

Understanding Deep Sea mineralization: A sustainable path forward with CO₂ storage

Basalt-seawater-CO₂ interaction simulating Arctic Mid-Ocean Ridge (AMOR) environment.
The mineral trapping of CO₂ and the mineral resources formation at Deep Sea: An experimental study

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Background and Motivation

I am a Geologist, with a Ph.D. in Hydrothermal Geochemistry carried out at GNS Science, New Zealand, within the "Geothermal: The Next Generation" Programme (some pictures of New Zealand landscapes just below and [here](#)). My personal background in aqueous geochemistry is strongly focused on the experimental simulations of rock-fluid-CO₂ interaction at subcritical and supercritical condition for both offshore and onshore environments. The experimental approach is for me the foremost alternative to directly duplicating these geological settings, and it represents the closest that I can get to *actually observing* the real environment. Joining the [SEAS](#) programme at [UiB](#) offered me the great opportunity to continue my experimental studies aimed at the better understanding of some of the mechanisms regulating these geological settings.

I aim to provide reliable geological data to the development of facilities designed for decarbonization.

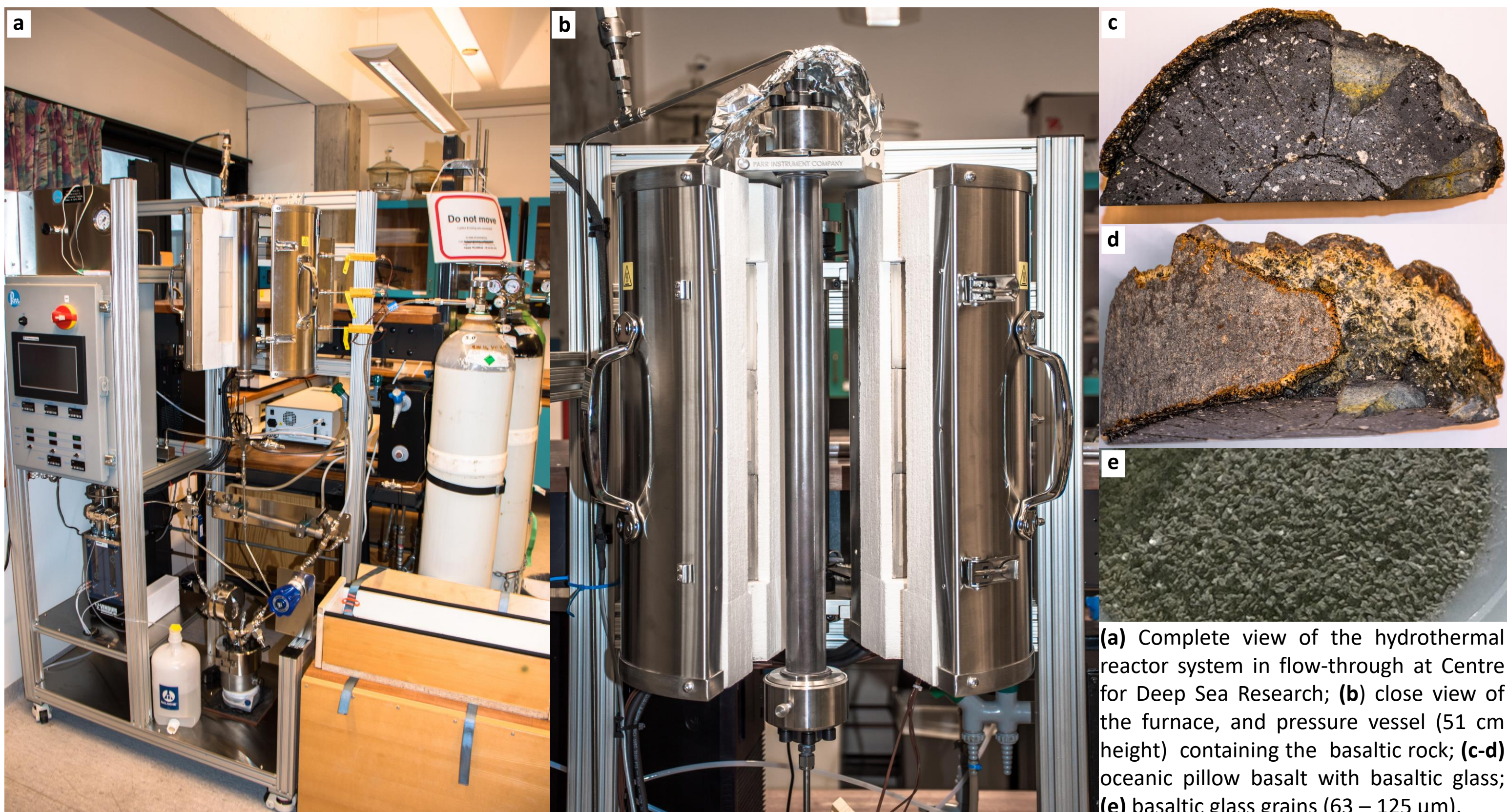


Current Academic Project

