1) actively precipitating (<3 yr) FOHS-HFO scale in pipes carrying acidic mine water, 2) much older (>1000's yrs), naturally weathered HFO from *in situ* gossan, and 3) remobilized iron deposits, which contained lithified clastics and zones of HFO precipitate.

We used published biogenicity criteria [6,10,11] as guidelines to characterize the biogenicity of mineral filaments. These criteria included A) an actively-precipitating environment where microbes are known to be coated in minerals [2,5,6,8,13], B) presence of extant microbial communities with carbon signatures, C) structures observable as a part of the host rock, and D) biological morphology, including cellular lumina, multiple member population, numerous taxa, variable and 3-D preservation, biological size ranges, uniform diameter, and evidence of flexibility.

This study explores the relevance and detection of these biosignatures to possible Martian biosignatures. Similar filamentous biosignatures are resolvable by the Mars Hand Lens Imager (MAHLI) onboard the Mars Science Laboratory (MSL) rover, Curiosity, and may be identifiable as biogenic if present on Mars.

Methods: We collected samples of pyrite, HFO, and quartz boxwork from surface gossan during the winter of 2010–2011, and samples of FOHS-HFO scale from a mine water effluent pipe in 2012. We characterized microbially-associated HFO and FOHS precipitation by identifying 1) mineral phases with XRD, reflected light microscopy, and energy dispersive x-ray spectrometry *via* SEM and 2) mineral-coated microbial textures and morphology with SEM and optical microscopy. We evaluated mineral filament biogenicity using published criteria [6,10,11].

Results & Interpretations:

Mineral Morphologies: Pipe Scale. Pipe scale formed through microbial oxidation of Fe(II) to Fe(III) in acidic (pH 2.5 to 3.0) mine water with subsequent precipitation of schwertmannite and minor goethite [12]. The SEM images of the scale showed mineral spheres (diameters 0.8–3.8 μm , measured with ImageJ), unmineralized microbial filaments (diameter \sim 0.4 μm), and FOHS filaments (diameter \sim 2.4 μm) coated by <1 μm particles with central lumina \sim 0.6 μm wide (Fig. 1A).

Mineral Morphologies: Surface Gossan. Mineral filaments associated with gossan were coated with <1 μm wide HFO crystals. *In situ* gossan samples included HFO filaments (diameters 2.4–31.8 μm , mean = 9.8 μm) with colloform texture (Fig. 1B), mineral spheres either nucleated on HFO filaments or relic quartz boxwork (two populations average 5.7 and 20.5 μm wide, respectively), and bladed crystals (elongated crystals that radiate from a central point to form lamellar aggregations). In remobilized iron deposits, oriented fabrics consisted of muted-colloform HFO filament masses (diameters 1.1–19.7 μm , mean = 7.8 μm) that form masses of oriented filaments with \sim 0.5 μm wide central lumina (Fig. 1C).

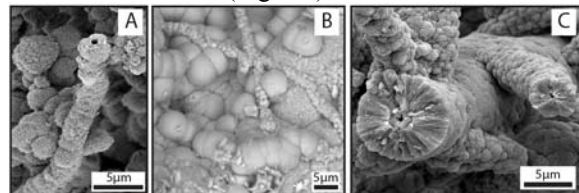


Figure 1. A) FOHS- and B) HFO-mineralized filaments in *in situ* gossan and C) remobilized iron deposits.

Biosignature Preservation Pathways. Mineral filaments preserved microbial textures and the mineral precipitation microenvironment controlled biosignature morphology. The HFO filaments in gossan were morphologically similar to mineralized microbial filaments that formed from acid water in the pipe scale.

Within *in situ* gossan, microbial filaments are coated with <1 μm wide HFO particles to form bumpy HFO filaments that preserve the original microbial filament structure. Bumpy HFO filaments are 2.5–5.5 μm in diameter, span voids in the rock, and form overlapping, densely spaced, filament networks. In some samples, smooth spheres coat bumpy HFO filaments to form agglomerations of spheres that only vaguely preserve the original filament morphology (Fig. 2B).

Next, bladed crystals formed lamellar aggregations. They are composed of elongated and flattened crystals that radiate from bumpy filaments and smooth spheres (Fig. 2C). Many bladed features coalesced at different angles to form an extensively hatched surface. In other areas, oblate spheroids (average diameter 9.9 μm) coalesce to form knurled surfaces that overgrow bumpy HFO filaments. Oblate spheroids are composed of 3 interlocking barbell crystals that form a hexagonal plate. Plates grow side by side to form the oblate spheroids with crenulated edges, with the hexagonal plate structure exposed on the sphere's top and bottom. Oblate spheroids accumulate by growing edge-on-edge to form an agglomeration of spheres, but neither form curvilinear, self-supported features nor coat bumpy HFO filaments directly (Fig. 2A).

