Exploiting thermally and microbially induced carbonate precipitation to improve reservoir storage integrity

Supervisory Team	• **Dr. Kate Dobson, University of Strathclyde** • **Dr. James Minto, University of Strathclyde** • **Prof. Vernon Pheonix, University of Strathclyde**

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Overview

Use of subsurface storage is a key part of the transition towards a low carbon energy system, allowing for both reduction of existing atmospheric CO_2 though carbon capture & storage, and implementation of other low carbon contributions to the energy mix including compressed air energy storage (CAES) and hydrogen storage. The critical component of temporary (CAES and H_2) or permanent (CO_2) storage solutions, is ensuring the geological system (reservoir) and the engineering infrastructure (well casings) are stable under injection and storage conditions.

This project will explore how thermal and microbial hydrolysis of urea can be used to control the precipitation of $CaCO_3$. When correctly controlled this process has the potential to provide an alternative treatment strategy for sealing leakage pathways in CCS/hydrogen wells, as well as controlling the compartmentalisation of the reservoir. Within the range of reservoir systems likely to be storage targets, controlling the spatial and temporal distribution of CaCO3 will be critical in proving long term integrity, but could also pay a role in maximising storage capacity. Unwanted precipitation could dramatically reduce storage efficiency, acting as a barrier to flow. The applicant will use novel high pressure and temperature flow-cells (NERC GeoX Suite) that can recreate a range of storage reservoir conditions and track the permeability evolution through time under variable flow and fluid injection scenarios. The flow cells are all X-ray microtomography compatible, allowing simultaneous measurement of microstructure (porosity) and permeability, and real time quantification of the rate and spatial distribution of precipitation under geological conditions in a range of target lithologies. The project will use both laboratory and synchrotron-based tomography during $CaCO_3$ precipitation over a range of spatial and temporal scales, and capture the evolution and migration of

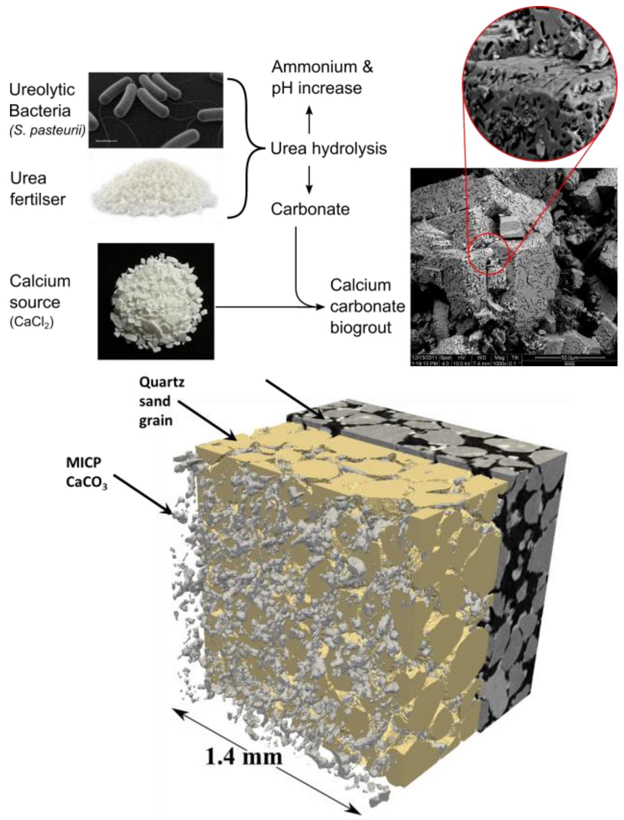

Fig. 1. This project focusses on applying the latest 4D (3D + time) x-ray tomography imaging methods to track the passage of fluids and precipitation of $CaCO_3$ in rocks in real time. This image shows how $CaCO_3$ can affect pore morphology (top) and how x-ray computed tomography can be used to quantify and track how precipitation effects flow in 3D.

