

## Chapter 6

# The second great climate shift in the last 65 million years

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The most recent period of the Earth's history, the Cenozoic era, began 65 million years ago with a bang: a meteorite impact that ended the rule of the dinosaurs, but disturbed only briefly the super-warm climate of the times. However, for the past 50 million years, the Earth has been cooling and it is now becoming clear that this long-term cooling trend may be reversed in the last few decades (IPCC, 2001). In this chapter, I outline the evidence for this view, which is becoming widely accepted by those who study the Earth's climate system and its past history.

Although geologists have been learning about the Earth's history for hundreds of years, a real understanding has developed merely in the last four decades through deep-sea drilling and analytical chemistry. Thousands of cores have been extracted from the seabed, and analysed by tens of thousands of scientists in hundreds of laboratories. They have increased our understanding of many aspects of the Earth's history, but I intend to focus on just two: the Earth's surface temperature, and carbon dioxide (CO<sub>2</sub>) levels in the atmosphere.

## **Greenhouse world**

Until 65 million years ago, when dinosaurs still roamed the Earth, the planet's geography was somewhat different from now in several respects. The Atlantic Ocean was much narrower to both the north and south, Australia was still joined to Antarctica, and New Zealand was under the sea off the coast of Australia.

However, the Earth's temperature was very different. This was a warmer planet by between 6°C and 10°C, and CO<sub>2</sub> levels were between two and eight times higher than pre-industrial values (Bice et al. 2006). It was what scientists now call a 'greenhouse world'. Life on Earth was severely challenged on that day 65 million years ago when a meteorite 10 km wide hit the Yucatan Peninsula, leaving a 200 km crater and sending many cubic kilometres of shattered debris and dust into the stratosphere. As a consequence, not only the dinosaurs but around sixty percent of all species on Earth died out. There was undoubtedly a major impact on the Earth's climate for decades or even longer. Cooling effects from the dust of the explosion gave way to warming as the dust settled out, and increased CO<sub>2</sub> from the fires that followed. But the impact of this huge event did not cause a measurable long-term shift in the Earth's climate system.

If the meteorite event did not affect global temperature for more than a brief period, another event ten million years later certainly did. This event has the code name PETM (Paleocene-Eocene Thermal Maximum), because it coincides with the time boundary 55 million years ago between the Paleocene and Eocene periods. It has really been recognised only in the last few years. Scientists had been puzzled by massive extinctions in marine microfossils at that time, and had noted a large increase in the proportion of isotopically light carbon in sedimentary strata of that age beneath the ocean floor. They could also see a sharp change in deep-sea sediment cores – from white carbonate representing the slow continuous 'rain' of white calcareous planktonic algae, to the black organic residue of their dissolved remains – indicating a more acidic ocean. The cores also show over several centimetres the gradual return of the white algae as the oceans recovered in the following 100,000 years.

The most likely explanation for these changes is a massive discharge of methane hydrate from beneath the sea floor - scientists estimate it to have released over 2000 gigatonnes of carbon into the atmosphere from the extent of the shift toward light carbon isotopes in the organic residue (Zachos et al., 2005). This would have more than quadrupled the amount of CO<sub>2</sub> in the atmosphere (methane decays rapidly to CO<sub>2</sub>) and raised global temperature by more than 5 °C. However, as the deep-sea record shows, the climate did return to normal and the greenhouse world continued.

## **Transitional world**

Ten million years on, global temperatures peaked, starting the decline that continued until the last century. However, a truly significant and persistent change took place around 34 million years ago, when global temperature dropped by just over a degree. This brought about the first big Antarctic ice sheet. We can see this from the shift to heavy oxygen in deep-sea isotopes, adjusting to 'light' oxygen trapped in water in the new ice sheet, and also from the first glacial deposits of that time found today around the Antarctic margin.

Many scientists have wondered why these changes happened. Initially, they were thought to be the result of changes in ocean circulation as the continents drifted away from Antarctica. But more recently, scientists have been investigating whether the shifts were linked to declining carbon dioxide levels due to changes in plants and increasing weathering and mountain uplift, which soaked up the CO<sub>2</sub>.

