Polar predictions

Dr Alistair Crame, Professor Jane Francis, Dr Stuart Robinson and **Dr Vanessa Bowman** discuss how their UK-based research project tackles the challenges of understanding palaeoclimate and how this information can improve current climate change research

How does the study of past environments and climates shed light on the impact of major environmental change?

JF&VB: Understanding past environments is key to making predictions about future changes in the Earth System that may affect humanity. Since the 1980s, environmental groups have been increasingly active in raising awareness about human-induced global warming or, more accurately, climate change. This is largely due to the continual worldwide burning of fossil fuels for energy, which releases gases into the atmosphere, warming the planet beyond its natural variability.

Our notions of the impact of this warming – which includes increased storm frequency, more marked seasonal extremes and global sea level rise – are reliant on predictions made by complex global climate computer models. Global governmental strategies for mitigating these physical environmental changes are based on the results of thousands of peer-reviewed scientific articles. These studies feed information into climate models, interpret the results and are summarised every few years in the Intergovernmental Panel on Climate Change report.

The study of past environments and climates is an essential part of this process. It uses the pre-human geological record to understand the Earth System's past activity and response to climatic change, which occurred naturally and periodically for many reasons including changes in the Earth's orbit, meteorite impacts and the movement of the continents. By looking to the geological record of the climatically-sensitive polar regions – particularly during times of global warmth – we can provide critical insights into the reaction of ice sheets to increased temperatures.

Can you summarise the cutting-edge geochemical techniques the team employs to study past climate change?

SR: As we cannot travel back in time and measure temperature directly, geologists use a range of tools, including geochemistry, to reconstruct past temperatures. These methods rely on empirical relationships between temperature and some chemical characteristic of a particular mineral, fossil or sediment. In the last decade, the range of geochemical tools available for studying past climates has increased, which allows us to crosscheck different techniques. Furthermore, traditional geochemical methods were generally only applicable to sediments deposited in seawater but some of the new tools allow us to reconstruct temperatures on land too.

The PALEOPOLAR team is studying organic molecules (lipids) produced by bacteria and Archaea as part of their cell membranes. In some modern environments, such as seawater and soils, the relative abundance of these lipids varies with temperature. We can extract these molecules from bulk sediment samples using organic solvents and then identify them and quantify their abundance using mass spectrometry. The Upper Cretaceous and Lower Paleogene sediments from Seymour Island on the Antarctic Peninsula contain molecules produced by soil bacteria, which were probably washed into the shelf sea with the abundant fossil wood and terrestrial pollen. Using these molecules, we are able to reconstruct soil temperatures for the Antarctic Peninsula at much higher temporal resolution than by alternative methods.

Why are fossils, of plants in particular, used as a tool for interpreting past climate?

JF&VB: We study details of the cell structure of fossil wood, which reveals the tree type and – from the analysis of growth rings – the temperatures and rainfall during the growing season. We can also estimate this information by observing the shape of leaf edges. Organic-walled microfossils (spores and pollen), extracted from rock using acids and viewed using a microscope, give further detail about plants growing in the region and terrestrial climate. In addition, fossils of marine plankton (dinoflagellate cysts) provide information about oceanic temperatures, nutrient levels and water depth.

Collaboration is clearly fundamental to your work. How do you ensure effective communication within the research group?

AC, JF, SR & VB: Funded projects include regular day-long progress meetings where contributors present their work to the rest of the team, discuss how the results compare and brainstorm ideas for interpretation: how do our results address our hypotheses? Have we made any significant breakthroughs? What is the impact of our results? How do we effectively disseminate our findings?

In what ways do you engage with the research community more broadly to increase PALEOPOLAR's wider impact?

AC, JF, SR & VB: Research is also presented at both national and international conferences where discussions from very different perspectives and disciplines often ensue. These generate new ideas that build on current results and develop future research directions. Effective communication also occurs subsequent to these forums, when scientific manuscripts and grant proposals are written, circulated and discussed amongst co-authors.

Understanding the **Antarctic**

In an effort to improve understanding of faunal evolution and its relationship to climate change, the **PALEOPOLAR** project is challenging existing theories about the Early Cenozoic era using an integrated, multidisciplinary approach in the polar regions

THE EVOLUTION AND SURVIVAL of Antarctic flora and fauna is a complex and absorbing subject area. Its comprehension requires detailed awareness of past biodiversity and environmental conditions derived from investigating fossil and geological records alongside modern analogues. Accurate reconstruction of past environments can only be delivered through effective coordination of diverse fields including biological, geological, geochemical and modelling approaches.

