Introductory Articles

INTRODUCTION

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Societal Relevance of Quaternary Research

S A Elias, Royal Holloway, University of London, Surrey, UK

Introduction

The great 19th-century geologist and natural historian, Charles Lyell (1830), is generally credited as being the author of the concept of Uniformitarianism (*see* History of Quaternary Science). Simply stated, this concept says that "the present is the key to the past." In other words, we may interpret the ancient history of the planet through our understanding of modern-day processes. This concept represented a major step forward in scientific thought, greatly influencing contemporary scientists, such as Charles Darwin (*see* History of Quaternary Science). However, in this article I hope to make it clear that the reverse of Lyell's concept is equally true: the past is the key to the present. In other words, a knowledge of the past is key to our understanding of the present world, especially in the multiple disciplines known as the environmental sciences. No matter which aspect of the environment one considers, be it the atmosphere, the oceans, the cryosphere, the lithosphere, or the biosphere, it is impossible to fully comprehend modern processes and conditions without a knowledge of the past. To try to understand present-day environments without a knowledge of their Quaternary history would be like trying to understand the plot of a long novel by reading only the last page.

Climate History

The Quaternary period saw a large number of climatic oscillations (*see* Introduction) on a scale that was probably greater than at any other time in the last 60 million years (Bradley, 1999). Thus, a study of Quaternary climate change provides us with an understanding of climatic variation on a much larger scale than has been recorded in historic records of the last few centuries. An understanding of the magnitudes and rates of climate change during the Quaternary period is necessary to develop our comprehension of modern climate. Much of climate modeling is based on data derived from reconstructions of ancient climates. These models require long-term data, and these are only available from ancient climate records, reconstructed from various kinds of proxies, such as geochemical records from polar ice cores, and terrestrial and oceanic fossil records.

The predicted amplitude of global warming in the 21st century varies greatly from one scientific study to another, but in the absence of any mitigating policies, Wigley and Raper (2001) predicted with a 90% probability that by the end of the 21st century, global mean temperatures will rise between 1.7 to 4.9°C. This level of warming is certainly unprecedented within recorded history, but it falls within the boundaries of more than one previous interglacial period, including the last interglacial (ca. 120,000–115,000 years ago), when mean temperatures were substantially warmer than they are today in many parts of the world. Evidence from the Vostok Ice Core in Antarctica (*see* Antarctic Stable Isotopes) indicates that at the beginning of the interglacial, between about 130,000 and 127,000 years ago, regional temperatures climbed as much as 3°C higher than today (Kukla *et al.*, 2002) (**Fig. 1**). As Velichko

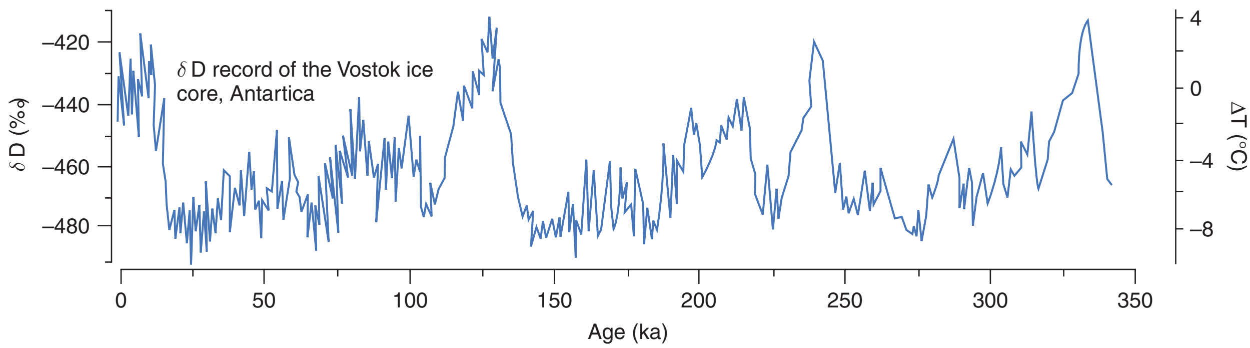

Figure 1 Deuterium isotope record from the Vostok ice core, Antarctica, showing large-scale fluctuations in temperature during the last four glacial–interglacial cycles. After Petit *et al.* (1999).

et al. (1993) observed, there is abundant proxy evidence of large-scale climatic change during the Quaternary, especially in the northern high latitudes. During the long series of glacial–interglacial cycles, high latitude temperatures appear to have fluctuated by about the same amount as that projected for the next century (*see* Paleoclimate Relevance to Global Warming).

