MICROBIAL MATS AND SEDIMENTARY CONDITIONS 3.2 GA IN TIDAL DEPOSITS FROM THE MOODIES GROUP.

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Introduction: Although atmospheric oxygen levels increased dramatically at 2.4 billion years ago (Ga), the timing of production of oxygen by phototrophs remains poorly constrained. Morphological evidence for Paleoarchean life and opportunities to test for very early oxygenic photosynthesis are limited to a few greenstone belts (i.e., the 3.55-3.20 Ga Barberton Greenstone Belt [1, 2] and the 3.52-2.95 Ga Pilbara Supergroup [3]). The ~3.22 Ga Moodies Group (Barberton Greenstone Belt) contains some of the oldest siliciclastic sediments deposited in tidal settings. These rocks include "crinkly" laminations interpreted to be lithified microbial mats. Biogenicity evidence includes morphology correlated to sedimentary facies, negative $\delta^{13}C_{org}$ from carbonaceous matter, and rare putative microfossils [1, 2].

Assessing biogenicity on early Earth or extraterrestrial targets requires multiple techniques. PIXL (Planetary Instrument for X-ray Lithochemistry) on the Mars2020 Perseverance rover uses X-ray fluorescence spectrometry (XRF) to correlate rock elemental compositions and textures over small areas (typically <1 cm^2) [4]. It is often used in tandem with SHERLOC (Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals) to identify rock components and their textural relationships. The combination of instruments is designed to enable the search for biosignatures at the scale of sedimentary laminations and we have replicated that process in the Moodies.

Methods: In 2022, we collected samples from outcrops in units MdQ1 and MdS1 of the Moodies Group [5]. Cut slabs were scanned with a Bruker M4 TORNADO^{PLUS} µXRF to identify mineralogical and compositional variations associated with sedimentary structures. Scans were collected using a tube voltage and current of 50 kV and 600 µA, respectively, and an ~15 µm analytical spot size stepped in 20 µm increments. Preliminary Raman spectroscopy and thin-section petrography on selected samples will refine mineral identifications and resolve features smaller than the µXRF spot size. Our primary objectives are 1) to test for potential biosignatures associated with Moodies crinkly laminations and related structures, 2) to test for fine-scale evidence of early *in situ* oxidation/reduction processes associated with sedimentary microbial communities (e.g., oxidation or reduction of sedimentary Fe, S, Cr, and other species), and 3) to use detrital redox-active grains (e.g., pyrite, arsenopyrite, etc.) as paleoredox tracers of processes occurring in the sediment source terrain and transport system.

Preliminary Results: Initial µXRF investigation of these samples has identified clear evidence that microbial communities altered the cohesiveness of sedimentary laminations, altering patterns of sediment accumulation and erosion and producing distinctive sedimentary structures. Here we describe structures, neither of which were initially identified in outcrop.

Textures and Mineral Associations. The sample from MdS1 was collected from dark, centimeter-scale sandstone beds exposed along a recent road cut. The beds showed abundant evidence of erosive scour but few sedimentary bedform structures. µXRF scans show that the beds are composed of medium-to-coarse feldspar and quartz/chert sand grains capped by 1–2-mm-thick laminations enriched in zircon, rutile, chromite, and pyrite silt and very fine sand grains (hereafter referred to as heavy minerals) and a pore-filling K-rich aluminosilicate (**Fig. 1**). We interpret these capping laminations as the tops of cohesive microbial mats that trapped silt and very fine grains during intervals of low sediment accumulation or sediment bypass based on the long (~2 cm) "tails" on the structure's left side (**Fig. 1**) that suggests a structure more cohesive than an abiotic mud chip as well as their

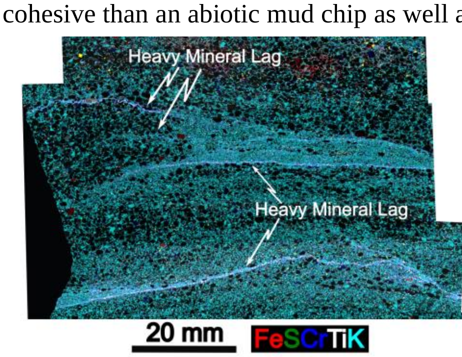

Figure 1. Collage of merged elemental maps from µXRF scans. Cross section view of two possible microbial mats from the MdS1 unit in the Moodies Group. Grain colors: yellow=pyrite, black =quartz/chert, white=rutile, blue=chromite, turquoise=K-rich aluminosilicate or feldspar.

heavy mineral enrichment relative to bulk sediment. In the uppermost of the laminations shown here, a single heavy mineral-lined lamination caps two different beds marked by different average grain sizes, likely juxtaposed by erosion of the finer bed, suggesting that the mat may have grown over the new layer formed by sedimentation in the eroded patch.

