Identifying microbial biosignatures on Mars using the *Perseverance* payload: a case study using microbial mats from the Palaeoarchaean.

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Introduction: The search for life beyond Earth is focussed on Mars, which is uniquely compelling in that it appears to have been habitable during its early history, (the Noachian; 4.1–3.7 Ga) [1-2]. The Mars 2020 *Perseverance* rover mission seeks to reconstruct diverse Noachian–Hesperian palaeoenvironments and is equipped with a suite of instruments capable of identifying potential fossil traces of life (biosignatures) [3]. Through sampling and caching a diverse suite of geological samples, Mars 2020 also represents the first step toward Mars Sample Return (MSR) [3-4]. Potentially organic- and biosignature-bearing sedimentary rocks are high-priority targets for MSR since they may answer major questions in astrobiology [3-4]. *Perseverance* is currently exploring Jezero crater, a Noachian locality that once hosted a delta-lake system with habitability and biosignature preservation potential; astrobiological targets of interest include fine-grained sedimentary rocks associated with delta deposition [5].

Correlative micro-analysis on Mars: *Perseverance* is equipped with highly complementary instruments capable of studying geological targets from kilometre to micron scales. Following landscape and outcrop characterisation, proximal science is conducted using the rover arm, on which WATSON, SHERLOC and PIXL are mounted [6-7]. These instruments provide the highest-resolution textural and chemical data on abraded rock patches and are capable of conducting co-located imaging (WATSON), deep-UV Raman and fluorescence mapping (SHERLOC) and X-ray elemental mapping (PIXL), thereby identifying micron-scale correlations between rock fabric/texture, organic content, and chemical and mineral phase distributions.

Materials: In order to evaluate the potentials of correlated SHERLOC–PIXL science on mature biosignatures similar to those expected on the Noachian Mars, we studied samples from the Palaeoarchaean Buck Reef Chert (~3.42 Ga Onverwacht Group, Barberton greenstone belt), which are dominated by anoxygenic photosynthetic microbial mat ecosystems that colonised a carbonate platform [8]. Samples were sourced from the ICDP BARB-3 core, presented in [9]. Such microbial biosignatures are considered key targets for Martian astrobiology and are prime targets for sampling by *Perseverance* and eventual MSR [3].

Methods: SHERLOC-like measurements were conducted using the SHERLOC Brassboard instrument at NASA JPL. The Brassboard is a terrestrial analogue of the SHERLOC flight instrument and generates similar spatially resolved spectral maps along with co-boresighted high resolution (10.1 µm/pixel) microscopy images. Each sample was characterised following a similar methodology to SHERLOC operations *in situ* on Mars, i.e., a survey scan (36x36 points, 7x7 mm, 100 pulses per point, 200 µm spacing between points) was performed in order to rapidly map strong signals across a large area, after which regions of interest were analysed by detail scans (10x10 points, 1x1 mm, 800 pulses per point, 100 µm spacing between points).

PIXL-like analyses were conducted on a Bruker M4 Tornado µX-Ray Fluorescence spectrometer instrument at Caltech. Analyses were conducted at 2 mbar to closely approximate PIXL analyses on Mars where surface pressures are ~6 mbar. Large area maps were analysed using high resolution mapping with a 20 µm spot size. Regions of interest (co-located with SHERLOC-like microspectroscopy) and line scans were analysed using a 120 µm spot size to closely replicate PIXL analyses conducted *in situ* on Mars.

