Identification and engineering of microbes for critical metal extraction and remediation

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Key words:	Biominerals, Engineering Biology, Biotechnology, Bioleaching, Robotics, Raman Spectroscopy, Directed Evolution
Research theme(s):	• Earth Resources • Oceanography, Climate and Palaeoenvironment • Palaeobiology and Evolution
Eligible courses for this project:	• DPhil in Earth Sciences (3-4 years) • Interdisciplinary Life and Environmental Science Landscape Award (ILESLA) • Intelligent Earth (UKRI CDT)

Overview

A wide diversity microorganisms have the capacity to form minerals, a process called microbial biomineralization [1]. In addition to carbonates, phosphates, silica, and iron oxides, biomineral types that are shared with Eukaryotes, microbes capable of biomineralizing industrially relevant metals as diverse as uranium, tellurium, selenium, palladium, gold, silver, copper, or rare-earth elements, have now been described. Bacteria can actively and selectively accumulate metals in environments where they are present at trace concentrations, and precipitate them as stable minerals under thermodynamically unfavourable conditions, providing an opportunity to recover metals from low-concentration mixed fluids, in a way that can be less costly and more environmentally sustainable than chemical methods. Furthermore, the (nano)particles formed by biomineralizing bacteria often possess properties (e.g., size, shape, chemistry, crystal structure) that are strictly controlled by the microbes, and that make them attractive materials for a range of technological applications such as water remediation, energy storage, catalysis, and biomedical applications such as antimicrobial activity or bioimaging [2]. Only a small fraction of the existing diversity of metal-biomineralizing bacteria has been discovered so far, mainly due to analytical limitations. Meanwhile, past applications of bio-leaching processes have largely utilised natural microbes, which may accumulate minerals (whether this is essential to their metabolism or otherwise), but are not innately optimised for this function [3]. In other cases microbes identified as strong natural accumulators in laboratory settings have been deployed in new environments and applications of interest, yet due to their acute sensitivity to environmental conditions struggle in these harsh settings [4].

To address these challenges, this project will begin with discovery and identification of microbes that are strong natural accumulators of critical metals, and then optimise these with unique robotic bioengineering platform technologies to thrive in application environments – achieving scale-up that is both economically and environmentally sustainable.

Methodology

Beginning with discovery, we have developed high-throughput Raman screening methods for the in-vivo characterization of microbial biominerals directly in microbial cultures of environmental samples [5]. We will deploy this method to rapidly identify metal-containing minerals of interest from liquid samples (e.g., mine drainage, geothermal fluids) as well as in enrichment cultures from these environments. Raman-activated cell sorting and sequencing [6] will then allow us to identify the microorganisms spatially associated with these metals, and attempt to cultivate them. The genomic information obtained will allow us to identify new genes involved in metal biomineralization, enabling the future use of synthetic biology tools to engineer the biomineralization process and further improve it for different applications. We will first focus our screening process on microbial metal-sulfides, as these Raman-active minerals can incorporate several heavy metals of interest (e.g., Cu), and can form nanoparticles for applications such as semiconductors, organic contaminant photodegradation, and photovoltaics [7].

Identified microbes will then be engineered with unique evolutionary bioreactors developed by our team. The idea of adapting cells to thrive in novel environments is not new, yet such approaches have often been limited by the fact that when microbes are optimised for a specific task in the lab, this can lead to simultaneous de-optimisation for viability in application environments. To overcome this challenge, over the past years our team developed a unique robotic platform which we will leverage alongside our expertise in strain optimisation to take selected natural accumulators of metals of interest and evolve these over thousands of generations of evolution to grow on low-cost laboratory media with pH and temperature extremes [8]. Then, will adapt strong accumulators to maximise growth on liquid samples collected from application sites.

Overall, this will be an interdisciplinary project which will suit ambitious applicants from a variety of backgrounds. The successful candidate will be integrated in the two co-supervising teams working between Earth Sciences and Biotechnological research, and benefit from a collaborative environment with other researchers working in microbial engineering and sustainability.

Timeline

Year 1: Literature review, training in Raman screening platform and use of evolutionary automation robotics. Initial wet-lab experiments with model organisms.

Years 2 and 3: Screening of organism libraries, analytical work, presentation of research at national conferences.

Year 4: Data integration, thesis completion, papers for international journals/conference presentation.

Training & Skills

The student will be trained in laboratory techniques specific to the project (wet-lab microbiology), as well as in a range of analytical techniques for mineralogical and material characterization (e.g., Raman spectroscopy). Depending on previous experience and skills, training will be also provided on the computational aspects of the project (statistics, machine learning). The DPhil programme will also provide opportunities for soft-skills training, such as planning and managing a research project, interpreting data and presenting scientific results, and writing scientific papers for publication.

References & Further Reading

[1] Cosmidis & Benzerara, Comptes Rendus Géoscience (2022).
[2] Cosmidis, Microbial Biotechnology (2023).
[3] Nims, et al., Scientific Reports 9 (1), 7971 (2019).
[3] Rasoulnia et al., Critical Reviews in Environmental Science and Technology (2020).
[4] Azim et al., Frontiers in Microbiology (2023).
[5] Nims, et al., Scientific Reports 9 (1), 7971 (2019).
[6] Zhang et al., Frontiers in Optics, 2023.
[7] Su et al., Science of The Total Environment 825, 153767 (2022).
[8] Ye et al, Chemosphere, 2017.

Further Information

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