Estimates of atmospheric CO from organic compounds in ancient sediments show there was an irregular decline from a range from 600 to 2000 ppmv to between 200 and 400 ppmv between 50 and 30 million years ago. This suggests a threshold that, once passed, allowed snow to build up on Antarctica, further cooling the atmosphere by reflecting solar radiation and re-inforcing the cooling. Computer models show that with twice the current levels of CO<sub>2</sub>, there would have still been a large ice sheet, but for CO<sub>2</sub> at three times the present levels, only small ice caps form (Figure 1, DeConto and Pollard, 2003a). For CO<sub>2</sub> at intermediate values, the models show that known and predictable wobbles in the Earth's spin and in its orbit around the sun (Milankovitch cycles, Wikipedia, 2006), have enough effect to cause the ice sheet to vary in size by 50% or more, changing sea level between 30 and 60 metres. That indeed is what we observe from cyclic fluctuations every 40,000 years in the isotope record from deep-sea sediments, and also in strata we have cored from the Antarctic margin from around 34 to 17 million years ago.

## **Icehouse world**

For reasons that are still not understood, around 14 million years ago the Antarctic ice sheets became stable and persistent. Even though atmospheric CO<sub>2</sub> had reached pre-industrial levels, the Earth became a cool planet. Around seven million years ago, a small ice sheet formed on Greenland, and from two and a half million years ago, large ice sheets – even bigger than the Antarctic ice sheet – formed over northern North America and Europe. In fact, ice came as far south as New York, and covered most of northern Europe.

However, like the earlier Antarctic ice sheets the northern ice sheets were also unstable, fluctuating on Milankovitch frequencies, with their effect on global ice volume and temperature recorded in deep-sea sediments. Figure 6.2 in the colour section shows this record for the last four million years, representing most of the time that our own genus, *Homo*, has walked the Earth. Here we see the 40,000-year cycles from the Antarctic ice sheet becoming larger at two and a half million years as the Northern Hemisphere ice sheets developed and, in the last million years, becoming much bigger still as the ice sheets reached modern proportions and the cycle frequency shifted from 40,000 to 100,000 years.

The climate history of the last million years is becoming exceptionally well known from ice core records from central Antarctica. The first deep cores were taken by the Russians at Vostok Station near the centre of the Antarctic ice sheet in the late 1980s and 1990s, and it was from these that the patterns in temperature and CO<sub>2</sub> levels, and the 100,000 year cycles for the last 400,000 years, were first recognised (Petit et al., 1999). They show temperature moving through time in concert with atmospheric CO<sub>2</sub> and methane (Figure 6.2), and for the last 400,000 years, all three have moved within a limited band – CO<sub>2</sub> within a range of 180-300 parts per million (ppm), methane within a range of 350-750 parts per billion (ppb), and temperature change (at Vostok) within a range of 10°C. For the rest of the earth the average temperature shift over the same time period was only 5°C, the polar regions being more sensitive. It is also worth noting that the deep Antarctic core taken by the EPICA project recently takes this record back to over 800,000 years (EPICA, 2004).

The reason for these climate cycles is the same as variation in the Earth's spin and orbit around the sun, although the change in the amount of energy is less than 100<sup>th</sup> of the shift in temperature we observe. The current thesis is that a tiny temperature increase from the Earth's wobbles causes an increase in CO<sub>2</sub> from the Earth's biota. This is further amplified through increased water in the atmosphere, leading to higher temperature, more CO<sub>2</sub>, more water vapour and so on, until a new equilibrium level is reached. Some scientists believe there is another, more hazardous, factor in methane hydrate trapped 'frozen' in many places beneath the floor of the world's oceans. They argue that the warm interglacials, which formed remarkably

quickly as the ice core records show, were given a boost from massive methane discharges that followed the initial warming (Kennett et al., 2002). Estimates of methane hydrate beneath the sea floor have recently been reduced (500 to 2500 gigatonnes, Milkov, 2004) but are still enough for methane to be a potential threat to climate stability.

As Figure 6.2 shows, CO<sub>2</sub> levels have now gone well beyond the envelope of the last 400,000 years, and geochemical estimates of several different types indicate levels are already higher than at any previous time in the last 25 years (Royer, in press). The oceans have started to warm, the Arctic ice pack to shrink, the mid-latitude glaciers to melt, and sea level to rise faster from loss of Greenland and Antarctic ice. We have yet to feel to the full effect of the rise in greenhouse gases because of the thermal inertia of water, ice and earth – the present rise of around 0.6°C is probably only half of the ultimate temperature rise from greenhouse gases already emitted. Other consequences are also becoming obvious – increased weather extremes with flooding, droughts and hurricanes and acidification of the oceans directly from rising CO<sub>2</sub> levels. So where are we heading?