preferential flow pathways with the aim of understanding the fundamental principles that govern the reactive-transport, nucleation-precipitation, and hydrodynamic-feedback processes

Methodology

This project will use the latest 4D (3D + time) x-ray tomography imaging methods to capture the porosity networks within the geological samples, and then track flow, and the transport of the suspended fine particles through that pore network. It uses the latest in situ experimental flow cells (NERC GeoX, 2019; Godino et al 2019) to enable experiments at a range of flow rates, fluid compositions, particle volume fractions and size distributions, and under different reservoir conditions (confining pressure and temperature). Combining these experimental flow cells with non-destructive *in situ* x-ray tomography allows this project to capture the behaviour and evolution of the flow inside the samples, as it happens; allowing the location of fluid and the suspended particles to be observed in real time.

The key project aims are to:

- Optimise the *in situ* x-ray tomography compatible reactive transport flow cell apparatus to capture flow and $CaCO_3$ precipitation
- Perform X-ray tomography experiments to exploring the precipitation (spatial distribution through time) under a range of different conditions (fluid composition, flow rate, temperature) map aggregate formation in terms of flow, fluid chemistry and changing pore network characteristics
- Use image analysis and image-based modelling to develop understanding of the pore scale processes, and define the key controls and critical conditions in evolving pore networks
- Apply this knowledge to perform additional experiments to quantify how precipitation processes vary in lower porosity samples, or those with complex bedded/fractured samples, and in different lithologies

Data collection will be mostly at Strathclyde, using existing x-ray tomography and experimental apparatus are already been installed. Experiments may also be undertaken at the Diamond Light Source synchrotron facility as part of this project.

By applying the latest 4D x-ray tomography and associated image analysis methods, the student will perform textural analysis to track the mobilisation, transport and deposition of the suspended load. Then through the relationships between how parameters such as particle concentration, size distribution and fluid rheology and the invasion, transport and deposition of fine particulate material the student will develop understanding of fines migration, and the mechanisms in a range of geological and engineering settings feeding into flow simulations and industry practice.

Timeline

Year 1: literature review, laboratory training, CDT training activities development of data analysis protocols, data analysis

Years 2 & 3: tomography and lab based precipitation experiments, scanning of additional CT samples**,** model development, additional 4D tomography experiments at Diamond Light Source, data analysis, papers for international journals. Start thesis preparation. CDT Training activity.

Year 4: completing thesis, writing papers.

Training & Skills

The project will suit a student with a broad interest in addressing major geoscience questions using experimental, quantitative and numerical methods. You will learn how to use a range of high-level analytical methods (x-ray tomography, image analysis, fluid flow analysis, modelling), and to integrate data types to gain insight from both scientific and industrial perspectives.

As part of a CDT cohort, you will receive 20 weeks bespoke, residential training, including field trips, in a range of topics that will put your PhD project in the broader context of the transition to a carbon free economy. Training is split over the first 3 years of study and instructors will be expert academics from across the CDT partnership as well as from companies funding the training programme, and regulatory authorities.

Further Reading

Dobson, K.J., *et al.* (2016). 4D imaging of sub-second dynamics in pore-scale processes using real time synchrotron x-ray tomography. *Solid Earth* DOI: 10.5194/se-7-1059-2016, 2016.

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Godinho et al. (2019) Time-lapse imaging of particle invasion and deposition in porous media using in situ X-ray radiography. *J. Pet. Sci. & Eng*. DOI: 10.1016/j.petrol.2019.02.061

Minto, J. M., *et al.* (2019). Development of a Reactive Transport Model for Field-Scale Simulation of Microbially Induced Carbonate Precipitation. *Water Resources Research*. DOI: 10.1029/2019WR025153

Further Information

For more details or information on how to apply, please contact Kate Dobson:
katherine.dobson@strath.ac.uk; 0141 552 4400