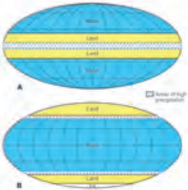
FIFTY MILLION YEARS AGO the earth was very different from the planet we live on today – it was both warmer and wetter, with rainforest extending all the way up to northern Canada and down to Patagonia. So how did we go from this lush, vibrant earth to the ice-locked cool planet we have now? What caused the beginning of the Ice Age? If you look at a map of the world 50 million years ago and a map of the world today they seem to be the same, but look closer and small differences become apparent. Movements of the continents around the face of the planet are very slow, but minor changes have had a profound effect on global climate.

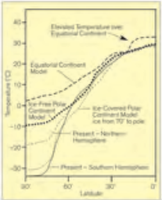
What makes a cold planet?

To create an ice age the first thing you need is continents at the poles. Geologists have run simple climate models to demonstrate this idea, showing that if you put all the continents around the Equator – the so-called 'tropical ring world' – the temperature gradient between the poles and the Equator is about 30°C (54°F). This is due to a trick of both the atmosphere and the oceans. The fundamental rule of climate is that hot air rises and cold air drops; this is why in the tropics the land heats up and the air rises, resulting in towering cloud formations developing as the moisture in the air cools and condenses. At the poles it is cold so the opposite happens – the air falls, pushing outwards away from the pole as it hits the ground. So although ice forms at the pole when the sea water freezes, this ice is blown away from the pole towards warmerwater where it melts. This maintains the balance and prevents the temperature of the pole falling below 0°C (32°F). If, however, there is land on the pole or even around the pole, ice can form permanently, and the Equator–pole temperature gradient is much greater – over 65°C (117°F). This is exactly what we have today in the Southern Hemisphere. In contrast, if you consider the Northern Hemisphere, the continents are not actually positioned over the pole, but surround it, so instead of a single huge ice sheet as we have on Antarctica, there is a smaller one on Greenland, and the continents act like a fence keeping all the sea ice in the Arctic Ocean. The Equator–pole temperature gradient of the Northern Hemisphere, therefore, is somewhere between the extremes of an ice-locked Antarctica and a land-free pole: about 50°C (90°F).

The size of the Equator–pole temperature gradient is important for our climate because it is the main driver of the oceanic and atmospheric circulation moving heat from the Equator to the poles. So this temperature gradient defines what sort of climate the world will have. A relatively cold earth such as the one we live in today has an extreme Equator–pole temperature gradient and thus a very dynamic climate. This is why we have hurricanes and winter storms – the climate system is trying to pump heat away from the hot tropics towards the cold poles.

previous pages Aerial view of a glacier near Juneau, Alaska. This is just one of 38 glaciers that are fed by North America's fifth largest icefield.



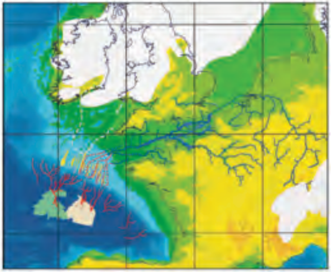


far left The temperature gradient between the Equator and the poles is controlled by where the continents are positioned. If all the continents are at the Equator (A) the gradient is 30°C; if they are at the poles (B) then this gradient can increase to over 60°C.

left The modern-day temperature gradients are shown on the graph, compared with model simulations using the continental configurations in A and B.

below We live in an age of ice, with large ice sheets on Greenland and Antarctica. In the Arctic, sea ice expands and contracts seasonally and even in summer (as shown below) covers much of the Arctic Ocean.

HOW THE AGE OF ICE BEGAN

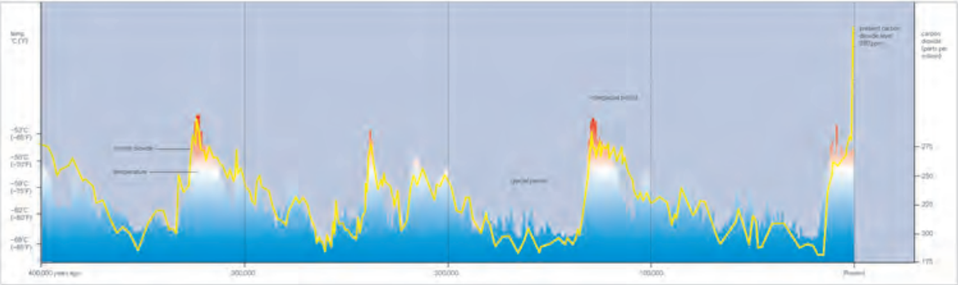


left During the last glaciation 18,000 years ago, global sea levels were 120 m (394 ft) lower than today. These levels left the North Sea and English Channel completely dry. There was instead a mega-river flowing out to the Atlantic Ocean combining the water discharge of the Thames, the Rhine and the Seine.

formed by the lowering sea levels, allowing species of all kinds of animal to invade new areas. Around the world, islands such as Sri Lanka, Japan, Sicily, Papua New Guinea and the Falklands became part of the adjacent mainland. Significantly, the chain of islands across the Bering Sea, which separates northeast Asia from Alaska, also became joined, so that during the end of the last glacial period as the climate started to warm up humans were able to cross from Asia into North America for the very first time, colonizing a brave new world (see Chapter 5).