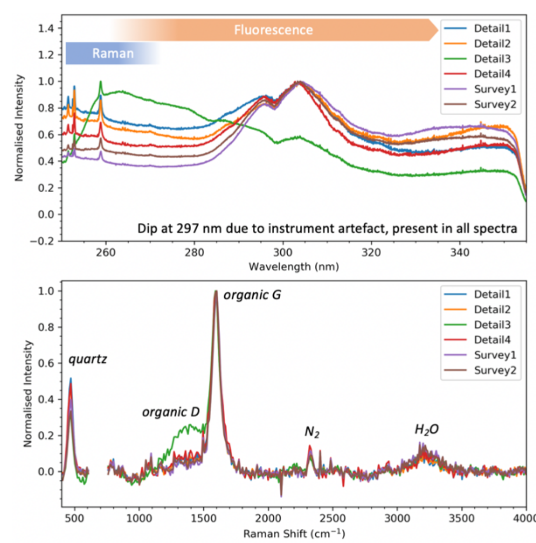

Fig. 1. Representative SHERLOC deep-UV Raman and fluorescence analyses of large area (7x7 mm) and details (1x1 mm) within Buck Reef Chert samples.

Results: Regions of interest in Buck Reef Chert samples comprised microbial mats composed of carbonaceous material, set within a chert–siderite matrix.

WATSON-like imaging: Images of the core samples and regions of interest (Fig. 2A–B) show variably laminated fabrics comprising thin dark-toned layers intercalated with thin–thick light-toned layers. Dark-toned layers are relatively homogeneous, whereas light-toned layers feature some granularity (Fig. 2B). Dark toned layers reflect mat laminations and light-toned layers are sedimentary interlayers.

SHERLOC-like DUV Raman and fluorescence: DUV fluorescence is generally dominated by a peak at ~305 nm, however, secondary veins are dominated by a peak at ~270 nm (Fig. 1). Fluorescence mapping highlights three signatures with maxima at ~300 nm, ~340 nm, and ~260 nm; in some samples, the 340 nm signal correlates with mat lamination morphology (Fig. 2C). Corresponding Raman spectra (Fig. 1) show peaks of quartz (450 cm^{-1}) and carbonaceous materials; mat laminations are dominated by the G-band at 1600 cm^{-1}, whereas veins are dominated by the D-band at ~1350 cm^{-1}. Raman spectroscopic mapping clearly highlights the dominance of the G-band signature throughout the sample and its broad correlation with the trend and spatial distribution of microbial mat layers, as well as intercalated quartz laminae (Fig. 2D). Ratio mapping of quartz against the carbon G-band confirms this broad anticorrelation (Fig. 2E).

PIXL-like elemental lithochemistry: PIXL maps of the same regions show that the sample is dominated by Si, Fe and Mn (Fig. 2F–I). Si correlates with quartz detected by SHERLOC and is inversely correlated with Fe and Mn, while Fe and Mn are strongly correlated throughout. Ca was also detected in trace amounts in the Fe-Mn layers while S, Al, and Ti were detected in trace amounts but with no clear distributions.

Prospects for biosignature detection: Correlated WATSON–SHERLOC–PIXL analyses show that the studied samples have laminated architectures comprising thermally mature carbonaceous materials with morphologies and organic chemistries consistent with the presence of ancient but exceptionally preserved microbial mats. Elemental lithochemistry shows dominance of the sedimentary portion by quartz (silica) and iron carbonate, suggesting that the palaeodepositional environment was silica-rich and rich in Fe^{2+}. Both silica and Fe^{2+} have implications for biosignature preservation potential: the former enhances preservation [10] while the latter may or may not reduce preservation [11]. Combined, these correlative analyses suggest a habitable aqueous setting colonised by microbial mat ecosystems and are consistent with the known biogenic origin of organic fabrics in the Buck Reef Chert [8-9]. Microbialites are prime targets for MSR and our findings affirm that materials with similar organic–inorganic properties should be considered compelling targets for return if identified in Jezero crater.

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Fig. 2. Correlated SHERLOC–PIXL study of microbialites. A-B) WATSON-like image. C) SHERLOC-like fluorescence survey scan. D) SHERLOC-like DUV Raman survey scan. E) SHERLOC-like detail scans and quartz (turquoise) and organic (brown) ratio maps. F-I) PIXL-like elemental maps: Si, Fe and Mn.