My current research focuses on the experimental simulations of basalt-seawater-CO₂ interaction for the study of mechanisms regulating the mineral trapping of CO₂ and the formation of mineral deposits on the seabed. The work is conducted by combining laboratory facilities at the [Centre for Deep Sea Research](#) and [Equinor ASA](#).

Main Questions and Research Plan

Generally, we must rely on computational and experimental approaches to investigate the processes that occur when fluids interact with rock materials at temperatures and pressures found on and below the seabed. Current computer software packages (e.g., PHREEQC, MINTEQA, Geochemist's Workbench®, TOUGHREACT) can be used to model these environments utilising thermodynamic data which are relatively well-known, at least up to 300°C. At present, however, in sub-seafloor environments, physicochemical conditions often exceed this temperature and computer modelling is more problematic due to a lack of appropriate thermodynamic data. The experimental approach offers the *only* alternative to directly replicate the basalt-seawater-CO₂ interaction that occurs in submarine hydrothermal systems. Such studies are challenging due to many technical and physical parameters involved, including the sophisticated equipment required. However, the information derived is of great value.



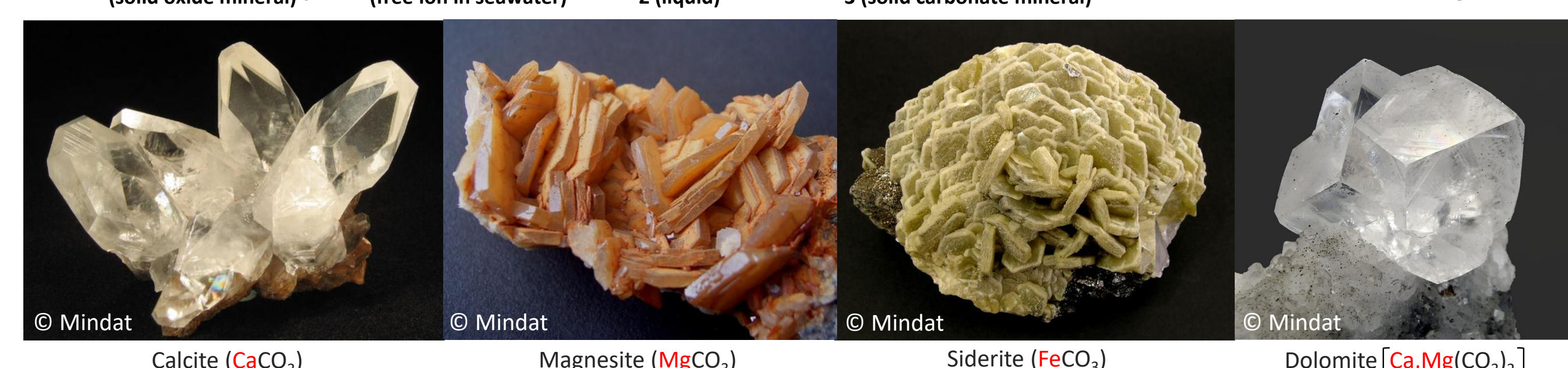
(a) Complete view of the hydrothermal reactor system in flow-through at Centre for Deep Sea Research; (b) close view of the furnace, and pressure vessel (51 cm height) containing the basaltic rock; (c-d) oceanic pillow basalt with basaltic glass; (e) basaltic glass grains (63 – 125 µm).

