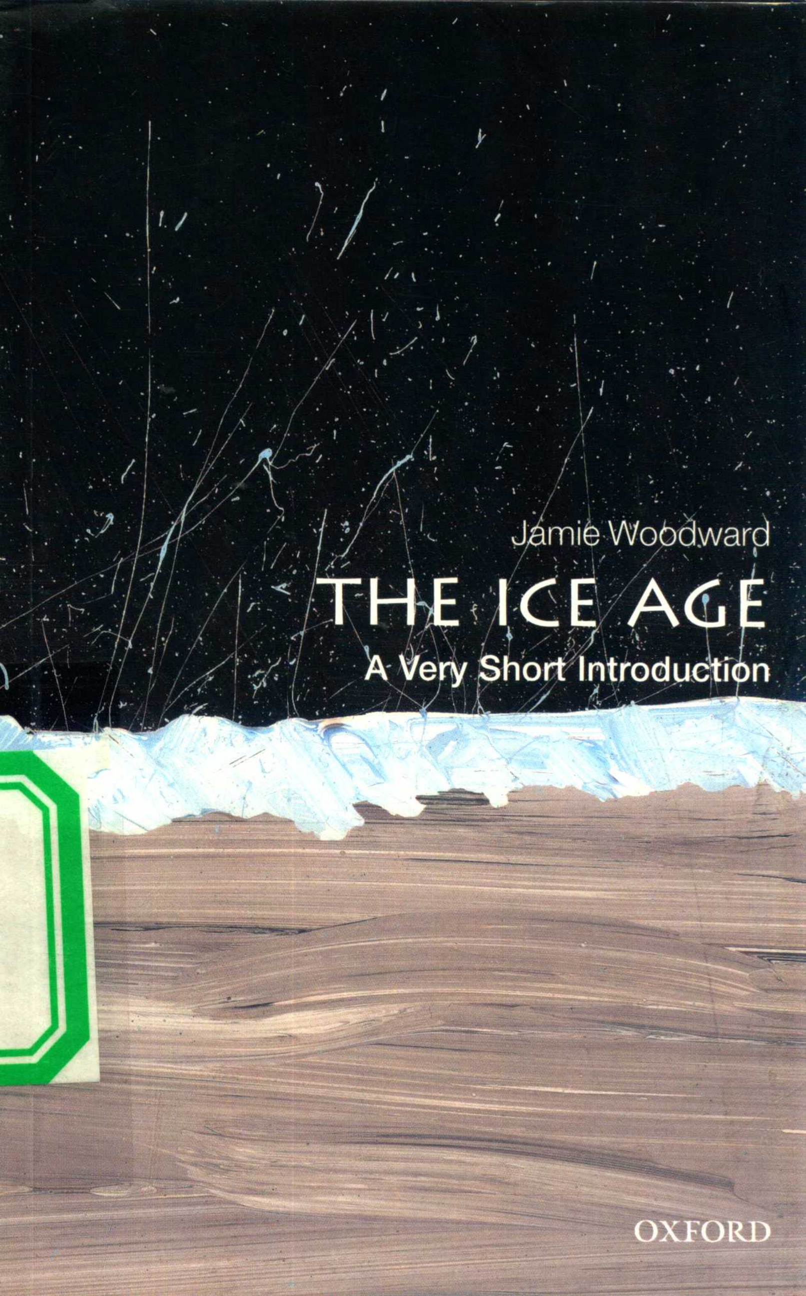

Jamie Woodward

THE ICE AGE

A Very Short Introduction

OXFORD

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Contents

Prologue

A letter from Darwin

When Adam Sedgwick died in January 1873 at the age of 87 he had held the Woodwardian Professorship of Geology at Cambridge for 55 years. Sedgwick was one of the founding fathers of the discipline. One of the nine candidates to succeed him, William Boyd Dawkins (1837–1929), a lecturer in geology in Manchester and an expert on the fossil remains of ice age mammals, asked Charles Darwin to support his application. Darwin responded as follows:

> DOWN, BECKENHAM, KENT
> February 3rd 1873
> MY DEAR SIR,
> I have great pleasure in expressing my opinion that you are very well fitted to fill the Woodwardian Chair in Cambridge, now vacant by the death of its former venerated occupier. You have paid close attention to the geological history of the more recent periods, and I think everyone will admit that these present an extraordinary amount of difficulty; so that your success in this line of research offers an excellent test of your ability. It will also, I think, be admitted that the study of the more recent periods is not only very difficult, but of the highest importance. Therefore I earnestly hope that you may be successful in your application, and if so, I do not

doubt that you will be the means of encouraging the study of geology in the University.

