Phanerozoic CO2 and Mass Extinctions

IAPETUS2 Doctoral Training Partnership

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Throughout Earth's history, CO is thought to have exerted a fundamental control on climatic and environmental changes. On geological time-scales long-term CO2 change is considered to have been mainly regulated by volcanic outgassing and the chemical weathering feedback, while short-term changes in atmospheric CO2 have prominently occurred during mass extinction events linked to episodes of massive volcanism and/or extra-terrestrial phenomena. This view of the long and short-term key drivers of CO2 change on Earth, however, fundamentally suffers from the lack of quality and high-resolution atmospheric CO2 estimates, in particular in time intervals beyond the reach of the marine sediment record (Fig. 1).

This project will reconstruct atmospheric CO2 levels during key periods of Earth's history from the rock record, alongside changes in seawater chemistry. Possible intervals include the early Palaeozoic biodiversification and end-Ordovician extinction, land colonisation of plants and end-Devonian mass extinction, the Late Palaeozoic Ice Age and Permian-Triassic mass extinction, Triassic greenhouse and end-Triassic mass extinction, Jurassic ocean anoxic events and biodiversity crises, or Cretaceous events and mass extinction. Focusing on an interval of choice, long and short-term drivers of atmospheric CO2 and global changes will be investigated, and the role of background CO2 and climate state on inducing a mass extinction examined.

To do this, the student will employ novel isotopic and elemental approaches to fossil remains of marine organisms preserved in the rock record. Boron isotopes will be used to reconstruct ocean pH and atmospheric CO2 (Jurikova et al., 2020; Rae et al., 2021). 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. Recent developments on the use and calibration of brachiopods as geochemical archives now open the possibility for extending CO2 reconstructions into earlier periods (Jurikova et al., 2019). Complementary isotopic analyses (C, O, and e.g. Li, K, Ca, Sr, Mg, S) will be made on the same specimens to provide additional constraints on climate (e.g. temperature) and global processes (e.g. weathering, volcanism). The acquired data will be placed in context of previously published literature and ultimately synthesised with the aid of geochemical and climate models and numerical techniques.

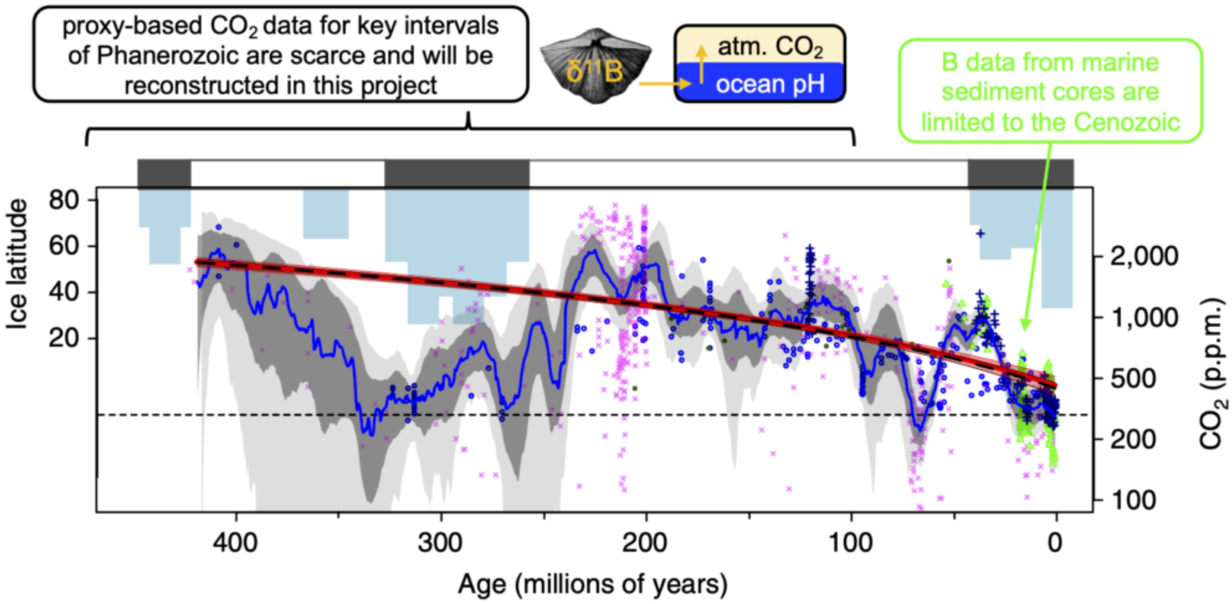

Image Captions

Figure 1. Latest compilation of Phanerozoic atmospheric CO2 estimates from a range of proxies from Foster et al. 2017.

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 MC-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, K or S isotopes).

Analyses will be made on marine carbonate fossils, mostly 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, the student will use a laser ablation system to make in-situ analyses and evaluate microstructural variability and degree of preservation within the fossils, in combination with microscopy and petrographic analyses.

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

Training in clean laboratory methods and mass spectrometry, method development, experimental set-up, sample selection and inspection, initial measurements, literature review, optional fieldwork.

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

Finalize data sets, apply numerical techniques, prepare written manuscripts and write thesis.

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. 2020, Nat. Geosci. 13, 745–750, https://doi.org/10.1038/s41561-020-00646-4
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Rae et al. 2021, Ann. Rev. Earth Planet Sci. 49, 599–631, https://doi.org/10.1146/annurev-earth-082420-063026
Foster et al. 2017, Nat. Comm. 8, 14845, https://doi.org/10.1038/ncomms14845

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Key Words

- Carbon cycle
- Climate
- Isotope geochemistry
- Ocean Chemistry
- Fossil Record