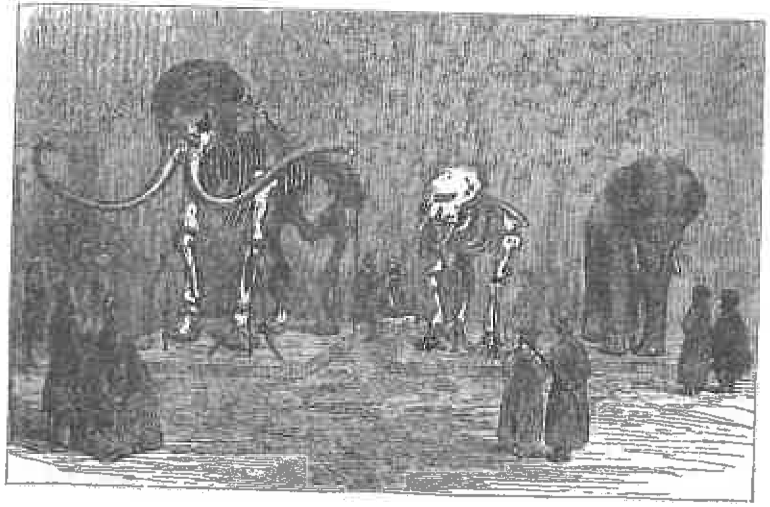


2. The Adams Mammoth

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?