Believe me, my dear Sir,

Yours sincerely,

CH. DARWIN

Boyd Dawkins had been appointed in Manchester in 1869 on the recommendation of Thomas Huxley (1825–95). His reputation was built on the study of fossil fauna from the Quaternary Period—the most recent and shortest of the geological periods that is synonymous with the environmental fluctuations of the Great Ice Age. This period, the last 2.58 million years of Earth history, is the subject of this book.

It was the discovery of fossil animal bones of cold-adapted species such as reindeer, muskox, and arctic fox—which now live in the treeless landscapes of the Arctic tundra—that provided some of the earliest clues that the climate of the now temperate zone had been much colder in the recent geological past. But for much of the 19th century climate change was a controversial topic and most of the leading geologists were climate change sceptics. Darwin's own scientific career ran alongside, and from time to time contributed to, the great 19th-century debate on whether glaciers had been more extensive and climate much colder in the recent geological past. The glacial theory, as it became known, produced one of the most heated and protracted scientific controversies of the 19th century. It was an exciting time of colourful characters and big ideas.

This is not a book about Darwin, but, as we shall see, he was uniquely qualified to comment in the 1870s on the significance of ice age research and on the suitability of William Boyd Dawkins to follow in the footsteps of Adam Sedgwick. His brief letter of February 1873 and the background to its assertions are therefore worthy of some elaboration here. They illuminate key aspects of the glacial debate, show why ice age research is a critical part of the natural sciences, and provide valuable context for much of this book.

It is important to remember that Darwin regarded himself as a geologist when he boarded the *Beagle* in December 1831 and that he returned to England in 1836 the year before the Swiss naturalist Louis Agassiz (1807–73) presented his bold idea of a great ice sheet covering much of Europe, Siberia, and North America. Agassiz toured Scotland in the autumn of 1840 with the Oxford geologist William Buckland (1784–1856) seeking evidence for the former action of glaciers. Both presented papers on their glacial research to the Geological Society in London later that year. Because Darwin was secretary of the Geological Society from 1838 to 1841, he was fully immersed in the machinations of the glacial debate in Britain.

By pointing out that the study of the most recent periods is 'of the highest importance' Darwin provides a powerful endorsement for Boyd Dawkins' research agenda and for the study of the glacial period more generally—this is what we now call Quaternary science. In the 1870s many scholars were still coming to terms with the notion that humans had lived alongside now extinct ice age beasts such as the mammoth and woolly rhino. Darwin, more than anyone in the 1870s, was aware of the enormous importance of developing an improved understanding of the recent geological past, its environmental fluctuations, and the antiquity of humans and other animal species. Even though he was frustrated by the sparseness of the human fossil record, Darwin was also convinced that the environmental changes of the recent geological past formed the backdrop to the evolution of our own species, even if the precise timescale involved was yet to be established. Exploring the relationship between climate change and human evolution remains a key field of enquiry today.

In 1839, following geological fieldwork in the Scottish Highlands the previous summer, Darwin published a paper on the enigmatic landscape features near Ben Nevis known as the Parallel Roads of

1. The Parallel Roads of Glen Roy

Glen Roy (Figure 1). Several theories had been advanced to explain the origin of the distinctive ledges that run along both sides of the valley. Darwin argued that Glen Roy was once an inlet of an ancient sea that covered much of central Scotland. He suggested that the Parallel Roads were shorelines marking changes in the level of this sea.

