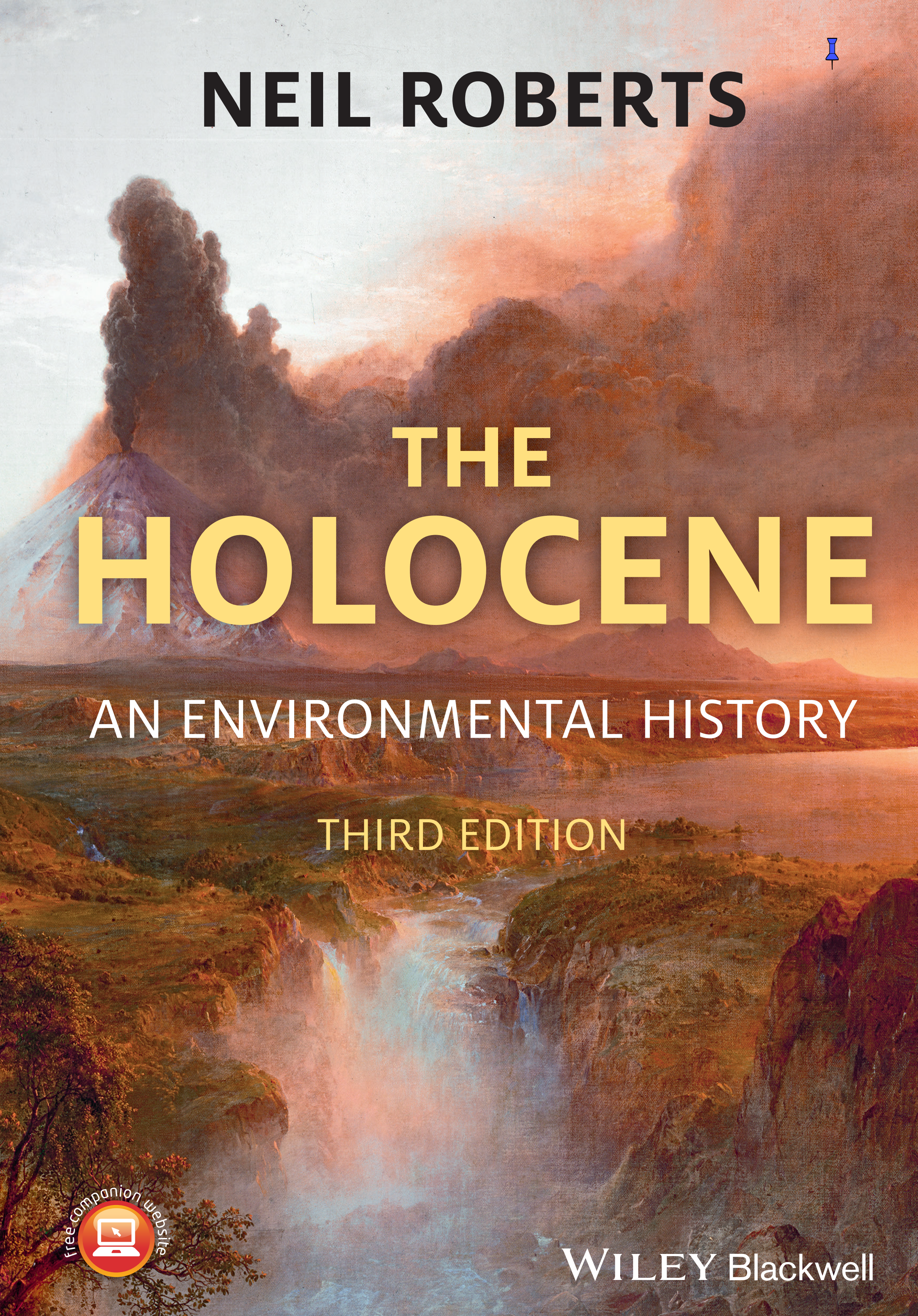

NEIL ROBERTS

THE HOLOCENE

AN ENVIRONMENTAL HISTORY

THIRD EDITION

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THE HOLOCENE

To Glyn and Betty for putting me on the right road,
and to Sylvie and Sara for keeping me there.

THE HOLOCENE AN ENVIRONMENTAL HISTORY

THIRD EDITION

PROFESSOR NEIL ROBERTS

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ENVIRONMENTAL SCIENCES
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Preface to the third edition

Since 1986, when the first edition of this book was published, Holocene research has grown enormously, above all linked to wider concerns about global environmental change. Developments over recent decades have included new techniques of field and laboratory analysis, as well as remarkable discoveries such as Ötzi, the ice man. Important new data syntheses have been published and stimulating conceptual ideas have emerged. Some of these have prompted lively debate, such as Bill Ruddiman's early anthropogenic greenhouse impact. In a related vein, Paul Crutzen and Gene Stoermer proposed that we have now entered a new geological epoch dominated by global human impact – the Anthropocene. If this comes to be accepted, then the Holocene will already have ended! These and other developments demanded to be incorporated in a new edition of the book in order to bring it up to date. More than 500 new references have been added, so that the Bibliography now includes three times the number of items in the first edition – such is the pace at which Holocene research has been produced and published in the last three decades. At the same time, I have sought to retain the best of the older classic literature by pioneering scholars such as Ed Deevey, Winifred Pennington, Sir Harry Godwin and Johannes Iversen – 'giants on whose shoulders we stand'.