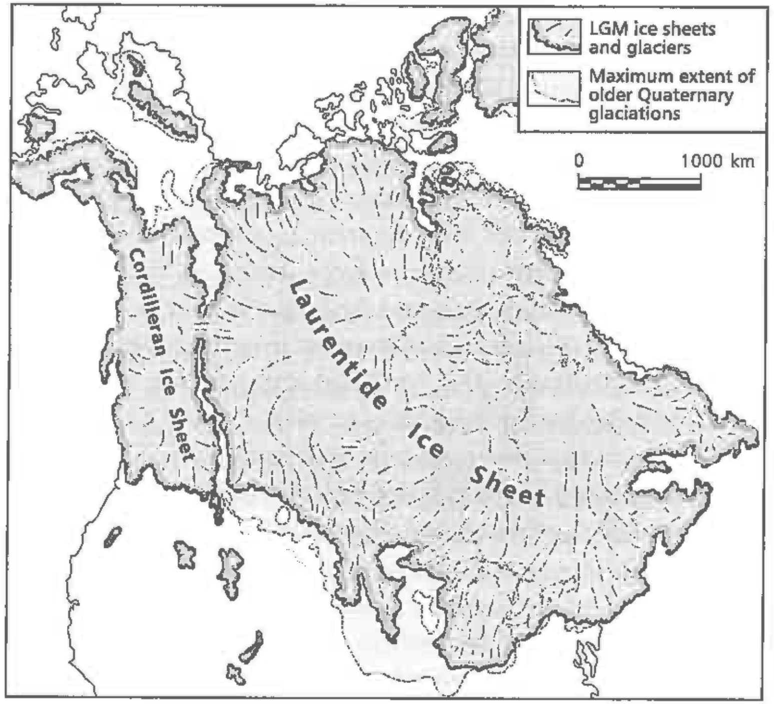
The great ice sheets

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

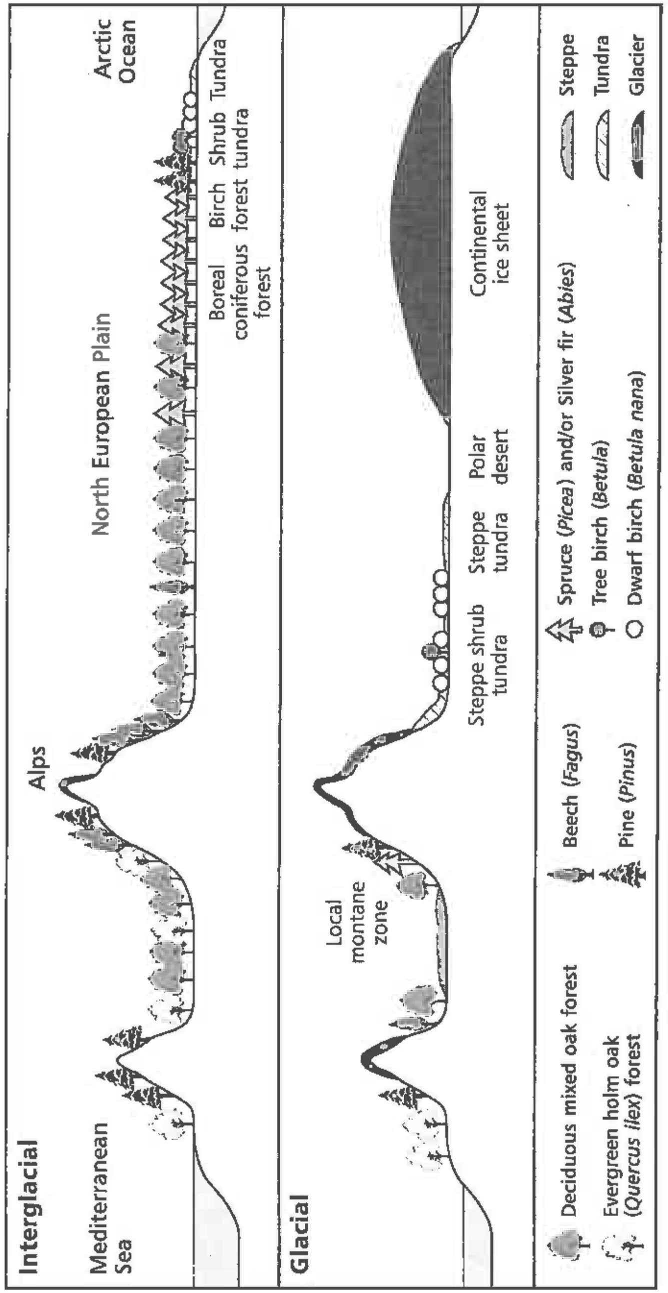
Box 1
The cryosphere

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 Greenland cover an area of about 15.7 million km^2 and have a combined volume of almost 30 million km^3. If all this ice became liquid, sea level would rise more than 65 m. We are still very much within a glacial epoch.

Ice age Europe

Large ice sheets also developed in Europe. Figure 4 shows transects from the high Arctic to the Mediterranean Sea under interglacial and glacial conditions. Much of the continent is covered in woodland during interglacial stages (note that this shows vegetation without any disturbance by humans) and sea levels were similar to or higher than the present. At the LGM, however, European geography was transformed. The Baltic and North Seas were dry land and Britain was connected to mainland Europe. Beyond the British and Scandinavian ice sheets, much of central and northern Europe was a treeless tundra steppe habitat. As in North America, large herbivores like mammoth, reindeer, and bison roamed the landscapes to the south of the ice sheets and were tracked by groups of Palaeolithic hunters. Such reconstructions of Quaternary geography illustrate how landscape processes and ecosystems across the northern hemisphere were completely reorganized as the climate system shifted between glacial and interglacial modes.

The British Isles lie in an especially sensitive location on the Atlantic fringe of Europe between latitudes 50 and 60° north. Because of this geography, the Quaternary deposits of Britain record especially dramatic shifts in environmental conditions. The most extensive glaciation saw ice sheets extend as far south as the Thames Valley with wide braided rivers charged with meltwater and sediment from the ice margin. Beyond the glacial ice much of southern Britain would have been a treeless, tundra steppe environment with tracts of permanently frozen ground (Figure 4).



