DIAGENETIC ALTERATION OF BIOSIGNATURES PRESERVED IN SPRING CARBONATES: IMPLICATIONS FOR MARS. S.L. Potter-McIntyre[1] , J.Williams[1], C. M. Phillips-Lander [2], and L. O'Connell[1]
[1]Southern Illinois University, Geology Department, Parkinson Lab Mailcode 4324, Carbondale IL, 62901, pottermcintyre@siu.edu, [2]University of Oklahoma, School of Geology of Geology and Geophysics.

Introduction: On Earth, microorganisms commonly enhance mineral precipitation and mediate mineralogical and chemical compositions of resulting deposits [e.g., 1, 2]. Most previous research on biosignatures has focused on comparing modern processes with very ancient (>1 Ga) putative microbially induced sedimentary structures [MISS; e.g., 1, 3, 4] creating inherent uncertainty in their interpretation because diagenetic alteration may be significant [4,5]. Hot springs such as those at Yellowstone have received significant attention as analogs for origin of life and extraterrestrial life studies [4, 6]. However, cold spring systems are important because they also may represent a formation mechanism of some carbonates in the solar system, particularly analogous to those in lacustrine settings such as the carbonates at Gale crater, Mars [7].

Purpose of Study: A unique field site with actively precipitating carbonate and Fe (oxyhydr)oxide microbial mats and a succession of older carbonate deposits from the same spring system (up to 400 ka) are present in Ten Mile Graben, Utah, USA. A previously undescribed Jurassic laminated carbonate unit within the Morrison Formation is also exposed in Ten Mile Graben. This research characterizes these modern saline, slightly alkaline, SO_4^{2-}- and Fe-undersaturated, cold (16-20°C) springs as well as providing the first description of the Jurassic Brushy Basin Member of the Morrison Formation carbonate deposit. Chemical, mineralogical, and morphological biosignatures in calcium carbonates and iron (oxyhydr)oxides precipitated in the modern springs are compared with the Jurassic examples to show how these biosignatures are modified over geologic time. These successively older carbonate microbialites provide a novel opportunity to investigate how biosignatures are progressively preserved and/or altered during diagenesis on geologic time scales. Understanding the alteration and preservation of biosignatures is essential for recognizing these signatures in the rock record of both early Earth as well as Mars.

Geologic Setting: The 148 Ma Brushy Basin Member of the Morrison Formation is primarily a volcaniclastic shale interpreted to have been deposited in a fluvio-lacustrine setting that extends from New Mexico to Montana in the western US [5, 8]. The upper part of the unit in the Four Corners regions of the US is interpreted to have been deposited in an ephemeral, groundwater-fed, alkaline saline lake system named Lake T'oo'dichi' [8]. Thick carbonate deposits are undocumented in this member; however, a laterally restricted (~10km^2) 3-10 m thick laminated carbonate is present in the Ten Mile Graben area northwest of interpreted Lake T'oo'dichi'.

Ten Mile Graben hosts a series of CO_2-driven geysers and springs, active and fossil microbial carbonate mats, and carbonate veins. U-Th dating of carbonates and embedded veins reveal that CO_2 has constantly leaked to the surface for >400 ka [9]. Mineral precipitation in both the Quaternary spring system and the Jurassic carbonate unit has likely also been influenced to a large extent by microbial participation.

Methods: Field research was performed using traditional field characterization methods. Lithofacies were documented and relations to laterally vertically adjacent lithofacies were observed. Representative samples were collected for scanning electron microscopy to identify modern morphological microbial features and associated mineral compositions and habits. Older samples were analyzed for microbial fossils and trace fossils as well as mineralogy. Energy dispersive X-ray technology associated with the SEM was used to identify chemical composition and infer mineralogy.

Observations: In the modern Big Bubbling Spring sample, a cluster of ~2µm diameter smooth hollow sheaths is observed (Fig. 1A). EDS analysis shows the sheaths contain 65 wt.% iron (although results are semi-quantitative). A similar ~2 µm diameter sheath is preserved in the 200ka samples (Fig. 1B) and it is also composed of iron (66.52 wt.%). The 200ka sheath is encased in an Fe-rich honeycomb structure. This honeycomb structure is also observed in the 250ka (not shown), the 400ka, and the Jurassic samples (Fig. 1D, E, F). Possible preserved sheaths (2 µm diameter and 60.36 wt.% iron)

are observed in the 400ka sample as well (Fig. 1C). Other microbial fossils are present in the 400ka sample: a spherule with a hollow center, and a segmented stalk (Fig. 1D). The spherule and the segmented stalk are present within the honeycomb structure. The hollow spherule is ~2 µm diameter with a smooth-walled hollow center that is ~0.5 µm in diameter. The spherule is iron-rich (66.25 wt.%); arsenic (0.43 wt.%) and manganese (0.13 wt.%) are also present. The segmented stalk is a mold of a linear series of ~2 µm diameter spherical impressions within the honeycomb structure. It is also iron-rich (71.95 wt.%) and contains arsenic (0.49 wt.%), manganese (0.20 wt.%). Sheaths and associated honeycomb structures are present in the Jurassic sample surrounded by anhedral calcite (Fig. 1E, F).