The Ice Age also affected the atmosphere: carbon dioxide, as we have seen, was reduced by a third and methane by a half. This was due to massive changes in the carbon system. Methane, for example, was greatly reduced because of the drier conditions during the glacial periods. At the moment a lot of natural methane is produced in tropical wetlands when plants rot under water – in the Amazon, an area the size of Britain is flooded every year – so in a drier world less methane is produced. Both carbon dioxide and methane are important greenhouse gases so their reduction allowed more of the heat generated through solar radiation to escape the atmosphere, helping to cool the planet. As we will see later in this chapter, this factor may actually have been instrumental in the waxing and waning of the ice sheets. Finally, the total weight of plants on the land could have been reduced by as much as half.

Carbon dioxide is an important greenhouse gas, which we know from ice cores was reduced by a third during each glaciation, helping to make these periods even colder. On the graph below, the record of carbon dioxide is shown as a yellow line, while temperatures over Antarctica are shown in blue, with the warmest peaks indicated in red. The graph clearly demonstrates the powerful correlation between carbon dioxide and temperature. The alarming increase in carbon dioxide at the present may presage significant global warming.



were similar in appearance to the gangly youth from Kenya are found in Southeast Asia dating to roughly the same time range. These remains are classified as *Homo erectus*, which is now widely viewed as an Asian variant of the same, or very similar, people that were found in Africa. At a slightly later point in time – about 1.4 million years ago – handaxes appear in the Near East. These probably reflect yet another movement out of Africa.

The Heidelberg phenomenon

Roughly three-quarters of a million years ago, a new form of *Homo* evolved in Africa and spread northwards into Eurasia, repeating the earlier pattern. The new people are often referred to as *Homo heidelbergensis* (or Heidelberg Man), which seems odd for a group from sub-Saharan Africa, but reflects the history of fossil discovery. In 1908, a robust human jaw was found in ancient river deposits near the German city of Heidelberg. It now appears that this jaw, along with other skeletal remains in Europe that are about half a million years old, all belong to the same group. These people were more similar to ourselves than any previous form of human. The brain was significantly larger – almost the same size as the modern human brain. While the skull retained some primitive features, it lacked the massive brow ridges and large jaws and teeth of earlier *Homo*.

Homo heidelbergensis continued to make handaxes – as well as cleavers and picks – often with great skill and attention to form. But they also developed a novel way of producing stone flakes for smaller tools that allowed them more control over the size and shape of the flake. The method is usually referred to as the 'prepared-core technique', and it seems eventually to have led to the manufacture of composite tools and weapons (i.e. fitting blades and points into wooden handles or shafts). In addition to this, with *Homo heidelbergensis* we have the first convincing evidence for the use of controlled fire – evidence for this among earlier humans is ambiguous. These improvements in technology – in the ability to manipulate the environment – presumably reflect enhanced cognitive skills, although they seem rather modest when matched against the large increase in brain size that *Homo heidelbergensis* exhibits.

Human fossil remains from this period are scarce in the Near East, and it is the sudden appearance of artifacts similar to those of comparable age in Africa that suggests the arrival of the Heidelbergers. The site of Gesher Benot Ya'aqov in Israel is filled with handaxes and cleavers dating to about 800,000 years ago made from giant flakes of

below A new species of human, often referred to as *Homo heidelbergensis*, evolved in Africa about three quarters of a million years ago and spread north into Eurasia, including western Europe.

opposite below At Boxgrove in southern England, *Homo heidelbergensis* groups moved across a low-lying coastal plain roughly half a million years ago, hunting or scavenging meat from large mammals.

volcanic rock. They are quite similar to the tools that people had been making in Africa from about 1 million years ago onwards. And it is Gesher that yields the oldest traces of controlled fire.

From the Near East or possibly northwest Africa, *Homo heidelbergensis* spread north into Europe, becoming the first human population to establish a substantial presence on the continent and occupy latitudes as far north as the city of London and beyond. Handaxes are found in Italy dating to 640,000 years ago. Roughly half a million years ago – the same age as the Heidelberg jaw – they show up in southern England at the site of Boxgrove.

above A new technique of preparing stone cores that allowed greater control of the size and shape of the flakes struck off them was developed roughly half a million years ago.

