Microbial carbon fixation in geothermal environments as an analogue to early Earth habitability (Ref IAP2-18-82)

University of St Andrews, Earth and Environmental Sciences
In partnership with Newcastle University

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Overview

The carbon cycle underpins all life on Earth. Fixation of inorganic carbon by autotrophic organisms forms the basis of this carbon cycle, achieved primarily via six biochemical pathways. These are traceable through the detection of genes that code for the enzymes required for these reactions. In the microbial world, chemo- and photoautotrophic carbon fixation pathways include the Calvin Benton Bassham cycle (CBB) for cyanobacteria, reductive tricarboxylic acid cycle (rTCA) for microaerophiles and anaerobes, 3 hydroxypropionate bi-cycle (3-HP) for green non-sulfur bacteria, and reductive acetyl-coenzyme A pathway (CoA) for anaerobes. Likewise, archaeal methanogenesis – the metabolic process of reducing carbon dioxide (CO2) to methane (CH4), is considered one of the most primitive metabolisms used by life.

Microbial communities are dynamic microbial consortia that form an interaction with the immediate geochemical environment. This project will investigate how inorganic carbon is fixed by autotrophic microbial communities in basalt-hosted geothermal areas that serve as natural analogues for habitats on early Earth. Hydrothermal pools in Iceland will be used as an analogue to early Earth geothermal environments, collectively spanning a wide range of pH (1 – 8), temperature (6 – 80 °C) and redox state (anoxic to oxic). These provide a variety of environments within which to investigate microbial autotrophy.

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Methodology

This cross-disciplinary project will combine fieldwork with stable isotope geochemistry and genomic analysis.

1. Fieldwork

The student will conduct one fieldtrip to geothermal areas in Iceland, including Krysuvik and Kerlingarfjoll. These sites have microbial communities occupying a range of geochemically-varied habitats. Samples acquired will include microbial biomass, sediment, gases, and water. In situ environmental measurements will also be taken.

2. Geochemistry

Geochemical analyses conducted at Newcastle University includes: (i) gas geochemistry, including H2, and C and H stable isotope analyses of CO2 and methane; (ii) organic geochemistry (GC-MS and LC-MS); (iii) thermodynamic modelling of environment geochemistry to identify potential microbial energy yields. Geochemical analyses conducted at the University of St Andrews includes (i) water chemistry (IC); and (ii) carbon stable isotope analysis of sedimentary, dissolved, and biomass organic carbon.

3. Microbial metagenomics

Bulk genomic DNA will be extracted from biomass and sediments in the Molecular Geobiology Laboratory at the University of St Andrews. DNA will be sequenced using two complementary methods: high resolution, low throughput MinION sequencing and high throughput, low resolution Illumina sequencing. The resulting data will be analysed with respect to identifying complete carbon cycling pathways within sampled communities. Polymerase Chain Reaction (PCR) assays will also be conducted for the taxonomic 16S rRNA gene; carbon fixation marker genes cbbM/cbbL (CBB/RuBisCO) and aclB (rTCA/ATP citrate lysase); and methanogenesis marker gene mcrA (methyl-coenxyme M reductase). Dr Sophie Nixon, University of Manchester, will also serve on the supervisory panel. Dr Nixon's expertise includes DNA metagenomic analysis and microbial carbon cycling, and as such will advise on this aspect of the project.

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. DNA extractions from existing Iceland samples will be done, providing preliminary data and training in laboratory techniques. Fieldwork to Iceland (5 days) will take place in summer. This will be followed by gas and water geochemistry analysis. DNA extractions from new Iceland samples will be done. The student will also attend a relevant summer school.

Year 2 will involve sequencing extracted DNA and further analysis of samples as necessary. The remainder of the year will focus on detailed analysis of metagenomic 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 geochemistry and metagenomic analysis. A manuscript will be submitted to a peer reviewed journal. Thermodynamic modelling will be conducted to place biogeochemical datasets into context. Thesis writing will begin.

Year 3.5 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) environmental and microbiological field sampling techniques, (ii) geochemistry analytical techniques (IC, GC-MS, LS-MS, EA), (iii) biomolecular techniques (DNA extraction and manipulation), (iv) metagenomic sequence analysis, and (v) basic thermodynamic modelling. Furthermore, the student will receive training and experience in presentation and communication skills, fieldwork logistics and project management.

References & Further Reading

[1] Cousins et al. (2018) Biogeochemical probing of microbial communities in a basalt-hosted hot spring at Kverkfjöll volcano, Iceland. Geobiology 16.

[2] Urschel et al. (2017) Carbon source preference in chemosynthetic hot spring communities. Applied and Environmental Microbiology 81.

[3] Telling et al. (2018) Bioenergetic constraints on microbial hydrogen utilization in Precambrian deep crustal fracture fluids. Geomicrobiology Journal 35.

[4] Stueeken et al. (2018) Environmental control on microbial diversification and methane production in the Mesoarchean. Precambrian Research 304.

Further Information

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