

The climate pulse

A deep-sea drilling expedition has uncovered important clues linking variations of Earth's orbit to how the climate changed periodically about 35 to 23 million years ago, the most recent time when levels of carbon dioxide in the atmosphere reached present-day highs.

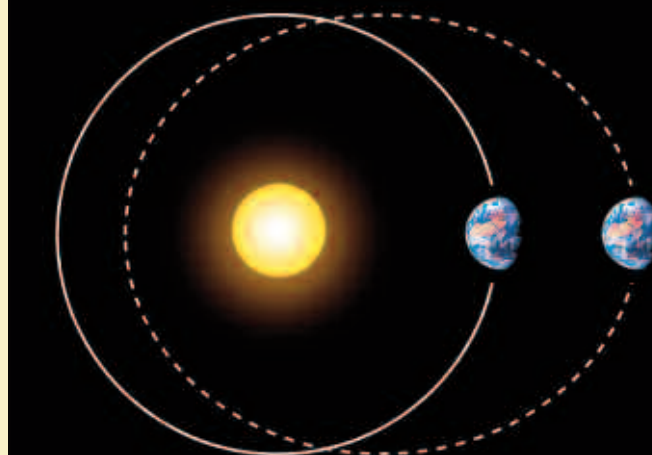
Heiko Pälike was on board.

Even to geologists, it is awe-inspiring to see how the sedimentary deposits of the deep Pacific work like a history book: each sedimentary layer tells a story just like the page of a book. The difference is that each 'page' is about two centimetres thick and took about a thousand years to write. Beneath the deep sea, sedimentary layers consist of clay but also many microfossil shells of algae and animals that once lived in the ocean either near the surface or dwelling at the bottom. Some of these organisms make their shells from calcium carbonate. We use the ratios of oxygen and carbon isotopes in fossil calcium carbonate, and how these ratios change over time, to reconstruct variations in temperature, ice-volume and biological activity millions of years ago.

The Oligocene, a period lasting 12 million years and which drew to a close 23 million years ago, was an extremely interesting epoch in Earth's history. The climate was slightly warmer than today, there was less ice, and carbon dioxide concentrations were similar to present-day levels. Mud from this period lies buried beneath the oceans, requiring high-tech drilling ships to grab these crucial samples.

By analysing tens of metres of sediment cores and thousands of samples we found that during the Oligocene the Earth's orbit around the sun had a striking influence on carbon dioxide concentrations, glacial conditions, ice-volume and the acidity of the oceans. The 'pulse' of these glacial and carbon dioxide variations changed on the dominant timescales of about 405,000 and 100,000 years, corresponding to the major orbital eccentricity cycles, which shape the Earth's orbit from more circular to more elliptical and back.

This is curious because the eccentricity of Earth's orbit does not cause that large a change in the amount of sunlight the planet receives, this energy budget is more strongly controlled by variances in the degree of Earth's tilt towards or away from the sun. The key to the mystery is the long time required to move carbon through the oceans. This acts as a buffer on carbon dioxide and biological processes. Each carbon atom placed in the ocean stays there for about 100,000 years resulting in the climate system accentuating very long 400,000-year periodic variations and



Earth's orbit moves from circular to elliptical on 100,000-year and 405,000-year cycles.

dampening shorter term 20,000-year variations. It takes fairly complicated modelling studies to re-enact this observed behaviour on our computers, but we have shown that this process is fundamental to the system, at least during the Oligocene.

Currently, the Earth is nearly circular in its orbit, and if the Earth's orbit exerts a major influence on climate today, it would take another 50,000 years before we could expect the next ice age. Even this is unlikely, as the amount of carbon dioxide present in the atmosphere today has reached levels not seen since the Oligocene. To get an accurate picture of what climate might be like in future decades, we would have to open the history book of oceanic mud even further, going back as far as the Eocene, about 34 to 55 million years ago.

What our modelling study suggests is that the effect of carbon released now will affect the oceans for many thousands of years to come, another effect of the residence time of carbon in the oceans.

As a researcher, it is often a very long road to publication. In the case of this study, we submitted initial proposals to visit specific spots in the Pacific with the drill ship a decade ago. The expedition took place in 2001, but the thousands of samples we needed to collect, process and analyse required another few years, culminating in publication in the American journal *Science* in 2006. It is extremely satisfying to see the full process in action, and we already have a follow-up expedition scheduled for 2008 using the Integrated Ocean Drilling Program's refurbished drilling ship. We have recently completed the Natural Environment Research Council and National Science Foundation co-funded site survey for the expedition. It was amazing to revisit the old drill site: the ocean looked just as vast and empty as everywhere else, and although only the GPS display confirmed that we had been there before, the place felt strangely familiar. ■

Dr Heiko Pälike is a geologist and palaeoceanographer at the National Oceanography Centre and School of Ocean and Earth Science, University of Southampton. Tel: 02380 593638, email heiko@noc.soton.ac.uk

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