Important though these changes are, the biggest shift since the publication of this book's first edition is the realisation that we are now living through an era of human-induced climate change. This is no longer the possibility it was in the mid-1980s, but a reality. Every single year since this book was first published in 1986 has been warmer than the twentieth-century average, and during that time the mean global temperature has risen by around 0.5°C. The Holocene provides a vital long-term context for current climate warming, not least because it tells us that the planet is moving into previously uncharted territory. Realisation of the reality of human-induced climate change has produced a scientific response, notably since the establishment of the IPCC in 1988, but so far much less in the way of political consensus, let alone action. With hindsight, the major change that has been occurring in the Earth System in recent decades is now clear to see, even if it was not evident at the time. Where it will take us in the decades to come is much harder to foretell.

Note on chronology

As in the second edition of this book, calendar years before present (Cal. yr BP) are used throughout, sometimes abbreviated to ka BP (thousand years before present).

Glossary items appear in **bold blue** in the text

Acknowledgements

Holocene research is inherently an interdisciplinary venture, drawing its source material from disciplines as diverse as biology, archaeology, geomorphology/geology and climatology. All of these are included within the realm of this book, but the resulting synthesis aims to ‘look to the past to interpret the present’, and as such is above all a work of geography. Geography seems particularly well fitted to a synthesising role, with its concern for variations in nature and culture across space and through time. As well as the debt to my home discipline, I am enormously grateful to colleagues who have over the years influenced ideas which appear in this book or who have commented on the text, among them Phil Barker, Rick Battarbee, Keith Bennett, the late Sytze Bottema, Jane Bunting, Robin Butlin, Chris Caseldine, Dan Charman, the late Denis Cosgrove, Pete Downs, Dan Engstrom, Ralph Fyfe, Françoise Gasse, Roland Gehrels, Andrew Goudie, Dick Grove, David Harris, Gordon Hillman, John Kutzbach, Henry Lamb, Scott Mooney, Rewi Newnham, Frank Oldfield, Bas Payne, Reinhard Pienitz, Jim Ritchie, Arlene Rosen, Bill Ruddiman, Heikki Seppä, the late Andrew Sherratt, Alayne Street-Perrott, Matt Telfer, Charles Turner, Claudio Vita-Finzi, Tom Webb, Herb Wright and Giovanni Zanchetta. Errors and omissions are of course my own. Thanks are due to the Director and researchers at the CNRS Laboratoire de Géologie du Quaternaire (now CEREGE) in Aix-Marseille, where the writing of the first edition of the book took place when I was on sabbatical leave. I am similarly grateful to Ian Hodder, the Stanford Archaeology Center and to a Blaustein fellowship for support during a subsequent sabbatical visit at Stanford University where much of the third edition was drafted. Thanks go to Val Pheby and Gwynneth Barnwell for secretarial help; Ann Tarver, Peter Robinson, Erica Millwain, Linda Dawes and Tim Absalom for cartography; the late Vernon Poulter for photographic assistance; and the Departments of Geography at Loughborough and Plymouth Universities. Staff at Wiley Blackwell Publishers, past and present, have also been instrumental in ensuring that this and previous editions finally appeared, and my thanks go to Jill Landeryou, Emma Gotch, Kelvin Matthews, Leander Shrimpton, Delia Sandford, Ian Francis and John Davey. My family showed great tolerance while I have been engaged in writing, and re-writing, this tome, and to them I shall be ever grateful. Finally, a special debt is owed to ‘la lumière et les paysages du Muy’ which supplied much of the original inspiration for this book.

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1

Introduction

Are the moors and downs of the British Isles natural landscapes or were they created by human agency? To what extent has soil loss through erosion increased on cultivated land compared with areas of natural woodland? And is the recorded rise in global temperatures since 1980 a result of the current increase in greenhouse gases in the atmosphere, or is it just part of climate's natural tendency to vary through time? Answers to problems such as these are often sought by monitoring contemporary environmental processes. For example, Gordon Wolman (1967) measured sediment yields from forested and cultivated land in the eastern United States and found that erosion was up to eight times higher for the latter. Alternatively, data from gauged field stations may be used, although the short time period of observation often proves to be a handicap. Most meteorological stations, for example, only have records going back to the first half of the twentieth century (Jones et al., 1999), and this makes it hard to identify any long-term trends of warming or cooling.

In fact, neither monitoring nor gauged records are likely on their own to provide complete solutions to the problems posed. This is because a longer-term view is required. An average human lifespan is so much shorter than the millennia of natural history that we tend to be aware only of short-term variations in the environment – the wet summer, the late spring, the 'record' flood. What we are much less aware of are slower, subtler changes such as alterations in the floristic composition of woodland, the silting up of estuaries and the advance and retreat of glaciers. Yet only a long-term perspective could tell us that Britain's downs and moors were transformed from their original woodland before written history even began (Simmons, 2003).

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Sources of information on past environments

For historic times, documentary sources can sometimes provide reliable observations on the former state of the natural environment. Tax records have been used to indicate late seventeenth- and early eighteenth-century climatic deterioration in southern Norway (Grove, 2004), while maps and legal documents show the changing position of Spurn Point spit on the east coast of England during the last 300 years (De Boer, 1964). Among the best historical sources are the early United States federal land surveys which mapped the pre-existing forest and grassland vegetation, and even recorded their species composition, before laying out land boundaries. Documentary data of this sort form an important part of historical ecology which applied to past flora and fauna (Sheail, 1980), historical geology when related to changes in the physical landscape such as rivers (Hooke and Kain, 1982) and historical climatology when linked to former climates (Bradley and Jones, 1992; Brázdil et al., 2005). In practice, the distinction between these sub-disciplines is often an arbitrary one.

