IAPETUS Doctoral Training Partnership

NERC SCIENCE OF THE ENVIRONMENT

Novel archives of CO_2 and oxygen change

University of St Andrews, School of Earth and Environmental Sciences

In partnership with Heriot-Watt University

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Overview

The cycles of carbon and oxygen are intimately linked, and have both fluctuated over Earth's history. These fluctuations are in-turn thought to have driven major shifts in Earth's environment and the life it supports. However until recently methods of reconstructing past oxygen and CO_2 levels in the ocean and the atmosphere were largely qualitative. Thanks to recent developments in geochemistry, rapid progress is now being made on more quantitative tracers of planetary redox and CO_2 conditions, and these methods are now primed to provide new insights into major events in the geological record of environmental change.

This project will use novel trace element ratios and isotope systems in marine carbonates to reconstruct changes in ocean/atmosphere CO_2 and ocean redox conditions in key intervals of the last 100 Million years.

CO_2 reconstructions will be based on the boron isotope composition ($\delta^{11}B$) of foraminifera (Foster & Rae 2016; Rae 2018), which reflects water pH – and thus CO_2 chemistry. This method has provided several high profile reconstructions during this time period (e.g. Anagnostou 2016, Gutjahr 2017), but records remain limited in temporal and spatial resolution.

To reconstruct redox conditions we will measure a suite of novel trace elements in foraminifera and bulk sediments, including iodine, uranium, manganese, cerium, molybdenum, and rare earth elements (e.g. Zhou et al., 2016). This will be paired with measurements of carbon isotope gradients between different species of benthic foraminifera to reconstruct bottom water oxygen concentrations (e.g. Hoogakker et al., 2015), and may be extended in key intervals with measurements of novel isotope systems (e.g. sulphur, molybdenum, uranium).

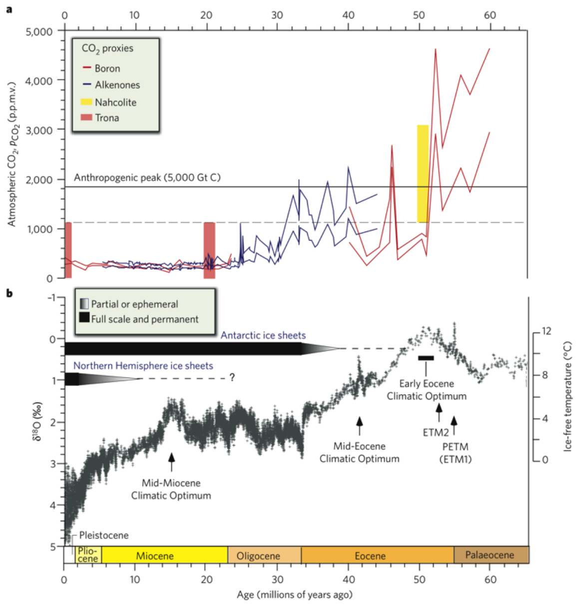

Fig 1: CO_2 and climate change over the last 60 Myr (Zachos et al. 2008). Despite recent additions to the CO_2 record (e.g. [www.p-CO2.org]()), records remain sparse and uncertain. Here we will increase the temporal and spatial resolution of CO_2 reconstruction during the last 100 Myr using the boron isotope measurements on foraminifera.

To aid interpretation, we will also use a quantitative modelling approach, pairing sedimentary redox modelling with Earth system model output.

The results of this work will improve understanding of environmental change during major transitions of the last 100 Myr, and will also help inform the use of these methods deeper in the geological record.

Fig 2: Dramatic changes in ocean redox conditions have taken place during several intervals of the last 100 Myr. Most notable are the Oceanic Anoxic Events, which are expressed as black shale layers in carbonate sequences, as shown above. Here we will develop methods to quantify oxygen levels both at times of extreme changes in redox (e.g. OAEs) and during more subtle transitions.

Methodology

Marine carbonate samples are made available from the IODP and may also be collected during dedicated fieldwork. These will be analysed for boron isotopes and trace elements in the St Andrews Isotope Geochemistry (STAiG) labs, following techniques established by Foster (2008) and Rae et al. (2011), and recently developed to improve precision on small samples. Trace elements will be measured on a new state-of-the-art triple quadrupole ICPMS, allowing removal of interferences from several key elements (e.g. REEs).

We will also take advantage of – and continue to develop – new protocols for sample preparation (including automation) that will allow faster throughput of samples and thus higher resolution records to be generated.

Controls on redox proxies will be further explored using sedimentary redox modelling, in collaboration with Dr Sandra Arndt at the Université Libre de Bruxelles. These may also be paired with output from the GENIE Earth system model.

The project is designed to be flexible, with the opportunity to focus on approaches, time intervals, and techniques of particular interest to the student.

Timeline

Year 1: Sediment core sampling, fieldwork, training in clean laboratory methods and mass spectrometry, initial measurements and training, literature review

Year 2: Generate long-term records. Sediment redox modelling. First manuscript.

Years 3 and 4: Finalize data sets including higher resolution intervals, apply numerical techniques, prepare written manuscripts and write thesis.

Training & Skills

The student will gain specific training in mass spectrometry, fieldwork, clean lab chemistry, and geochemical modelling, as well as broader education in geochemistry, oceanography, and climate science. 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

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