IMPERIAL

Uncovering the impact of mantle dynamics on Cenozoic ocean circulation

Supervisors

Lead Supervisor: Fred Richards

Research Group

Solid Earth–Fluid Earth Interactions (SoEFEI) Group (https://freddrichards.github.io/team/)

Project Summary

Despite being more sluggish than its atmospheric counterpart, oceanic circulation is just as critical in shaping Earth's climate due to the enormous quantity of water, heat, and dissolved carbon that it transports around the globe and exchanges with overlying air masses. Oceanic circulation patterns have undergone several reorganisations in the Cenozoic Era, each leading to major shifts in global climate. Many of these climatic transitions have been directly linked to changes in the presence, depth, and width of shallow oceanic gateways (e.g. the Eocene-Oligocene transition and the opening of Drake Passage), which regulate the formation and transport of saline deep water masses that drive the thermohaline element of oceanic circulation. However, while plate reconstructions allow the isostatic component of oceanic gateway palaeobathymetry to be estimated; the dynamic (i.e., mantle-flow-driven) contribution remains enigmatic. This unquantified but substantial (~100 m/Myr) signal makes it difficult to assess the relative importance of air-sea exchange and palaeobathymetry in driving past circulation changes, complicating our understanding of climate sensitivity and our ability to predict the impact of future warming on the ocean-atmosphere system.

This project will address this knowledge gap by integrating geochemical, stratigraphic, and seismic data, with geodynamic simulations to reconstruct the bathymetric evolution of ocean gateways, including Drake Passage, the Greenland-Iceland-Faroe Ridge Complex, and the Indonesian Ocean Gateway. By modelling past ocean-atmosphere system with and without these dynamic topographic contributions to palaeobathymetry, the successful candidate will be at the forefront of global efforts to quantify the impact of Earth's internal circulation patterns on those of its exterior.

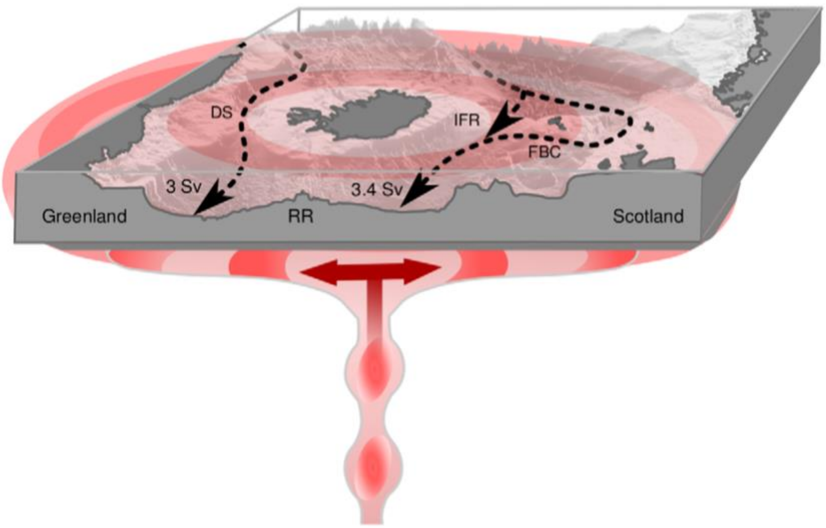

Figure 1: *Schematic cross-section through North Atlantic region around Iceland, showing plume conduit and head with periodic temperature perturbations indicated by red shading. These temperature perturbations— and their impact on the elevation of ocean gateways surrounding Iceland—are thought to modulate the flow of Northern Component Water (the precursor of North Atlantic Deep Water) from the Arctic to the Atlantic Ocean. Bathymetry of the region is shaded in grey. Flow of Northern Component Water is shown by black arrows and annotated with volume flux in Sverdrup. RR = Reykjanes Ridge; IFR = Iceland Faroe Ridge; DS = Denmark Strait; FBC = Faroe Bank Channel. Redrawn from Parnell-Turner et al. (2015, G^3).*

Research Context and Objectives

Efforts to develop a quantitative understanding of how circulation patterns in Earth's mantle interact with those of the overlying ocean have been frustrated by a lack of information their past states and the computational intractability of reconstructing mantle flow evolution back through time. Fortunately, we are now able to overcome these barriers thanks to two major advances. First, innovations computational inverse methods, seismology, mineral physics, tectonics, and igneous petrology now enable us to: produce reasonable estimates of Earth's present-day internal state; accurately 'retrodict' (i.e., predict backwards in time) its evolution; and validate these retrodictions against palaeotemperature and plate velocity constraints. Secondly, the volume and geographic coverage of sediment cores that have been collected and geochemically analysed—coupled with an improved knowledge of which isotope systems best record deep water transport variations—means we finally have the critical mass of primary data required to robustly test ocean gateway palaeobathymetry estimates produced by mantle flow reconstructions. By combining these recent breakthroughs, the successful applicant will determine the impact of mantle-flow driven palaeobathymetric change on the ocean-atmosphere system during three key climate transitions, placing new constraints on secular changes in Earth's climate sensitivity and its present-day value. These transitions are:

1) Eocene-Oligocene Transition (~34 Ma)—the largest long-term cooling event in the Cenozoic Era and the interval in which the Antarctic Ice Sheet grew close to its modern size. It has been suggested that the opening of Drake Passage and the onset of the Antarctic Circumpolar Current were critical drivers of this event.
2) Mid-Miocene Climate Transition (~9-14 Ma)—an enigmatic period of long-term cooling and Antarctic ice-sheet growth following the warm Mid-Miocene Climatic Optimum. This interval has recently been linked to the shoaling of the Indonesian Ocean Gateway and widening of Drake Passage.
3) Pliocene–Pleistocene Transition (~3 Ma)—an interval of significant cooling associated with the intensification of Northern Hemisphere glaciation. This transition has been tied to the progressive closure of the Central American Seaway and shoaling of the Greenland-Iceland-Faroe Ridge Complex and Indonesian Ocean Gateway.

Further reading:

Parnell-Turner, R., N. J. White, I. N. McCave, T. J. Henstock, B. Murton, and S. M. Jones (2015), Architecture of North Atlantic contourite drifts modified by transient circulation of the Icelandic mantle plume, *Geochem. Geophys. Geosyst.,* **16**, 3414–3435, doi:10.1002/2015GC005947.

Mitrovica, J. X., Austermann, J., Coulson, S. L., Creveling, J. R., Hoggard, M. J., Jarvis, G. T. & Richards, F. D. (2020), Dynamic Topography and Ice Age Paleoclimate, *Ann. Rev. Earth Planet. Sci.,* **48**, 585–621, doi: 10.1146/annurev-earth-082517-010225.

Who are we looking for?

The ideal candidate will have a background in Earth sciences, oceanography, physics, or a related field. They will have prior research experience, at least some familiarity with writing code for data analysis and/or numerical modelling, and the desire and versatility to work across traditional discipline boundaries.

The candidate will be joining a vibrant and supportive group, where training is carefully tailored to individual needs and goals. They will be supported in growing their academic profile through annual attendance of national and international conferences, and participation in specialist workshops, hackathons, and summer schools to develop new skills.