Written records are, however, restricted to literate cultures, and as late as AD 1500, they existed only in Europe, Asia and North Africa. There are consequently long periods of human history for which recorded observations are absent, termed prehistory by archaeologists. Moreover, written history covers very different time spans in different parts of the world. Whereas written history began around 5000 years ago in Mesopotamia with the Sumerians, and 2000 years ago in Britain with Julius Caesar, it only started in the 1930s in the highlands of Papua New Guinea when aircraft brought the first European contact. Prehistory has come to be associated in Western thought with all that is remote, both in time and in cultural affinity, to twenty-first-century life. On the other hand, to a New Guinea highlander (or a Maori or black Zimbabwean), prehistory represents a direct cultural heritage which ended only a few generations ago. All of this means that the attitudes towards the natural world of many past societies have either gone unrecorded, or have appeared in written form only through the eyes of others. Ethnobotanical and other studies, however, have revealed a remarkable indigenous knowledge of the natural environment and its uses by modern non-literate hunter-gatherers, peasant farmers and nomads (Cunningham, 2001).

It is not only from ancient times and distant places that historical data on the natural environment prove to be deficient. Old men may recall how, when in their youth, fine catches of salmon were taken from Scandinavian rivers now devoid of fish, but because no one recorded the pH of the water until acid rain became a problem during the 1970s, it is difficult to know whether the salmon were eliminated by **acidification** or simply overfished. Availability of documentary sources therefore tends to inhibit consideration of non-literate regions such as Papua New Guinea and problems such as acidification, which do not appear in historical accounts. The example of megafaunal extinctions (see Chapter 3) serves to illustrate the point. When told that much African wildlife is threatened by extinction, our reaction is one of horror. Yet extinctions of even greater magnitude have occurred within the time span of human history considered in this book, notably in the Americas and Australia where up to 90% of all large mammals were lost. However, this ecological crisis remains known only to a narrow audience of specialists because no contemporary written accounts of it were handed down to posterity.

This book aims to recount and try to explain changes in the natural world through time, including those in human–environment relations. If a truly cross-cultural perspective is to be taken on this, then we need to escape from the restrictions imposed by information derived solely from contemporary or documented historical sources. This is not to deny the critical importance of such sources, but while they have been employed extensively in studies of environmental relations (e.g. Glacken, 1967; Worster, 1993; McNeill, 2000), other sources have not. Without a time machine in which to return to the past, we have instead to rely on proxy evidence, including that from palaeo-science, which provides environmental histories, and archaeology, which provides human histories. These two sources sometimes come together as **environmental archaeology**, in which plant remains, animal bones and sediments from archaeological sites are studied to reconstruct their past economy and environment (Branch et al., 2005). These subjects share in common many techniques such as **radiocarbon dating** and pollen analysis, and they are often investigated together to form interdisciplinary research projects.

For the moment, it is sufficient to note some of the strengths and weaknesses of the palaeoenvironmental approach (Rymer, 1980; Oldfield, 2005). One of its weaknesses is that it cannot reconstruct attitudes to the natural world by former human societies in the way that historical sources can. Medieval cosmologies which placed ‘man’ in a holistic relationship with the natural world, for example, would be scarcely comprehensible without texts to explain them (Cosgrove, 2008). Environmental archaeology, with its concern for site economies and food remains, inclines the investigator towards an economic view of past human life (e.g. Higgs, 1972). This bias towards economic and away from social and cultural explanations is most easily countered where the archaeological past meets the anthropological present, for instance, with the Hopi Indians of the American southwest (Butzer, 1982). In the case of prehistoric Europe, it is not so easy. Even so, we occasionally get glimpses of past symbolic and ritual activities linked to the natural world; for example, pollen of meadowsweet (*Filipendula ulmaria*) from

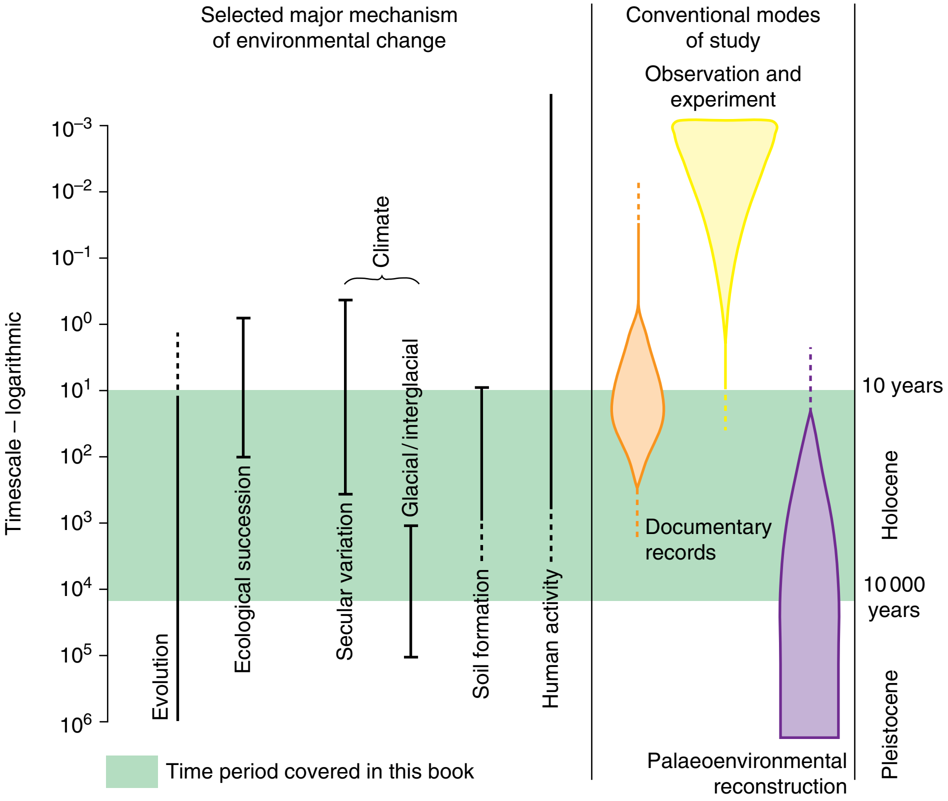

Figure 1.1 Mechanisms and modes of studying environmental change over different timescales (modified from Oldfield, 1983). Reproduced with permission of the Geographical Association.