Barely a year after its publication, however, and to his great dismay, Darwin's interpretation was challenged. Agassiz, who had seen similar features in the Alps, argued that the valley had been blocked by a large glacier during the ice age and the shorelines marked the former levels of an impounded glacial lake. Agassiz's glacial model prevailed. Darwin only abandoned his marine theory, with great reluctance, in the 1860s. He later called it 'one long gigantic blunder'.

In August 1831, to improve his knowledge of geology, Darwin had accompanied Sedgwick on the great professor's regular summer fieldwork stint in North Wales. Darwin was 22 and had just graduated from Cambridge. The two of them spent several days in the mountains of Snowdonia in the heart of what we now know is a classic glacial landscape. But Sedgwick and Darwin only had eyes for the very old solid geology of the Cambrian Period—the earliest known geological period at that time, as defined and named by Sedgwick himself. The two geologists, master and pupil, were surrounded by the work of ancient glaciers—yet both were oblivious to all of it. Writing in his diary many years later (1876) Darwin reflected on his own glacial epiphany in Snowdonia:

> We spent many hours in Cwm Idwal, examining all the rocks with extreme care, as Sedgwick was anxious to find fossils in them; but neither of us saw a trace of the wonderful glacial phenomena all around us; we did not notice the plainly scored rocks, the perched boulders, and the lateral and terminal moraines. Yet these phenomena are so conspicuous that, as I declared in a paper published many years afterwards in the *'Philosophical Magazine'* (1842), a house burnt down by fire did not tell its story more plainly than did this valley. If it had still been filled by a glacier, the phenomena would have been less distinct than they now are.

Not only did Darwin regard the study of 'the more recent periods' as being 'of the highest importance', his comment about the 'extraordinary amount of difficulty' involved in studying the most recent deposits and landforms in Earth history is especially poignant given his own profound disappointment over Glen Roy and his reflections on a missed opportunity at Cwm Idwal. This was a truly formative period for Darwin. The events of 1839 to 1842 left a lasting impression as he witnessed the power of a bold new theory.

Boyd Dawkins did not get the chair in Cambridge. He stayed in Manchester for the rest of his career pursuing many interests as the Curator of the Manchester Museum and the first Professor of Geology in the University. He was knighted in 1919. Boyd Dawkins held some controversial views on the role of glacial ice in Britain, but he is perhaps best remembered for his pioneering work on the fossil remains of ice age animals from British limestone caves as part of the golden age of Victorian geology. He also made important contributions to Palaeolithic archaeology. It was during his career that the foundations were laid for the modern interdisciplinary study of Quaternary ice age environments that we know today.

This book then is concerned with the remarkable environmental changes that have taken place during the Great Ice Age of the Quaternary Period. It explores the evolution of ideas and changing approaches to the study of the recent geological past; from the pioneers of the 19th century who first recognized that glaciers had once been much more extensive, to the pioneers of the 20th century who transformed our understanding of global climate change by extracting exquisitely detailed records from ocean sediments and ice cores. Most of all it aims to show why the study of the ice age is exciting and rewarding and is still 'of the highest importance' 140 years after Darwin wrote that letter.

Chapter 1
The Quaternary ice age

> Nothing excites the imagination more than the study of the Quaternary.
>
> Maurice Gignoux (1955)

Early ideas: elephants or mammoths?

In 1727, the physician, compulsive collector of curiosities, and shrewd investor in London property, Sir Hans Sloane (1660–1753), published *An Account of Elephants' Teeth and Bones Found under Ground*. It reported one of the first systematic investigations of mammoth fossils—describing finds of large bones and tusks (of both elephants and mammoths) from Quaternary deposits in Britain, France, and Siberia. Sloane's paper also included items from his own *Catalogue of Quadrupeds*. In the same year, Sloane succeeded Sir Isaac Newton as president of the Royal Society. He was an enormously influential figure and his work was widely read.