4. A transect across Europe during glacial and interglacial times

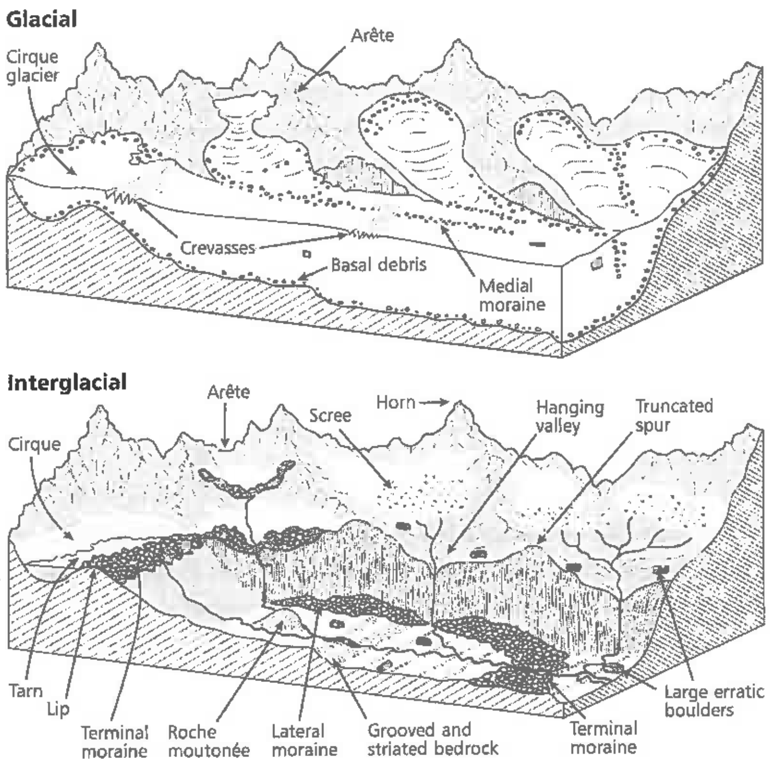
During warm interglacial stages these landscapes would have been transformed. Broad-leaved deciduous woodland with grassland was the dominant vegetation at these times. In the warmest parts of interglacials thermophilous (warm-loving) insects from the Mediterranean were common in Britain whilst the large mammal fauna of the Last Interglacial (*c.*130,000 to 115,000 years ago) included even more exotic species such as the short tusked elephant, rhinoceros, and hippopotamus. In some interglacials, the rivers of southern Britain contained molluscs that now live in the Nile Valley. For much of the Quaternary, however, climate would have been in an intermediate state (either warming or cooling) between these glacial and interglacial extremes. Exploring how ecosystems responded to these climate changes is a fundamental objective of Quaternary research.

The transects in Figure 4 are highly simplified but they provide an important statement on the wholesale and continental-scale reorganizations of life and landscapes that we have to conceptualize in the Quaternary Period. They show the broad pattern of vegetation change, but think also about how insects, birds, mammals, and fish, not to mention humans, coped with such large-scale reconfigurations of their ecosystems. Later in this book we will tackle some fundamental questions: How many times have these grand reorganizations taken place? What was the pace of change? Can we identify a typical state for planet Earth in the Quaternary?

Other important questions follow from such reconstructions. How can we reconstruct the dimensions of an ice sheet that no longer exists? How many glacial periods were there during the Quaternary and how long did they last? How can Quaternary records help us to better understand recent climate trends? This book will explore these questions and consider the kinds of information we need to tackle them.

Evidence of glacial action in the landscape

Glaciers produce a distinctive assemblage of erosional and depositional landforms (Figure 5). The erosional features are best preserved in hard rocks such as granites and limestones. In upland landscapes the tell-tale signs of the former presence of glacial ice include bowl-shaped, glacially eroded bedrock hollows known as cirques (also known as cwms or corries). Cirques are commonly backed by steep bedrock cliffs. An arête is a sharp ridge that forms between neighbouring cirques. During ice free periods cirques are commonly occupied by a lake (tarn) enclosed by a moraine or bedrock lip. Figure 5 shows a number of cirques and hanging valleys along a deep U-shaped valley. The latter was



5. A glaciated valley under glacial and interglacial (ice free) conditions

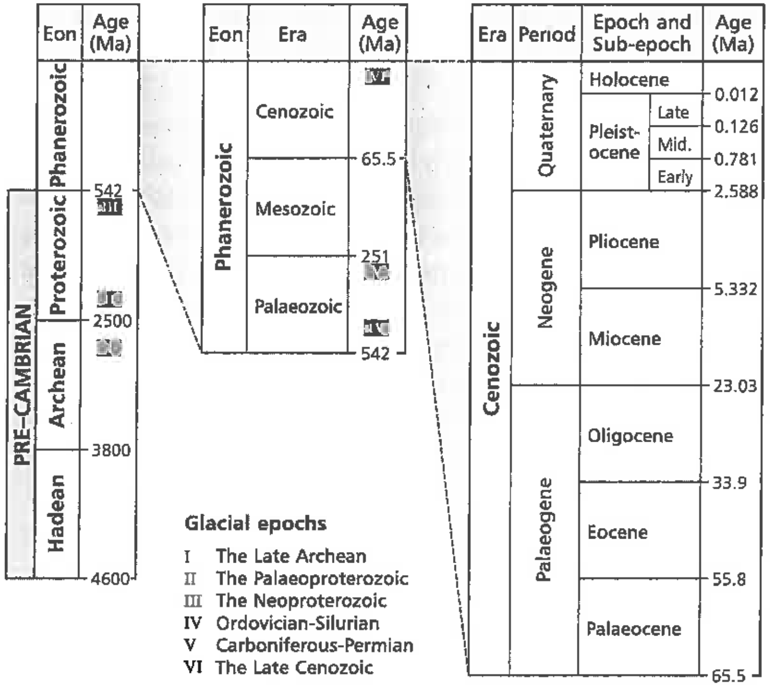
occupied by the main glacier. Polished and scratched bedrock surfaces are found in all parts of this upland landscape.