Interpretation: The Big Bubbling Spring sample contains Fe-(oxyhydr)oxide-rich sheaths that are likely the iron-oxiding bacteria (FeOB), Leptothrix ochracea. These organisms are morphologically conspicuous due to the smooth sheaths and they are common in saline, neutral to slightly alkaline water such as at Ten Mile Graben spring system. The sheaths are commonly encased in Fe-(oxyhydr)oxides. This early mineralization helps to preserve the sheath through geologic time and although some deterioration is observed in particularly the 400ka example, the microbial fossils is still recognizable. Ostwald ripening produces large crystals that encase and preserve fossilized sheaths and honeycomb structures in the Jurassic example.

Other microbial fossils and trace fossils are preserved in the samples. The segmented stalk impression preserved within the honeycomb structure in the 400ka mat suggests the honeycomb features are likely molds of clusters of cyanobacteria. However, these trace fossils are also associated with the preserved putative Leptothrix fossils which suggests a these consortia can be preserved together.

Conclusions: This study shows that microbial fossils and associated trace fossils can be preserved throughout geologic time with little degradation due to 1. Early permineralization by Fe-(oxyhydr)oxides, and 2. Diagenetic entombment by Ostwald ripening of carbonates. However, if destruction of body fossils does occur, trace fossils (e.g., honeycomb structures) can still be preserved and function as biogenic fingerprints (such as in the 400ka example).

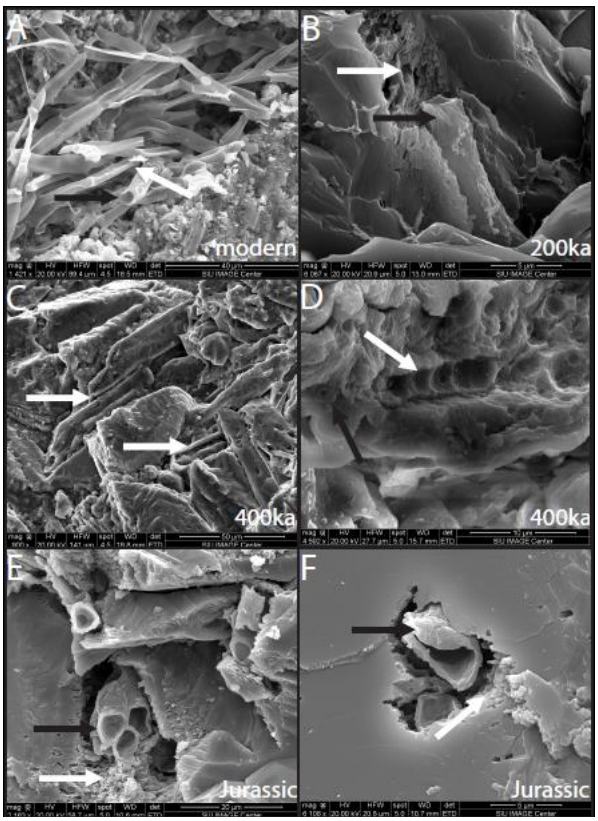

Figure 1. SEM images of sheath microbial fossils and associated microbial trace fossils. A) Modern mat sample. B) 200ka tufa terrace showing permineralized L.ochracea fossil (black arrow) encased in a honeycomb structure (white arrow). C) Possible L. ochracea fossils in 400ka tufa. D) Honeycomb structure in 400ka tufa with segmented stalk (white arrow) and preserved spherical body fossil with hollow center (black arrow). E) Sheath fossils in the Jurassic tufa (black arrow) encased in a honeycomb structure (white arrow). F) Jurassic sample with sheath fossil (black arrow) and honeycomb structure (white arrow) preserved by massive carbonate entombment.

References: [1] Petryshyn, V.A. et al. (2012) Geology, 499-502. [2] Corkeron, M. et al. (2012) Precambrian Research, 194-206. [3] Mojzsis, S.J. et al. (2003) Geochim.et Cosmochim. A., 1635-1658. [4] Parenteau, M.N., and Cady, S.L. (2010) Palaios, 25, 97-111. [5] Potter-McIntyre, S.L. et al. (2014) Astrobiology, 1-14. [6] Parenteau, M.N. et al. (2014) Astrobiology, 502-521. [7] Archer, P. D. et al. (2014) JGR: Planets, 237-254. [8] Turner, C.E., and Fishman, N.S. (1991) GSA Bulletin, 538-558. [9] Burnside, N.M. et al. (2013) Geology, 471-474.