Bronze Age burials in Scotland demonstrates how floral tributes were placed next to their dead (Tipping, 1994; Clarke, 1999).

On the other hand, one of the great advantages of archaeology and palaeo-science is their ability to identify long-term patterns of cultural or environmental development (Caseldine and Turney, 2010; Caseldine, 2012). This is especially important because the timescales of adjustment in many environmental systems span centuries or millennia rather than individual years, via processes such as soil maturation and ecological succession (see Figure 1.1). In the case of palaeo-science, environmental reconstruction can be applied to more recent as well as to long-term changes. Most lake sediments, for instance, have continued to accumulate up to the present day, and they can therefore be used to give a historical dimension to such contemporary environmental problems as pollution of freshwaters. The continuous nature of most palaeoecological records provides what Frank Oldfield (1977) aptly described as ‘a true continuum of insight’. This enables us to establish whether environmental changes have been episodic or gradual and to identify baseline conditions if they existed. These techniques, unlike written records, have the further advantage of being as applicable in New Guinea as they are in New England.

Nature and society

All of the world's landscapes and ecosystems are products of the natural and cultural processes that have shaped them over time to bring them to their present state. But what are those processes? Over the last one million years, a major factor has been climatic change, with the climate oscillating between Pleistocene glacials and interglacials. Only after the end of the last glaciation, around 12 000 years ago, did the world's climates and environments take on a recognisably modern form. Secular climatic variations of smaller magnitude and shorter duration have continued up to the present day. But whereas most environmental changes brought about by natural agencies have diminished in amplitude as one moves forward in time, there is one set of processes which has done precisely the reverse; human impact on the environment has increased progressively through time as *Homo sapiens* has been transformed from hunter-gatherer to city-dweller.

The oldest and simplest human mode of production is hunting, fishing and gathering (h-f-g), described by Mandel (1969, p. 34) as a 'primitive economy…in which the results are so meager that they must be shared to avoid death by starvation'. In fact, a wide range of anthropological studies suggest that far from eking out a meagre existence in a hostile environment, h-f-g groups probably represent the original affluent society (Sahlins, 1974; Simmons, 2008). Old World h-f-g populations are represented archaeologically by **Palaeolithic** and **Mesolithic** cultures.

Hunting and gathering was followed in the process of cultural evolution by peasant farming, the two being distinguished by the latter's exploitation of domestic plants and animals. The adoption of agriculture by h-f-g groups, termed the **Neolithic** revolution by Vere Gordon Childe, was a decisive moment in human history. Undeniably, it changed the basis of human relations with nature. The basic form of production in h-f-g and subsistence agricultural economies is simple and communal, with no systematic expropriation of surplus labour. This is not true, however, of more complex agricultural economies which supported feudal, classical and 'hydraulic' societies. The resulting states and civilizations typically – although not always – brought with them literacy and consequently the start of written history. Finally, the last two centuries of human history have witnessed the rise of industrial, and arguably post-industrial, economies and the global expansion of Western European culture. Human impact on the Earth system in recent centuries has become so large that it has been proposed that it should be designated as a new geological era – the Anthropocene (see Technical Box IX). Each stage in this social evolution of humankind has seen an increase in control over our relationship with nature (Simmons, 1996, 2008). As we have evolved from hunting to agriculture to industry and beyond, so human impact upon the environment has apparently come to counterbalance or even replace environmental influence over human affairs.

A great strength of an evolutionary approach to human–environment relations is that it is historically mediated. However, consideration of the historical dynamic is usually focused on the human half of the partnership (e.g. Diamond, 1997). The forces of nature are all too often viewed as an essentially passive backcloth against which human history is acted out. Although this environmental backcloth may change from one scene to another, it plays little or no active part in its own right. Perhaps the sky will be permitted to vary to show storm, snow or sun as a token gesture to the fact that nature is not static, but the forests and streams will be ever present, the natural landscape constant. It is above all this *ahistorical* view of nature that this book seeks to challenge. Climate, forests and rivers have their histories too.

By employing a long-term perspective, it becomes possible for us to ask interesting and important research questions, such as the following:

- When, where and how has our planet moved from a being nature- to human-dominated?
- Can the past provide us with meaningful targets for restoring damaged environments?
- What lessons can the Holocene offer us about societal responses to climatic adversity and other environmental crises?
- Has the Earth system crossed any ‘tipping points’ since the time of the Last Ice Age, and if so, what determined these non-linear responses?
- Can the Holocene tell us anything about the possible future course of climate, and what might happen to ice, ocean and biota on planet Earth?

This book not only asks but also attempts to answer these and other questions in the chapters that follow, and particularly in the concluding chapter.

The significance of the Holocene

The period over which most of these cultural and environmental changes have taken place is the **Holocene**. The Holocene – or post-glacial – epoch provides the time frame for this book, which is organised in chronological fashion, starting with the last glacial-to-interglacial transition and then working towards the present day.