The mat morphology changes and peters out horizontally (as seen on the slab) and laterally over 5 cm (as seen between cut slabs) suggesting the structure has a microbial origin and was part of a larger structure. It appears that one of these mats (upper structure in **Fig. 1**) is a reworked mat chip that has been recolonized by microbes while others (lower structure in **Fig. 1**) may be autochthonous as they are less distinct from the surrounding sediments. Previous work has only found thin, crinkled mats [1, 6] in the Moodies Group, thus these structures represent a new mat morphology.

Second, we document a tent-like microbial structure only rarely found in the Moodies Group and previously described from limited outcrop observations and a few thin sections from the MdQ1 section [1]. These structures have been interpreted to have been formed by groups of microbial filaments that twisted together as they grew vertically to form “tufted cones” (**Fig. 2**). Tufted mats from the Moodies have been described before [1], but this structure is on the order of 10x larger. Evidence for biogenicity includes fine-grained layers that define the heavy mineral lags. These lags occur on slopes greater than 45º supporting the need for “sticky” microbial layers to trap and bind sand grains [7]. The structure extends vertically through at least 7 cm of sediment and through about 5 cm of cut slabs also supporting the conclusion that this is a biogenic structure where microbes continued growing in response to sediment deposition. This syndepositional origin is more consistent with a biogenic origin versus a structure forming during metamorphism [8].

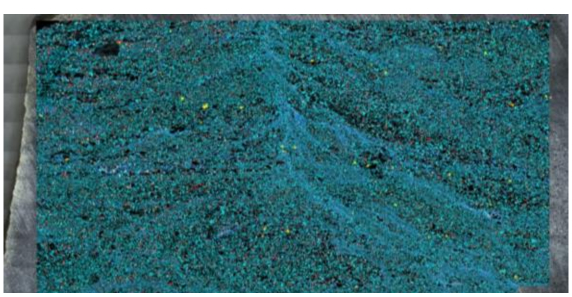

Figure 2. Collage of merged elemental maps from µXRF scans. Cross section view of possible tufted mat (light blue lines) from the MdQ1 unit in the Moodies Group. Grain colors: yellow=pyrite, black =quartz/chert, white=rutile, blue=chromite, turquoise=K-rich aluminosilicate or feldspar.

Process interpretation. We interpret alternating fine-grained, ungraded layers and coarser grained, inclined and normally graded layers on both sides of the tent-like structure **(Fig. 2)** as grain fall and grain flow layers, respectively. Their presence suggests bimodal current energies and alternating directions that trapped coarse sediment on the upflow side of the structure and fine sediment on the downflow side, consistent with existing shallow subtidal interpretations of this part of MdS1 [1]. This suggests that the tent ridge was strong enough to maintain synoptic relief over many tidal cycles, and that the associated mat rapidly recolonized sediment layers between sedimentation events.

The formation of a heavy mineral lag requires a second process to act on grain populations presorted by settling or transport in fluid [9]. The presence of these lags on relatively flat beds with irregular topography and on steeply dipping surfaces suggests that they formed by trapping on surfaces that were sticky or rough on the scale of ~10-100 µm. At their finest resolution, µXRF scans of mat lamination surfaces show imbricated zircon grains, consistent with the interpretation that they accumulated under the influence of gentle flows.

Raman spectroscopy and thin section petrology. Raman microspectroscopy combined with optical and electron microprobe petrography is used to test for the presence of oxidation rinds, carbonaceous linings, or both on redox active heavy mineral grains. This work also can test for carbonaceous matter in the laminations we have interpreted as fossil mats.

Implications for Planetary Research: The Moodies deltaic sedimentary rocks are partial analogs to the Jezero deltaic sedimentary rocks currently being explored by the Perseverance rover for the Mars2020 mission. Our success at identifying biogenic and sedimentological structures with a benchtop µXRF holds great promise for this and future planetary exploration. The PIXL instrument shows that an instrument capable of mapping structures (with spot size of 120 µm [4] can successfully be operated by a rover.

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