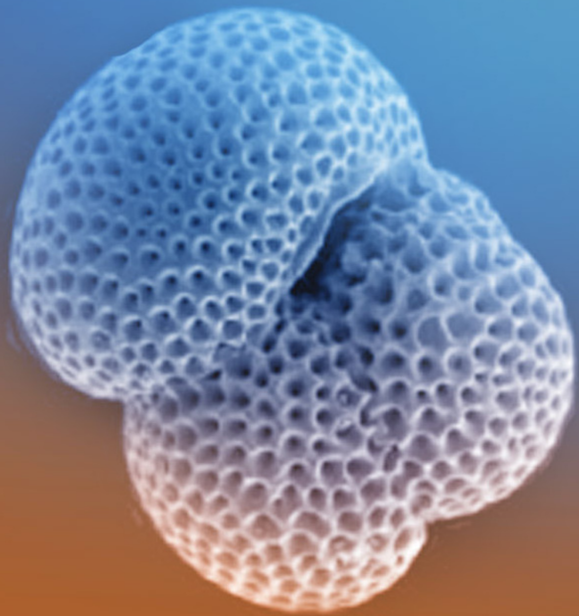
UK Ocean Acidification Research Programme

UK Ocean Acidification programme synopsis

Ocean acidification in the geological past



Lessons from the past

Global-scale ocean acidification is happening now, as a result of human activities adding CO_2 to the atmosphere. But ocean acidity has increased previously in the Earth's history, as a result of natural changes in atmospheric composition. Of particular interest are past releases of CO_2 that have occurred relatively rapidly in geological terms, since they may provide natural analogues for the effects of current acidification on chemical processes and marine life. Calcifying organisms (that construct their shells out of calcium carbonate) provide an important research focus, since they are preserved in the fossil record and are also likely to be especially sensitive to changes in ocean chemistry.

Most of the palaeo-oceanographic work in UKOA was carried out by a consortium project Abrupt ocean acidification events and their effects in the Earth's past, led by Paul Pearson at Cardiff University. Formal partners were at Southampton, University College London and the Open University, with additional contributions by researchers at Bristol, Oxford, Yale and elsewhere. These research groups investigated a variety of geological records from the deep sea and the margins of the ocean, with particular attention given to events around 56 million years ago, at the Paleocene - Eocene thermal maximum. Newly-recovered marine sediment samples from Tanzania provided very well-preserved planktonic microfossils, suitable for a range of novel geochemical and biological studies.

Specific aims of the consortium study were:

- To produce new estimates of seawater acidity and atmospheric CO_2 levels for the period 40-65 million years ago
- To study the response of the carbon cycle during the onset of the Paleocene - Eocene thermal maximum (PETM) using new data from Tanzania and elsewhere and new computer models
- To compare the PETM with other known ocean acidification events in the Earth's past
- To quantify the biotic response to ocean acidification events both directly (speciation, extinction, migration and, malformation) and indirectly (ecosystem function, biogeochemical cycles).

Key findings:

- The pH decrease during the Paleocene Eocene thermal maximum (PETM) was not particularly strong, as a probable consequence of the CO_2 release occurring over many thousands of years.
- Nevertheless, the PETM event caused the extinction of around half the species of deep-sea benthic foraminifera, with temperature increases and de-oxygenation contributing to such effects.
- Planktonic calcifiers survived the PETM, although with major changes in their distributions and abundances. Comparative studies on modern planktonic calcifiers indicate differing sensitivities to ocean acidification at different life stages.
- Current rates of ocean acidification are around 10 times faster, and reductions in pH and saturation state are therefore likely to be much larger, than anything in at least the last 65 million years.
- The suggestion that the PETM onset only took 13 years is disproved, through the identification of drilling artefacts in the cores.
- No past event perfectly parallels projections of future changes in ocean carbonate chemistry and their potential ecological impacts–a consequence of the rapidity of the current CO_2 release.

Outputs:

Anagostou E, John EH, Edgar KM et al. (under review) Atmospheric CO_2 concentrations were a primary driver of the evolution of Cenozoic climate.

Aze T, Pearson PN, Dickson AJ et al. (2014) Extreme warming of tropical waters during the Paleocene-Eocene Thermal Maximum. Geology, 42: 739-742.

Aze T, Gibbs S & Pearson PN (2014) What the past can tell us – palaeo-oceanographic research. In: Henning S, Roberts JM & Williamson P (eds) An Updated Synthesis of the Impacts of Ocean Acidification on Marine Biodiversity. Secretariat of the Convention on Biological Diversity. Montreal, Technical Series No. 75, 99 pages.