During the late Pleistocene, 25 000–12 000 years ago, the glacial climate made the Earth cold and unfamiliar. Canada lay buried beneath several kilometres of ice, Europe was largely devoid of forests, and the southeast Asian islands were joined to form a single land mass – these are some of the changes described in Chapter 3. This chapter also discusses human evolution and the enigmatic – and not unrelated – mass extinction of megafauna in Australia and the Americas. The huge shift in climate which occurred at the end of the last glaciation was important not only in its own right but also because it indirectly controlled many other parts of the Earth system. Post-glacial adjustments of plant and animal distributions, sea levels, geologic and soil-forming processes are discussed in Chapter 4, along with the changes in climate that took place during the first half of the Holocene. This time period, between 11 700 and 6000 years ago, is when we might look to if we were to search for nature's primeval, virginal baseline state – one free from 'significant' human disturbance. However, if it ever existed, this condition was to end with the **domestication** of plants and animals. The emergence of farming and its initial impact upon forest ecosystems are considered in Chapter 5. Chapter 6 focuses on later Holocene environments, notably those produced by complex agroecosystems such as those which developed around the Mediterranean basin and Mesoamerica. It also includes an account of the landscape history of Britain and Ireland. Chapter 7 moves forward to the last millennium; it discusses the impact of human populations upon land use and ecology as we expanded our occupation of the planet's lands and oceans during historical times and the role of industrial capitalism upon pollution of the atmosphere and freshwaters. Included too is the historical background to recent human-induced changes in atmospheric greenhouse gas concentrations, with its potential for altering the global climate. Finally, Chapter 8 brings these threads together to offer an overview of our changing relationship with nature, with implications for how we might put into practice our responsibility as environmental stewards.

But before embarking on a natural history of the Holocene, we need to establish how this remarkable story can be told. For this reason, Chapter 2 of this book is devoted to describing the main techniques that are available for us to reconstruct and date past environmental changes.

References

Bradley, R.S. and Jones, P.D. (eds) (1992) *Climate since AD 1500*. London: Routledge.

Branch, N., Canti, M., Clark, P. and Turney, C. (2005) *Environmental archaeology: theoretical and practical approaches*. London: Hodder Arnold.

Brázdil, R., Pfister, C., Wanner, H., Von Storch, H. and Luterbacher, J. (2005) Historical climatology in Europe – the state of the art, *Climatic Change*, 70, 363–430.

Butzer, K.W. (1982) *Archaeology as human ecology*. Cambridge: Cambridge University Press.

Caseldine, C. (2012) Conceptions of time in (paleo) climate science and some implications, *WIREs Climate Change*, 3, 329–38.

Caseldine, C.J. and Turney, C. (2010) The bigger picture: towards integrating palaeoclimate and environmental data with a history of societal change, *Journal of Quaternary Science*, 25, 88–93.

Clarke, C. (1999) Palynological investigations of a Bronze Age Cist burial from Whitsome, Scottish Borders, Scotland, *Journal of Archaeological Science*, 26, 553–60.

Cosgrove, D. (2008) *Geography and vision: seeing, imagining and representing the world*. London: I.B. Tauris.

Cunningham, A.B. (2001) *Applied ethnobotany: people, wild plant use and conservation*. London: Earthscan.

De Boer, G. (1964) Spurn head: its history and evolution, *Transactions, Institute of British Geographers*, 34, 71–89.

Diamond, J. (1997) *Guns, germs and steel. A short history of everybody for the last 13,000 years*. London: Jonathan Cape.

Glacken, C.J. (1967) *Traces on the Rhodian shore*. Berkeley: University of California Press.

Grove, J.M. (2004) *Little Ice Ages ancient and modern*, 2 vols. London: Routledge.

Higgs, E.S. (ed.) (1972) *Papers in economic prehistory*. Cambridge: Cambridge University Press.

Hooke, J.M. and Kain, R.J.P. (1982) *Historical change in the physical environment*. London: Butterworth.

Jones, P.D., New, M., Parker, D.E., Martin, S. and Rigor, I.G. (1999) Surface air temperature and its variations over the last 150 years, *Reviews of Geophysics*, 37, 173–99.

Mandel, W.M. (1969) Soviet marxism and the social science, in A. Simirenko (ed.), *Social thought in the Soviet Union*. Chicago: Quadrangle Press.

McNeill, J.R. (2000) *Something new under the sun: an environmental history of the twentieth-century world*. London: Allen Lane.

Oldfield, F. (1977) Lakes and their drainage basins as units of sediment-based ecological study, *Progress in Physical Geography*, 1, 460–504.

Oldfield, F. (1983) Man's impact on the environment: some recent perspectives, *Geography*, 68, 245–56.

Oldfield, F. (2005) *Environmental change*. Cambridge: Cambridge University Press.

Rymer, L. (1980) Epistemology of historical ecology, *Environmental Conservation*, 7, 136–8.

Sahlins, M. (1974) *Stone age economics*. London: Tavistock.

Sheail, J. (1980) *Historical ecology: the documentary evidence*. Cambridge: Institute of Terrestrial Ecology.

Simmons, I.G. (1996) *Changing the face of the earth*. 2nd edn. Oxford: Blackwell.

Simmons, I.G. (2003) *The moorlands of England and Wales. An environmental history 8000* BC–AD *2000*. Edinburgh: Edinburgh University Press.

Simmons, I.G. (2008) *Global environmental history 10000 BC to AD 2000*. Edinburgh: Edinburgh University Press.

Tipping, R. (1994) 'Ritual' floral tributes in the Scottish Bronze Age – palynological evidence, *Journal of Archaeological Science*, 21, 133–9.

Wolman, M.G. (1967) A cycle of sedimentation and erosion in urban river channels, *Geografiska Annaler*, 49A, 385–95.

Worster, D. (1993) *The wealth of nature: environmental history and the ecological imagination*. Oxford: Oxford University Press.

2

Reconstructing Holocene environments

Dating the past

Dating techniques are fundamental to an understanding of the natural and cultural changes which have taken place during the Holocene. Without them, events such as the **Neolithic** agricultural revolution would float aimlessly in time. Perhaps worse, without independent dating methods, we would be forced to depend on environmental and archaeological evidence to provide our chronologies, thus robbing this evidence of much of its potential meaning (Vita-Finzi, 1973).

