Frozen time

Researchers have pulled the oldest-yet core of ice from the Antarctic — giving us a 740,000-year record of the planet's climate. Gabrielle Walker braves the cold to find out how they did it, and what they hope to learn.

"Are you ready to go into the freezer?" It's a warm summer's day in Le Fontanil, southeastern France, but glaciologist Jerome Chappellaz is pulling on a hefty parka and snow boots. He punches a button and a door slides open into a vast commercial cold store, where whirring fans add a bitter wind-chill to the temperature of –25 °C. Although we have come to look at ice, we're first confronted with three floors of wooden pallets stacked up to the ceiling, bearing sides of beef, rings of yellow goat's cheese and boxes of frozen raspberries.

"We work with a raw material that is very close to melting, so we're always close to losing our samples," says Chappellaz, from France's leading glaciology laboratory — the Laboratoire de Glaciologie et Géophysique de l'Environnement (LGGE) in Grenoble, 15 kilometres from Le Fontanil. "But they have millions of euros of food in here, so there's no way they will let it thaw."

That's just as well, because the samples Chappellaz is talking about are far more precious than cheese. Tucked away in the attic, in scores of cardboard cartons cross-wrapped with black straps like slightly battered Christmas presents, is one of the world's most extraordinary archives — a record of ancient climate written into 15 kilometres of ice cores, taken from mountain glaciers and the frozen caps of Greenland and Antarctica. Chappellaz rummages in a carton, and lifts out a long thin wedge of ice, whose curved side is scored with spiral rings from each turn of the drill bit. Although it looks unremarkable, this core is setting the climate world buzzing. It comes from so deep in the Antarctic ice sheet that any bubbles have had the breath squashed out of them, and the ice is as clear as glass. Dating from roughly 740,000 years ago, it is also the oldest ice core ever retrieved.

The ice was drilled at Dome C in the East Antarctic ice sheet by a consortium called the European Project for Ice Coring in Antarctica (EPICA). It has nearly doubled the age record for an ice core — previously set by a core drilled 500 kilometres from Dome C, at the Russian station Vostok a decade ago. The flagship for ice-core research, the Vostok core extends back around 400,000 years, and contains four ice ages[1]. It was a resounding success for researchers, demonstrating — among other things — that carbon dioxide levels in the atmosphere have marched in exact step with temperature for hundreds of thousands of years[2].

L. AUGUSTIN/LGGE

Cold comfort

But, frustratingly, the Vostok core stopped in the middle of a period known as stage 11, which occurred about 425,000–395,000 years ago, and which the EPICA core has now fully embraced. Researchers are particularly keen to explore this period because it is the last time that the Earth's orbit was very nearly identical to its present one, making it a potential model for our own climatic future. With its record of atmospheric gases frozen into the ice, the EPICA core could also reveal secrets of a mysterious climate transition that started a million years ago.

The site at Dome C, chosen for its exceptionally thick ice, is flat, white, and bitterly cold, with temperatures ranging from − 50 °C at the start of the season to − 25 °C in the middle of the Antarctic summer. But it is a surprisingly pleasant place to work. Located at the summit of a dome of ice, it escapes the chilling winds that sweep down Antarctica's slopes. There are heated tents for sleeping, a sauna, and unrestricted hot showers. "It's really comfortable," says chief driller Laurent Augustin. "I call it Club Med."

The team's drill contains a metal tube 3.5 metres long and 10 centimetres wide, attached to a mechanical drill bit. During each run, a few metres of ice are collected in the tube, and brought back to the surface, where the core is removed, labelled and stored.

Each stage of the drilling has its own problems. For the first 1,000 metres, air bubbles tend to form in the boundaries between ice crystals, making the core so brittle that the sudden release of pressure at the surface can make it explode and shatter.

Ice chips formed by the grinding drill can also clog up the mechanism, jamming it in place. This happened in the 1998–99 season, leaving the drill irretrievably stuck. The team was eventually forced to abandon the hole and start again, with a brand new drill head. More cautious after such a delay, they reduced the amount of ice pulled up to just three, two or even one metre with each run, making it a

A. LORI/ENEA

G. WALKER; L. AUGUSTIN/LGGE

Below zero: Jerome Chappellaz (right) and his colleagues start to analyse the ancient ice cores drilled at Dome C (above) from 1996 to 2003.

time-consuming process. When they had reached down more than 3 kilometres, it took more than an hour to bring the core up to the surface.