Gibbs SJ, Poulton AJ, Bown PR et al. (2013) Species-specific growth response of coccolithophores to Palaeocene - Eocene environmental change. Nature Geoscience, 6, 218-222.

Gutjahr M, Sexton PF, Ridgwell R et al. (In prep.) Source, magnitude and rate of carbon release associated with the PETM.

Hönisch B, Ridgwell A, Schmidt DN et al. (2012). The geological record of ocean acidification. Science 335, 1058-1063.

O'Dea SA, Gibbs SJ, Bown PR et al. (2014) Coccolithophore calcification response to past ocean acidification and climate change. Nature Communications 5, 5363.

Pearson PN & Nicholas CJ (2014) Layering in the Paleocene / Eocene boundary of the Millville core is drilling disturbance. Proceedings of the National Academy of Sciences, USA, 111, E1064-E1065.

Pearson PN & Thomas E (2014) Drilling disturbance and constraints on the onset of the Paleocene / Eocene boundary carbon isotope excursion in New Jersey. Climate of the Past, 11, 95-104

Tyrrell T, Merico A & McKay DIA (2015) Severity of ocean acidification following the end Cretaceous asteroid impact. Proceedings of the National Academy of Sciences, USA; online, doi: 10.1073/pnas.1418604112

For full list of publications arising from this component of the UKOA programme, see separate hard-copy document or online at www.oceanacidification.org.uk

Earth’s history repeating itself – but not exactly

The geological record provides evidence of several major environmental changes in the past, including ocean acidification and its impacts on past marine life. Most data are from the last 100 million years, when calcifying organisms from the plankton have been preserved in sedimentary deposits. Such seafloor deposits of carbonate also provide long-term buffering capacity for the ocean, since they can be dissolved under high CO_2 conditions.

However, past ocean acidification events did not occur in isolation: other changes occurred at the same time. Thus they were primarily driven by increases in atmospheric CO_2, due to high volcanic activity, causing associated increases in global temperature and reductions in ocean oxygen levels (as a direct result of warmer ocean temperatures, and an indirect result of less ocean mixing). The Earth’s record of these three closely linked changes – ocean warming, acidification and de-oxygenation – therefore provide integrated analogues for what a multi-stressor future might hold: ‘hot, sour and breathless’.

Interpretation of fossil-based observations is assisted by carbon cycle modelling, with UKOA-supported studies showing that different rates of natural CO_2 release can produce different combinations of effects. Slower releases of CO_2, not surprisingly, give slower rates of ocean acidification; they can also de-couple its two main components, reduction in ocean pH and in carbonate saturation states, due to ocean buffering effects.

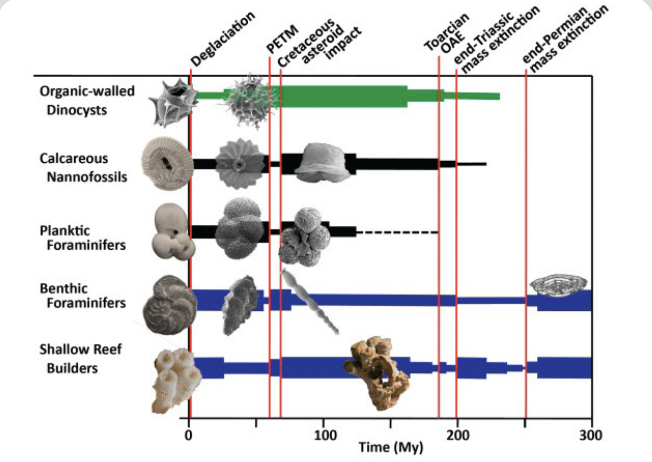


Figure from: Hönisch B, et al. (2012)

Thus it is not impossible for atmospheric CO_2 and ocean surface saturation state both to be high, although ocean pH is decreased; such conditions seemed to have occurred in the Cretaceous and Paleogene periods, around 35-100 million years ago, when there was high abundance of calcifying plankton.

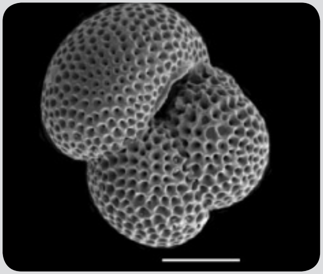
Comparisons of past events with future conditions are unlikely to be exact, since different timescales, and different primary causes, are involved. But those differences can themselves provide insights into the mechanisms, potential responses and the limits to adaptation, with awareness that in the past - as at present - global warming and ocean acidification occurred together.