Curiously, the most obvious reason for wanting to date the past may be the least important, that is, the desire to know how old something is simply for its own sake. It may stagger the imagination to think that there are trees living today in California's White Mountains which were saplings before Stonehenge was completed, but the significance of neither henge monuments nor the bristlecone pine is better explained as a result. A much more significant role for independent dating lies in the testing of hypotheses (Deevey, 1969). Take, for example, the mid-Holocene elm decline that is widely recorded in pollen diagrams from northwest Europe. If, as has been hypothesised, this was a consequence of prehistoric agriculture, then the fall in elm pollen values should coincide with the time of arrival of the first farming communities. Dating early Neolithic sites, on the one hand, and the appropriate section of pollen diagrams, on the other, allows the anthropogenic hypothesis to be tested. In particular, if the elm decline were found to pre-date

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the start of the Neolithic, then this hypothesis would be shown to be false, and our agricultural ancestors exonerated from blame (see Chapter 5 for further discussion of the elm decline).

Another reason for wanting to have precise estimates for the age of Holocene events is in order to calculate past rates of change. Some events, such as eustatically controlled sea-level rise, would have occurred at the same time everywhere across the ocean; that is, the change was a **synchronous** one. More usually, however, events begin earlier at some places than at others. The spread of a disease or the movement of a glacier snout are of this type, and they are termed **time-transgressive**. The rate of disease diffusion or of glacier retreat will vary, and precise dating techniques make it possible to establish whether rates were fast or slow, constant or variable. Dating is also essential to a number of the other techniques discussed later in this chapter. Past influx of pollen or of eroded sediment into a lake, for example, can only be obtained if a sound and detailed chronology exists for the sequence of lake sediments.

One simple form of dating is provided by the fact that in undisturbed sediments, younger layers overlie older ones. This law of superposition indicates which layer was deposited first, but it fails to provide the actual age of either. Preferably, the layers should be placed not only in a relative sequence but also firmly in time, and for this it is necessary to assign them absolute ages in years. Several approaches to absolute dating will be discussed here, including those based on historical records, those employing **radiometric dating** techniques and those utilising incremental dating methods such as tree rings.

Historical and archaeological dating

Perhaps the most obvious form of historical dating is that associated with documentary-based studies of past ecology or climate. For instance, medieval manuscripts recording the extent and condition of England's royal forests almost invariably have calendar dates attached to them, as do Icelandic chronicles referring to the presence of drift ice – and hence sea surface temperature – around that island. We may go further and suggest that without an historical age, documentary records such as these are of little use in helping to piece together past environments. Dating of this kind is especially important in regions such as Europe and East Asia where there exist long historical records. Historical or archaeological evidence can also be important in dating non-documentary records such as pollen diagrams. In the case of one sediment core taken from southwest Syria, the presence of an exotic pollen type, that of maize (*Zea mays*), helped show that the upper part of the core dated to recent centuries and not to the early Holocene as had previously been proposed (Bottema, 1977). Maize is native to the

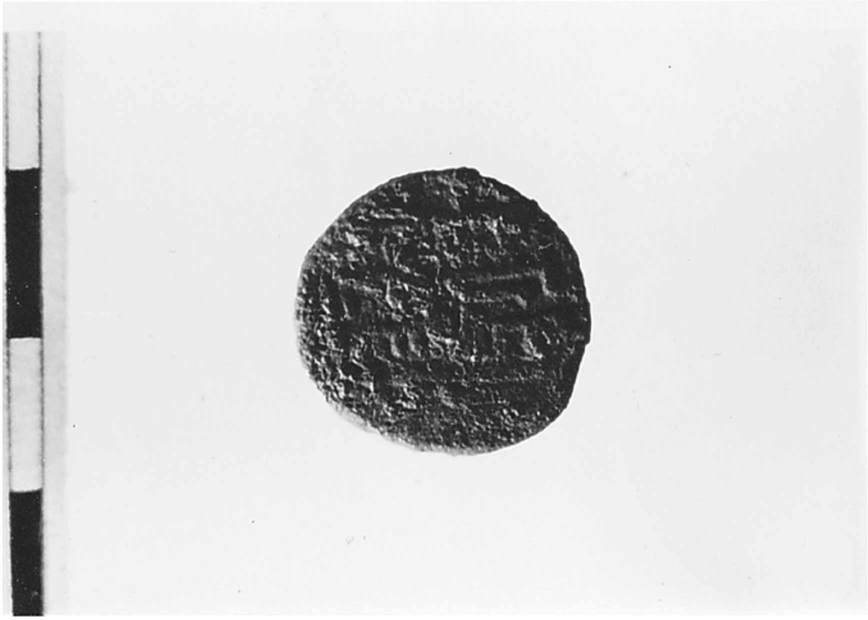

Plate 2.1 This Arab coin from Crete, made between 847 and 861 AD, helped date the alluvial fill in which it was found.

Americas and was only introduced into the Old World as a crop after the Spanish conquest of Mexico in the sixteenth century.

The remnants of past human activity can provide other important clues for dating Holocene environmental changes. A Roman tile drain buried beneath 5 m of alluvium, or a classical port now silted up and many kilometres from the sea, both testify to active sediment transport and deposition by rivers during the last 2000 years. Artifacts including pottery, stone tools and coins can all be assigned ages with greater or lesser precision (see Plate 2.1), as can less obvious cultural evidence such as hemp fibre from retting that has been incorporated in lake sediments. If discovered in a stratigraphic sequence, artifacts provide maximum ages for the layer in which they were found, maximum because they may have been reworked since being deposited initially. A bicycle frame pulled from supposedly mid-Holocene coastal dunes provides a – revised – maximum age for the dunes, for even if the bicycle were manufactured 50 years ago, it could have been dumped there as recently as last year. On the other hand, structures such as a former irrigation channel or a shell midden will not have been redeposited in the same way as artifacts can be, and they may therefore offer tighter dating control. In fact, built structures will often provide minimum rather than maximum ages, say for a land surface on which they are found. However, the use of human artifacts for dating purposes can be fraught with dangers, as it necessarily involves phenomena that are time-transgressive. The Stone Age may have ended by 4000 years ago in Europe, but it arguably lives on with certain isolated hunter-gatherer groups in the tropics.

