Quantifying CO2 storage in the glacial ocean

Curious12

Biogeochemical Cycles

IAP2-19-104

Overview

The cause of glacial-interglacial CO2 cycles is a first order, unsolved question in climate science. Although a number of viable mechanisms for glacial CO2 change have been proposed, suitable data to provide robust tests of these have been lacking. A major missing piece of this puzzle is the nature of CO2 storage in the deep ocean during glacial periods.

This project will quantify the extent and nature of deep ocean CO2 storage during the last glacial cycle, constraining the roles of changes in respired carbon, carbonate compensation, sea ice, and ocean circulation.

Deep ocean CO2 reconstructions will be based on the boron concentration (B/Ca) and isotope composition (d11B) of benthic foraminifera (Yu & Elderfield, 2007; Rae et al., 2011; Rae 2018), which record CO32- and pH respectively.

To quantify CO2 storage by the biological pump, we will reconstruct deep ocean oxygen using a suite of novel trace elements in foraminifera and bulk sediments, including iodine, uranium, manganese, and cerium (e.g. Zhou et al., 2016; Gottschalk et al., 2016). This will be complemented by carbon isotope gradients between different species of benthic foraminifera (e.g. Hoogakker et al., 2015), and preserved alkenone fluxes (Anderson et al., 2019). Interpretation will be guided by a sediment redox model.

Changes in circulation and temperature will be constrained using detailed depth profiles of d18O, d13C, Mg/Ca, and 14C.

These new depth profile data will allow constraints to be placed on advection versus diffusion, and the carbon budget to be examined for the ocean's abyss (Lund et al., 2011). Respired carbon can be calculated based on the difference between reconstructed oxygen content and oxygen-saturated values (based on temperature reconstructions). The extent to which this is driven by a stronger biological pump vs longer deep ocean residence time can be tested by comparison to radiocarbon, with constraints on the role of different water masses from depth and geographical distributions. Benthic d13C will be corrected for respired carbon to estimate preformed d13C, which is a function of air-sea gas exchange and thus sea ice extent. And comparison of respired carbon content to pH and CO32- profiles will allow us to quantify the efficiency of carbonate compensation.

Interpretations will be further guided by experiments with the GENIE Earth system model.

Methodology

Supervisory Team

Dr James Rae
University of St Andrews

Dr Babette Hoogakker
Heriot Watt University

Dr Eva Stueken
University of St Andrews

Dr Andrea Burke
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
- Oxygen
- Geochemistry
- Ice Age

Sediment core depth profile material is already in hand from four locations in the deep Atlantic and Pacific oceans. Analyses on sediment and foraminifera will be carried out in the St Andrews Isotope Geochemistry (STAiG) lab, recently developed to improve precision on small samples. Trace elements will be measured on a new state-of-the-art triple quadrupole ICPMS, allowing removal of interferences from several key elements (e.g. REEs).

Controls on redox proxies will be further explored using sedimentary redox modelling, in collaboration with Dr Sandra Arndt at the Universite Libre de Bruxelles. These may also be paired with output from the GENIE Earth system model.

The initial focus is the LGM, but it may also be possible to examine other portions of the glacial cycle and carbon release during deglaciation.

Project Timeline

Year 1

Training in clean laboratory methods and mass spectrometry, initial measurements and training, GENIE modelling, literature review.

Year 2

Generate detailed records. Sediment redox and GENIE modelling. First manuscript.

Year 3

Finalise data sets, apply numerical techniques. Second manuscript.

Year 3.5

Finalise manuscripts and write thesis.

Training & Skills

The student will gain specific training in mass spectrometry, clean lab chemistry, and geochemical modelling, as well as broader education in geochemistry, 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

Gottschalk et al. (2016), Nature Comms. 7, 1-11
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Further Information

Dr James Rae
Department of Earth and Environmental Sciences
University of St Andrews
St Andrews
KY16 9AL
+44 (0)1334 463901
jwbr@st-andrews.ac.uk