Predictions of future temperature changes, based on orbital forcing and increased greenhouse gas concentrations in the atmosphere (Loutre and Berger, 2003), suggest that anthropogenic (human-induced) effects may force global climate into an interglacial mode that may persist for 30,000–40,000 years, not unlike an interglacial period that occurred about 405,000–340,000 years ago.

Pace of Climate Change

Predicted rates of global warming in the coming decades are much faster than the rates of temperature change observed in recent centuries. For instance, Vinnikov and Grody (2003) analyzed upper atmospheric (troposphere) temperatures for the interval 1978 to 2002, and from these data they inferred a future global warming trend of 0.22 to 0.26 °C per decade. Has the Earth previously experienced temperature changes as rapid as this? Fossil beetle evidence from Britain indicates that even greater rates of warming have occurred in the past. For instance, at the end of the last glaciation, the temperature change during the transition from the glacial climates of the Younger Dryas interval to the post-glacial climates at the beginning of the current interglacial was extremely rapid and intense. The beetle evidence (*see* Late Pleistocene of Europe) suggests that mean summer temperatures warmed on the order of 0.35 °C per decade during this transition (Lowe *et al.*, 1995) (**Fig. 2**). This climate change led to wholesale changes in the flora and fauna of many regions. We cannot hope to predict the kinds of changes that may take place in the modern biota without a knowledge of how past biotic communities responded to large-scale climate change.

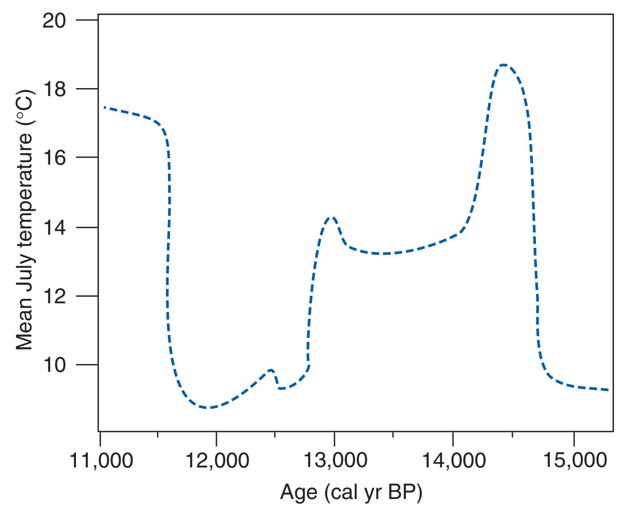

Figure 2 Reconstructed mean July temperature change during the interval 15,000–11,000 years ago in Britain, based on insect fossil analysis. Data from Lowe *et al.* (1995).

Ocean History

By studying the Quaternary fossil record from deep-sea sediments, paleoceanographers have come to understand the role of oceans in the transfer of heat from the tropics to the high latitudes, via ocean currents (*see* Paleoceanography). Broecker's (1987) model of the oceanic thermohaline conveyor belt demonstrated how this system functions, both past and present (**Fig. 3**). This thermohaline conveyor belt acts as a major conduit for the exchange of thermal energy, nutrients, and dissolved oxygen between the shallow and deep oceans of the world. There is little doubt that the conveyor belt's capability to transfer heat in large volumes and across vast distances profoundly influences global climate. There is some