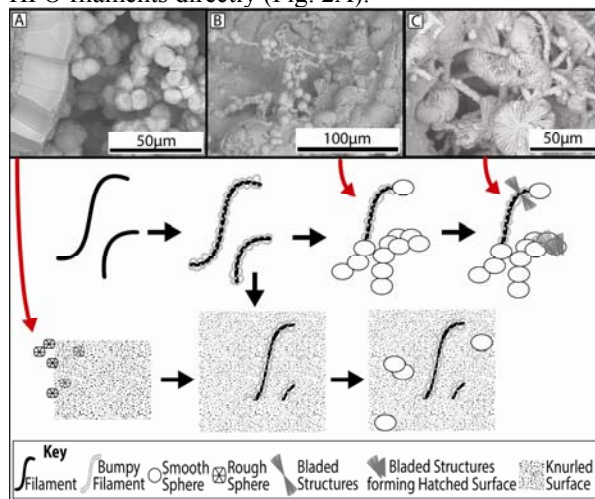


Figure 2. *In situ* gossan filament preservation schematic.

In remobilized iron deposits, mineral grains were transported down-gradient and re-lithified. Microbial filaments colonized the substrate to form spatially restricted microbial mats. We suggest that microbial filaments were quickly coated with inorganic HFO minerals transported during meteorological precipitation events. By contrast to *in situ* gossan, remobilized iron deposits had no quartz boxwork to mediate water flow or mineral precipitation, so filaments were coated with HFO precipitates during sheet flow events. This created the large-diameter, muted-colloform texture filaments identified in the remobilized iron deposits. The HFO filaments were coated with goethite slowly enough to increase diameter forming muted-colloform mineral-coating structures. When there was no microbial filament template for HFO precipitation, laminated and massive HFO precipitated (Fig. 3).

Biosignature Criteria. HFO filaments in the pipe scale, *in situ* gossan, and remobilized iron deposits all fit criteria A, B, C, and D. The only exception is that no central lumina have been observed in *in situ* gossan

HFO filaments. Based on fulfillment of these criteria, we suggest that these mineral filaments are mineral-coated microbial filaments preserved as biosignatures.

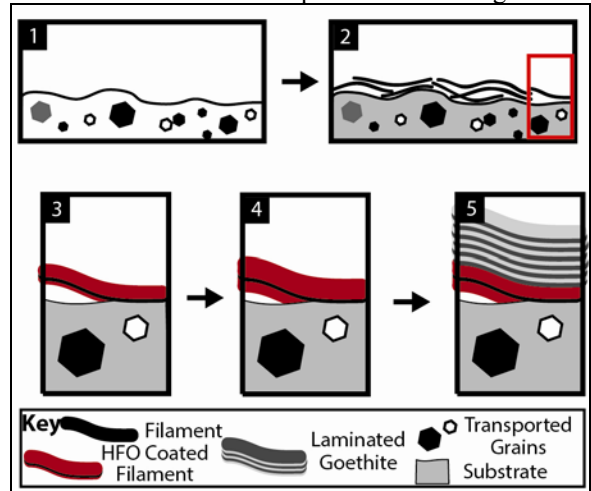


Figure 3. Remobilized iron deposit filament preservation schematic.

Mineral Biosignature Identification on Mars. Understanding how biosignatures are formed and preserved is crucial for identifying similar mineral biosignatures on Mars, if they exist. Zones of sinuous mineral filaments within mats at Iron Mountain are distinct at MAHLI's highest resolution, 13.9 $\mu\text{m}/\text{pixel}$. Although demonstrating biogenicity with only images at this resolution would be problematic on Mars with currently available technology, these textures could identify prime candidate locations for further characterization.

Conclusions: The characterization of mineral filaments as biosignatures provides insight into mineral biosignatures detectable by MSL. Individual filaments are below MAHLI resolution, but sinuous filaments forming mat-like textures are resolvable. With a suite of analyses acquired by the MSL instruments to define the geochemical and mineral environment, those features could be identified on Mars as similar to these filaments on Earth, and potentially biogenic. These features could be preserved in a crystalline hematite-bearing ridge on Mt. Sharp, which is on MSL's expected path [14].

References: [1] Burns, R.G. (1987) *LPSC XVIII*, 141-142. [2] Cady, S.L. and Farmer, D.J. (1996) *Evol. Hydrothermal Ecosyst. on Earth (and Mars?)*, 150-173. [3] Hofmann, B.A. and Farmer, J.D. (2000) *Planetary and Space Science* 48, 1077-1086. [4] Banfield, J.F. et al. (2001) *Astrobiology* 1, 447-465. [5] Jones, B. et al. (2001) *J. Geol. Soc. London* 158, 895-911. [6] Hofmann, B.A. et al. (2008) *Astrobiology* 8, 87-117. [7] Jones, B. (2010) *Sediment. Geol.* 232, 15-34. [8] Preston, L.J. et al. (2011) *Geobiology* 9, 233-249. [9] Peng, X. and Jones, B. (2012) *Sediment. Geol.* 257-260, 45-62. [10] Buick, R. (1990) *Palaios* 5, 441-459. [11] Schopf, J.W. et al. (2007) *Precambrian Res.* 158, 141-155. [12] Campbell, K.M. et al. (2013) *Geol. Soc. Am. Abstracts* 45, 287. [13] Rasmussen, B. (2000) *Nature* 405, 676-679. [14] Fraeman, A.A. et al. (2013) *Geology* 41, 1103-1106.