The discovery of elephant-like beasts in the superficial deposits of Europe and Siberia was rather problematic for 18th-century scholars because such creatures only lived in the tropics and climate change was not on the agenda. Sloane and his contemporaries believed that these animals had perished in the Biblical deluge and their carcasses had been washed northwards by the flood. In 1728, the German zoologist Johann Philipp Breyne (1680–1764) set out this position very clearly as the only reasonable explanation for the presence of mammoth bones in the frozen floodplains of Siberia:

> That those Teeth and Bones of *Elephants* were brought thither by no other Means but those of a Deluge, by Waves and Winds, and left behind after the Waters return'd into their Reservoirs, and were buried in the Earth, even near to the Tops of high Mountains. And because we know nothing of any particular extraordinary Deluge in those Countries, but of the universal Deluge of *Noah*, which we find described by Moses; I think it more than probable, that we ought to refer this strange Phenomenon to the said Deluge. In such Manner, not only the holy Scripture may serve to prove natural History; but the Truth of the Scripture, which says that *Noah's* Flood was universal, a thing which is doubted by many, may be proved again by natural History.

Such certainty (and circularity) was typical of the period and these beliefs were strengthened by the fate of an exotic gift to the Tsar of Russia. In 1713, Peter the Great (1672–1725) was presented with an Asian elephant by the Persian Ambassador. Unfortunately the poor creature soon perished in the brutal St Petersburg winter and ended up stuffed in the Imperial Museum. Elephants just weren't cut out for the frozen north.

In 1753, following an act of Parliament, Sloane's extraordinary collection of curiosities—mammoth tusks and all—was opened to the public alongside King George II's library as the British Museum in Bloomsbury. For the rest of the century, mammoth bones and teeth continued to be mysteries of an antediluvian world. It took an astonishing discovery from the frozen wastelands of Siberia (that would itself become a ground-breaking museum exhibit) to put such curiosities on a more secure scientific footing.

Cuvier's insights and the Adams Mammoth

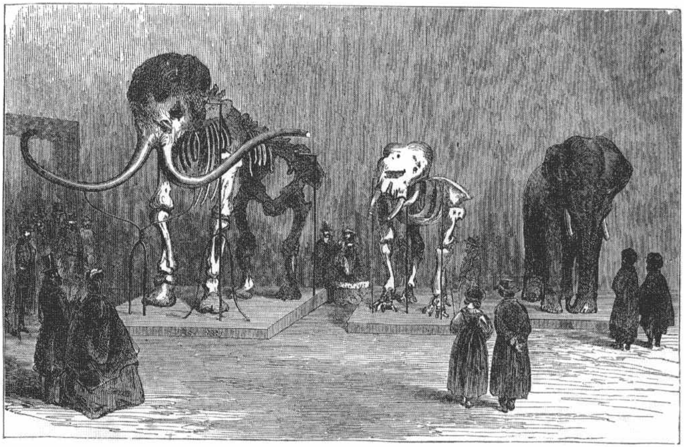
In 1799, just weeks apart, two quite remarkable discoveries were made in the lower reaches of large rivers that would, in very different ways, transform our understanding of the past. In the same summer that the Rosetta Stone was unearthed from the mud of the Nile Delta, a hunting party in eastern Siberia discovered a frozen mammoth carcass in a steep bank of the mighty River Lena not far from the Arctic Ocean. As the river sediments thawed the ancient beast was slowly exhumed—within a few years the entire carcass had slumped to the ground at the foot of the bank. Preyed upon by polar bears and wolves, the decomposing mass was partly defleshed and some of the large bones were dragged away. In 1804, the leader of the hunting party, Ossip Shumakhov, returned to the site, sawed off the giant tusks, and sold them to an ivory merchant for 60 roubles. News of the extraordinary discovery soon reached St Petersburg.

In the summer of 1806, Mikhail Adams (1780–1838), a Russian botanist under the patronage of Tsar Alexander I, trekked to the site to recover what was left of the mammoth. Although the trunk was missing, the skeleton was almost complete and large sections of skin with its woolly fleece and long hair were still intact. Many parts of the skeleton were firmly held together by cartilage, ligaments, and skin. Over 16.5 kg of mammoth wool and hair were gathered up from the carcass and the sandy river margin. Adams claimed he managed to buy back the original 3-metre-long tusks. He then shipped everything to St Petersburg—a distance of some 11,800 km. The Adams Mammoth is still one of the most complete mammoth carcasses ever found. Its skin and thick hairy fleece were exceptionally well preserved and samples were sent to museums across Europe.