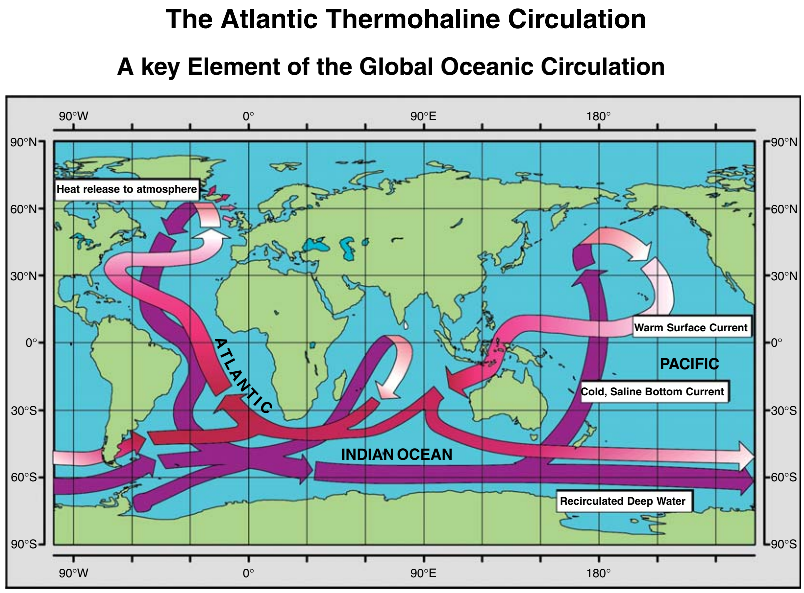

Figure 3 Schematic diagram of the global ocean circulation pathways, the 'conveyer' belt (after Broecker W, modified by Maier-Reimer E).

evidence that the current climatic warming, especially in the high latitudes, may be weakening the thermohaline circulation (Häkkinen and Rhines, 2004). Current oceanographic research (Curry and Mauritzen, 2005) suggests that the northern regions of the North Atlantic Ocean have been diluted by increasing amounts of freshwater since the 1960s. If the conveyor belt were to shut down, climate models indicate that much of Europe would be 5–10 °C colder, the equatorial regions would be 4–5 °C warmer, and Greenland would be as much as 16 °C colder than it is today. Rainfall patterns would radically change, and the atmosphere would become dustier (Broecker, 1999). Again, without the paleontological data from Quaternary marine sediments, we would have little or no understanding of these phenomena.

Sea Level Change

There is a growing body of evidence that the current level of global warming is going to bring about substantial rises in sea level, as polar ice caps melt. The Intergovernmental Panel on Climate Change (IPCC) (2001) has estimated that sea level will rise 50 cm above current levels by the year 2100 (**Fig. 4**). This is a substantially greater rise in sea level than occurred in the last century. The ecological and human impacts of rising oceans would be substantial, including increased flooding, coastal erosion, salination of aquifers, and loss of coastal agricultural land and living space (IPCC, 2001). The loss of living space is particularly critical, given that 50% of the world's population lives within 6 km of the sea, and that 14 of the 15 largest cities are coastal.

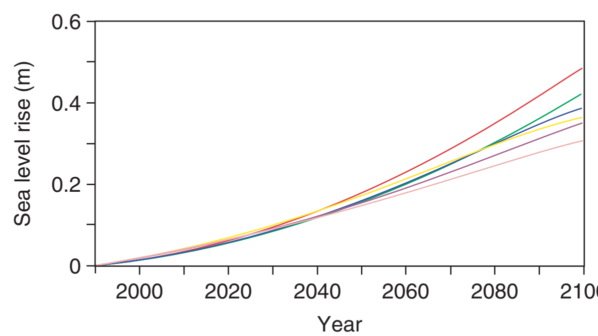

Figure 4 Predicted global sea-level rise during the 21st century, based on six different models. Data from IPCC, (2001).

Again, one must refer to the Quaternary record to find sea levels that were as high, or higher than the predicted levels in the coming century. Reconstructions of global mean sea level during the last interglacial period (*see* Eustatic Sea-Level Changes, Glacial-Interglacial Cycles) place it 6–7 m above modern mean sea level at about 125,000 years ago (Chapell and Shackleton, 1986; Bard *et al.*, 1993). By studying the effects that these higher sea levels had on ancient coastal landscapes, we are able to develop more useful models of what may happen in the future.