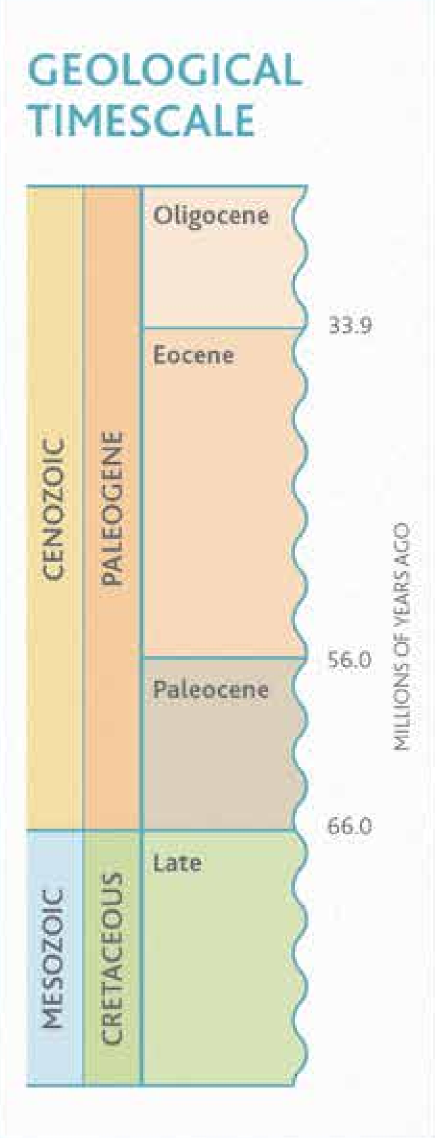
The PALEOPOLAR project, funded by the Natural Environment Research Council (NERC) – which includes researchers from a number of UK universities and the British Antarctic Survey – has set out to develop a climate record for the earliest Paleogene in order to better understand the impacts of global disturbances on the evolution of life in the polar regions. It builds on a previous NERC-funded project studying climate and biotic change up to the famous mass extinction event, 66 million years ago. These challenges have led the team to investigate Seymour Island off the Antarctic Peninsula, where there is an exceptionally thick and well-exposed sequence of rocks from the Late Cretaceous to Early Paleogene periods. In the past it has been described as the 'Rosetta Stone' of Antarctic palaeontology.

LATE CRETACEOUS ANTARCTIC ICE CAPS?

New results from the team contest a long-held conviction concerning the climate of Antarctica during the latest Cretaceous to earliest Paleogene. Fossil studies suggest that this was a period of global warmth representative of a 'greenhouse climate', with some clear indications that temperate and lush rainforests were present on the continent. However, separate lines of inquiry now suggest the episodic occurrence of seasonal sea ice at this time, is possibly suggestive of small ice caps at high altitudes on the Antarctic continent.

Using sediment samples collected from Seymour Island, ranging in age from 66-70 million years, the group's analysis suggests that a particular small, spiny dinoflagellate cyst underwent periodic and significant increases in abundance that implies algal blooms. Dinoflagellates (plankton) produce resting cysts as part of their life cycle, which accumulate and are preserved in sediments recording ocean conditions. These periodic algal blooms, recognised in the Seymour Island geological record as vast accumulations of resting cysts, appear to be analogous to those occurring in polar regions today due to returning nutrients and light brought by the melting of winter sea ice. Corroboration of this theory comes from a variety of spores, pollen and fossilised invertebrate shells from the same geological strata that support the evidence from the dinoflagellate cyst record that temperatures were cold enough, at times, for sea ice.

Further to this, computer models and analysis by others have suggested that in order for sea ice to grow around Antarctica during the winter in the geological past, it is likely that some ice would already have formed on land. Such limited ice caps are most likely to have developed on the peaks in the middle of the continent that comprise part of the Transantarctic Mountains. These findings are the first to support a highly


GEOLOGICAL TIMESCALE

> PALEOPOLAR's investigations have led to the unanticipated discovery that various modern Antarctic marine genera date back at least 50 million years, with some estimated to be more than 60 million years old. The roots of the modern icehouse fauna are in the ancient greenhouse world

contested hypothesis suggesting the presence of Antarctic ice caps during a period of predominantly 'greenhouse' climate.

