

VOYAGE TO THE SUB-ANTARCTIC

A five-week marine science voyage to the sub-Antarctic, between January and February this year, investigated a range of ocean properties and processes involved in the cycle of carbon from the atmosphere to the deep ocean. The research, which is critical to understanding the likely impacts of climate change on ocean ecosystems, involved scientists from the Australian Antarctic Division, Antarctic Climate and Ecosystems Cooperative Research Centre, CSIRO Marine and Atmospheric Research and several international institutions. The following articles outline the early results of four research projects conducted during the *Sub-Antarctic Zone Sensitivity to Environmental Change* voyage.

LOOKING TO THE PAST FOR CHANGES IN THE PRESENT

By comparing the fossil record with modern day planktonic species, scientists from the Antarctic Climate and Ecosystems Cooperative Research Centre (ACE CRC) are investigating changes in ocean ecosystems wrought by increasing amounts of anthropogenic (man-made) carbon dioxide.

Since the industrial revolution, increasing amounts of anthropogenic carbon dioxide (CO₂) have been entering the global ocean; changing the carbonate chemistry¹ and pH of the surface ocean and increasing ocean acidity. The ecological effects of changing ocean carbonate chemistry are uncertain, but are thought to include reductions in the ability of some marine organisms, such as coccolithophorids², planktonic foraminifera², corals and pteropods³, to form shells. These ecological changes in turn may alter the capacity for the ocean to continue to absorb CO₂ from the atmosphere, and so set up a feedback that could exacerbate the rate and impacts of global greenhouse processes.

Ongoing research by the ACE CRC, comparing foraminifera deposited centuries ago in sediment cores with their living counterparts, seeks to document the effects of ocean acidification on the ability of these organisms to form shells.

The foraminifera have experienced similar geochemical shocks in the past. Reconstructions of surface water carbonate chemistry using shell weights of planktonic foraminifera in deep-sea cores, display changes that have similar timing and magnitude to those inferred from ice cores for atmospheric CO₂ during previous glacial cycles. These past cycles are of similar magnitude to the anthropogenic CO₂ effect.

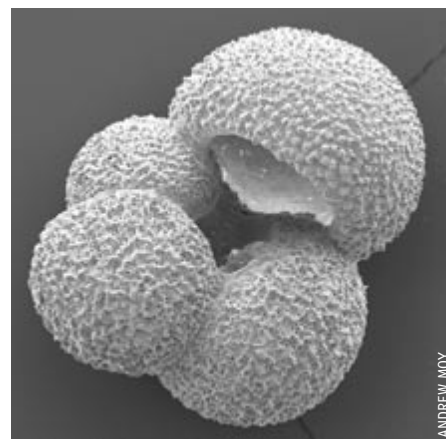
The effects of increased atmospheric CO₂ are already detectable in the carbonate chemistry in the surface ocean. The anthropogenic CO₂ in the Southern Ocean corresponds to a decrease in carbonate ion (CO₃²⁻) concentration, equivalent to a pH decrease of 0.11 units. This increase in acidity is predicted to cause a change in calcification of the most abundant planktonic foraminifera species in the sub-Antarctic Southern Ocean.

Foraminifera and coccolithophorids secrete shells of calcite, the most stable and robust form of calcium carbonate. Other plankton form shells of aragonite – a mineral phase more vulnerable to the effects of acidification than calcite. In addition to collecting the calcitic foraminifera, we collected samples during the recent *Sub-Antarctic Zone Sensitivity to Environmental Change* voyage, to document the impact of acidification on pteropods – which secrete aragonite shells – over the past few decades. We found pteropods to be surprisingly abundant in the plankton community of the Southern Ocean, both in sub-Antarctic sediment traps and in net tows taken during the voyage.

The Southern Ocean provides an excellent setting for such an analysis because it crosses major surface-ocean gradients in carbonate chemistry and calcium carbonate production, and spans the latitudes of maximum oceanic uptake of CO₂.

The Southern Ocean also contains more CO₂ than other oceans because cooler water absorbs more CO₂ than warmer water. Thus it is a biogeochemical harbinger for the impacts of acidification which may spread throughout the global ocean. The Australasian Sector of the Southern Ocean (south of Australia) is also the site of several long-term studies of ocean chemistry and oceanography, providing substantial background information from which changes can be measured.

By combining data from samples of foraminifera and other calcareous plankton collected from sediment traps, with geological records from seabed cores, we have the potential to detect changes in the carbonate chemistry and the ecologies of calcareous organisms since the



The planktonic foraminifera, *Globigerina bulloides*, is being studied for its response to ocean acidification. This specimen was collected in a sub-Antarctic sediment core.



This pteropod, *Cavolinia uncinata*, also called a 'wing-footed' pelagic snail, from the Gulf of Alaska, is threatened by ocean acidification. The animal reaches 7-10 mm in length and feeds by secreting large feeding nets or bubbles to which tiny food particles (such as phytoplankton) stick.

industrial revolution, and place them into the context of longer term, pre-industrial dynamics. This 'natural experiment' can only be done with microfossils of existing marine organisms, as they are the same species living in the modern ocean that have experienced the geochemical perturbations of the past 600 000 years.

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1 When CO₂ dissolves in the ocean it forms carbonic acid (H₂CO₃). Increasing acidity disrupts the formation of calcium carbonate (CaCO₃), a major structural component of the shells of several important planktonic organisms.

2 Coccolithophorids and foraminifera are single celled organisms that contribute to the plankton in the ocean. Plankton is composed of phytoplankton – single cell marine plants such as algae – and zooplankton, which includes single and multi-cellular animals (including krill) and other organisms not classed as animals, which eat phytoplankton. The white cliffs of Dover in England, and similar chalk deposits, are made up of the remains of coccolithophorids – a marine alga. Foraminiferans are neither plant nor animal, but belong to a group called 'protists'. They feed on phytoplankton, bacteria and other planktonic organisms.

3 Pteropods are planktonic, snail-like animals (molluscs).