Coastal Deposition and Erosion

As sea levels rise and storm intensity increases with global warming, many of the world's coastlines are being eroded (**Fig. 5**). The impacts on society are relatively large and costly. For instance, a recent report by the Heinz Center for Science, Economics and the Environment states that in the United States, approximately 1,500 homes will be lost to coastal erosion each year for the next several decades, at an annual cost to coastal landowners of approximately $530 million (Heinz Center, 2000).

Of course, coastal erosion has been going on for many thousands of years, and has been documented by marine geologists studying Quaternary near-shore deposits. What is happening today is just the most recent episode in an ongoing Holocene marine transgression. The erection of coastal defenses has halted the process, at least temporarily, but ultimately the phenomenon is inexorable. Quaternary geologists have been studying such processes as the supply and sink of coastal sediments, interactions of the retreating shoreface with older deposits, and long-term changes in the direction of shoreline changes (*see* High Energy Coasts Sedimentary Indicators) (McNinch, 2004). They have found that variations in the rates and directions of shoreline change are strongly controlled by changes in ocean wave and tidal energy (van der Molen and van Dijck, 2000). These are highly complex problems that are difficult to model, but data from Quaternary studies are essential to the process.

Environmental Change in Oceanic Ecosystems

The world's continental shelves are highly productive marine ecosystems (Lohrenz *et al.*, 2002). However, we do not fully understand the role of continental shelves in the global climate system. The science of paleoceanography is providing the information needed to gain a better understanding of this role. Specifically, we need to know more about changes in continental shelf productivity during times of different sea levels, the storage of nutrients on continental shelves, and how changes in sea level affect the total sea surface area. As with the other problems discussed here, these are not just 'academic' issues. For instance, they affect the biological productivity and diversity of the oceans, both of which have direct implications for the world's fisheries.

Figure 5 Coastal erosion. Photo from Peter French.

Cryosphere History

The waxing and waning of ice sheets has been the dominant environmental phenomenon of the Quaternary, either directly or indirectly affecting every region of the globe. In the current climate, polar ice caps are thinning, mountain glaciers are retreating in most regions, and many are in danger of disappearing altogether. Notable among these are the glaciers and snowfields that are perched on the tops of high mountains near the Equator (*see* Africa). A recent study of Mt Kilimanjaro's summit in Africa (Irion, 2001) showed a 33% loss of ice since 1989 and an 82% decline since 1912. At the current rate of melting, this ice cap will be gone within a few years (**Fig. 6**). Similarly, the massive Quelccaya ice cap in the Peruvian Andes is melting (*see* South America). The ice cap shrank from 56 km^2 in 1976 to just 44 km^2 in 2001, and it may disappear within the next 20 years.

The Antarctic and Greenland ice sheets together hold 33 million km^3 of ice, representing enough water to raise global sea level by 70 m (Rignot and Thomas,

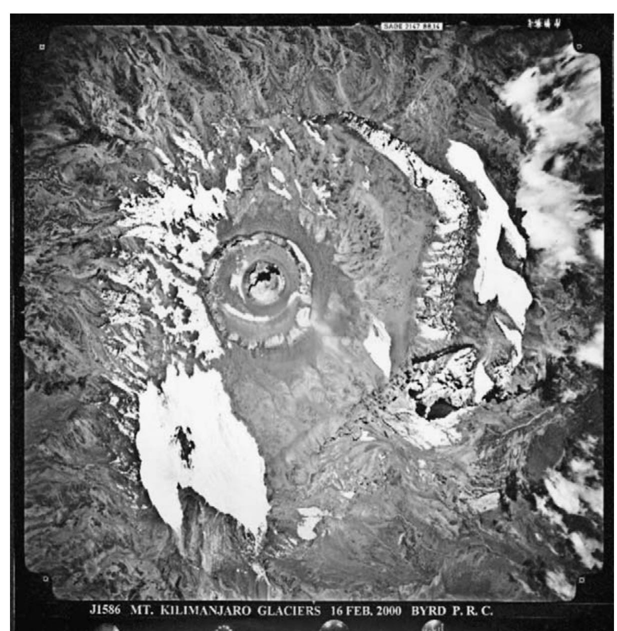

Figure 6 Aerial photograph of the top of Mt Kilimanjaro, showing the remnants of the ice cap. Photo courtesy of Byrd Polar Center, Ohio State University.

