Earth’s Deep Time CO2 and Mass Extinctions

IAP-25-099

Throughout Earth’s history, CO2 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 (Figure 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 hothouse 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 (Foster et al., 2017). This method has been successfully applied to constrain changes in CO2 over the Cenozoic (Rae et al., 2021; CenCO2PIP 2023), 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., 2025; 2020). 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.

This IAPETUS PhD studentship will operate alongside the recently awarded ERC Starting Grant to Hana Jurikova, as part of which we will be generating the first record of atmospheric CO2 and ocean pH over the past 500 million years, offering exciting opportunities for the student to engage and collaborate on related research, further develop complementary and transferable research skills, and exchange knowledge.

Image Captions

Figure 1

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 laser ablation and 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 straightforward (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.

CO2 will be calculated from boron isotopes using advanced statistical and Bayesian approaches, and its role and feedbacks will be explored through Earth System and Climate Models (e.g. cGENIE, HadCM3).

Project Timeline

Year 1

Training in clean laboratory methods and mass spectrometry, method development, experimental set-up, sample selection and inspection, initial measurements, and literature review. Optional fieldwork and visit to museum brachiopod collection to collect samples.

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, present results at a conference, 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, as well as broader education in geochemistry, geology, palaeontology, oceanography, climate science and modelling. Over the course of the PhD, the student will gain transferable skills such as critical thinking, scientific writing, statistics and data analysis, and problem-solving, as well as time management and working towards a long-term goal.

References & further reading

CenCO2PIP 2023, Science 382, eadi5177, https://doi.org/10.1126/science.adi5177
Jurikova et al. 2025, Nat. Geosci 18, 91–97, https://doi.org/10.1038/s41561-024-01610-2
Jurikova et al. 2020, Nat. Geosci. 13, 745–750, https://doi.org/10.1038/s41561-020-00646-4
Foster et al. 2017, Nat. Comm. 8, 14845, https://doi.org/10.1038/ncomms14845
Rae et al. 2021, Ann. Rev. Earth Planet Sci. 49, 599–631, https://doi.org/10.1146/annurev-earth-082420-063026

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