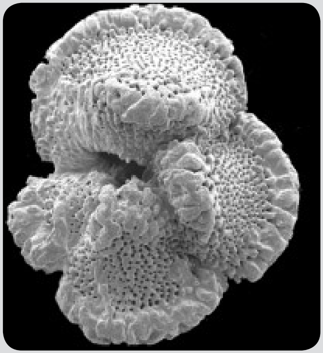
Deciphering natural diaries

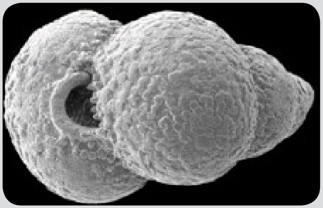
The fossilised remains of marine organisms provide information on their past distributions, abundances and evolution. They can also tell us very much more – since the chemical composition of shells and skeletons reflect the conditions in which they were alive. Analyses of the fossils of calcified micro-organisms such as foraminifera (single-celled animals, living in the water column and on the seafloor) and coccolithophores (planktonic single-celled algae), have proved to be particularly valuable, extending the instrumental record of acidity changes back by many millions of years.

Thus the 'natural diaries' of foraminifera provide a record of changes in seawater temperature and chemistry, linking with other information on how different species responded, in terms of growth rates, body size, abundances, geographical ranges, and, in some cases, their extinctions. Measurements of oxygen isotope ratios in the shells of individual specimens provide data for the temperature estimates, whilst boron isotope analyses provide matching data on changes in seawater pH. The boron measurements can also be used to determine the amount of CO_2 released to the atmosphere during specific perturbations of the global carbon cycle.

Foraminifera and coccolithophores remain ecologically-important groups in today's ocean, contributing to marine food webs, ecosystem functioning and biogeochemical feedbacks. Their past responses are therefore highly relevant to potential impacts in the future.





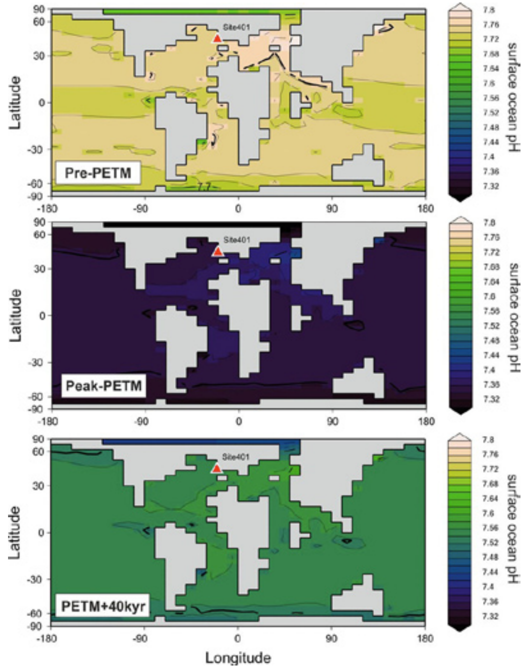


Focus on events 56 million years ago

Relatively recent geological events inherently provide better comparisons with present day changes, since organisms and their environments are more similar, and the fossil evidence is likely to be more accessible. Conditions during the Paleocene–Eocene thermal maximum (PETM) around 56 million years ago, are of particular interest, since the amount of carbon naturally added to the atmosphere then was similar to that likely to be released by human activities (3,000 - 5,000 gigatonnes). The PETM carbon release took place over a few thousand years; its effects lasted for around 170,000 years, and included a global temperature rise of over 5oC, a lowering of ocean pH and the dissolution of carbonate at the seafloor.

Studies of fossils from the PETM show severe extinctions of deep-sea benthic foraminifera, with up to 50% of species disappearing from the record. Those that survived were usually smaller and thinner shelled. Whilst planktonic foraminifera and coccolithophores living in the water column were not subject to mass extinctions, they did show range shifts, with tropical communities migrating polewards, to higher latitudes.

Overall, the temperature increase seems to have had greater impact than the ocean acidification effects, particularly for those species that can only slowly change their population ranges, such as sessile molluscs and corals.



