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Assessing the role of submarine volcanism in driving biogeochemical cycles on the early Earth

University of St Andrews, School of Earth & Environmental Sciences

In partnership with Durham University

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Key Words	1. Paleoproterozoic ocean; 2. Hydrothermal circulation, 3. Early life; 4. Nutrient cycling; 5. Phosphorus speciation

Overview

Background: Hydrothermal vents on the ocean floor have long been postulated as cradles of life on Earth, because they offer numerous geochemical niches and mineral catalysts to drive prebiotic reactions [1]. Building upon that view, this project aims to test if hydrothermal circulation also contributed to the sustenance of Earth's biosphere over the first two billion years of its history. Today, one of the major sources of nutrients to the ocean is oxidative weathering of the crust, but prior to the rise of atmospheric O_2, this source was absent. On the other hand, geochemical evidence shows that the early Earth was volcanically more active than it is now [2], and previous studies have documented biosignatures from hydrothermally active sites in the Archean [e.g., 3, 4]. It is therefore conceivable that hydrothermal vents constituted a significant nutrient source to the overlying water column (Fig. 1).

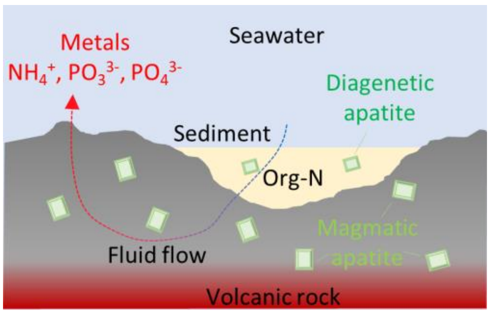

Figure 1: Schematic of hydrothermal nutrient mobilisation from sediments and mafic rocks.

To test this hypothesis, this project will capitalize on fresh drill core material from the Paleoproterozoic Zaonega Formation (2.0 Ga), which comprises thick packges of organic-rich sedimentary rocks that are interbedded with strongly hydrothermally-altered mafic lava flows and intrusions (Fig. 2) [5]. Hot fluids may have mobilise ammonium from organic matter and thus acted as a recycling mechanism of fixed nitrogen. Further, it is possible that sedimentary or magmatic phosphorus was transported by hydrothermal fluids, possibly in the reduced form phosphite [6].

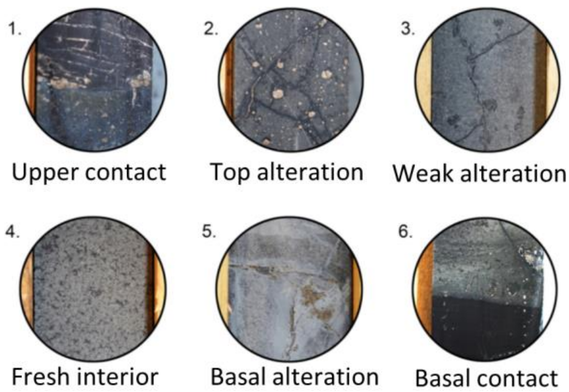

Figure 2: Images of drill core from the Zaonega Formation, showing different degrees of alteration [5]

Reduced phosphorus is readily bioavailable and has been detected in modern geysirs [7, 8]. It can be preserved in the rock record [6], but so far only a handful of analyses have been carried out. The rocks from the Zaonega Formation provide an ideal setting for tracking nutrient mobilization and potential phosphate reduction to phosphite, because this unit is known to be P-enriched [9]. If reduced phosphorus liberation can be documented from this setting, it would represent a major advance in understanding the habitability of the early Earth, when phosphorus is likely to have been a scarce nutrient [10].

Methodology

- **Sample collection:** Many samples are already available at St Andrews, but additional material may be collected from core libraries in Norway and Estonia and from field sites in NW Russia.
- **Petrological and geochemical characterization:** Characterization of mineral assemblages by light microscopy; bulk rock characterisation by XRF and solution ICP-MS. Alteration minerals will be measured with hyperspectral reflectance spectroscopy. These data will be crucial for assessing the effects of hydrothermal fluid flow on rock chemistry. A subset of samples will be analysed for Sr isotopes at Durham to estimate fluid fluxes.
- **Nitrogen extraction:** Bulk rocks and kerogen separates will be analysed by gas-source mass spectrometry for nitrogen isotopes and abundances to test if ammonium was transported by hydrothermal fluids.
- **Phosphorus speciation:** Phosphorus will be extracted from carbonates, speciated by ion chromatography and analysed by ICP-MS. Method development for phosphorus speciation will be an important aspect of the PhD project.

Timeline

Year 1: literature research, training in laboratory techniques. Begin sample preparation and petrological characterisation.

Year 2: Complete major and trace element analyses. Begin method development for phosphorus specieation and sample preparation for nitrogen analyses.

Year 3-3.5: Analyses of phosphorus and nitrogen across mafic and sedimentary rocks. Compilation and publication of results.

Training & Skills

- Training in petrology, isotope geochemistry, and biogeochemical cycles.
- Training in several analytical techniques (sample collection and preparation; gas source mass spectrometry for nitrogen isotopes; ICP-MS for trace elements; XRF for major elements; spectroscopy for alteration minerals; ion chromatography for phosphorus speciation)
- Interpretation of geochemical data within an interdisciplinary context over Earth's history
- Communication skills through presentations of the results at national and international conferences
- Scientific writing through publication of results in peer-reviewed scientific journals

References & Further Reading

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Further Information

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