Radiometric dating methods

Radiometric dating techniques were discovered and have been applied since the middle of the twentieth century. They involve the radioactive properties of different materials which contain within them a natural time signal, most often involving the principle of isotopic decay. Most natural elements are a mixture of several **isotopes**, which have the same chemical properties and atomic numbers but different numbers of neutrons and hence different atomic masses. One isotope is always dominant for each element; for instance, in the case of carbon, the dominant isotope is carbon-12 (or ^{12}C). Carbon isotopes with different atomic masses are ^{13}C and ^{14}C, of which the latter is by far the least abundant. Carbon-14 is also different from the other two in that it is isotopically unstable; in other words, it decays to form stable ^{14}N over time. Most importantly, unstable isotopes such as ^{14}C decay at a fixed rate. The rate of radioactive decay is not a straight line but occurs rapidly to begin with and slows down progressively over time (see Figure 2.1). Because decay rates are measurable, unstable isotopes represent natural archaeological or geological clocks. The clock is set to zero when isotopic decay starts, and the time elapsed can be gauged from how far the decay process has proceeded since then, as indicated by the amount of radioactivity left in the element. The decay rate for a particular isotope is most usually recorded by its half-life, or the time taken for its radioactivity to be reduced by half. Half-lives of different elements vary from the very short (e.g. radon-222, 3.8 days) to the very long (e.g. potassium-40, 1300 million years). In general, the useful dating range of individual isotopic methods is about 10 times their half-life. Beyond this, radioactive emissions are difficult to distinguish from normal background levels of radioactivity. Consequently, different isotopes provide dating methods for very different time periods, and only a few of these will be useful for the Holocene.

The most important of the radiometric dating methods for the Holocene is based on the isotope carbon-14. **Radiocarbon dating** was pioneered by Willard Libby at Chicago in the late 1940s, work which later earned him the Nobel Prize for Chemistry (Burleigh, 1981). ^{14}C is formed in the upper atmosphere by cosmic ray bombardment of nitrogen (N) atoms. The resulting carbon isotope is rapidly oxidised to form carbon dioxide (CO_2) and is then mixed uniformly and rapidly through the atmosphere. Photosynthesis leads to ^{14}C being taken up by plants, which in turn is passed on to higher organisms including ourselves. Consequently, ^{14}C is present in small but significant quantities in all living organisms. When organisms die, their ^{14}C content is no longer replenished, and the isotopic

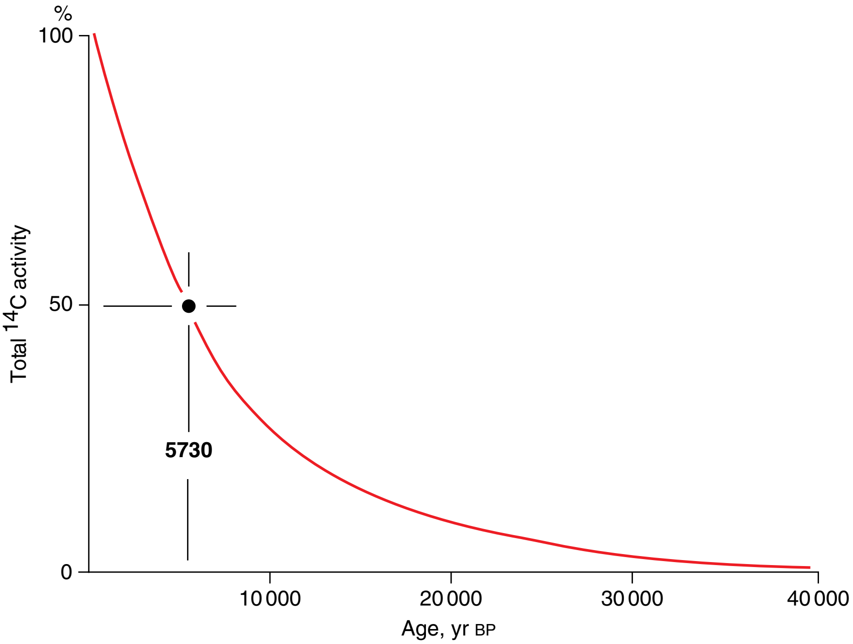

Figure 2.1 Decay curve for radiocarbon.

clock is set in motion. Libby calculated the half-life of ^{14}C experimentally as 5560 ± 30 years, a value close to the present best estimate of 5730 ± 40 years. Libby cross-checked samples which he had dated by the ^{14}C method against materials of known historical age, most of which came from ancient Egypt and were up to 5000 years old. The close level of agreement led him to believe that his radiocarbon dating method was a valid one and that it could be applied universally.

