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Drilling back in time

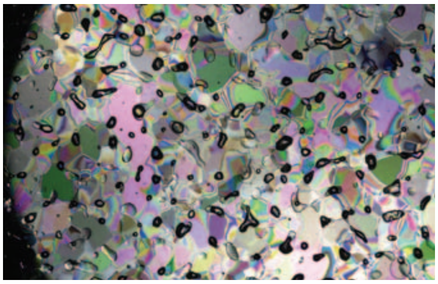
The recently published 800,000-year greenhouse-gas records from Dome C, Antarctica, show that old ice still bears surprises. As long as the records challenge our understanding, we should go back for more.

Ice cores are a climate scientist's time machine. Deep within the Antarctic ice sheet, more than 3,000 m below the surface at Concordia Station, Dome C (75° 06′ S, 123° 21′ E and 3,233 m above sea level), lies ice that contains 800,000-year-old air. This is the air that *homo antecessor* breathed, a hominin species that long preceded the Neanderthals. And this precious ancient air is neatly frozen into place, stacked as a continuous timeline of layered deposits that accumulated as snow fell on the Antarctic plateau year after year.

Lifted to the surface in almost a decade of efforts by the team from the European Project for Ice Coring in Antarctica (EPICA), the Dome C ice core has enabled the reconstruction of Antarctic temperatures from the past 740,000 years (*Nature* **429,** 623–628; 2004), and measurement of methane, nitrous oxide and carbon dioxide concentrations over the past 650,000 years (*Science* **310,** 1313–1317, 1317–1321; 2005). After several more years of painstaking analysis, the greenhouse-gas records have finally been completed, now extending continuously throughout the past 800,000 years (*Nature* **453,** 379–383, 383–386; 2008).

Remarkably, what might have been expected to be a largely confirmatory exercise, given all we know from earlier cores, has brought new riddles to light. Twice between 800,000 and 650,000 years ago, atmospheric CO_2 concentrations did the unthinkable: they briefly dropped below the hitherto established envelope of 180 to 280 p.p.m.v. of natural CO_2 levels in recent geological time — while temperatures remained at normal glacial levels. Indeed, one of the two blips records 172 p.p.m.v., the lowest atmospheric CO_2 levels ever measured in ancient ice.

In the 'EPICA challenge', posed to the Earth system modelling community in 2004,



S. KIPFSTUHL AND B. STAUFFER

ice-core scientists asked palaeoclimate modellers to predict the greenhouse-gas record over the past eight glacial cycles using the published long temperature curve from the Dome C ice core (*Eos* **85,** 363; 2004), before the CO_2 and methane measurements were completed. The challenge did not seem impossible: over the past 150,000 years, temperature and CO_2 levels were extremely tightly coupled (the coefficient of determination, r^2 is 0.89). But it is unlikely that any of the currently available models will be able to predict the two dips in CO_2 concentrations, each less than 3,000-years long. According to our understanding of past links between temperature and CO_2 levels, they simply should not be there.

Much care was taken to avoid errors in the CO_2 measurements, with independent analyses of alternating slices of ice at two different laboratories. Furthermore, CO_2 levels are directly measured in ancient air, without reliance on proxies. Therefore, the easiest explanation — a measurement artefact in the CO_2 record — seems unlikely. The temperature record, although not measured directly, is equally well established. But if we accept both records as true, the new results will require some deep thinking. By no means do two periods of less than 3,000 years with decoupled temperatures and CO_2 levels call into question the amply supported link between atmospheric CO_2 levels and climate, which otherwise holds down to the millennial level, but the two observed short-term excursions will need to be explained, and the question arises of whether there are more of these blips from longer ago than 800,000 years.

This is not the only finding in need of fresh insight. The EPICA team suggest that there may have been long-term trends in atmospheric CO_2, which rose by 25 p.p.m.v. between 800,000 and 400,000 years ago and fell by 15 p.p.m.v. thereafter. Whether this is part of a longer-term 400,000-year cycle needs further investigation with longer records. Finally, the extended methane records reveal a change in the dominant periodicity of atmospheric methane levels, from prominent 100,000-year cycles in the early record to today's more precession-driven cycles of about 20,000 years. In contrast, climate and CO_2 were increasingly locked in a 100,000-year cycle. It is not clear what mechanisms drove these changes.

Clearly, the extended greenhouse-gas records raise new questions. Some answers will be accessible only through ice cores that take us even further back in time. Plans are afoot: a Chinese drill project and the International Partnerships in Ice Core Sciences (IPICS) both aim for the prize of the oldest continuous ice record (*Nature* **446,** 126–128; 2007).

The task is daunting: choose the wrong place and a decade of drilling may be in vain. The broad area of Dome Argus (80° 22′ S, 77° 21′ E and 4,093 m elevation), where China's drill project is scheduled to start in 2009 or 2010, is a promising site. But the ice masses sit on a subglacial mountain range making it important to choose just the right spot in order to avoid a folded or otherwise disturbed record.

Will it be possible to retrieve an annually layered core of 1.5-million-year-old ice? The only way to find out is to try.