Experimental High-Pressure, High-Temperature Evolution of Microbial Biosignatures

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Key Words
Experimental; Biosignatures; Microorganisms; Early Earth; Geochemistry

Overview
Our knowledge of microbiological evolution is informed by organic, morphological, and geochemical biosignatures preserved within a rock record that is destroyed or modified over geological time [1]. Chemically-precipitated sediments, particularly carbonate and siliceous phases, host microfossils spanning much of Earth history, some in association with both early and recent terrestrial hot spring environments, thought to be a likely habitat for the earliest microbial life on Earth. The petrographic relationships between microbially-derived kerogen and the surrounding inorganic host rock or mineral matrix are particularly important in establishing microfossil biogenicity, in addition to understanding microbe-mineral systems themselves prior to geological sequestration into the rock record. Microbial biosignature assemblages captured within mineral substrates experience extreme pressures (P) and temperatures (T) during rock burial and metamorphism. Significant experimental effort has furthered our understanding of microbial biomineralization at the Earth’s surface, and more recently high-pressure high-temperature (HPHT) experiments are now shedding light on microfossil taphonomy during the geological sequestration process. As improving analytical techniques expand biosignature studies into increasingly metamorphosed terrains [2], there is a further need to understand the influence of higher pressure-temperature conditions on biosignature preservation and modification. Recent experimental work [3] conducted by our team has significantly expanded the PT space in which microbial biosignature taphonomy has been investigated. This project will build on this work.

Methodology
This cross-disciplinary project will use natural microbial communities from early-Earth analogue environments to experimentally investigate their capture into the geological record and subsequent transformation. High-Pressure, High-Temperature experiments will be conducted at the University of St Andrews using a piston-cylinder press. Experimental products and their respective starting materials will be analysed by Scanning Electron
Microscope, Electron Microprobe, Raman Spectroscopy, light microscope, and destructive organic analysis (University of Newcastle).

(1) Samples - the student will use natural phototrophic and chemotrophic microbial biofilms collected from a variety of geothermal and mineral spring environments. These sites have microbial communities occupying a range of geochemically-varied habitats and capture a metabolic and morphological diversity likely present on the early Earth. Biomass starting material will be characterised via DNA sequencing to provide a taxonomic profile of the microbial communities present in each sample.

(2) Experiments - multiple high-pressure, high-temperature experiments will be run to test the following hypotheses: (i) prior silicification enables better preservation of microbial biosignatures during burial, (ii) biogenic trace element assemblages remain spatially associated with microbially-derived organic matter, (iii) sulfur globules found within sulfur oxidising bacteria preserve their petrographical integrity within a mineralogical matrix, and (iv) temperature plays a larger role in biosignature destruction than pressure. These experiments will be conducted within the Geobiology Laboratory and the High Pressure Laboratory at the University of St Andrews. Experimental variables will include starting material type and mineralisation state; temperature, pressure, and duration of experiment.

(3) Analysis - multiple micro-analytical techniques will be employed, with specific techniques dependent upon the experiment purpose and hypothesis being addressed. Broadly, experimental run products will first be analysed using non- or minimally-destructive techniques, including Raman spectroscopic mapping and FTIR spectroscopy, SEM imaging and elemental mapping. Destructive geochemical analyses includes organic geochemistry conducted at Newcastle University (GC-MS and LC-MS), and thin section petrography.

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**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 to develop project hypotheses and devise an experimental plan. Fieldwork preparation (permits, equipment, logistics) will be conducted in collaboration with sister projects. DNA extractions from existing samples will be done, along with geochemical analyses, providing preliminary data and training in laboratory techniques in preparation for Year 2. Fieldwork to Iceland will take place in summer and DNA extractions from new Iceland samples will be done. The student will also attend a relevant summer school.

Year 2 will principally involve running piston cylinder experiments, analysing the resulting products and their starting materials, and drafting a manuscript. The student will present their work at an international conference, such as the annual Goldschmidt geochemistry conference.

Year 3 will involve completion of experimental work and follow-up analysis, and synthesising data. A manuscript will be submitted to a peer reviewed journal. Thesis writing will begin. The student will attend an international or national meeting.

Year 4 will focus on completion of the PhD thesis, and the handling of submitted manuscript(s), and attendance at a national meeting, funds permitting.
Training & Skills

The student will be trained in (i) environmental and microbiological field sampling techniques, (ii) organic geochemistry analytical techniques (GC-MS, LS-MS, EA), (iii) basic biomolecular techniques (DNA extraction and analysis), (iv) use of a piston cylinder apparatus, and (v) microanalytical and spectroscopic techniques. Furthermore, the student will receive training and experience in presentation and communication skills, fieldwork logistics and project management.

References & Further Reading


For more information contact Dr. Claire Cousins (crc9@st-andrews.ac.uk)