Undersea seismic structure imaging: from fluid flow to deep sea mining applications

Project Highlights:

- We will develop new cutting-edge passive seismic subsea imaging methods
- We will explore the continuously excited seismic ambient noise field
- The new seismic images will be interpreted in terms of subsea fluid flow and deep sea minerals

Overview

High-resolution seismic imaging is crucial for storing and monitoring CO2 in the subsurface to reduce global warming, for assessing geothermal and mineral resources and, more generally, for monitoring subsurface fluid flow. With the explosion during the past decades of dense land seismic networks and antennas, contributing to build massive continuous seismic databases, it is now possible to exploit not only earthquake data but as well continuous background noise data through correlation techniques. Using correlations of ambient seismic noise instead of deterministic sources became a new paradigm in seismology during the last decade. Yet, vast regions of our planet are still poorly covered and poorly understood: the oceans and the structure beneath them.

Conducted in 2021-22, the UPFLOW amphibian experiment (Figure 1; *https://upflow-eu.github.io*; PI: A. Ferreira) was the largest and longest ocean bottom seismometer (OBS) deployment carried out so far in the Atlantic ocean. It deployed 50 and recovered 49 ocean bottom seismometers (OBSs) in a ~1,000×2,000 km^2 area in the Azores-Madeira-Canary Islands region starting in July 2021 for ~13 months, with an average station spacing of ~150-200 km. This project will develop and use fundamental new seismic imaging methods exploring the ambient seismic noise field and will apply them to UPFLOW's data.

The region of the Atlantic covered by the UPFLOW experiment encompasses seafloor massive sulfides (SMS), which are associated with both active and inactive hydrothermal vents along oceanic ridges. This includes the Lucky Strike and Rainbow vent fields, which contain some of the largest SMS deposits in the Atlantic (e.g. German et al. 2016). They tend to have a high sulfide content but are also rich in copper, gold, zinc, lead, barium, and silver (e.g., Hein et al., 2013). Moreover, being an active volcanic region, there are significant potential sources of geothermal energy and thus monitoring fluid flow in the region is of paramount importance.

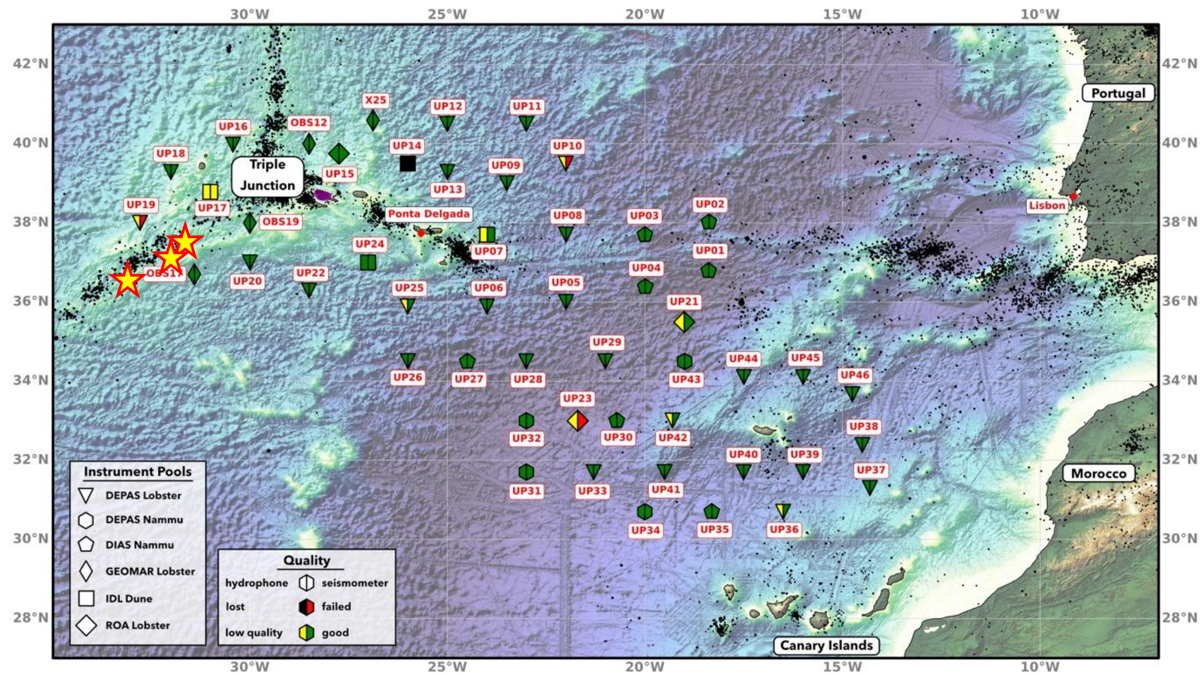

Figure 1: Geographical distribution of the UPFLOW experiment. The map displays seismicity data from 1970 to 2022 (filled black circles) obtained from the IRIS event catalogue. Recent seismic activity/seismicity in 2022 (small purple scatters) is sourced from CIVISA (Azores). The different symbols (inverted triangles, hexagons, pentagons, diamonds, squares) show OBSs from different instrument pools (see figure's key), while the colour indicates the quality of the data. The left side of the symbol represents hydrophone stations, and the right side represents seismometer stations. Stations are colour-coded: black indicates lost data or instrument, red indicates damaged or unusable data, yellow indicates incomplete data, and green indicates good-quality data. The majority of the stations show high-quality data. Stars represent known active SMS vent fields.

Key research questions:

This project aims to answer the following key research questions:

1) What are the smallest seismic subsurface features that we can image using UPFLOW's data?

