Linking Phanerozoic carbon cycle perturbations, mass extinctions and large igneous provinces using novel geochemical proxies

Curious12

Global Environmental Change

IAP2-19-036

Overview

The Phanerozoic Eon (past ~541 Million years) was marked by a number of fundamental events such as mass extinctions or ocean anoxic events that have shaped the course of the evolution of life and climate on Earth. Large igneous provinces (LIPs), known for their rapid production of voluminous magma and carbon release, have been synchronous with several of these events, however, the link between them still remains poorly understood. Illuminating the underlying link is critical for untangling the driving mechanism of extinctions, and their feedbacks and consequences, as well as for improving our overall understanding of climatic and ecological sensitivities.

This project will provide new constraints on pH and CO2 during key Phanerozoic periods (such as e.g. the Permian-Triassic boundary), alongside further changes in seawater chemistry – via weathering and volcanism – associated with carbon cycle variations.

To do this we will measure novel isotope and trace element ratios in selected fossil brachiopods and other carbonate archives from specific time intervals. Boron isotopes (d11B) will be used to reconstruct seawater pH (Jurikova et al., 2019; Foster & Rae 2016). This method has been successfully applied to constrain changes in CO2 over the Cenozoic, but deep-time reconstructions remain limited due to the lack of suitable, well-preserved archives (Fig. 1). Recent developments on the use and calibration of brachiopods as geochemical archives open the possibility for extending CO2 into earlier periods.

In this project, we will take the advantage of these archives together with a suite of novel geochemical proxies associated with a new ERC project, to provide constraints on carbon cycle and climate feedbacks during key periods of Earth's evolutionary history.

Boron isotope data will be integrated with complementary proxies and tracers of seawater chemistry, such as e.g. lithium, magnesium, calcium, strontium, and isotopes, made on the same unique archives. Measurements will take advantage of a bespoke new laser ablation system and new collision-cell ICPMS instrumentation. These will allow us to constrain secondary controls on the carbonate system, as well as evaluate the preservation of the fossils and constrain potential intra-shell heterogeneities (Fig. 2).

Supervisory Team

Dr. James Rae
University of St Andrews

Dr. Darren Mark
University of Glasgow

Dr. Hana Jurikova
University of St Andrews

Further Information

for informal enquiries, contact:

Dr. James Rae

jwbr@st-andrews.ac.uk

University of St Andrews

Key Words

- Carbon Cycle
- CO2
- Mass extinctions
- Large igneous provinces
- Geochemistry

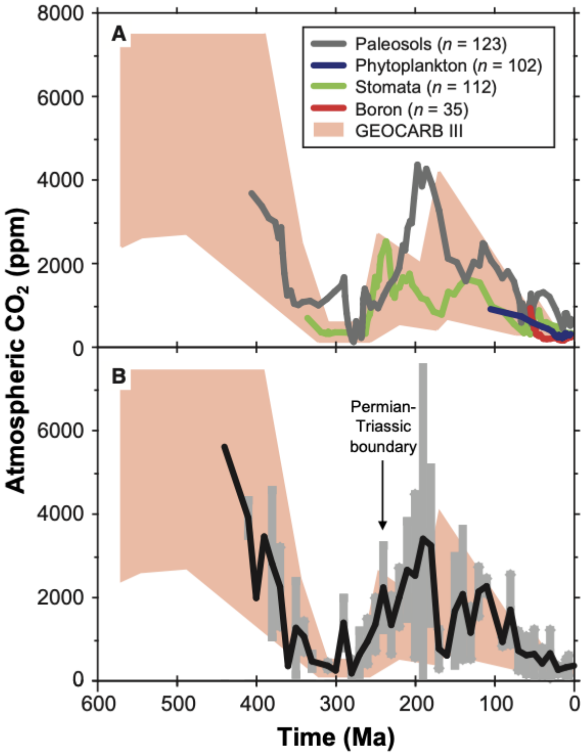

Figure 1: Phanerozoic evolution of atmospheric CO_2 as reconstructed from a range of proxies including palaeosols, phytoplankton, stomatal indices and boron isotope data, as well as GEOCARB III model scenario (A), and a combined record (B) from Royer et al. (2004). The black curve and grey boxes in B show the average and standard deviation ($\pm$ 1σ) for 10 Myr time-steps. Major uncertainties still exist in the long-term CO_2 trends, let alone over specific time intervals, such as e.g. the largest mass extinction at the Permian-Triassic boundary. Boron data is currently mainly limited to the Cenozoic.

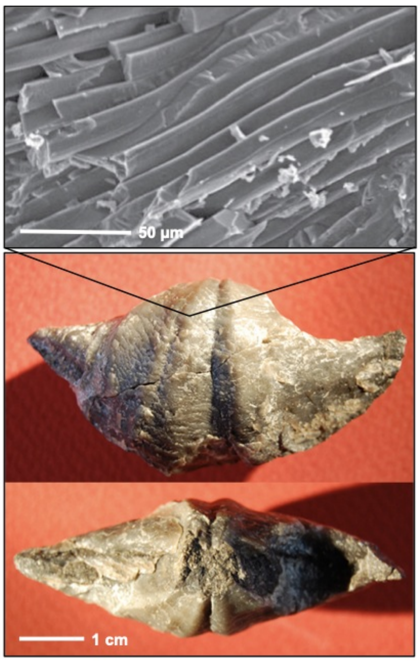

Figure 2: Brachiopod *Comelicania sp.* highly abundant in late Permian sections in northern Italy. The secondary electron microscope (SEM) image illustrates the typical well-preserved microstructure (low-Mg calcite fibres) of these specimens, which makes them excellent geochemical archives for reconstructions of past ocean chemistry and climate.

Methodology

This project will involve the application of boron isotopes as well as the development of new complementary methods for trace element and isotope analysis using novel collision-cell ICPMS instrumentation. This opens new possibilities for analyses not previously possible by argon-plasma instruments, and may make previously challenging measurements more straight-forward (e.g. Ca or S isotopes).

Analyses will be made on carbonate fossils, chiefly brachiopods, but additional archives such as bivalves or echinoderms may also be explored. Samples will be available from existing collections, and fieldwork may also be undertaken to bolster these samples sets.

As well as solution-based analyses, we will use a laser ablation system to make in-situ analyses and evaluate microstructural variability and degree of preservation within the fossils.

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

Project Timeline

Year 1

Year 1: Training in clean laboratory methods and mass spectrometry, method development, experimental set-up, sample selection and inspection, initial measurements, literature review, possible fieldtrip.

Year 2

Year 2: Complete experiments, generate boron, carbon and oxygen isotope records from fossil carbonate archives, complemented with novel isotope and trace element systems.

Year 3

Years 3 and 3.5: Finalize data sets, apply numerical techniques, prepare written manuscripts and write thesis.

Year 3.5

Year 3.5: Finalize data sets, manuscripts and thesis.

Training & Skills

The student will gain specific training in mass spectrometry, clean lab chemistry, and experimental geochemistry, as well as broader education in geochemistry, geology, palaeontology, 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

Jurikova et al. (2019), GCA 248, 370-386.
Foster & Rae (2016), Ann. Rev. 44, 207-237.
Royer et al. (2004), GSA Today 14, 4-10.

Further Information

For further information, please contact:

Dr James Rae
Department of Earth and Environmental Sciences
University of St Andrews
St Andrews
KY16 8YG
+44 (0)1334 463901
jwbr@st-andrews.ac.uk