### **The next 300 years**

This trend is not going to stop of its own accord any time soon. Modellers and climatologists are now projecting CO<sub>2</sub> increases and consequential average temperature rises of around 3°C by 2100 – possibly a little less, but from recent reports more likely rather more. Meanwhile, the World Energy Association forecasts a 50 percent increase in fossil fuel use over the next 20 years. In the “business as usual” scenario we can reasonably expect all of the accessible fossil fuel deposits to have been exhausted by the year 2300, resulting in the release of 5400 gigatonnes of carbon and raising average global temperature about 8°C (Bala et al., 2006). Figure 6.3 shows the projected outcome in the context of the temperature history of the earth described above.

With ‘business-as-usual’ by the end of the century and the Earth 3°C warmer, the Earth’s climate will have risen out of the ‘ice-house’ state of the past 14 million years, and before much longer, will have returned to the ‘greenhouse world’. Even the increase of 3°C would mean the loss of Arctic sea ice, the low-mid latitude glaciers, the Greenland Ice Sheet and mostly likely that of West Antarctica – a total rise of about 12 metres in sea level.

Our knowledge of the past gives us some important insights into the scale of the problems facing the planet. The greenhouse world of the past, with its high CO<sub>2</sub> levels, would have been at least 6 degrees warmer and had no ice sheet. Already, we know conclusively from ice cores that our CO<sub>2</sub> levels are higher than at any time in the last 800,000 years. We know about the methane ‘kick’ of 2,000 gigatonnes that occurred 55 million years ago. We also know that there is about the same amount of methane hydrate lying beneath the floor of the world’s oceans today, which could be triggered by a warmer world.

If the temperature increases projected for the next 100 to 300 years are realised, we can expect the Earth to return to the greenhouse world of more than 34 million years ago. This would be the second great climate shift of the last 65 million years. But I am an optimist. We may not have much time, but at least the science is now clear enough and the solution is straightforward – reduce greenhouse gases in the atmosphere to a safe level. This Climate Change and Governance Conference will help us begin to do that.

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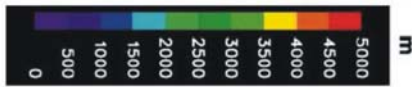
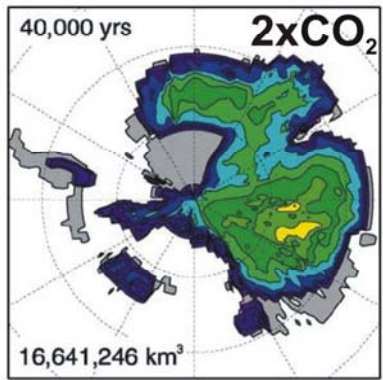
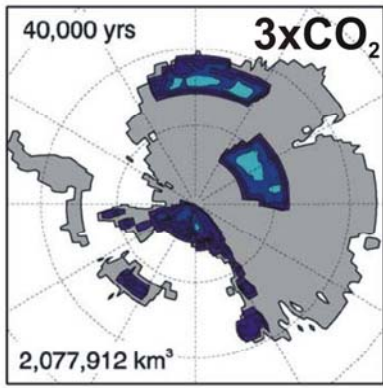


Figure 1. Computer models showing Antarctic ice extent and volume for 2 times and 3 times pre-industrial CO<sub>2</sub> levels (DeConto & Pollard, 2003b). The ice-free area of the continent is shown in grey. The present ice sheet covers this almost entirely and has a volume of around 30,000,000 km.

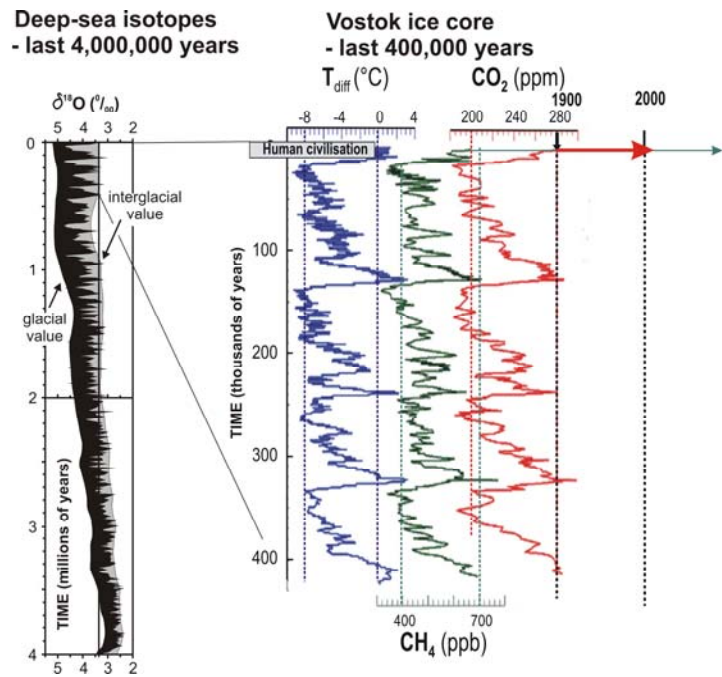


Figure 2. Climate records from deep-sea sediments for the last 4 million years and from ice cores for the last 400,000 years.