Figure 7 Photograph of Pine Island Glacier taken by Tom Kellogg onboard the U.S. Coast Guard icebreaker *Glacier*, 1985, in Pine Island Bay.

2002). Current research by several different research groups indicates that the Greenland Ice Sheet is thinning, especially near the coasts (*see* Dynamics of the Greenland Ice Sheet). The Antarctic story is more complicated. It appears that the West Antarctic Ice Sheet is thinning (**Fig. 7**) (*see* Dynamics of the West Antarctic Ice Sheet) overall, but it is thickening in some regions and thinning in others (Rignot and Thomas, 2002). Large sectors of ice in southeast Greenland, West Antarctica, and the Antarctic Peninsula are changing rapidly, but glaciologists do not yet understand the processes involved. Modeling is a key element in developing that understanding, and the best sources of data for such models come from paleoenvironmental research. It is clear that just as global climate affects polar ice sheets, so also ice sheets affect global climate. As Clark *et al.* (1999) have said, given the importance of ice sheets in the climate system, establishing the factors that control their evolution and behavior is necessary to understanding their influence on climate over the long term. This applies equally to questions about the future stability of the polar ice sheets.

Lithosphere History

The study of geomorphology, or the processes that act to shape the surface of the Earth, is rooted firmly in Quaternary science. Understanding the Earth's geomorphic history is the key to understanding current geomorphological problems. A knowledge of contemporary Earth surface processes is critical for the study of the hazards and sustainability of the landscape.

Soil Studies

Modern soils in the rich agricultural regions of the middle latitudes of the Northern Hemisphere owe much of their formation to Pleistocene glaciations. Glaciers and ice sheets pulverized layers of bedrock and organic matter that fell within the ice boundaries, creating the mixtures of sand, silt, and clay that became the best suited soils in which to grow crops. This is due to their moisture retention characteristics and nutrient storage ability. These soils can be considered part of the world's Pleistocene heritage (*see* Overview)

These rich agricultural soils are the product of thousands of years of glacial and postglacial environments. They are durable but still susceptible to degradation through over-use and poor land management practices. Soils in other regions of the world vary in their ability to sustain agriculture. By one estimate (Oldeman, *et al.*, 1991), about 15% of the Earth's land surface has been seriously degraded by human activities (**Table 1**). Perhaps 25% more of the Earth's soils are at risk of serious degradation (World Resources Institute, 1990). The loss of agricultural land through erosion is estimated at 6 or 7 million hectares (ha) per year, with an additional annual loss of 1.5 million ha as a result of waterlogging, salinization, and alkalinization (Brundtland *et al.*, 1987). Thus the ever-expanding human population of the world is essentially using up the vital resource of arable soil at an alarming rate. It took many thousands of years for these soils to develop, but only a few centuries to degrade.

Table 1 1991 soil degradation statistics by region (after Oldeman *et al.*, 1991)

Region	*Human-induced soil degradation (million ha)*	*Total land surface (million ha)*	*Percent of land with soil degradation*
Africa	494	2,966	17
Asia	748	4,256	18
South America	243	1,768	14
Central America	63	306	21
North America	95	1,885	5
Europe	219	950	23
Australasia	103	882	12
World	1,964	13,013	15

Geologic Hazards

Our understanding of most geologic hazards has been greatly enhanced by Quaternary studies. The reason we must probe into the past to understand these phenomena is that most of them are highly sporadic and largely unpredictable, despite the best efforts of geoscientists. Such catastrophes as large volcanic eruptions, earthquakes and tsunamis, take place only rarely in any given region. These phenomena are discussed in a document published by the United Nations Environment Program (2005). The interval between events may be hundreds or even thousands of years – well beyond the span of recorded history. The Quaternary record affords us insights into the timing and intensity of past catastrophic events.