Advanced methods of laboratory experiments of fluid-rock-gas interaction can contribute vital information to the understanding of important geological situations occurring in sub-seafloor hydrothermal systems. An important aim will be to thermodynamically inter-relate the evolved reacted experimental fluid chemistry with the observed hydrothermally-produced secondary mineralogy. In previous experimental studies (mostly carried out in batch reactor systems), some insight was gained into the basalt-seawater-CO₂ exchanges that gave rise to the fluid chemical signature; however, several fundamental questions remain. The results of my experimental research will give access to further knowledge of several ocean floor processes occurring at AMOR (and onshore environments), including:

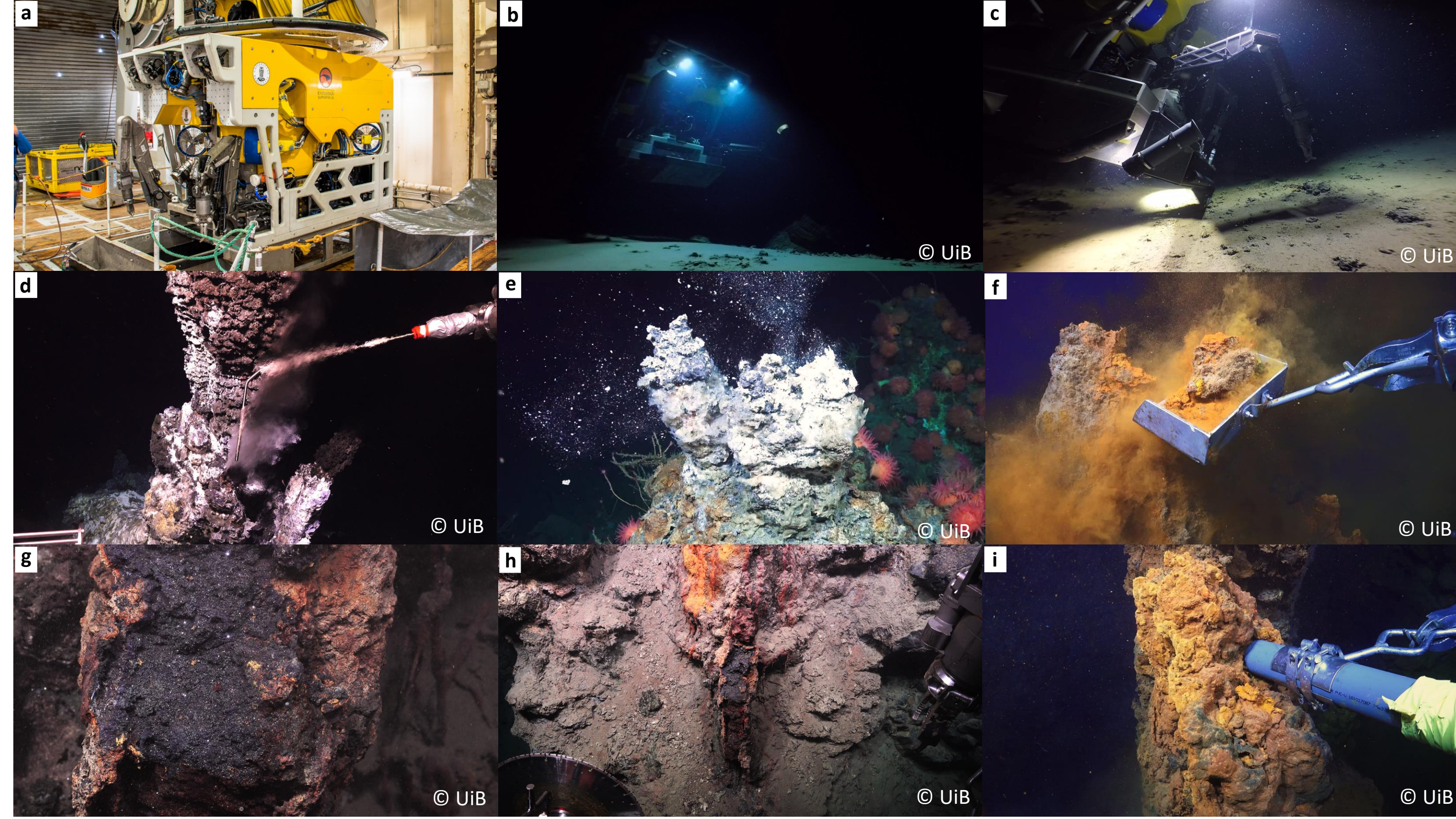
- the effect of basalt-seawater-CO₂ interaction on the fluid chemical evolution, mineral solubilities, secondary mineral formation, and permeability at several hydrothermal conditions;
- the mass transport across lithological boundaries in the subseafloor due to reaction with hydrothermal fluids;
- the time scale of chemical alteration in mafic system (i.e., kinetics of reactions).

