PROJECT TITLE: Deep Earth perspectives on hydrogen storage

University of Bristol Theme: Climate and Environment Research Challenge Area
Research Group(s): Petrology

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Project keywords: Deep Earth, high-pressure, hydrogen economy, solid state storage, advanced analytical techniques

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Fig 1: Nanoscale imaging of protons in olivine using PiFM [1].

Fig 2: FT-IR spectra of promising hydrogen storage material MgB$_2$[2].

Project Background: Reducing CO$_2$ emissions to combat climate change with the aim of reaching net-zero and limiting global warming to under 1.5°C is a global effort to which the British and Australian governments have committed under the Paris agreement. This requires a move away from our traditional fossil fuel energy sources. Solar powered electricity is now an available alternative but suffers from only being available during the day thus requiring some form of energy storage for night power requirements. Hydrogen offers an attractive method for both the storage and transportation of energy produced using solar. Many methods of hydrogen storage are being explored including the storage of hydrogen as a high-pressure gas or liquid in subterranean caverns, but issues around safe containment make storage in a solid a more practical option [3].

While our understanding of how hydrogen binds and unbinds in these systems is limited, we can draw on a different source for inspiration: in the deep Earth, small but significant quantities of H$^+$ and OH$^-$ ions are dissolved in a range of nominally anhydrous minerals (NAMs), including the silicates and iron alloys that constitute the mantle and core respectively, leading to a potential reservoir of multiple ocean masses of water [4]. The mechanism and magnitude of this solubility has significant implications for the geodynamic and geochemical evolution of Earth, while the cycling of water between the surface and the interior was critical in producing a habitable surface environment throughout deep time [5].

Project Aims and Methods: It is the aim of this project to study both natural and synthetic proton bearing systems using a range of state-of-the-art experimental techniques, including Raman and Fourier-Transform IR (FTIR) spectroscopies, IR Atomic Force Microscopy (AFM-IR) [6] and synchrotron-based X-ray diffraction (XRD). We will also explore the use of inelastic neutron scattering and Atom Probe Tomography (APT), to develop a fundamental understanding of the binding of protons in solid materials. UoB is world-renowned for studies of the deep Earth water cycle, while MU hosts the Sustainable Energy Research Centre, which counts hydrogen production and utilisation amongst its themes. Both institutions house complementary analytical equipment perfectly designed for these studies: Simon Clark at MU has access to a cutting-edge AFM-IR...
instrument capable of studying dissolved H\(^+\) and OH\(^-\) at nanometre spatial resolution while UoB has both Raman microscopes and a new Faculty-funded FTIR instrument that can measure samples inside a variety of sample environments, including high-pressure diamond anvil cells, allowing us to study materials synthesized at non-ambient conditions. User facilities for neutron scattering, XRD and APT are available in both the UK and Australia.

**Candidate:** The ideal candidate will have a background in the Earth or Materials sciences and a strong interest in mineral chemistry or mineral physics. Preferably the candidate will hold a master’s degree involving a large component of experimental research utilizing analytical methods such as Raman and FTIR spectroscopy and XRD both in the laboratory and at central facilities.

**Training:** The successful candidate will be provided with training in state-of-the-art research methods available in the laboratories of both the University of Bristol and Macquarie University as well as methodologies available at central research facilities such as Spallation neutron sources.

**Background reading and references:**

[1] Patabendigedara, S. et al. (2021). Determining the water content of nominally anhydrous minerals at the nanometre scale. [https://doi.org/10.1063/5.0025570](https://doi.org/10.1063/5.0025570)


**Useful links:**

http://www.bristol.ac.uk/earthsciences/courses/postgraduate/

https://www.mq.edu.au/research/phd-and-research-degrees

**Eligibility:** UK and International students are eligible for University of Bristol and Macquarie University Scholarships. The Scholarships are fully funded for 4 years and cover university fees, living expenses at the UKRI and Macquarie University standard rates, and an allowance of £2000 per year towards research expenses. One return air fare will be provided from the UK to Sydney, Australia. It is envisioned that the successful candidate will spend two years at the University of Bristol followed by two years at Macquarie University.

**Application deadline:** Thursday 29\(^{th}\) February, 2024, 23.59 GMT

(Interviews are expected to take place in mid/late March)

**Expected start date:** 9\(^{th}\) September 2024

**How to apply:** Applicants need to apply to both the University of Bristol and Macquarie University to be considered for this PhD.

1. **Apply to the University of Bristol at:** [http://www.bristol.ac.uk/study/postgraduate/apply/](http://www.bristol.ac.uk/study/postgraduate/apply/)

Please select “PhD in Geology” as the programme in the online application system. Please specify the project title and supervisors for the project that you are applying for. To ensure your application
is considered under the University of Bristol Scholarship funding scheme you must complete the Funding page in your online PhD application as follows:

- For “What is your likely source of funding?” select Studentship
- For the free text field “Please give the name of your scholarship or studentship” enter University of Bristol Scholarship.
- Set “Percentage from this source” to 100%
- Set “Is this funding already secured?” to No

2. Apply to Macquarie University at: https://www.mq.edu.au/research/phd-and-research-degrees/how-to-apply

Please select “PhD in Engineering” as the program and “COTUTELLE” as the scholarship in the online application. Please provide the project-specific allocation number “20246091” in the relevant section of the form.

Please consider the entry requirements to the PhD program at Macquarie University before you submit your application https://www.mq.edu.au/research/phd-and-research-degrees/explore-research-degrees/doctor-of-philosophy

Applicants will also need to meet the eligibility criteria for the Macquarie University portion of the scholarship https://www.mq.edu.au/research/phd-and-research-degrees/how-to-apply/scholarship-opportunities