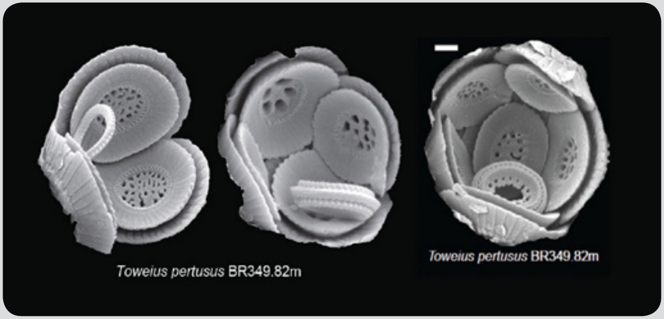
Model outputs constrained by data from site401 (red triangle) showing pH changes before, during and post PETM. (Gavin Foster)

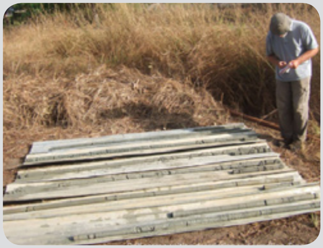
Biscuits help resolve timing controversy

Time-scales are crucial in making comparisons between past and present-day ocean acidification events. A new time-scale was recently proposed for the Paleocene-Eocene thermal maximum (PETM), on the basis that layering in sediment cores from New Jersey, USA was annual. That interpretation required the near-instantaneous release to the atmosphere of thousands of billions of tonnes of carbon, as either CO_2 or methane; for example, by cometary impact.

However, re-examination of the New Jersey cores by UKOA researchers showed that the apparently annual layers were an artefact of the sampling process. Sediment cores are extracted by cylindrical drills, and a combination of spinning and slippage can cause internal cracks or breaks in the core samples, forming discs or 'biscuits'. Thus the changes took place over several thousand years, rather than a decade or so.

Confirmation that present-day changes in ocean chemistry are occurring around ten times faster than those during the PETM means that ocean acidification impacts are likely to be much greater now than they were then. Thus today's more rapid changes do not allow the same opportunity for chemical buffering (hence greater reduction in carbonate saturation state for the same increase in atmospheric CO_2) and also less likelihood of biological adaptation.





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What is ocean acidification?

The global ocean currently absorbs more than a quarter of the CO_2 produced by burning fossil fuel and other human activities, slowing the rate of climate change. Global warming would therefore be far worse if it were not for the ocean. However, there is a cost: when CO_2 dissolves in seawater it forms carbonic acid, decreasing the pH and causing other chemical changes. These processes are known as ocean acidification.

The acidity (H+ concentration) of the surface ocean has already increased by nearly 30% due to these events, mostly in the past 50 years. If future CO_2 releases continue to follow current global trends, by 2100 ocean acidity will increase by as much as 150%, at a rate of change 10 times faster than at any time in at least the last 65 million years. Such a major alteration in ocean chemistry will have (and is already having) wide implications for marine life.

Ocean acidification is a relatively new field of research, with the overwhelming majority of studies carried out over the last decade. While the topic is attracting increasing attention among policy makers, international leaders and the media, there is still much to be understood about the fundamental biogeochemical, physiological and ecological processes; interactions with other stressors (notably temperature change) and the consequences of ocean acidification for society. UK scientists are at the forefront of these research areas, working in partnership with many international colleagues.

What is the UK Ocean Acidification research programme?

Widespread concern about ocean acidification emerged after the Royal Society report Ocean acidification due to increasing atmospheric carbon dioxide in 2005. A range of research initiatives were subsequently developed at both the national and international level.

The £12m, five year UK Ocean Acidification research programme (UKOA) was the UK's response, starting in 2010 and jointly funded by the Natural Environment Research Council (NERC), the Department for Environment, Food and Rural Affairs (Defra) and the Department of Energy and Climate Change (DECC).

The overall aims of UKOA were to increase understanding of processes, reduce uncertainties in predicting impacts and improve policy advice. Scientific studies have included observations and surveys; impacts on upper-ocean biogeochemistry; responses by seafloor organisms; effects on exploited species, food-webs and human society; ocean acidification in the geological past; and regional and global modelling. In addition to national policy liaison, UKOA has made significant contributions to the work of the Intergovernmental Panel on Climate Change (IPCC), the UN Framework Convention on Climate Change (UNFCCC), the UN Convention on Biological Diversity (CBD), the UN Sustainable Development Goals (SDGs) and many other governmental and non-governmental initiatives and activities.

NERC Science of the Environment

Department for Environment Food & Rural Affairs

Department of Energy & Climate Change

Living With Environmental Change

Boot KJ, Pearson P, Foster G, Turley C, Williamson P (2015)
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