The laboratory experiments will enhance the evaluation of deep geological resources in terms of:

1. **Carbon Capture Utilities Storage (CCUS).** Demonstration and quantification of the potential mineral trapping of CO₂ in basalt through the formation of secondary carbonate minerals in the Deep Sea. Elements such as Ca²⁺, Mg²⁺ and Fe²⁺ (already present in seawater as free ions and of derivation from the hydrothermal alteration of oxide minerals in basalt) in contact with liquid CO₂, and at relative basic/neutral pH of solution, form stable carbonate minerals (pictures below) by the following (geochemical) reaction:



2. **Mineral Deposits Formation.** Hydrothermal transport of heavy metals (e.g., Cu, Zn, Pb, Mn, Fe) and development of a mechanistic understanding of Seafloor Massive Sulfide (SMS) deposit formation at different environmental conditions.



(a-c) Remotely Operated Underwater Vehicle (ROV) [Ægir 6000](#) (UiB) ([Videos](#)) used for Deep Sea exploration, e.g., sampling of rocks/sulfide minerals and hydrothermal fluids; (d-i) SMS deposits associated with hydrothermal vent activity (pictures captured by [Ægir 6000](#)).

Marine Sustainability Context

Regarding the CO₂-basalt storage mechanism. Beside the well explored CO₂ storage within saline aquifers or depleted Oil and Gas fields, the permanent CO₂ storage by mineral trapping in basaltic rocks has huge potential and advantages. Basalts cover over 50% of the Earth's surface, making it the most abundant rock type in the Earth's crust. For Norway, and most Countries bordering the ocean, this highlights an encouraging prospective method for reducing atmospheric CO₂.

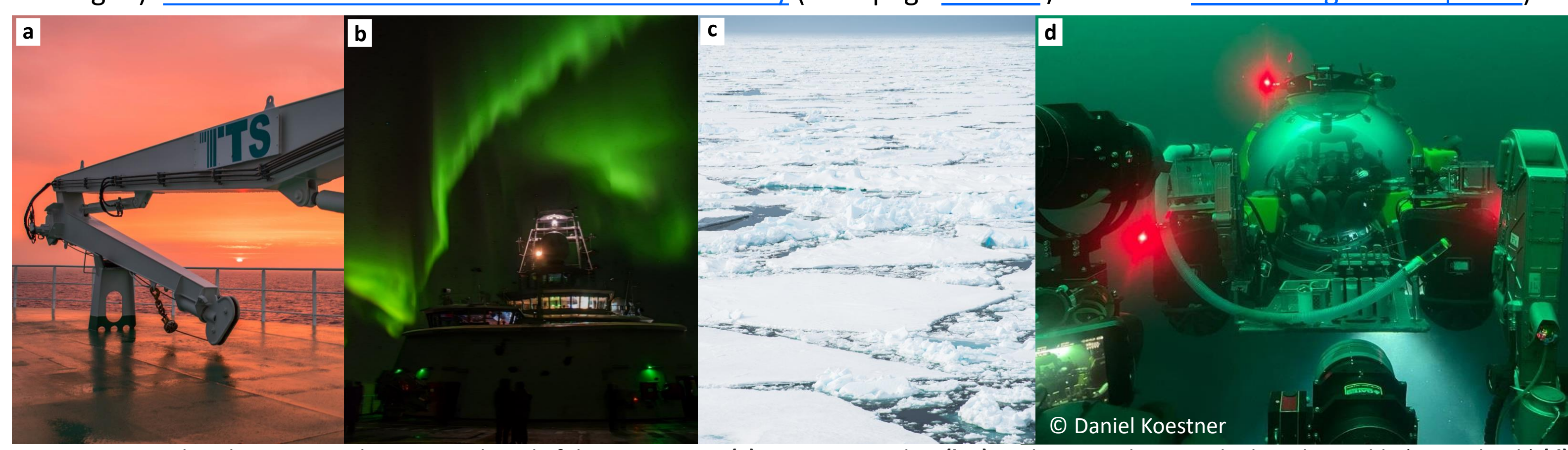
Results and Highlighted Activities

Internship

- Nov 2023 - Apr 2024. Equinor ASA, Sandsli, Bergen, Norway. CO₂ storage maturation project;

