The Southern Ocean's role in CO_2 change

University of St Andrews, School of Earth and Environmental Sciences

In partnership with **The British Antarctic Survey**

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Overview

The cause of glacial-interglacial CO_2 change has been described as the "holy grail" of palaeoclimate. Several decades of research have narrowed focus onto the Southern Ocean as the most important driver of glacial interglacial CO_2 change (Sigman et al., 2010), due its intimate link to the deep ocean (Rae & Broecker, 2018) and its unique biogeochemistry: as a high nutrient low-chlorophyll region, CO_2 brought to the surface from deep upwelling cannot be efficiently captured by biological productivity and may outgas to the atmosphere.

Several mechanisms have been proposed to explain how the Southern Ocean may have trapped more CO_2 during glacials, including iron fertilisation, ocean stratification, and a "lid" of increased sea ice. However while various tracers of these processes exist it has, until recently, not been possible to assess their impact on CO_2 storage and release.

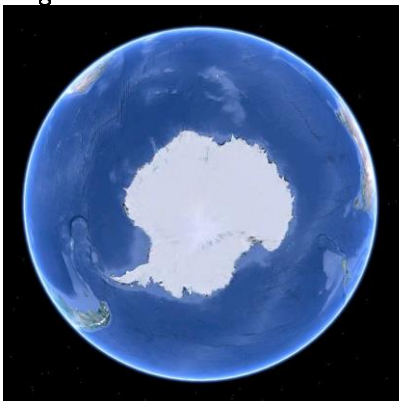

Figure 1: The Southern Ocean plays a crucial role in CO_2 and climate change.

Methodology

This project will use the boron isotope composition of fossil carbonates (Foster & Rae, 2016, Rae 2018) to reconstruct how Southern Ocean pH and CO_2 changed over glacial cycles. By comparing these data to multi-proxy records of biological pump efficiency, sea ice, and ocean circulation, we will work out the relative importance of these processes in CO_2 change during the evolution of glacial cycles.

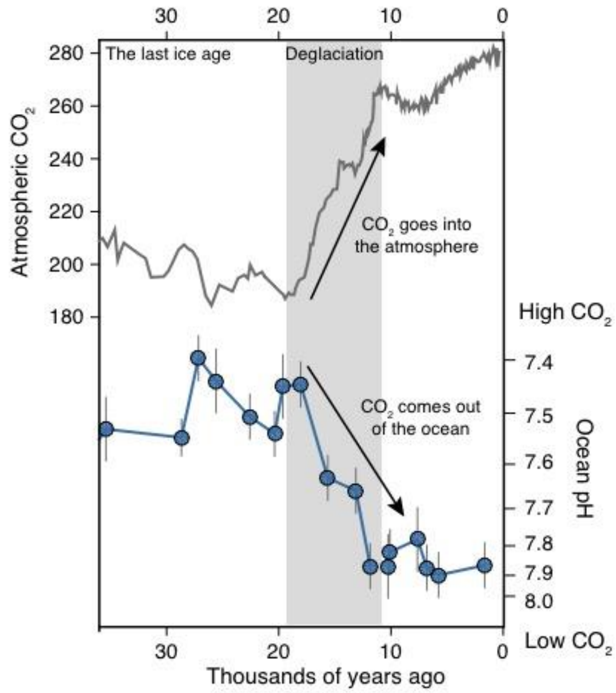

Figure 2: Deep Southern Ocean pH and CO_2 reconstruction based on boron isotopes in deep sea corals shows a mirror image pattern to atmospheric CO_2 change. Adapted from Rae et al., 2018.

This approach has recently yielded several high profile results in this region, including the most direct evidence to date of CO_2 release from the deep ocean (Figure 2; Rae et al., 2018) to the upper ocean and the atmosphere (Martinez-Boti et al., 2015). Boron isotope records in other HNLC regions have also been used to distinguish the impact of iron fertilisation and circulation change on ocean CO_2 outgassing, through comparison to multi-proxy data (Gray et al., 2018).

We will apply this same approach to foraminifera in sediment cores from the polar and subpolar regions of the Southern Ocean. Thanks to recent analytical developments in the STAiG lab at the University of St Andrews, it is now possible to analyse the small numbers of forams often found in these cores to high precision.

We will generate records on a range of timescales, focussing on the last deglaciation at high temporal resolution and the last glacial cycle. Depending on the interest of the student and the initial results, these may be extended back through multiple glacial cycles, or expanded geographically into different sectors of the Southern Ocean. There is also the possibility to compare results to idealised and Earth system model experiments.

Material is made available through partnership with the British Antarctic Survey, along with ongoing collaboration with the Alfred-Wegner Institute for Polar Research. The student will undertake sampling trips to these institutes, and may also partake in a research cruise.

The project will take advantage of cutting edge geochemical techniques available in the St Andrews Isotope Geochemistry labs (STAiG). These will focus on boron isotopes, which have seen recent development as a tracer of the ocean CO_2 system (Rae 2018), and are now well-poised to answer exciting questions about the nature of CO_2 change in the past. Extension to other isotope systems, including silicon and nitrogen, is also possible, and complementary trace element proxies will also be generated.

Timeline

Year 1: Literature review, sediment core sampling, sediment processing, foraminifera picking/counts, training and further development of clean laboratory methods and mass spectrometry, initial boron isotope and trace element measurements.

Year 2: Generation of boron isotope records, and draft initial paper(s)

Years 3 and 4: Finalize data sets, extending records in space and time, prepare written manuscripts and write thesis.

Training & Skills

The student will gain specific training in boron isotope analysis, mass spectrometry, micropaleontology, and clean lab chemistry, as well as training and expertise in climate science and oceanography. The student may also engage with numerical climate modelling and inverse techniques if interested. Furthermore, over the course of the PhD, the student will gain transferable skills such as scientific writing, statistics and data analysis, and problem-solving, as well as time management and working towards a long-term goal.

References & Further Reading

Foster & Rae (2016), *Annual Reviews, 44,* 207-237
Gray, Rae et al. (2018), *Nature Geoscience, 11 (5)* 340
Martinez-Boti et al. (2015), *Nature, 518,* 219-222
Rae (2018), *Boron Isotopes, Springer,* 107-143
Rae & Broecker (2018), *Biogeosciences, 15,* 3779-3794
Rae, Burke et al. (2018), *Nature, 562,* 569-573
Sigman et al. (2010), *Nature, 466,* 47-55

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