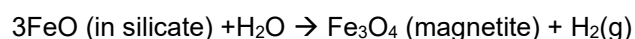


Monitoring the rate of natural hydrogen production using magnetism and isotope geochemistry

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Key words:	Natural hydrogen, net zero, reaction kinetics, rock magnetism, isotope geochemistry
Research theme(s):	Earth Resources
Eligible courses for this project:	- DPhil in Earth Sciences (3-4 years) - Interdisciplinary Life and Environmental Science Landscape Award (ILES LA)

Overview

Hydrogen plays a critical role in achieving net zero greenhouse gas emissions, a goal the UK aims to achieve by 2050. Hydrogen does not produce CO₂ during combustion, and will therefore be a critical energy source for achieving net zero. Growing interest in this challenge has led geologists to identify a large number of natural hydrogen sources (Zgonnik, 2020). Substantive natural hydrogen generation is detectable on the continents, driven by water-rock interactions in the continental crust (Ballentine et al., 2025; Lollar et al., 2014). Hydrogen arising from water-rock reactions occurs primarily through the oxidation of the FeO component of silicates to form magnetite and molecular hydrogen gas:



To determine the potential of a geological site for both natural or enhanced (so-called orange) hydrogen production, the reaction rates of the system must be well understood (Osselin et al., 2022). The current rate of hydrogen production, or the potential rate of enhanced hydrogen production must be high for a site to be viable. However, there are currently several barriers to determining optimal sites for natural and orange hydrogen production. Determining the kinetics of natural hydrogen production has proven challenging. The kinetics of lab-based reactions are enhanced with high water-rock ratios and the mineral surface areas are amplified by crushing the reacting minerals. Reaction rates must be artificially high to detect measurable products on observable timescales. These experiments have therefore led to poorly constrained reaction kinetics, with peak reaction rates spanning several orders of

magnitude, and peak reaction temperatures spanning 100°C (Lamadrid et al., 2021). Effects of salinity, pH and other external factors also remain poorly explored.

Reaction rates under natural conditions are much slower, creating an additional set of challenges. Since hydrogen can diffuse through experimental containers, experiments over long periods of time to determine slow reaction rates are difficult to measure directly. Similarly, other reaction products (e.g., serpentine, magnetite) that may be used as a proxy for H₂ generation are difficult to detect petrologically on short time periods. We will look to develop new methods to trace the kinetics of hydrogen generation using rock magnetic and isotopic approaches in both laboratory and field environments.

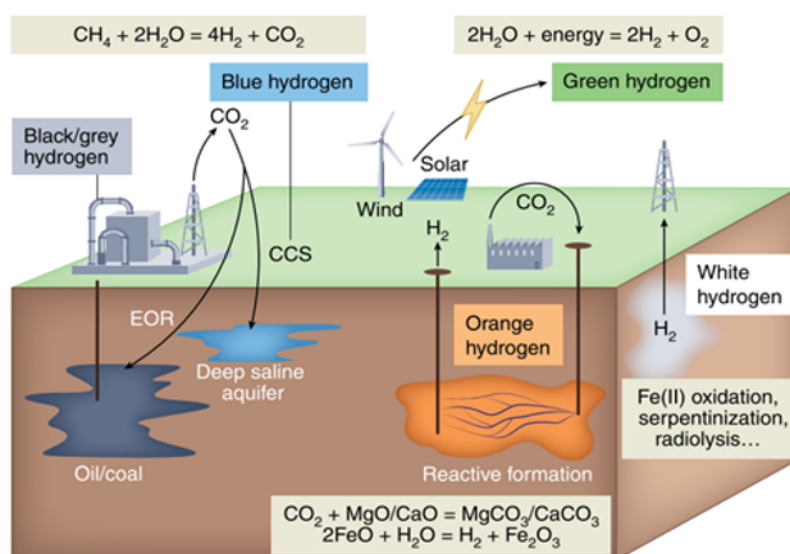


Figure showing the different mechanisms by which hydrogen can be generated (taken from Osselin et al., 2022). The project will focus on the generation of natural 'white' hydrogen, and stimulated natural 'orange' hydrogen production.

Methodology

The project will involve synthesizing hydrogen-producing reactions in the lab and monitoring reaction progress by assessing their rock magnetic properties and noble gas isotope signatures. Field campaigns will involve mapping out magnetic anomalies with sub-km resolution, and collecting gas samples for isotopic analysis.

Timeline

Year 1: The student will undertake a literature review and design their first set of laboratory experiments. Results will be simulated in Geochemist's Work Bench to predict experimental outcomes. The student will be inducted into the Noble Gas Isotope and Paleomagnetism Laboratories. A paper draft is expected by the end of the first year.

Years 2 and 3: Laboratory experiments on synthetic samples will be completed. A field campaign will be carried out, and a second set of experiments conducted on natural samples. The student will present results at both national and international conferences. One to two papers should be submitted for publication by the end of the third year.

Year 4: The student will compare synthetic and natural sample results with simulations to infer the best conditions for natural hydrogen generation. Results will be summarised during

thesis writing, and any additional papers submitted for publication. Results will be presented at an international conference, with a focus on networking and future career steps.

Training & Skills

- Rock magnetism
- Petrology and electron microscopy
- Noble gas isotope geochemistry
- Geological fieldwork
- Gas sampling
- Coding (Python)
- Modelling (Geochemist's Work Bench)
- Scientific writing and presenting

References & Further Reading

Ballentine, C.J., Karolyt , R., Cheng, A., Sherwood Lollar, B., Gluyas, J.G., Daly, M.C., 2025. Natural hydrogen resource accumulation in the continental crust. *Nat. Rev. Earth Environ.* 6, 342–356. <https://doi.org/10.1038/s43017-025-00670-1>

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Osselin, F., Soulaire, C., Fauguerolles, C., Gaucher, E.C., Scaillet, B., Pichavant, M., 2022. Orange hydrogen is the new green. *Nat. Geosci.* 15, 765–769. <https://doi.org/10.1038/s41561-022-01043-9>

Zgonnik, V., 2020. The occurrence and geoscience of natural hydrogen: A comprehensive review. *Earth-Science Rev.* 203, 103140. <https://doi.org/10.1016/j.earscirev.2020.103140>

Further Information

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