2) What are the patterns of subsea fluid flow in the mid-Atlantic region?

3) What is the geothermal energy and deep sea minerals exploration potential in the region?

Methodology:

The student will perform seismic imaging using seismic ambient noise and interpret it to understand mineral resources potential in the mid-Atlantic. The student will use cutting-edge algorithms to measure Rayleigh wave ellipticity and invert it for sub-surface structure (e.g., shear-wave speed, density; Jones, Ferreira et al., 2023ab, 2021). The student will also explore transdimensional ambient noise tomography approaches (e.g., Crowder et al., 2021), which are highly complementary to ellipticity analysis since the former is a single-station approach while the latter is a network approach. The student will investigate time-dependent variations in structure and interpret the results in terms of fluid flow and natural resources.

The student will benefit from UPFLOW's very successful partnerships with local stakeholders in the Azores and in continental Portugal (e.g., national seismic and monitoring agencies), ensuring the project involves all relevant stakeholders from the outset, who will also assist the interpretation and discussion of the results.

Possible timeline:
Year 1: Receive training in seismology, natural resources, data analysis, coding (python) and seismological forward and inverse methods. Start building subsea seismic images using Rayleigh wave ellipticity data and ambient noise cross-correlation data, including uncertainty quantification.

Year 2: Finish seismic images based on ellipticity data. Present the results in a major international conference (e.g., EGU) and in a smaller more targeted workshop (e.g., SPIN workshops), and submit one paper to an international journal (e.g., JGR, GJI). Start building seismic images exploring transdimensional ambient noise tomography methods. Carry out first interpretations in terms of fluid flow and natural resources.

Year 3: Finish images based on ambient noise tomography and combine them with those obtained from ellipticity data analysis. Present the results in a major international conference (e.g., EGU) in a smaller more targeted workshop (e.g., SPIN workshops), and submit one paper to an international journal (e.g., JGR, GJI). Interpret the results in terms of fluid flow and resources. Submit a paper to an international journal (e.g., GRL) with a synthesis of the results.

Training and skills:
TARGET researchers will participate in a minimum of 40 days training over the 3.5 years of study composed of:

- an annual one-week workshop dedicated to their year group, and tailored to that cohort's needs in terms of skills development – *for the first three years of their study*;
- an annual all-TARGET workshop with cross-year interactions, advanced training and opportunities to specialise in particular areas – *all years of study*;
- a number of one-day workshops;
- additional online events and in-person workshops attached to relevant conferences.

In addition to the TARGET mandatory training the student will receive project-specific training as well as benefiting from a rich training environment at UCL. They will join a 60+ cohort of PhD students in a vibrant department and will have access to UCL's doctoral training, including academic writing, entrepreneurship, and presentation skills. They will also be trained to teach and will gain experience as a demonstrator in our department. The student will join the UCL Earth Resources Centre and be encouraged to attend and contribute to group meetings, seminars and-networking events.

Partners and collaboration:

The student will regularly visit the University of Edinburgh to interact with Prof. Andrew Curtis and his group – at least three times per year for at least one week in each visit. Monthly online meetings between the student and whole supervisory team will allow discussion of progress, and the student and supervisory team will meet at least once per year at UCL or at Edinburgh. Importantly, the student will be fully engaged in regular discussions with all relevant stakeholders in the Azores and in continental Portugal, building on the strong relationships developed within the context of the UPFLOW project.

Requirements: Applicants should ideally have a MSci/MSc degree in geophysics, physics or applied mathematics, with an interest in subsurface imaging, energy and resources.

Further reading:

Crowder, E., Rawlinson, N., Cornwell, D. G., Sammarco, C., Galetti, E. & Curtis, A. (2021) 'New insights into North Sea deep crustal structure and extension from transdimensional ambient noise tomography', *Geophysical Journal International*. 224, 2, p. 1197–1210

German, C.R., Petersen, S. and Hannington, M.D., 2016. Hydrothermal exploration of mid-ocean ridges: where might the largest sulfide deposits be forming?. *Chemical Geology*, *420*, pp.114-126.

Jones, GA; Ferreira, AMG; Kulessa, B; Schimmel, M; Berbellini, A; Morelli, A; (2023) Constraints on the Cryohydrological Warming of Firn and Ice in Greenland From Rayleigh Wave Ellipticity Data. Geophysical Research Letters , 50 (15) , Article e2023GL103673. 10.1029/2023gl103673

Jones, Glenn; Kulessa, Bernd; Ferreira, Ana; Schimmel, Martin; Berbellini, Andrea; Morelli, Andrea; (2023) Extraction and applications of Rayleigh wave ellipticity in polar regions. Annals of Glaciology 10.1017/aog.2023.1

Jones, GA; Ferreira, AMG; Kulessa, B; Schimmel, M; Berbellini, A; Morelli, A; (2021) Uppermost crustal structure regulates the flow of the Greenland Ice Sheet. Nature Communications , 12 , Article 7307. 10.1038/s41467-021-27537-5.

UPFLOW project (PI: A. Ferreira): *https://upflow-eu.github.io*

BBC News (2023) about the UPFLOW expedition: https://www.bbc.co.uk/news/science-environment-64253634

UCL Earth Resources Centre: https://www.ucl.ac.uk/earth-sciences/research/research-groups/earth-resources-centre

Further details:

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https://www.ucl.ac.uk/earth-sciences/people/academic/prof-ana-ferreira

For more information on the UCL Earth Resources Centre please visit https://www.ucl.ac.uk/earth-sciences/research/research-groups/earth-resources-centre