How did the first animals and plants change our planet?

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Introduction

This project aims to understand the changes in Earth's surface conditions during the Paleozoic era, which saw the evolution of land plants and the rapid diversification of animal life. Specifically we will focus on proposed large shifts in atmospheric CO_2 and O_2 concentrations, which have been linked to the evolution of the terrestrial and marine biospheres and their effects on the delivery and cycling of the key limiting nutrient phosphate [Lenton et al., 2016; Mills et al., 2018; Van de Velde et al., 2018]. This will be achieved using a combination of state-of-the-art geochemical analyses of ancient sedimentary rocks and the application of mathematical 'Earth System' models, with the potential for targeted fieldwork to collect additional samples covering specific periods of interest. The balance between laboratory work and computer modelling is flexible depending on the skills of the candidate.

Background

The geological record of the Cambrian period (541-485 million years ago, Ma) documents the explosion of animal life on planet Earth, and the following Ordovician and Silurian periods (together ~485-416 Ma) saw the evolution of the first land plants and terrestrial arthropods. Until recently, it has been thought that these newly developed terrestrial and marine ecosystems did not significantly impact the global elemental cycles that regulate climate, but this assumption has now begun to be questioned.

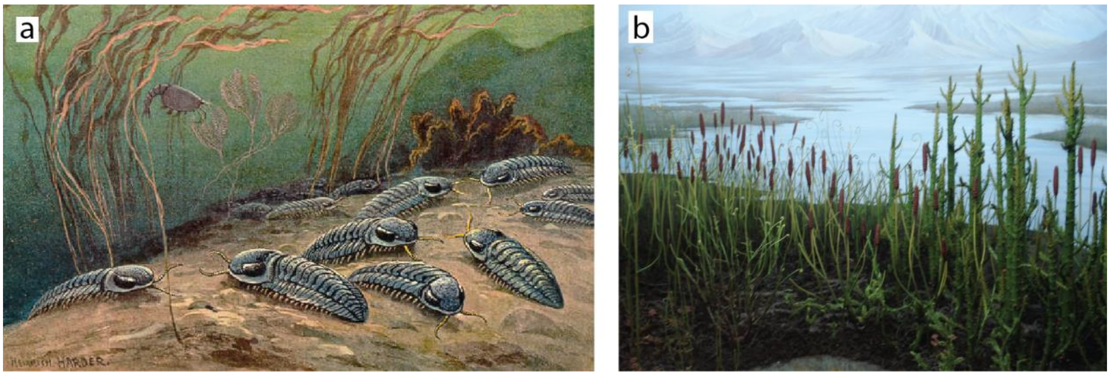

Figure 1. Artists' impressions of the Cambrian marine (a) and Silurian terrestrial (b) ecosystems. Modified from Wikimedia commons.

The early Paleozoic is characterised by widespread ocean anoxia, uncertain fluctuations in atmospheric oxygen, and substantial glacial episodes. Current research suggests that these changes in surface conditions may be related to the evolution of both the animal [Van de Velde et al., 2018] and plant [Lenton et al., 2016] kingdoms over this timeframe, and recently developed laboratory techniques and computer models will allow quantification and testing of these ideas.

Aims and approach

This project aims to improve the geochemical record of ocean redox conditions, in addition to applying novel geochemical techniques to evaluate changes in the oceanic influx of nutrients and their behaviour, during the early-mid Paleozoic. Via biogeochemical modelling of these analyses, the project aims to elucidate the mechanisms behind long term global environmental change during this pivotal period of Earth history.

The following key questions will guide the research:

1) Did changes in global phosphorus cycling accompany the expansion of the terrestrial and marine biospheres in the Paleozoic?
2) What were the dynamics of deep ocean oxygenation throughout the Cambrian, Ordovician and Silurian periods?
3) Did the initial expansion of plant and animal species drive long term climate shifts, or can these be attributed to tectonic or geomorphological factors?

An initial focus of the project will be the sampling of excellently preserved continuous drill core sections held by the British Geological Survey. Laboratory measurements of the speciation of iron and phosphorus will provide unprecedented insight into ocean redox conditions and marine nutrient cycling. These analyses will be combined with bulk element analyses and isotopic ratios of carbon and sulphur, which respond to changes in global tectonic processes, weathering and biogeochemical cycling. Some of these techniques have been developed by the project team, and research at Leeds will be carried out in the modern and well-equipped Cohen Geochemistry Laboratories within the School of Earth and Environment. There will be opportunities to visit field sites and collect additional carbonate and black shale samples as the project progresses.

The second focus of the project is Earth system computer modelling. Long-term biogeochemical 'box' models link the global cycles of carbon, sulphur, oxygen and phosphorus (among others) to reconstruct long term climate [e.g. Figure 2]. The University of Leeds is a leading institution in the development of these models and the researcher will work to improve the ongoing modelling efforts of the project team [e.g. Mills et al., 2016; Van de Velde et al., 2018; Krause et al., 2018] by investigating more detailed ocean modelling [e.g. Wallman, 2003; Clarkson et al., 2015] and new functions representing the evolving global biota [Lenton et al., 2016].