Scientific Research Cruises

- Arctic Polar Circle: (1) [Molloy Deep](#) trench, Greenland Sea (May 2022) on board the [RV Kronprins Haakon](#) (departure from Svalbard); (2) [Mohns Ridge](#), Greenland-Norwegian Sea (Jun-Jul 2022) on board the [RV G.O. Sars](#) (departure from Bergen); (3) [Knipovich Ridge](#), Greenland-Norwegian Sea (Nov 2022) on board the [RV Kronprins Haakon](#) (departure from Svalbard). Norway: (4) Norwegian Sea and Sognefjord (Jul-Aug 2023) on board the [RV OceanXplorer](#) (departure from Bergen): [Video UiB & OceanX - Research Cruise in Norway](#) (Web page [OceanX](#) / YouTube: [Introducing OceanXplorer](#)).



Some pictures taken during research cruises on board of the [RV G.O. Sars](#) (a), [Kronprins Haakon](#) (b-c), and [OceanXplorer](#) inside the submersible (300m depth) (d).

Conferences

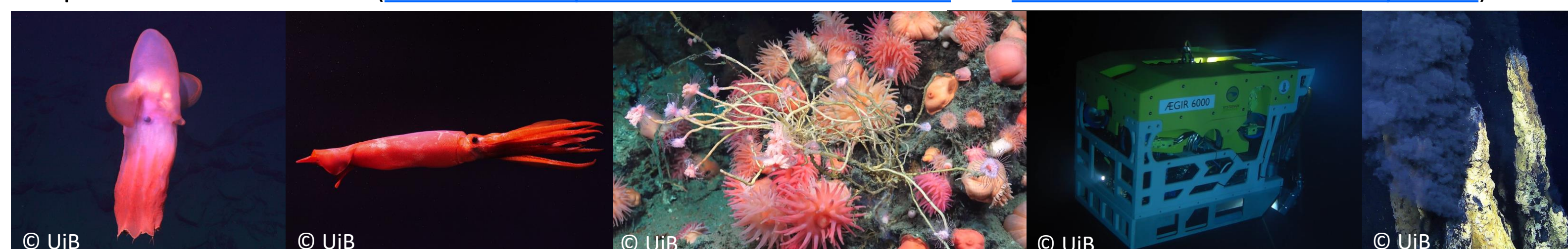
- Oct 26th - 27th 2022. [Deep Sea Minerals Conference](#), Bergen, Norway (viewer);
- Jun 19th - 21th 2023. [The 12th Trondheim Conference on CO₂ Capture, Transport and Storage](#), Norway (viewer).

Workshop

Aug 27th - Sep 1st 2023. [NordVulk Summer School 2023](#) on CCUS in the Nordic countries, Iceland (Photos: [Reykjanes Peninsula / Fagradalsfjall lava fields](#)).

External Collaborations

- Nov 2022 - Sept 2023. Collaboration with [Wild Space Productions](#) (WSP) and [Freeborne Media](#), two documentary production hubs based in Bristol (UK). Selection, description, and delivery of video footage showing Deep Sea environment for the episode that deals with the Arctic Ocean (some sequences from the episode just below) in the new five-part series "Our Oceans", premiering globally on Netflix in 2024. Visit in Bristol for *private premiere* of the episode on June 6th 2023 ([UiB and Wild Space Productions with Netflix](#) and [Netflix - Six new documentary series](#)).



Current Projects

- 2023 - 2025. The audio-visual project "Meditations on the Deep Sea" in collaboration with SEAS colleague [Daniel Koestner](#) et al., OceanX and UiB (Video Clips: [Netflix footage - Deep ocean - Red Sea - OceanX submersible](#)).

Aim

The combination between my experimental work on CO₂-basalt storage (academic research goal) and the potential use of the laboratory results for the development of CCUS technologies in the field (internship goal) is the ultimate aspiration of my project.

Supervisory Team

Supervisor: [Ingunn Hindenes Thorseth](#), Prof. in Geomicrobiology and Geochemistry, UiB;
Project Leader: [Rolf Birger Svarstad Pedersen](#), Prof. in Geochemistry and Marine Geology, UiB;
External mentor: [Sascha Bussat](#), Specialist Reservoir Geophysics, Equinor ASA.