Volcanic Eruptions

Sitting astride the boundaries of the world's tectonic plates, volcanoes are a major hazard to human life in many parts of the world. Volcanic eruptions have claimed more than a quarter of a million lives since the destruction of Pompeii in AD 79 (**Table 2**). The principal hazard is not lava, which usually flows sufficiently slowly to allow all but the closest inhabitants to the volcano to escape. Volcanic ash, or tephra, is the principal hazard. It is ejected in far larger quantities than lava in most eruptions (**Fig. 8**), and can travel thousands of kilometers, often circling the globe in a plume that is visible from space (**Fig. 9**). In rare cases, ignimbrites are ejected during volcanic eruptions. These are pyroclastic rocks consisting of glass shards, crystals, and lithic fragments. Ignimbrites are formed by the deposition of hot, rapidly expanding, turbulent magmatic gases. This happened in the 1902 eruption of Mt Pelée in the Caribbean island of Martinique, killing all but two people on the island. When volcanic ash and rock mix with water, they may form a lahar, which sweeps rapidly down the mountain into surrounding valleys. Volcanic tephra layers deposited in Quaternary sediments are the chief means by which scientists reconstruct the history of prehistoric eruptions (*see* Tephrochronology). We can say with absolute certainty that some of the volcanic eruptions that took place in the Pleistocene were far greater, and affected larger areas, than anything in recorded history. For instance, 600,000 years ago, the central part of what is now Yellowstone National Park, Wyoming, exploded in an enormous volcanic eruption The eruption spewed out nearly 1,000 km^3 of debris. What is now the park's central portion then

Figure 8 Photograph of volcanic eruption, Kanaga Volcano, Aleutian Islands, Alaska, 1994. Photo courtesy of the U.S. Geological Survey.

Figure 9 Eruption of Rabaul volcano, Papua New Guinea, 1994, as seen from the space shuttle. Photo courtesy of NASA.

Table 2 Major historic volcanic eruptions

Locality	*Date*	*Estimated human death toll*
Pompeii and Herculaneum, Italy (Vesuvius)	AD 79	Thousands (uncounted)
Iceland (Laki volcano)	AD 1783	9350
Kyushu, Japan	AD 1793	14,300 (triggered avalanche and tsunami)
Sumbawa, Indonesia (Tambora volcano)	AD 1815	92,000 (10,000 directly; 82,000 through starvation and disease)
Central Ecuador (Mt Cotopaxi)	AD 1877	1,000
Krakatau, Indonesia	AD 1883	36,000
St Vincent, West Indies (Soufriére volcano)	AD 1902	1,680
Martinique, West Indies (Mt. Pelée)	AD 1902	40,000
Northern Columbia (Nevada del Ruiz)	AD 1985	25,000
Total loss of life		>250,000

collapsed, forming a 45- by 75-km caldera (or basin). Tephra from this eruption is known to have blanketed more than 5 million km^2 of western and central North America (Smith and Siegel, 2000). If an eruption on this scale were to happen today, it would ecologically devastate large regions, and cause climatic cooling for several years afterwards because of the screening of sunlight by volcanic ash and gases in the atmosphere. To put this Yellowstone eruption into context, the largest volcanic eruption in historic times was from Tambora, in Indonesia, in 1815. That eruption is estimated to have ejected about 150 km^3 of ash into the atmosphere (Oppenheimer, 2003). This is less than one-third the amount estimated for the Yellowstone eruption. Anomalously cold weather hit the northeastern United States, maritime provinces of Canada, and Europe the following year. The year of 1816 came to be known as the 'Year without a summer' in these regions.

The Yellowstone volcanic eruption story is a cautionary tale. Far greater eruptions have taken place in prehistory than have happened in historic times. Our knowledge of the prehistoric eruptions has come through the analysis of ancient volcanic deposits. Tephrochronology, the study of volcanic ash deposits, has helped scientists determine the source of ash deposits (through chemical finger printing). By piecing together regional histories of volcanic activity, Quaternary scientists have been able to reconstruct the size and timing of ancient volcanic eruptions. By working with modern vulcanologists, we have begun the difficult task of predicting volcanic eruptions. The science of volcanic eruption prediction is far from exact, but it has enabled the evacuation of some threatened regions before major eruptions took place. For instance, in 1991, vulcanologists were able to warn the people living near Mt Pinatubo in the Philippines, a few days before devastating eruptions took place. In total, 58,000 people were evacuated from a 30-km radius around the volcano (Wolfe and Hoblitt, 1996).

