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Short Communication

The ocean bottom deposit collection at the Natural History Museum, London as a tool to investigate the effects of climate change

Epifanio Vaccaro
Palermo University, UK

Abstract :

The Natural History Museum (NHM) in London is home to an estimated 80 million items dating back as far as 1753. The NHM is recognized as a world leading centre of natural history collections and research. Many of the collections have great historical as well as scientific value, such as The Ocean Bottom Deposit (OBD) collection. This includes the Sir John Murray, HMS Challenger expedition (1872-76) collections as well as samples from about 40,000 sea bed locations around the world. It is the most comprehensive British collection of seabed samples and cores but also includes approximately 65% from the Atlantic Ocean, 20% from the Pacific Ocean and 15% from the Indian Ocean. The OBD collection is invaluable for studies of the ocean and ocean floor, including research looking at global change, climatic warming, ocean acidification and marine pollution. This historical collection has a large number of calcifying organisms that provide a benchmark for changes in carbonate production in marine ecosystems through time. A project led by museum researchers has compared the calcification capability of today???s plankton species with their counterparts from pre-and early-industrial time. This has been based on plankton tows collected during historical expeditions and has provided new insights into anthropogenic climate change. Recent work has also investigated the foraminiferal content of benthic samples from the collection and shown a method for selecting samples that show a late 19th century baseline for the marine environment.

Introduction:

The HMS Challenger expedition from 1872 to 1876 can claim to be the foundation of modern oceanographic studies. This historic voyage was the first to specifically gather data on a broad range of ocean features, including ocean temperatures, seawater chemistry, currents, marine life, and the geology of the seafloor. In 2022 scientists will celebrate 150 years since the HMS Challenger first left port to begin this ground-breaking oceanographic expedition. During this time scientific and technological methods have advanced substantially, but the wealth of knowledge associated with the modern ocean systems is in stark contrast to the fundamental lack of baseline ocean data from the Industrial Revolution onwards.

The wealth of historical collections housed at museums and similar institutions across the world can often be overlooked for cutting edge climate research. At the Natural History Museum, London, the Ocean Bottom Deposits (OBD) collection, which includes vast amounts of material from the HMS Challenger expedition, provides an almost unique source of microfauna to compare pre-industrial oceans to those of today. In this study: "The Challenger Revisited Project", the collection provides a unique opportunity to study the effects of one of the most urgent questions of our time with regards to anthropogenic environmental change: ocean acidification (OA).

It is now widely accepted that OA is an imminent threat to our oceans, and although we have a good understanding of the related changes in ocean chemistry, the widespread biological impacts of OA remain unclear. Since the beginning of the industrial revolution (1760 onwards), CO2 emissions from the burning of fossil fuels and changes in land use have led to an increase in atmospheric CO2 levels concentrations of 280 ppm to, presently, over 400 ppm7, with a dramatic change in magnitude and rate of the human imprint from 1950 onwards known as "The Great Acceleration". Without significant mitigation, CO2 values are expected to rise to between 550 and 1000 ppm, depending on emission scenarios, by the end of this century7.

Oceanic carbonate ion concentrations decrease as a consequence of increased atmospheric CO2 levels, which, in turn, has a negative effect on the capacity for calcifying organisms (such as molluscs, crustaceans, corals, and foraminifera) to form their essential skeletal or shell material out of calcium carbonate. Worryingly, recent laboratory experiments and marine chemical models suggest that eventually calcification rates could slow to the point where they are outpaced by dissolution, and during the 21st century, corals and other calcifying organisms may suffer a great decline. Planktonic foraminifera are one such group that are highly important contributors to carbon cycling in the ocean. They are not only responsible for a quarter or more of global carbonate production, but also an integral component of the marine food chain. However, to date there is little information available with regards the impact of OA on calcification rates of planktonic foraminifera. While lab-based studies are invaluable in assessing short-term controls on calcification in certain species, they do not allow for adaptation in planktonic foraminifera, which have to date, never reproduced in a laboratory environment.

