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Snowguns, seesaws, and CO_2: million-year to millennial climate and productivity change in the Arctic

University of St Andrews, Department of Earth and Environmental Sciences
In partnership with Durham University

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Overview

The Arctic Ocean and its surrounding subpolar basins lie at the epicentre of modern climate change. Current trends and future predictions show rapid loss of sea ice, with major implications for biological productivity, resource availability, and global climate (Liu et al. 2012). However although these conditions are alarming, geologically speaking they may not be unprecedented: over the last 3 million to 20 thousand years the Arctic region saw abrupt changes in marine productivity, fundamentally different modes of ocean circulation, and storage and release of CO_2. The geological past may thus hold the key to understanding the modes of operation of the Arctic environment in the future.

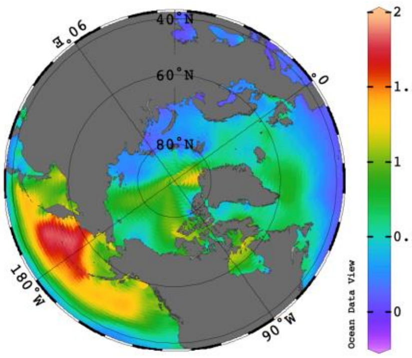

Fig 1: Phosphate concentrations reveal strong gradients in circulation and biogeochemistry.

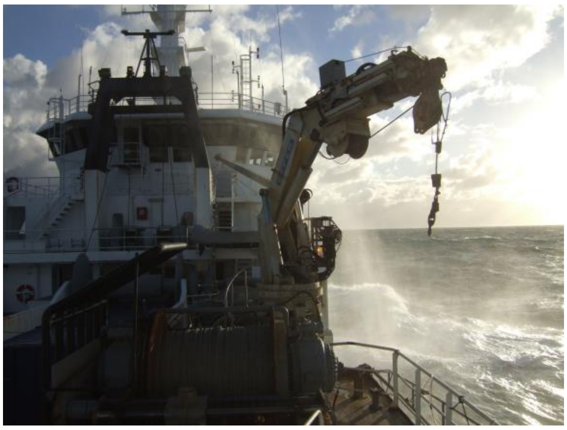

Fig 2: Core and water sample collection.

Two of the most dramatic intervals of environmental change in Arctic region include the millennial-scale climate shifts of the last ice age (Rae et al. 2014), and the transition from warm, low-ice climates to more intensive Northern Hemisphere glaciations around 3 Million years ago (Haug et al. 1999). Although the timescales are different, several of the environmental factors surrounding these events are similar, suggestive of fundamental modes of operation of high latitude environments and ecosystems (Sigman et al. 2004). Furthermore, it has been suggested that these oceanic conditions are mirrored in the Southern Ocean on similar timescales (Haug & Sigman, 2009). This may indicate a collection of unifying processes that govern the role of high latitude oceans during climatic transitions.

However current mechanisms to explain these conditions are split between polar ocean stratification versus more invigorated circulation in cold climates, with different implications for sensitivity to climate change and CO_2. As a result the role of high latitude ocean circulation changes in major climate transitions remains unknown.

Methodology

This project seeks to understand the modes of environmental change in the subpolar North Pacific and North Atlantic, by creating records of past changes in ocean temperature, circulation, and biological productivity. This will involve new sediment core material, analysed using novel geochemical methods, and synthesis of results with a variety of modelling approaches.

Material is made available through ongoing collaboration with the Alfred-Wegner Institute for Polar Research, Woods Hole Oceanographic Institute, Oregon State University, and the International Ocean Drilling Project. 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 new St Andrews Isotope Geochemistry labs (STAiG). These include boron isotopes, which have seen recent development as a tracer of the ocean CO_2 system (Rae et al., 2011), and are now well-poised to answer exciting questions about the nature of CO_2 change in the past (e.g. Martinez-Boti et al., 2015). These boron measurements will be paired, for the first time, with silicon isotope measurements on diatoms and sponge spicules, respectively tracing the usage and abundance of this key nutrient. To examine changes in physical circulation and climate, we will produce records of sea surface temperature and salinity change, using paired $\delta^{18}O$-Mg/Ca in planktic foraminifera along with organic SST proxy measurements at Durham University.

Depending on interest of the student, interpretation of the data may be accompanied by experiments with numerical models, including box models, the GENIE earth system model, and analysis of General Circulation Model output.

Timeline

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

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

Years 3 and 4: Finalize data sets, apply numerical techniques, assess model output, prepare written manuscripts and write thesis.

Training & Skills

The student will gain specific training in micropaleontology, boron isotope analysis, mass spectrometry, 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 (2008), *EPSL*, *271*, 254-266.
Liu et al. (2012), *PNAS*, *109*, 4074-4079.
Haug et al. (1999), *Nature, 401,* 779-782.
Haug & Sigman (2009), *Nature Geoscience, 2*, 91-92.
Martinez-Boti et al. (2015), *Nature, 518,* 219-222.
Rae et al. (2011), *EPSL*, *302*, 403-413.
Rae et al. (2014), *Paleoceanography, 29,* 645-667.
Sigman et al. (2004), *Nature, 428,* 59-62.

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