Barely a decade earlier, in 1796, the brilliant French anatomist Georges Cuvier (1769–1832) became the first person to argue that the mammoth was a distinct species quite different from modern elephants. He was therefore able to declare that this species was extinct. Cuvier established extinctions as a scientific fact. To explain the extinctions he observed in the fossil record he became the most prominent advocate of what later became known as catastrophism, suggesting that new species were created after sudden events wiped out earlier ones. The mammoth was one of the first extinct animals to be discovered and investigated scientifically—the first dinosaur was not named until the 1820s. Cuvier is the father of modern vertebrate palaeontology and comparative anatomy—it was said he could recreate the anatomy of an extinct creature from just a handful of bones.

Most importantly, the well preserved hair and wool remains of the Adams Mammoth convinced Cuvier that, unlike Peter the Great's elephant, this large, fleshy creature was adapted to the frozen world of the Arctic. It had lived and died in the frozen north—there was no need to invoke post-mortem carriage from tropical climes by Biblical floods. These seminal conclusions placed the mammoth as a key fossil indicator of Arctic conditions. Discoveries of mammoth bones in the Quaternary deposits of the temperate latitudes now assumed much greater significance. Cuvier's conclusions laid down fundamental principles for what would become ice age research. The modern era of debating climate change had begun.

In 1808, the Adams Mammoth skeleton was reassembled by the German naturalist and explorer Wilhelm Tilesius von Tilenau (1769–1857). Tilesius used an elephant skeleton in the St Petersburg museum collection to help him rebuild the mammoth, replacing two missing leg bones with carved wooden replicas. Imagine the frustration on finding that the first mammoth kit had pieces missing! Standing about 3 m in height and over 5 m long, it was the skeleton of an adult male that died when it was about 45 years old. The magnificent reconstruction was put on display in the Imperial Museum in St Petersburg where it towered over the stuffed carcass of Peter the Great's Asian elephant that stood nearby (Figure 2).



2. The Adams Mammoth

Tilesius made a detailed drawing of the skeleton that was widely distributed in both scholarly publications and the popular press. The Adams Mammoth began to feature prominently in university lectures in Europe and North America. This was one of the earliest attempts to reconstruct the skeleton of an extinct animal and the first time that a mammoth skeleton had been put on public display. Unfortunately, as the image of the museum gallery clearly shows, the enormous mammoth tusks were mounted pointing outwards instead of inwards. This mistake was not rectified until 1899—exactly one hundred years after the carcass was first discovered protruding from the frozen banks of the Lena River. Despite this error, between them, Cuvier, Shumakhov, Tsar Alexander I, Adams, and Tilesius had paved the way for the mammoth to become *the* iconic symbol of the Quaternary ice age.

The nature of the Quaternary

What the Quaternary Period lacks in length is more than compensated by the wonderful variety and exquisite detail of its sedimentary records. These records, on land and on the ocean floor, preserve evidence of profound and global-scale changes in climate, landscapes, and ecosystems. It is important to appreciate from the outset that the Quaternary ice age was not one long episode of unremitting cold climate. The Quaternary is all about change. How much, how often, how fast?

By exploring the landforms, sediments, and fossils of the Quaternary Period we can identify *glacials*: periods of severe cold climate when great ice sheets formed in the high middle latitudes of the northern hemisphere and glaciers and ice caps advanced in mountain regions around the world. We can also recognize periods of warm climate known as *interglacials* when mean air temperatures in the middle latitudes were comparable to, and sometimes higher than, those of the present. As the climate shifted from glacial to interglacial mode, the large ice sheets of Eurasia and North America retreated allowing forest biomes to re-colonize the ice free landscapes.