The team celebrated reaching 1,000, 2,000 and 3,000 metres with parties and champagne. And when field tests showed that the core had passed Vostok's age, there was a buzz with every metre that came up. "It was very exciting," says Eric Wolff from the British Antarctic Survey in Cambridge, UK, who spent two seasons as chief scientist at Dome C. "You knew you were getting stuff that had never been seen before."

But close to the end the project hit yet another snag. At 3,100 metres, the team realized that the ice was now close to melting point, thanks to geothermal heat. That's problematic, because melting ice can refreeze on the drill and trap the whole mechanism. They managed to retrieve some of the melting ice, but intend to return to the site next November for the remaining 100 metres, using a plastic bag filled with ethanol as antifreeze for the drill bit. "It's not very elegant, but it works," says Augustin. That final section could reach back to 900,000 years or even further. "None of us knows what we'll find at the bottom of Dome C — that's why it's exciting," says Dominique Raynaud of the LGGE, who is the coordinator for the next stage of the project.

Climate clues

After the cores were drilled, they were sent to participating labs in Europe by ship, with a quarter-slice of the entire core remaining in Antarctica in case an accident befell the travelling ice. Some surprising results — including the core's extreme age — have already emerged[3] (see also the article in News and Views on page 611), though much of the Dome C core remains to be studied.

The most eagerly awaited findings are from the samples of ancient air trapped in its ice — a record that is unique to ice cores. Chappellaz and his EPICA colleagues have been measuring everything they can in the ice's air, from carbon dioxide, methane and nitrous oxide to the isotopes of nitrogen and oxygen. However, the measurements are laborious and time-consuming; so far, they have only managed to confirm Vostok's records in the top part of the core and reveal the composition of the atmosphere during stage 11.

That already shows that the amount of CO_2 in the air during stage 11 was similar to our own pre-industrial level[3]. As Earth's orbit was much the same then, this suggests that stage 11 was very like our present balmy interglacial, and that without the effects of global warming we would probably have to wait some 16,000 years for another ice age. "It's a wonderful window into the future as well as the past," says Raynaud.

Measurements of the ratio of isotopes of oxygen in the ice and the sizes of the ice crystals, both of which vary with temperature, have also shown that before 450,000 years ago the climate cycles seemed flatter, with a smaller difference between the extremes of ice ages and the warmer interglacials[3]. Researchers think this is a sign of the tail-end of a mysterious transition in our climate's history.

A million years ago, ice ages recurred about every 40,000 years — the same timescale on which wobbles in the Earth's tilt alter the amount of sunlight hitting its surface. But now our ice ages return every 100,000 years. This is the timescale on which Earth's orbit becomes more or less elliptical, but this does not provide enough of a change in the amount of sunlight to explain the ice ages. So why should the cycle length have changed?

One possible explanation is that CO_2 levels may have gradually fallen, making the world progressively colder, says Wolff. This would have caused successive ice ages to grow larger and larger ice sheets — something that marine records suggest has been occurring over the past 2 million years.

Eventually, the ice may simply have become too slow on its feet to respond to the 40,000-year beat, and could have been forced to adopt the more stately, 100,000-year driving force. The Dome C core should soon reveal whether this is right. "If carbon dioxide really is the key, this is the only convincing way of getting it," says Wolff.

EPICA researchers around Europe are now furiously crushing and measuring their ice to see what the greenhouse-gas record will reveal. "It's a strange feeling to look at a sample melting after we have extracted the air," says Chappellaz. "Water that fell as snow in the middle of Antarctica 700,000 years ago will end up in the Isère river in the middle of Grenoble. And every time we open one of our containers, a fragment of atmosphere that's hundreds of thousands of years old disappears back into the air." ■

Gabrielle Walker is a science writer based in London.

1. Petit, J. R. *et al. Nature* **387**, 359–360 (1997).
2. Petit, J. R. *et al. Nature* **399**, 429–436 (1999).
3. EPICA community members *Nature* **429**, 623–628 (2004).