The models can be 'driven' using the geochemical data obtained in the project (e.g. $\delta^{13}C$, $\delta^{34}S$, chemical index of alteration) in order to investigate the potential changes in biogeochemical cycling, and may also be used as a predictive tool whereby the geochemical records are estimated for a given hypothesis and then compared to data (for the redox state of the deep ocean, for example).

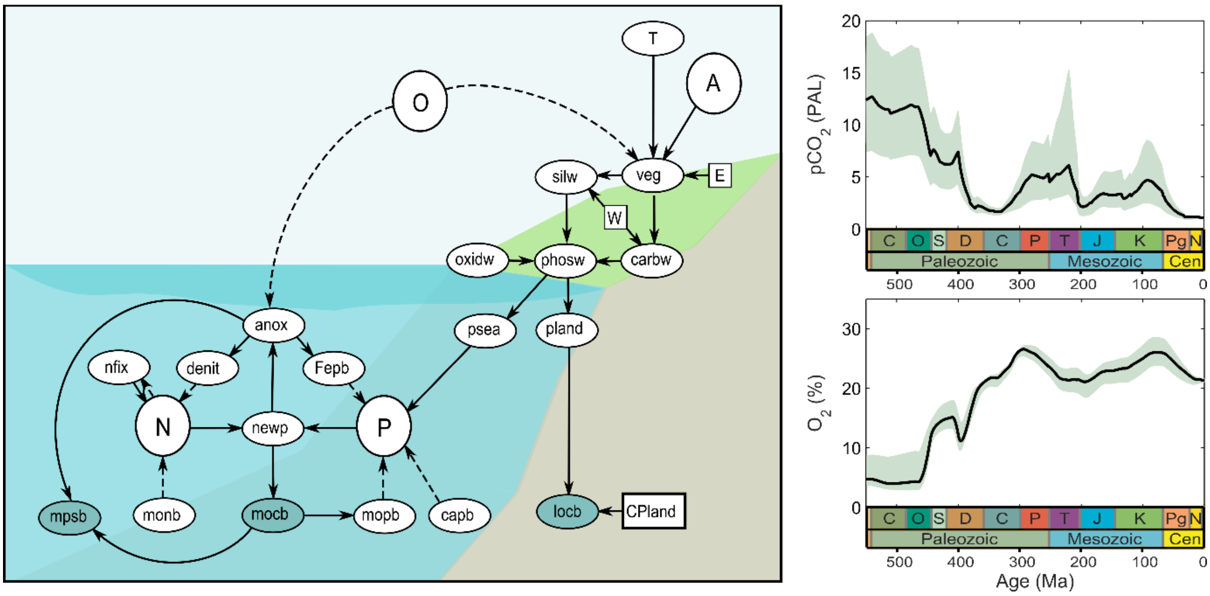

Figure 2. Example of Earth System box modelling [Lenton, Daines and Mills, 2018], showing the terrestrial and marine biogeochemical cycles (left) alongside model predictions for variations in atmospheric O_2 and CO_2 concentration over the Phanerozoic Eon.

Impact of the research

The question of the ability of life to alter and regulate climate on a global scale is a top priority in the Earth sciences, and papers on this subject appear regularly in top geoscience journals, as well as leading interdisciplinary publications such as *Science* and *Nature*. All of the project team, and several of our previous PhD students, are active researchers who publish in the most prestigious journals. Moreover, the field of Earth systems science is relatively new, and many topics remain unaddressed. This project will not only provide an excellent suite of geochemical data for an exciting period in Earth history, it will directly address some of the key questions in the field that are also of interest to the general public. We therefore expect the impact of this project to be highly significant within the scientific community and beyond.

(Click to see research in this field co-authored by Dr Mills in the Guardian newspaper)

(Click to see research in this field co-authored by Dr Mills and Prof Poulton in the Daily Mail newspaper)

Training

There is scope within this project to develop a wide skill set, which is multidisciplinary in nature yet inextricably linked: the researcher will receive training in both numerical modelling and cutting edge laboratory techniques from world leaders in these fields, and will have the opportunity to collect additional samples with the help of expert geologists. The researcher will also be trained in the scientific method, concise writing and presentation, along with a broad range of additional courses offered by Faculty Graduate School.

Partners and collaborators

The project will benefit from the expertise of an external supervisor at British Geological Survey.

Entry requirements

A good degree in the physical sciences, mathematics or computing is required, and the candidate should have a strong interest in Earth history and geoscience. Formal training in laboratory geochemistry, geology or numerical techniques is not essential, but experience in at least one of these fields is advisable. All necessary training will be provided as part of the project.

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