Landforms produced by the deposition of glacial sediment include lateral and terminal moraines, drumlins, and large erratic boulders. Darwin observed many of these features in Cwm Idwal in North Wales in 1841. Thick sheets of boulder clay (also known as till) cover large tracts of the landscape that were once covered by Quaternary ice sheets. Glacial deposits recognized in ancient hard rocks much older than the Quaternary are known as tillites. Many of the terms for glacial features were first coined in the Alps by German and French speaking observers. Meltwater streams draining from glaciers also produce distinctive fluvial sediments and landforms.

Glaciologists make a distinction between three main types of glacier (valley glaciers, ice caps, and ice sheets) on the basis of scale and topographic setting. A glacier is normally constrained by the surrounding topography such as a valley and has a clearly defined source area. An ice cap builds up as a dome-like form on a high plateau or mountain peak and may feed several outlet glaciers to valleys below. Ice sheets notionally exceed 50,000 km^2 and are not constrained by topography. In Antarctica most ice is transported to the coast via a series of fast moving ice streams. Large blocks of ice can calve off into the ocean to form icebergs.

The Quaternary in the geological timescale

The position of the Quaternary Period in the geological timescale is shown in Figure 6. It sits at the top of the pile. The final period of the Cenozoic Era, it accounts for just a tiny fraction of Earth history—about 0.056 per cent of the 4.6 billion years since the formation of our planet. The term Quaternary was first introduced in the 18th century by the Italian geologist Giovanni Arduino (1714–95). It is the only survivor from the time when the geological record was divided into four parts: Primary, Secondary, Tertiary, and Quaternary.



6. The Quaternary Period in the geological timescale

The Quaternary is sub-divided into the Pleistocene and Holocene epochs (Figure 6). The end of the Pleistocene marks the end of the last glacial period and the beginning of the Holocene (11,700 years ago)—the current interglacial—when the large ice sheets of Europe and North America had melted away for the last time. This was the last time the Earth's climate system shifted from glacial to interglacial conditions. The Holocene is often referred to as the post-glacial and includes the present day.

Glacial epochs in Earth history

We live in unusual times. For more than 90 per cent of its 4.6-billion-year history, Earth has been too warm—even at the poles—for ice sheets to form. Ice ages are not the norm for our

planet. Periods of sustained (over several million years) large-scale glaciation can be called glacial epochs. Tillites in the geological record tells us that the Quaternary ice age is just one of at least six great glacial epochs that have taken place over the last three billion years or so (Figure 6). The Quaternary itself is the culmination of a much longer glacial epoch that began around 35 million years ago (Ma) when glaciers and ice sheets first formed in Antarctica. This is known as the Cenozoic glacial epoch.

There is still much to learn about these ancient glacial epochs, especially the so-called Snowball Earth states of the Precambrian (before 542 Ma) when the boundary conditions for the global climate system were so different to those of today. Exploring when and why large-scale glaciation was initiated at much earlier times in our planet's history is also important because it can shed light on the nature of climates for periods which don't have fossil records.

Quaternary sediments and fossils

This book is concerned with the Quaternary ice age—it has the richest and most varied records of environmental change. Because its sediments are so recent they have not been subjected to millions of years of erosion or deep burial and metamorphism. Most Quaternary deposits are therefore not lithified (turned to hard rocks): they are soft sediments that can be sampled at high resolution with a knife rather than a hammer. They are often rich in fossils, large and small, that have undergone little or no alteration since burial. In aquatic settings, such as lakes and peat bogs, organic materials such as insects, leaves, and seeds, as well as microfossils such as pollen and fungal spores can be exceptionally well preserved in the sediment record. This allows us to create very detailed pictures of past ecosystems under glacial and interglacial conditions. This field of research is known as Quaternary palaeoecology.

Early observers of Alpine landscapes recognized the work of glaciers in places that were then ice free. They made the link between the processes, sediments, and landforms they observed at the margins of active glaciers and landscape features they saw further down valley—often great distances from the snouts of the nearest modern glaciers. But postulating longer and thicker glaciers in the Alps was one thing, making the case for Quaternary glaciers in the mountains of the British Isles, and for immense sheets of ice covering much of Europe and North America was, as we shall see, quite another.