Windows on the greenhouse

Ed Brook

Data laboriously extracted from an Antarctic ice core provide an unprecedented view of temperature, and levels of atmospheric carbon dioxide and methane, over the past 800,000 years of Earth’s history.

Palaeoclimatologists are scientific detectives. Using indirect clues from concentrations of stable isotopes and trace elements, and from fossils and other components of the geological record, they infer changes in climate long before they themselves were on the scene. Direct evidence of past environmental conditions is rare, which makes it all the more valuable where it does occur. In this issue, members of the EPICA (European Project for Ice Coring in Antarctica) collaboration present the latest, and longest, record from perhaps the most valuable of these archives: the atmospheric gases trapped and preserved in ice cores extracted from Earth’s polar regions.

Polar ice cores provide us with the long view of the cycling of greenhouse gases such as carbon dioxide and methane. Their potential is being realized by a relatively small band of international scientists who are gradually drilling further down into the ice cap and progressively analysing older ice cores. Until recently, the Vostok ice core from eastern Antarctica set the benchmark — an iconic 440,000-year data set that became a central backdrop for discussions about modern climate change.

That ante was upped in 2005 by a 650,000-year record from EPICA’s ‘Dome C’, another drilling site in eastern Antarctica where much older ice could be extracted. An 800,000-year reconstruction of temperature change from the core already existed. Now, after years of careful work and collaboration, Dome C has yielded a complete reconstruction of the history of atmospheric carbon dioxide (Lüthi et al., page 379) and methane (Loulergue et al., page 383) over the past 800,000 years.

The fundamental conclusion that today’s concentrations of these greenhouse gases have no past analogue in the ice-core record remains firm. The general long-term behaviour of methane and carbon dioxide, following patterns driven ultimately by slow changes in Earth’s orbit, continues throughout the older sections of the records. The remarkably strong correlations of methane and carbon dioxide with temperature reconstructions also stand (Fig. 1, overleaf).

The data further reinforce the tight link between greenhouse gases and climate, a link maintained by as-yet only partially understood feedbacks in the Earth system. Variations in methane levels are most probably caused by variations in the influence of temperature and rainfall on wetlands in the tropics and boreal (high-northern-latitude) regions. Carbon dioxide variability is almost universally viewed as an oceanic phenomenon, a consequence of the large pools of carbon sequestered there. Changes in ocean circulation, biological productivity, carbon dioxide solubility and other aspects of ocean chemistry have been implicated, but the exact mix of mechanisms is not clear.

In considering these extended records in detail, intriguing nuances emerge. Their most prominent feature is a sawtooth-shaped variability on 100,000-year timescales. As reported last year, the amplitude of the 100,000-year temperature cycle reconstructed at Dome C seems to have changed fundamentally about 450,000 years ago (Fig. 1). Warm phases (interglacials) in the later period have been warmer, whereas cold phases (glacials) seem similar throughout the record. The carbon dioxide record generally shares this pattern, with muted cycles in its older part. Methane also follows the trend, though not as strongly: relatively high methane maxima in the oldest interglacial cycle approach those of later warm periods.

A curious facet of the extended carbon dioxide record is unusually low levels of the gas during the two earliest glacial–interglacial cycles. Lüthi et al. speculate that, taken as a whole, the carbon dioxide record is hinting at a longer-term cycle in mean levels of the gas that takes 400,000–500,000 years to complete. The eccentricity of Earth’s orbit — its deviation from a perfect circle — does vary with a 413,000-year period. But whether this or some other mechanism explains any variation awaits the retrieval of an even older ice core.

The extended records also provide information about shorter-term, millennial-scale climate change taking place within the longer cycles. Data from ice cores in Greenland covering the past 110,000 years show that variations in methane levels were extremely closely coupled to episodes of abrupt warming and cooling in the mid-to-high latitudes of the Northern
House-gas variability pose questions as to the effect of changes in ocean circulation on the deuterium–hydrogen ratio of the ice, reinforce the tight coupling between greenhouse-gas concentrations and climate observed in previous, shorter records. The 100,000-year ‘sawtooth’ variability undergoes a change about 450,000 years ago, with the amplitude of variation, especially in the carbon dioxide and temperature records, greater since that point than it was before. Concentrations of greenhouse gases in the modern atmosphere are highly anomalous with respect to natural greenhouse-gas variations (present-day concentrations are around 380 p.p.m. for carbon dioxide and 1,800 p.p.b. for methane). The carbon dioxide and methane trends from the past 2,000 years 11,14

Figure 1  A long look back. a. The 800,000-year records of atmospheric carbon dioxide (red; parts per million, p.p.m.) and methane (green; parts per billion, p.p.b.) from the EPICA Dome C ice core 1–2, together with a temperature reconstruction (relative to the average of the past millennium) based on the deuterium–hydrogen ratio of the ice, reinforce the tight coupling between greenhouse-gas concentrations and climate observed in previous, shorter records. The 100,000-year ‘sawtooth’ variability undergoes a change about 450,000 years ago, with the amplitude of variation, especially in the carbon dioxide and temperature records, greater since that point than it was before. Concentrations of greenhouse gases in the modern atmosphere are highly anomalous with respect to natural greenhouse-gas variations (present-day concentrations are around 380 p.p.m. for carbon dioxide and 1,800 p.p.b. for methane). b. The carbon dioxide and methane trends from the past 2,000 years 11,14

The rhodopsin story continued

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Determination of the architecture of an invertebrate photoreceptor protein, squid rhodopsin, is a notable event. It illuminates the mechanism of invertebrate vision and a ubiquitous intracellular signalling system.

Many invertebrates have excellent visual hunters that rely on their acute visual abilities to catch their prey. As in vertebrates, the properties of the photoreceptor protein rhodopsin contribute significantly to those abilities. So one reason for the attention that will be paid to the paper on page 363 of this issue 2, in which Murakami and Kouyama present a high-resolution crystal structure of rhodopsin from the squid retina, is that it will help in understanding invertebrate vision. But the paper’s significance extends far beyond that.

Rhodopsin is located in the cell membrane of photoreceptor cells. When activated by light, it undergoes a conformational change that triggers the action of a heterotrimeric GTP-binding protein (G protein) lying just beneath the cell membrane. Rhodopsin, therefore, is a member of the superfamily of G-protein-coupled receptors (GPCRs), all of which contain seven structural domains that each span the membrane. However, invertebrate rhodopsin signals through the α-subunit of a G-protein (rather than transducin, the α-subunit for vertebrate rhodopsin), leading to activation of phospholipase C and eventually the opening of a calcium channel (rather than activation of cyclic GMP phosphodiesterase, leading eventually to closing of a cation channel, which occurs in vertebrates 4).

In other words, Murakami and Kouyama’s are the first to determine the structure of a Gα-coupled GPCR. The wider significance of the paper is that many hormone and neurotransmitter receptors signal through Gα, including vasopressin and oxytocin receptors as well as serotonin and acetylcholine receptors in the brain. And many drugs, such as antihistamines and angiotensin antagonists, target Gα-coupled receptors.

The functional unit of squid rhodopsin group IPICS (International Partners in Ice Core Sciences), has set itself the immediate target of establishing a continuous 1.5-million-year record to attempt to answer these questions. The search for the right sites is beginning, and is likely to take several years. The best places are undoubtedly in eastern Antarctica, most probably in remote, high regions where snowfall rates and temperatures are extremely low. Meeting the challenge of drilling those cores should open up a further window on goings-on in the greenhouse.

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