ORIGIN OF THE ANTARCTIC MARINE FAUNA

Major variations in Early Paleogene climates within the south polar regions are also linked to a surprising finding from the PALEOPOLAR team's studies that various modern Antarctic marine invertebrate genera can now be traced back at least 50 million years in the Seymour Island fossil record, with some even estimated to be more than 60 million years old. This implies that these species evolved in the region during the generally warm early to mid-Paleogene period and yet were able to survive the severe cooling of the later Cenozoic.

So, how could these organisms have survived for so long, and in such a rapidly deteriorating environment? The answer may lie in the phenomenon of extreme polar seasonality. In the polar regions, the tilt of the Earth's axis causes long, dark winters whatever the prevailing climate. This, in turn, means that the supply of marine phytoplankton at the base of the food chain would have pulsed with the seasons, and it is likely that only the most generalist feeders would have thrived in such an environment. Evidently, some of these generalists were already in place 50-60 million years ago. As the climate then cooled dramatically, and permanent ice caps formed, certain species gradually evolved methods to deal with these much lower temperatures – for example, fish developed antifreeze in their blood resulting in the distinct polar biota we see today.

The origins of polar marine fauna are also linked to another of the team's interests: the variation in biodiversity between the poles and the tropics. Today, the tropics are markedly more biodiverse, but it is still not entirely clear why this should be. It would seem only sensible to assume that temperature must be involved, but temperature is not energy and as such cannot be directly utilised by organisms. Nearly all animals depend either directly or indirectly on primary productivity for their basic energy source and the PALEOPOLAR team's findings suggest that there may have been a strongly pulsed supply of this energy in the polar regions for vast periods of geological time. Latitudinal gradient in seasonality, rather than temperature, may therefore be responsible for the very marked latitudinal gradient in species diversity seen in the present day.

IMPLICATIONS FOR THE FUTURE

These avenues of research are allowing the development of a more detailed understanding of how environmental variation affects life. This is vital for future predictions, since the warm climates of the Late Cretaceous and Early Paleogene are seen as a 'worst-case scenario' if current greenhouse gas emission trends continue. We are also beginning to realise that there were times in the past when the polar regions represented important evolutionary centres. To conserve what we have today, it is vital that we understand where and how faunas and floras have evolved through geological time.

Above all, one thing is clear – the more that is understood about the link between climate and biodiversity change on a wide variety of timescales, the more successfully strategies can be employed to both slow anthropogenic climate change and minimise its negative impacts.

The gastropod *Prosipho* occurs both in the present day in the Antarctic Ocean and in 50 million year old rocks on Seymour Island. Shell length = 2 cm.

INTELLIGENCE

PALEOPOLAR

OBJECTIVES

- To determine the scale of the Cretaceous-Paleogene (K/Pg) mass extinction in Antarctica, 66 million years ago, and the nature and timing of biotic recovery using marine and terrestrial fossils
- To reconstruct latest Cretaceous-Early Paleogene environments and temperature in Antarctica through analysis of sedimentary, geochemical and palaeontological evidence
- To understand biotic radiations in the polar regions during the latest Cretaceous-Early Paleogene 'greenhouse' interval of global warmth
- To understand the response of climate to evolving vegetation in the polar regions through this interval using state of the art climate models

KEY COLLABORATORS

Dr Rowan Whittle; **Dr Jen Jackson**, British Antarctic Survey, UK • **Dr Jon Ineson**, Geological Survey of Denmark and Greenland, Denmark • **Dr Alan Beu**, GNS Science, New Zealand • **Dr Dan Condon**; **Dr Jim Riding**, British Geological Survey, UK • **Dr Dave Kemp**, Open University, UK • **James Witts**, University of Leeds, UK • **Dr Dan Lunt**, University of Bristol, UK • **Dr Liz Harper**, University of Cambridge, UK

FUNDING

Natural Environment Research Council: NE/I005803/1 • NERC AFI grant NE/C506399/1

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NERC SCIENCE OF THE ENVIRONMENT