Exploring the impact of land plant evolution on Palaeozoic ocean oxygenation

University of St Andrews, Earth & Environmental Sciences
In partnership with Heriot Watt and CASE partner Applied Petroleum Technology

Apply under: https://www.iapetus2.ac.uk/studentships/

Supervisory Team
- Dr Catherine Rose, University of St Andrews
- Prof. Thomas Wagner, Heriot Watt University
- Dr Eva Stüeken, University of St Andrews
- Dr Darren R. Gröcke, Durham University

Key Words
1. Palaeozoic
2. Ocean redox
3. Stable isotopes
4. Organic geochemistry

Overview
Life on Earth today is largely dependent on oxygen as a source of energy and as a driver of oxidative weathering. It has long been thought that modern atmospheric levels of $O_2$ were established in the Neoproterozoic, around 600 million years ago (Ma), and thus caused the Cambrian explosion of complex life (e.g. Shields-Zhou and Och 2011). However, recent computational models and statistical analyses of global geochemical datasets suggest a more nuanced trajectory (Figure 1). Oxygenated conditions in the Neoproterozoic deep ocean may only have been transient (Sahoo et al. 2016), and it may have required the expansion of land plants in the early Palaeozoic to raise atmospheric $O_2$ to modern levels (Dahl et al. 2010, Lenton et al. 2016, Krause et al. 2018). This emerging view would have major implications for our understanding of the drivers of early evolution. For example, it may explain the emergence of fishes in the Devonian (Dahl et al. 2010), and it could be linked to trends in the extent of bioturbation over time (Tarhan et al. 2015).

However, the evidence for Palaeozoic oxygenation is so far only based on long-term trends in isotopic data, averaged over a diverse range of depositional settings (Dahl et al. 2010, Krause et al. 2018). Different proxies have been applied to different rock units, making it difficult to identify potential covariances. While this approach has been valuable in providing a theoretical framework (Lenton et al. 2016), it limits our ability to derive cause-effect relationships between $O_2$ production, nutrient supplies, marine productivity and ocean redox. To address these questions, multi-proxy high-resolution geochemical records spanning from the Ordovician to the late Devonian are needed.

Figure 1: Atmospheric $O_2$ levels (a) and the reconstructed maximum volume of marine biomass (b) through the Phanerozoic, modified from Krause et al. 2018. The time interval marked in orange captures the rise of land plants and will be investigated in this study.
The aim of this project is to explore a combination of organic and inorganic geochemical tracers and stable isotope stratigraphy in well-preserved Palaeozoic sections from Austria, Estonia and USA that span the Ordovician to Devonian time interval. The data will be used to: (a) correlate sections regionally and globally; (b) reconstruct the redox evolution and nutrient reservoirs of these marine basins; (c) test for influx of plant biomass reflected in organic biomarkers, and elemental ratios; and (d) identify linkages between these records that can speak to the presence or absence of a direct terrestrial influence on marine habitats.

Methodology

The project will include a range of geological and geochemical techniques, including:
- Field work and detailed sedimentary logging of the Palaeozoic sections in Austria (Figure 2) and Estonian. The Austrian strata include multiple facies from the upper Ordovician to the upper Devonian, while the Estonian deposits extend from the upper Cambrian to the lower Devonian. In addition, organic rich evaporitic cores from the Michigan Basin, USA will be incorporated into the study.
- Analyses of carbon (organic and inorganic), nitrogen and sulphur (硫酸盐 and 硫化物) isotopes as tracers of redox and productivity (e.g. Stüeken 2013, Rose et al. 2019).
- Analyses of C/N and C/H ratios in extracted biomass as indicators of its source and maturity.
- Major and minor elemental analyses to establish sediment provenance and potential enrichments in redox sensitive proxies.
- Extraction of organic biomarkers indicative of plant biomass input to marine sediments.
- Kerogen microscopy as an independent constraint on biomass provenance

The isotopic and elemental abundance analyses will be carried out at the University of St Andrews, supervised by Dr Catherine Rose and Dr Eva Stüeken and Durham University, supervised by Dr Darren Gröcke. Organic geochemical analyses will be performed at Heriot Watt under the supervision of Prof. Thomas Wagner.

Timeline

YEAR 1: Field work in Austria will be conducted in the summer immediately before the start of the project. Samples will be collected from onshore and offshore sections (e.g. Brett et al. 2009). Fall and winter of year 1 will be used for sample preparation and analyses at both St Andrews and Durham. The student will spend a few weeks in the spring in Edinburgh to perform organic geochemical analyses on selected samples. During this year, core material from the Michigan Basin, USA (Dr Gröcke already has this core material) will also be processed for elemental and organic geochemical analyses.

YEAR 2: Drill cores and field sections in Estonia will be sampled in the summer of year 2, again covering a range of facies from Ordovician to Devonian strata. The sampling will be carried out with local support from Dr Aivo Lepland and Dr Kalle Kirsimae. The samples will be prepared and analysed for inorganic and organic proxies over the course of the year, greatly expanding on existing data sets (e.g. Richardson et al. 2019).

YEAR 3: The last year will be used for the completion of geochemical analyses from both settings. Selected samples will also be submitted for non-traditional stable isotope analysis (e.g., molybdenum, osmium). The results will be synthesized into peer-reviewed international scientific publications. Year 3 will also provide room for an internship with CASE partner Applied Petroleum Technology.

YEAR 3.5: Completion of the dissertation.

Training & Skills

The student will gain training in geological techniques, including field sampling, sedimentary logging (e.g. Figure 3) and petrography.
Furthermore, the project will provide extensive training in specialised laboratories that perform inorganic, organic and stable isotope geochemical analyses. A 3-month internship with our CASE partner Applied Petroleum Technology will provide additional opportunities to gain hands-on experience and training in kerogen microscopy and organic analytical techniques. Transferrable skills will include quantitative data analysis, time management, public presentations, scientific writing and teamwork.

Transferrable skills will include quantitative data analysis, time management, public presentations, scientific writing and teamwork.

References & Further Reading


Further Information

For additional questions contact Dr Catherine Rose (cvr@st-andrews.ac.uk).