Since its discovery, many thousands of ^{14}C age determinations have been carried out by over hundred different laboratories. About half of all dates have been for archaeological investigations, with most of the rest having been for studies of past environments, and with the vast majority of radiocarbon dates being of Holocene age. The results of radiocarbon dating are usually presented as ages in years before present, normally written using the notation ^{14}C yr BP. In practice, the present is taken as AD 1950 in order to prevent dates appearing to be older simply because they were analysed more recently. Archaeological chronologies use the BC/AD system more often than the yr BP one (alternatively known as BCE/CE; Before and during the ‘Common Era’), but the former can be turned into the latter by simply adding 1950 or – as a quick approximation – 2000 years to BC dates. Also listed along with each individual ^{14}C date are a laboratory code number and an error function representing one standard deviation about the mean. Thus, 8160 ± 110 ^{14}C yr BP (BM – 1666) was dated at the British Museum radiocarbon laboratory and indicates that there is a 68%

probability that the ^{14}C age of this sample lies between 7940 and 8380 yr BP. It should be borne in mind that radiometrically determined dates are statistical estimates, and they should be treated as such. ^{14}C dating can be used to determine the age of any material containing carbon, including wood, charcoal, peat, seeds, bone, carbonate, shell, iron, cloth, rope, groundwater and soil. Among the more exotic dated materials have been ostrich eggshell, lime mortar and human brain!

The ^{14}C method cannot, however, be applied directly to samples of very recent age. The burning of fossil fuels since the Industrial Revolution has caused an injection of geologically old carbon into the atmosphere which has lowered its ^{14}C content and made recent samples seem older than they actually are – the so-called Suess effect. More recently still, this has been overcompensated and further complicated by the testing of atomic weapons. In short, conventional ^{14}C dating is of limited use for samples younger than about 150 years. Many other forms of sample contamination are possible, and although ash from a careless investigator's cigarette has doubtless accounted for more than one erroneous ^{14}C date, contamination is usually of natural rather than of human origin. Carbon both older and younger than the date of the death of the sample may be involved. The latter is a particular problem in areas of limestone or coal-bearing bedrock, and in those experiencing active volcanic activity. This problem can be especially difficult to assess where bicarbonate-rich lake waters have been taken up by aquatic plants which subsequently formed part of the lake sediment. The dilution of ^{14}C levels causes ages to appear older than they actually are, known as the hard-water effect (Deevey et al., 1954). Contamination by young carbon, by contrast, makes dates appear too recent. There are countless such sources, including rootlets penetrating into underlying stratigraphic layers, recalcification of mollusc shells, and animal burrows in archaeological sites. However, many problems of contamination by younger material can be avoided by careful selection of samples in the field and by pretreatment during dating. Young carbon is, in any case, a much more serious problem for samples of Pleistocene than of Holocene age. Since 1980, improved dating precision has also been achieved by measuring ^{14}C directly using a mass spectrometer (Hedges, 1991). This **AMS** (or Accelerator Mass Spectrometer) **dating** method allows the dating of small samples weighing as little as 10 mg. It allows scientists to pick out and date individual seed remains, especially of land plants which should be free of any hard-water error, or charcoal fragments. More controversially, it allowed the age of threads from the Turin Shroud to be determined, which could otherwise have been dated only by destroying the shroud itself. The result showed the shroud to be a – very clever – medieval forgery, fabricated between AD 1260 and 1390.

Some materials are often considered to be more prone to contamination than others – for example, bone, shell and soil – but ^{14}C dating will be more reliable if samples of these materials are adequately prepared before age determination. In the case of bone, only the protein collagen should be dated (Gillespie, 1984, p. 13), while mollusc shell should be tested by X-ray diffraction and acid leached or mechanically cleaned if necessary. Soil, of course, takes longer to form than either of these two, but the consequent broad time range associated with ^{14}C dates on buried soils is as much a stratigraphic as a dating problem (Matthews, 1985). ^{14}C age determination of soil should ideally involve dating selected organic fractions; but even without this, Rothlisberger and Schneebeli (1979) obtained consistent and meaningful results in their study of Holocene soil and moraine stratigraphy in the Swiss Alps. All of these contamination problems are local to sites under study. By contrast, the one major revision to the ^{14}C timescale since Libby's initial discovery involves variations that were global in scale. It was initially assumed by Libby that there had been no significant changes in atmospheric levels of ^{14}C during recent millennia. Libby carried out ^{14}C determinations on historically dated materials to check this, but after initial enthusiasm, he subsequently found that older dates systematically underestimated the true age of samples. This was confirmed in 1965 when Hans Suess presented results comparing ^{14}C dates with those from another dating method – dendrochronology. These results are discussed in detail later, but suffice it to say that ^{14}C dates older than 2500 years significantly underestimate actual age. But because these deviations from true age are systematic and worldwide, it is possible to apply correction, or calibration, factors to ^{14}C determinations to turn them into true, or calendar dates. The need for ^{14}C calibration has not, therefore, invalidated the ^{14}C method, which remains a remarkably robust and successful one.

Other radiometric techniques of increasing importance are Luminescence and Uranium–Thorium (U-Th) dating. **Luminescence**, or optical, dating was initially applied to archaeological materials such as pottery, burnt clay and flint (Aitken, 1990). It was then discovered that 'bleaching' of the sample, which resets the radiometric clock, could be accomplished by exposure to sunlight as well as by firing. Thermoluminescence (TL) dating subsequently came to be successfully applied to the quartz or feldspar grains of windblown sediments such as sand dunes and loess, assuming that they were not deposited in night-time darkness! Other variants have since been added to this technique, such as Optically Stimulated Luminescence (OSL), which require shorter 'bleaching' times and are capable of dating other types of sediment such as river alluvium (Aitken, 1994; Duller, 1996; Wintle, 2008). U-Th dating is based on a more complex decay chain than ^{14}C, with a sequence of 'daughter' isotopes being produced from the original 'parent' (Smart, 1991; Ivanovich and Harmon, 1995). On the other hand, the half-lives involved are longer than with ^{14}C, so that the technique can be used to date older materials. Unstable uranium or thorium isotopes are taken out of water by corals, or precipitated in cave speleothems or in lake carbonates. U-Th, especially with the use of a high-precision mass spectrometer, has proved valuable in calibrating the radiocarbon method beyond the range of dendrochronology (Edwards et al., 2003; Fairbanks et al., 2005).