Attempts to evaluate the impact of OA on calcification in the oceans have been hindered by an inability to directly compare the calcification capability of today's plankton species with equivalent specimens from exclusively pre-and early-industrial times. Field-based studies have tried to compare the calcification ability of a modern plankton species today with their pre-industrial counterparts by using seafloor sediments to represent 'pre-industrial' times. However, one centimeter depth of deep sea sediment may represent 100's of years of Earth's history, therefore this method inevitably incorporates a mix of specimens from a large window of geological time, leading to potential circularity when comparing data from these sediments to modern sediment traps or plankton tows.

Multiple plankton tows collected by the HMS Challenger crew from across the world's ocean basins between 1872–1876 provides a resource that resolves issues highlighted in both lab-based and field-based studies; the tow material contains the planktonic foraminifera, of a known age, that were alive in the open ocean at the time of sampling. Thus, the HMS Challenger collection provides exceptional baseline data for 19th–21st century ocean acidification evaluation. Here we present the results of a focused study from the central Pacific Ocean, a region identified as being vulnerable to ocean warming, ocean acidification, and ocean deoxygenation with increasing atmospheric CO2 levels. The results of this study highlight the utility of museum collections for studies of anthropogenic climate change, and demonstrates an urgent need for more empirical data.

Conclusion:

Initial findings of the Challenger Revisited project have revealed a reduction in shell thickness of up to 76% in selected species of planktonic foraminifera over the last c. 140 years, which corresponds to a period of profound change in our oceans. Ocean acidification is not the only stressor faced by the world's oceans in the coming decades and over the time period studied here. Rising temperatures and deoxygenation are also likely to have a substantial impact on marine ecosystems, and eastern boundary upwelling systems are likely to be strongly affected by all three stressors. A recent study by Roemmich et al. (2012) comparing Challenger sea surface temperature measurements (1872–1876) to a more recent data set from the Argo Programme (2004–2010) revealed substantial warming of the modern upper ocean, with a warming signal that is global in its extent. We propose OA as the lead cause for the observed reduction in calcification of planktonic foraminifera as our results closely mirror results from laboratory studies and field observations from the Arabian sea. However, It could be argued that rising temperatures, deoxygenation and OA are intrinsically linked and therefore these stressors should not be separated. More work is required to further explore the application of this method by increasing sample sizes and undertaking comparative studies in other ocean basins. Though the HMS Challenger samples only provide a snapshot of early industrial ocean conditions, the method has potential for global reconstructions. The "Challenger Revisited project" will be expanded beyond the Pacific Ocean, and the methodology can be applied to other historical expedition collections such as the Terra Nova [1911–1915] and Discovery [1920–1930s] when comparatory contemporary expedition materials are available.

Whilst all specimens analysed showed some reduction in shell thickness, the degree to which different species responded varied greatly. Specimens of N. dutertrei, a non-spinose, thermocline-dwelling planktic foraminifera that possesses intracellular chrysophyte alga revealed up to 76% reduction in shell thickness between the preindustrial and the modern, whereas G. ruber specimens display a far smaller decrease in shell thickness (~20%). G. ruber is a spinose multichambered species known to occupy the mixed layer of the ocean and hosts photosynthesising algal symbionts (dinoflagellates) which can alter the chemistry of the sea water immediately surrounding the shell and therefore enhance calcification. Numerous studies have demonstrated that a variety of calcifying organisms respond negatively to decreasing ocean pH, such as coccolithophores, pteropods and corals. However, certain photosynthesising organisms have been shown to benefit from higher availability of dissolved CO2.

To further investigate all drivers for these differences in shell thickness, the effect of depth habitat on calcification ability is worth further study, as is how photosymbiont hosting foraminifera and also the types of symbionts may be more resilient to decreasing pH. Studies of the fossil record have shown that foraminifera, when under extreme stress, will shed their symbionts in the process of bleaching.

In addition, the application of directed geochemical analyses have the potential to disentangle the multiple factors that could be driving the reductions in shell thicknesses shown here. Boron isotope analysis on comparable historic and modern planktonic foraminifera shells can provide accurate reconstructions of pH conditions at the time of shell development, which in turn links the reduction of ocean carbonate ions as the driver for reduced shell calcification. There is therefore the potential to gain new insights into the rate of change taking place in the oceans, contributing greatly to our understanding of the sensitivity of global climate systems to CO2 forcing. Such insights are crucial for predicting the future climate and health of the oceans.