Using microbial biomarkers, geochemistry and petrology in Precambrian and Pleistocene lake sediments to unravel early planetary biospheres (Ref IAP2-18-83)

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In partnership with University of Glasgow

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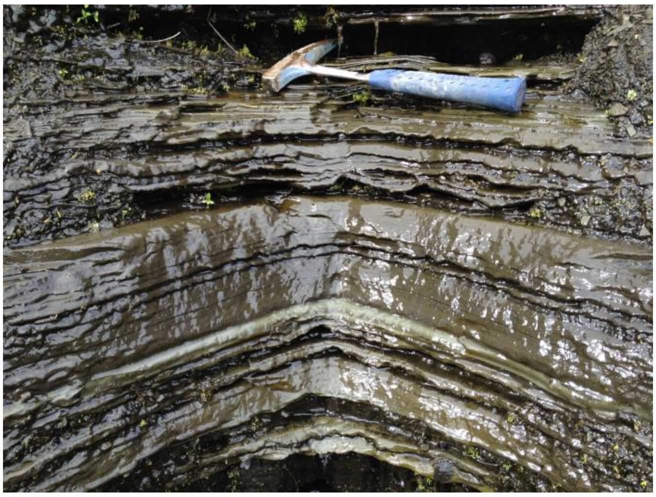
Overview

Precambrian lacustrine sediments provide a unique record of terrestrial biology that can inform us about the evolution of early microbial life on Earth, and potentially other once-habitable planets. However, much of this geological record is hard to decipher, owing to metamorphism and alteration by secondary processes. Further afield, the exploration of Mars will potentially add much to our understanding about the evolution of early microbial life and environments here on Earth. Where the geological record >3.5 Ga on Earth has been destroyed or substantially altered, the equivalent record on Mars is exceptionally well-preserved. Early Earth and Mars have a shared geological history, and it is within this time period that microbial life on Earth originated and subsequently evolved. This project will use Neoarchean (2.7 Ga; Australia), Neoproterozoic (1.2 Ga; Scotland) and Pleistocene (10 Ka; Iceland) sedimentary deposits to establish the nature and biogenicity of microbial biosignatures, in addition to their immediate environmental and petrographic context. By using examples that span a wide range of ages, environments, and bulk geochemical composition, it will be possible to identify a range of organic, geochemical, and spectral biosignatures within the geological record of early Earth, and potentially Mars. Geological localities are described below.

(1) EMSTRUR, ICELAND:
These pristine basaltic silt- and mudstones were deposited within a proglacial lake and subsequently consolidated. They contain organic-rich horizons and well-preserved sedimentary microstructures. They offer a young example of a complete lake-bed sequence that was primarily fed by volcanic sediments.



(II) PILBARA, AUSTRALIA:
Neoarchean deposits preserved within the Pilbara craton have long been investigated to understand more about the earliest inhabited environments on Earth. This project will utilise existing collections, and will

represent the oldest, and most organic-poor end member of the materials investigated.

(III) STOER GROUP, SCOTLAND:
The Stoer group in NW Scotland contains the oldest fossils in Scotland, and provides evidence for the early colonisation of terrestrial environments. These rocks host well-preserved microbial sedimentary structures, in addition to organic microfossils.

Methodology
This cross-disciplinary project will combine fieldwork with geochemistry and petrology.

1. Fieldwork: The student will undertake fieldwork to the west coast of Scotland and the central highlands of Iceland. Geological samples will be acquired and contextual geological observations and measurements made.

2. Geochemistry: Organic geochemical analyses of ancient kerogens will be conducted at the University of Glasgow, including: Gas Chromatograph Mass Spectrometry and Liquid chromatography–mass spectrometry (LC-MS). Detailed geochemistry analysis conducted at the University of St Andrews will include organic carbon stable isotope analysis and trace element geochemistry.

3. Petrology: Fine-scale petrology, hyperspectral imaging, and compositional analysis will be conducted at the University of St Andrews and University of Glasgow, including both Scanning and Transmission Electron Microscope (SEM and TEM) analysis, and elemental mapping with either Elemental Dispersive X-ray Spectroscopy (EDS) or Electron Microprobe Analysis (EMPA). In addition, visible – shortwave infrared hyperspectral imaging will also be conducted on selected samples to cross-correlate microscale organic or biogenic features with spectroscopic properties.

Timeline
Year 1 will involve literature and desk-top studies to allow the student to gain understanding of core topics and techniques, and the student will liaise with the supervisory team. Fieldwork preparation (permits, equipment, logistics) will be conducted for Scotland and Iceland. Organic and geochemical analysis from existing Pilbara samples will be done, providing preliminary data and training in laboratory techniques. Fieldwork to Scotland (5 days) and Iceland (7 days) will take place in early spring and early summer, respectively. This will be followed by further analyses. The student will also attend a relevant summer school.

Year 2 will focus significantly on organic geochemical analysis, petrographic imaging, and hyperspectral imaging. The remainder of the year will focus on detailed analysis of data, and drafting a manuscript. The student will present their work at an international conference.

Year 3 will involve synthesising data, and completion of any remaining geochemical and organic geochemical analyses. A manuscript will be submitted to a peer-reviewed journal. Thesis writing will begin.

Year 4 (6 months only) will focus on completion of the PhD thesis, handling of submitted manuscript(s), and attendance at an international conference, funds permitting.

Training & Skills
The student will be trained in (i) geological field methods, (ii) organic analytical techniques (GC-MS, LS-MS), (iii) geochemistry (EA, LA-ICP-MS, EMPA), and micro-imaging (SEM, TEM, hyperspectral imaging). The student will acquire presentation, communication, fieldwork logistics, and project management skills.

References & Further Reading
[1] Steeuken et al. (2017) Environmental niches and metabolic diversity in Neoarchean lakes. *Geobiology* 15.
[2] Flannery et al. (2018) Chapter 5 - Archean Lakes as Analogues for Habitable Martian Paleoenvironments. *From Habitability to Life on Mars* p. 127.

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