The deep-sea record shows regular cycles in oxygen isotopes that reflect cooling and build-up of ice. Each lasted 40,000 years until around a million years ago, after which they lengthened to 100,000 years (from Barrett, 1999, with data from Shackleton, 1995).

Ice cores record both temperature and atmospheric greenhouse gases (CO<sub>2</sub> and CH<sub>4</sub>) (data from Petit et al., 1999), and show how these have moved in lock-step over the last 400,000 years. The increase in CO<sub>2</sub> in the last century is shown by the two vertical dashed lines, and 2005 levels of CO<sub>2</sub> and CH<sub>4</sub> are shown by the arrows.

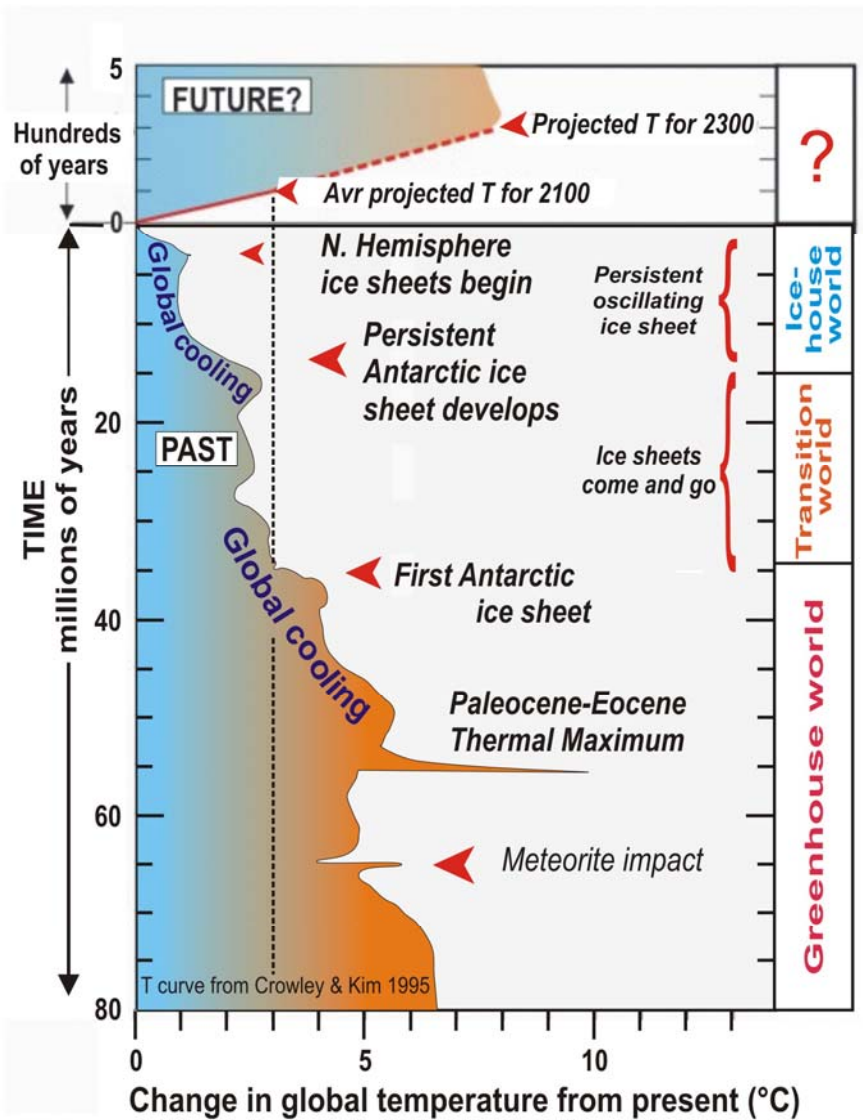


Figure 3. A graph showing the change in average global temperature over the last 80 million years (modified from Barrett, 2003, based on the temperature curve of Crowley and Kim, 1995, with the addition of the effects of the PETM methane discharge described by Zachos et al., 2005).

The “Future” part of the graph shows the rise in temperature to be expected from energy projections, with the earth warming into the “greenhouse” world of more than 34 million years ago soon after the turn of this century.