THE ICE AGE BESTIARY

Giant Mice and Dwarf Elephants

Islands around the world have produced giants and dwarves of a variety of species, ranging from surprisingly large mice to tiny elephants. Changing sea levels can isolate animals on islands, or they can swim or raft there. There is an evolutionary trend on islands for small animals to get bigger as there are usually few predators, and for large animals to get smaller as there is a limited amount of vegetation to support them. Some animal families, such as the elephants, have dwarfed repeatedly: dwarf mammoths have been found on Wrangel Island in northern Russia, St Paul in the northern Pacific and the California Channel Islands, while dwarf stegodons are reported from islands in Southeast Asia. Dwarf straight-tusked elephants have been found in the Mediterranean, and those from Crete tell a tale of repeated colonization. Crete in the early Ice Age had pygmy elephants and hippos and a giant mouse the size of a brown rat. Later, mainland-sized elephants colonized the island, along with deer which evolved rapidly into dog- and moose-sized forms with at least four others in between. The Mediterranean dwarf elephants were smaller than a family dining table, and the juveniles were the size of cats. The majority of animals that are found on the Mediterranean islands are those that are capable of swimming and move in herds, such as elephants and deer, while sloths managed to colonize many of the islands in the Caribbean. Several animals arriving at once makes the chances of successful colonization much more likely. Small islands naturally have limited space available, so these populations were never abundant and the arrival of a new species such as brown rats or humans has led to massive extinctions of these unique faunas all over the world.

right Dwarfed forms of straight-tusked elephants, Palaeoloxodon antiquus, have been found on several of the Mediterranean islands. Why they were so small is not well understood, but possible reasons are shortage of food and a lack of predators on islands.

opposite A skeleton of an extinct species of pygmy hippopotamus from Madagascar. Dwarfed forms of hippopotamus have been found on several islands, as they are capable of swimming for some distance in salt water.

below Map of the Mediterranean showing the dwarf and giant species found on the islands.

The Columbian mammoth evolved in the Americas. It was the biggest of the mammoth species, and had the longest tusks – the largest recorded Columbian mammoth tusk was found in Texas and is 4.9 m (16 ft) in length.

plains among the pronghorn antelopes, herds of Harlan's ground sloths, 3.6 m (12 ft) tall and weighing 1,500 kg (3,300 lb) would have been grazing slowly forwards, while yesterday's camel would have been browsing at the forest edges. The Florida bear was found nowhere else but North America, and the elephant-like mastodons and gomphotheres were the last surviving representatives of families that had flourished throughout the world in earlier time periods, but now had a final stronghold in the Americas. Mammoths dispersed twice into North America: the ancestors of the Columbian mammoth arrived first and this species evolved *in situ*, while towards the end of the Ice Age the woolly mammoth came across the Bering land bridge. The Columbian mammoth was the largest of all mammoths, with a shoulder height of 4 m (13 ft). Given that it lived in warmer climates, although sometimes at high

altitude, it is likely that it was not as hairy as its arctic cousin. Unlike the mammoths, some other animals were found in restricted areas, with many found in Central and South America only reaching as far as the southeast portion of the United States, around Florida, where the truly giant ground sloths and gomphotheres trod.

In the north lived the mammoth steppe fauna that stretched from Europe across Beringia and into the Americas. Life is tough for all animals, a constant battle to find food, find a mate and stay safe. Dima's story (above) highlights the role of chance in survival, but accidental death, old age or diseases are not the only things that can kill an animal. The story of Blue Babe, a bison in the prime of life, gives us insight into another aspect of life on the mammoth steppe – the battle between predator and prey. Blue Babe was a steppe bison, aged between 8 and 9 years, who, to judge from the extensive fat deposits on his body, had spent a good year grazing on the Alaskan

The stuffed skin of Blue Babe, a male steppe bison, *Bison priscus*, found in the Alaskan permafrost in 1979. Many of the holes and scratchmarks on the skin were made by lions when attacking and later feeding on the carcass.

member of a family that had lived among the dinosaurs but had since died out on all other continents. There were also two huge browsing tortoises, both of which were heavily armoured, with horns around the backs of their skulls and a large club on the ends of their tails. The dominance of reptiles as top carnivores in Australia may be a reflection of how these animals get energy from their food. Reptiles use fewer calories than mammals, so where food was scarce only a few good kills were needed to keep a *Megalania* fed for a year, whereas mammals need to eat much more frequently to stay alive.

If the reptiles were unusual, the mammalian predators were even stranger to our eyes. As well as the grass-eating lineages of kangaroos, there was another that had

above left: A cast of the skeleton of the giant wallaby *Protemnodon*. Some species of *Protemnodon* weighed up to 100 kg (220 lb). The skeleton clearly shows why kangaroos are sometimes termed 'Macropods' (literally 'big feet'), as they have a large but narrow hind foot, with only two toes (the fourth and fifth) taking the weight of the animal.

left: The thylacine, *Thylacinus cynocephalus*, probably had a similar role to a small canid such as the red fox. This photograph, however, shows how the thylacine differed in bodily proportions, with a very long, thick tail, short legs and a relatively small head. It also had a striped coat, which led to its alternative name of the 'Tasmanian tiger'.

below: For over 100 years bounties were paid for killing thylacines as they preyed upon livestock, but it is likely to have been a combination of persecution and disease that ultimately led to their extinction.

evolved to become an omnivorous scavenger. These creatures, named *Propleopus*, may have weighed 70 kg (154 lb) and, rather like a modern dingo, they would have eaten whatever they could find. Another predator was the Tasmanian tiger or thylacine. These dog-sized carnivores were extensively hunted during the European colonization of Australia and the last one died in 1936. Unlike the other extinct animals discussed we have a good idea of the colour, size and shape of the thylacines from photographs and films of the last few survivors and