Imaging thermo-hydraulic effects in engineered barriers for radwaste repositories

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Project background - Fluid-rock interaction concerns our society's interests in applications such as hydrocarbon exploration, geothermal heat extraction and chemical- and nuclear waste disposal. In the case of repositories of high-level, heat-producing radioactive waste or spent nuclear fuel, ground water that reaches the waste container will trigger corrosion that ultimately releases radionuclides to the environment. In most repositories, a sophisticated system of engineered barriers around the waste container is designed to limit transport of materials, physically and chemically, and slow down the corrosion process until the activity of the waste is harmless. In the Finnish and Swedish nuclear waste repositories, a copper/steel container, which holds the high-level nuclear waste, is surrounded by an additional barrier made of low-permeability bentonite. Both together are stored underground, in drill holes or caverns in granitoid bedrock. The assembly interacts with the geosphere in two ways. First, the bentonite is expected to swell when in contact with ground water. The swelling pressure is anticipated to close any porosity, seal the container from ground water flow and dampen any impact from the outside. Second, the heat emitted from the container diffuses into the bedrock and likely causes a limited amount thermal damage, which enhances permeability in the bedrock and therefore ground water flow towards the barrier.

Both aspects of the engineered barrier have been investigated in great detail. However, all previous studies were restricted to indirect observation; due to the lack of a suitable imaging technique, processes on the scale of millimetre and below could not be directly documented. This PhD thesis builds on the current installation of the world’s first combined neutron- and x-ray tomograph at the Institute Laue-Langevin in Grenoble. This instrument allows the simultaneous acquisition of two time-resolved 3-d datasets that image different aspects of particle/matter interaction. In a series of ground-breaking experiments that use a purpose-built experimental vessel, we will image fluid interaction with a heat-emitting dummy waste canister and its host rock simultaneously with neutrons and x-rays. The unique datasets acquired in this thesis allow us to image and quantify, in 3D, the evolution of water saturation and bentonite swelling, solvent migration and damage around a waste canister. This thesis will produce results of high international relevance and visibility.

Key research questions:
The unique experimental data acquired in this thesis allow addressing some questions of fundamental importance concerning the storage of high-level nuclear waste. Amongst them are:
How does a fluid front infiltrate the bentonite barrier, what are its pathways? How does the swelling pressure in the barrier evolve and how does swelling affect both, the canister as well as the host rock?

How does the sample saturate and how do solutes diffuse in the engineered barrier?

How does the system react to heat production that exceeds the regulatory limits? In particular, how does the volume change that comes with the production of illite from montmorillonite affect fluid migration? How does thermal damage affect the host rock and its transport properties?

Methodology, including a timetable for the programme of research

Time-resolved 3D imaging is transforming experimental geosciences. Our research group at the School of Geosciences has several years of experience with these novel capabilities and is amongst the leaders in designing experimental vessels that allow studying geological processes at crustal conditions in 4D. We are currently engineering the neutron- and x-ray transparent experimental pressure vessel that is going to be used in this thesis.

This thesis provides an excellent opportunity to work on a unique and pioneering instrument (https://next-grenoble.fr/) that, for the first time, combines x-ray and neutron-based imaging. In addition, the thesis will utilise innovate image correlation techniques that allow to extract a maximum of information from these multidimensional datasets. Post mortem work on the samples will be conducted at our School’s microanalytical facilities.

The first experiments at ILL will take place in late 2017, with a further series planned for 2018. Data analysis will be conducted in close collaboration with the colleagues in Grenoble (including the co-supervisor) from early 2018 onward.

Training

A comprehensive training programme will be provided comprising both specialist scientific training and generic transferable and professional skills. The project will expose the student to a very international research environment, with training provided in a range of novel experimental and analytical techniques and thereby offers the opportunity to acquire a unique and desirable skillset. The successful candidate will be embedded in a growing and ambitious research team that takes prides in being amongst the pioneers in time-resolved 3D imaging of fluid-rock interaction, with a steady output of high-level research. The student will be presenting his/her results at a variety of national and international meetings and will have abundant opportunities to build a professional network in the nuclear waste storage, experimental geoscience and x-ray/neutron imaging communities.

Requirements

We look for an exceptionally motivated geologist/geochemist/petrologist who ideally has some experience in experimental geosciences and a significant interest in fluid/rock interaction processes, the design and realisation of an ambitious experimental programme, x-ray (and neutron) imaging, image analysis and nuclear waste storage.

A project summary

This thesis combines two time-resolved 3D datasets to study how fluid infiltration and thermal damage affect a nuclear waste storage canister and the engineered and natural geological barriers surrounding it.