PROJECT BARIUM: Publishable summary

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Ice core records show that atmospheric carbon dioxide (pCO_2), an important greenhouse gas that drives and amplifies climate change, varies naturally over a range of timescales. Biological productivity in the oceans is a major contributor to carbon drawdown, and an important factor controlling atmospheric pCO_2. The Southern Ocean is linked with these climatic events, in part due to upwelling and subduction of deep waters during which carbon and heat are exchanged with the atmosphere, and partly because it exerts a primary control on the distribution of nutrients to a large portion of the modern ocean, which in turn regulates algal population structure and carbon uptake.

The aim of project BARIUM was to further the understanding of oceanic carbon storage over a range of timescales in the region of the West Antarctica Peninsula (WAP), the region experiencing the most rapid atmospheric and oceanic warming in recent decades. Here, we utilized components of the biogeochemical cycle of barium (Ba) to understand and investigate different aspects of organic and inorganic carbon storage. The analyses carried out during the reintegration period provided data suitable for testing hypotheses linking Southern Ocean circulation to global climate over a range of timescales, and linking the response in biogeochemical cycles to future climatic change.

Barium (Ba) cycling has been a focus of chemical oceanography and palaeoclimate studies for over twenty years, and can provide uniquely an insight into both organic and inorganic carbon storage. Ba export to the seafloor, measured in the form of "biogenic barium", has been used as a chemical archive for the export of carbon to the seafloor. Evidence indicates the incorporation of Ba into the calcite shells of single-celled foraminifera (denoted by Ba/Ca) relates to ambient Ba concentrations and, in the deep sea, dissolved inorganic carbon and alkalinity, and so ocean circulation. However, there are many open questions surrounding the cycling of Ba in seawater, and its application as a paleoproxy. What are the major inputs and outputs of Ba in the oceans, and how do processes such as glacial and riverine inputs, deep-water upwelling and particle scavenging influence Ba distribution? How does Ba cycling in seawater relate to biological productivity? What determines how foraminifera record Ba/Ca? How do sedimentary processes influence Ba/Ca? In addressing these questions, it will be possible to interpret Ba_{bio} and foraminiferal Ba/Ca records more robustly in terms of past ocean chemistry and carbon cycling. We also extended our project by measuring the isotopic composition of the barium in some of our samples. Barium stable isotope analysis provides a new approach for investigating Ba cycling in seawater, and an additional new tool for probing the marine barium cycle.

I have formed a small research group dedicated to project BARIUM, comprising two PhD students, Stephane Bates and Kimberley Pyle. Stephanie worked on aspects of the project relating to Ba/Ca in foraminifera, and on barium isotopes in seawater and foraminifera; Kimberley worked on investigating dissolved barium in seawater and sea-ice from Southern Ocean and WAP. They have also both been on field expeditions to collect samples, and have acquired other samples from existing collections.

We have produced a high resolution, high precision dataset of dissolved barium from the West Antarctica Peninsula, Drake Passage and Scotia Sea. From the WAP shelf, our results reveal insight into the processes that control sources and sinks of barium in seawater (sediment dissolution, sea-ice processes, ocean circulation and biological productivity), as well as showing that there is significant interannual variability as a result of changes in these physical and biological processes. Our open ocean

results show how the physical structure of the frontal zones within the Southern Ocean influences the behaviour of barium in seawater.

We have also produced climate records extending back through time, comprising sedimentary records of foraminiferal Ba/Ca from the Southern Ocean, which will provide information on changes inputs of barium in the past. We have found significant differences between the barium concentration of the Southern Ocean between today and a "time-slice" 125 thousand years ago, during the last warm period (interglacial) before the last ice age. Ice core records show that this period was warmer than the preindustrial period, and had a higher pCO_2 record, and is a potential analogue for the predicted warming into the next few decades. Our results have implications for how the circulation of the Southern Ocean may respond to a warmer world, and for our predictions of future change. We have also produced the first barium isotope measurements for foraminifera, and for seawater in the Equatorial Atlantic. Our results highlight the value of barium isotope measurements for understanding the processes controlling Ba distributions in seawater and thus the mechanisms that underpin Ba-based proxies in palaeoceanography.

Our findings will be of great interest to policy makers and industry. The high-latitudes are experiencing some of the fastest atmospheric and oceanic warming observed over the past few decades. There is significant interest from UK (for example from the UK Government Department of Business, Innovation and Skills), EU and international governments in developing a greater understanding of atmospheric and oceanic circulation, hydrology and sea-ice, and ice sheet dynamics in the high latitudes. To understand these processes, we need to combine chemical oceanographic tracers, and palaeoclimate records of these tracers - such as being investigated by Project BARIUM - with physical models and observations. We have already been able to extend our project to the Arctic, via a new collaboration with Norwegian colleagues, including collaborating on a field campaign in 2015 and workshops in 2016 to bring together academics and policy makers.

Our website is at: http://oceanbarium.wordpress.com/