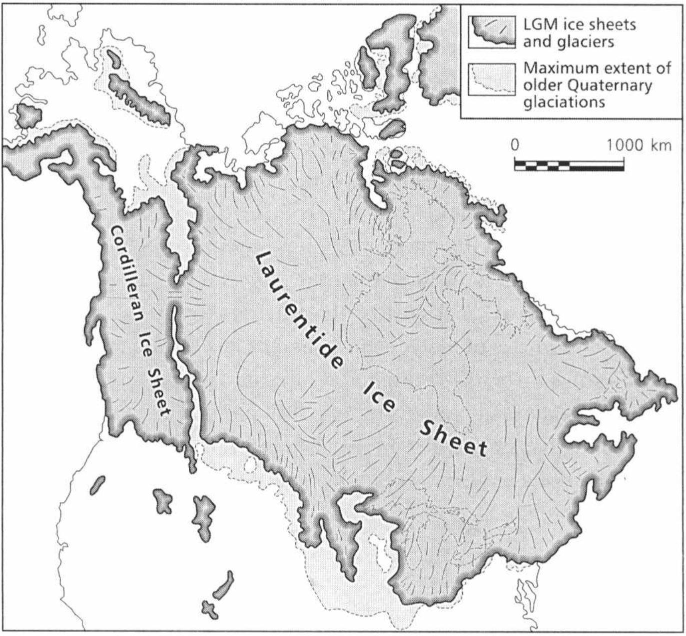
It is also important to recognize that the ice age isn't just about advancing and retreating ice sheets. Major environmental changes also took place in the Mediterranean region and in the tropics. The Sahara, for example, became drier, cooler, and dustier during glacial periods yet early in the present interglacial it was a mosaic of lakes and oases with tracts of lush vegetation. A defining feature of the Quaternary Period is the *repeated* fluctuation in climate as conditions shifted from glacial to interglacial, and back again, during the course of the last 2.5 million years or so. A key question in ice age research is why does the Earth's climate system shift so dramatically and so frequently?

The great ice sheets

Today we have large ice masses in the Polar Regions, but a defining feature of the Quaternary is the build-up and decay of continental-scale ice sheets in the high middle latitudes of the northern hemisphere. Figure 3 shows the Laurentide and Cordilleran ice sheets that covered most of Canada and large tracts of the northern USA during glacial stages. Around 22,000 years ago, when the Laurentide ice sheet reached its maximum extent during the most recent glacial stage, it was considerably larger in both surface area and volume (34.8 million km^3) than the present-day East and West Antarctic ice sheets combined (27 million km^3). With a major ice dome centred on Hudson Bay greater than 4 km thick, it formed the largest body of ice on Earth. This great mass of ice depressed the crust beneath its bed by many hundreds of metres. Now shed of this burden, the crust is still slowly recovering today at rates of up to 1 cm per year. Glacial ice extended out beyond the 38th parallel across the lowland regions of North America. Chicago, Boston, and New York all lie on thick glacial deposits left by the Laurentide ice sheet.

From an archaeological perspective, understanding the changing geography of the globe during glacial and interglacial stages is of the utmost importance. With huge volumes of water locked up in the ice sheets, global sea level was about 120 m lower than present at the Last Glacial Maximum (LGM), exposing large expanses of continental shelf and creating land bridges that allowed humans, animals, and plants to move between continents. Migration from eastern Russia to Alaska, for example, was possible via the Bering land bridge.

Understanding the shifting dimensions of the Cordilleran ice sheet and the Pacific coastal zone (and the timing of these changes) is critical in this respect and especially during the last deglaciation as ice sheets retreated and sea levels began to rise. Did humans move south along the west coast of Canada or did they make use of an 'ice free corridor' between the Laurentide and Cordilleran ice sheets? These are the two most likely routes for the migration of humans into North America at the end of the last glacial period (Figure 3).



3. North American ice sheets at the Last Glacial Maximum

Box 1
The cryosphere

Earth is unique in our Solar System because water is abundant in all three phases—in solid, liquid, and gaseous form—and is continuously cycled around the planet. Without large oceans of liquid water and a fully active hydrological cycle, it would not be possible to build ice sheets and melt them again. The frozen parts of the Earth system are known as the cryosphere: from the Greek *cryos* meaning cold. Today, freshwater accounts for barely 2.5 per cent of the water on Earth (the other 97.5 per cent is salty ocean water) and almost 70 per cent of this freshwater is bound up as ice sheets and permanent snow. The ice sheets of Antarctica and