Earthquakes and Tsunamis

There is no doubt that earthquakes and the resulting tsunamis (Fig. 10) have killed more people in historic times than any other geologic hazard. As shown in Table 3, major earthquakes in the past 1,200 years are known to have killed more than 4 million people. This total includes more than 2 million people in just the 20th century. As human populations rise, and the number of poorly-built multi-story buildings increases, these numbers are likely to grow larger. But, like volcanic eruptions, earthquakes are relatively rare events in any one region, and we have yet to develop any meaningful ways of predicting them. Geoscientists may be able to predict that there will be a major earthquake somewhere along a given fault system, but as of now they can only say that it will probably happen within the next decade or the next century. Some of the

Figure 10 Satellite image of a tsunami striking the coast of Sri Lanka following the massive earthquake in the Indian Ocean, 29 December 2004. The image shows the backwash of the tsunami. Photo copyright DigitalGlobe.

Table 3 Major historic earthquakes (>10,000 casualties)

Locality	*Date*	*Estimated human death toll*
Damghan, Iran	AD 857	200,000
Ardabil, Iran	AD 893	150,000
Aleppo, Syria	AD 1138	230,000
Chihli, China	AD 1290	100,000
Shaanxi province, China	AD 1556	830,000
Shemakha, Caucasia	AD 1667	80,000
Sicily, Italy	AD 1693	60,000
Tabriz, Iran	AD 1727	77,000
Lisbon, Portugal	AD 1755	70,000
Calabria, Italy	AD 1783	50,000
Messina, Sicily	AD 1908	70,000–100,000
Avezzano, Italy	AD 1915	29,980
Gansu province, China	AD 1920	200,000
near Tokyo, Japan	AD 1923	>140,000
Xining, China	AD 1927	200,000
Gansu, China	AD 1932	70,000
Quetta, Pakistan	AD 1935	30,000–60,000
Northern Turkey	AD 1939	100,000
Ashgabat, Turkmenistan	AD 1948	110,000
Assam, India	AD 1950	20,000–30,000
Peru	AD 1970	66,000
Tangshan, China	AD 1976	655,000
Tabas, Iran	AD 1978	25,000
Mexico City	AD 1985	25,000
Armenia	AD 1988	25,000
Northwest Iran	AD 1990	>50,000
Izmit, Turkey	AD 1999	>17,000
Bhuj, India	AD 2001	>20,000
Bam, Iran	AD 2003	>30,000
Sumatra, Indonesia (marine earthquake and tsunami)	AD 2004	>226,000
Total loss of life from major historic earthquakes		>4,000,000

most useful data in the study of earthquakes comes from Quaternary science, where ancient earthquakes have left behind clear indicators in buried sediments. For instance, Fumai *et al.* (1993) were able to reconstruct a 100-year recurrence interval for the San Andreas Fault zone, 70 km northeast of Los Angeles, based on sedimentary evidence. Earthquakes caused debris-flow deposits, ruptured, tilted, and folded bedding planes in the sediments.

The timing of an earthquake in the year AD 1700 along the coast of Washington state, USA was able to be accurately dated through analysis of tree-rings (*see* Dendrochronology) Yamaguchi *et al.* (1997) studied Japanese historical evidence for a large tsunami of previously unknown origin, and were able to pin down the source of the earthquake that caused it. They proposed that a magnitude 9 earthquake in the Cascadia subduction zone of the Pacific Northwest region of North America was the trigger for the tsunami that occurred on 26 January 1700. Tree-ring records from the central Cascadia region (**Fig. 11**) support this theory. When the earthquake struck, much of the coast between southern British Columbia and northern California was abruptly lowered, submerging some coastal forests in more than a meter of tidewater. Yamaguchi *et al.* studied the annual growth rings of some Sitka spruce trees that survived this tidal submergence, and the rings in some trees show changes in width and anatomy consistent with disturbance (tilting, increased flooding, or both) in AD 1700 and for a few years afterward.

Tsunamis may also occur in tectonically stable areas, as shown by the Storegga Slide that struck the coasts of Scotland and Norway, about 7,000 yr BP (Dawson *et al.*, 1988).

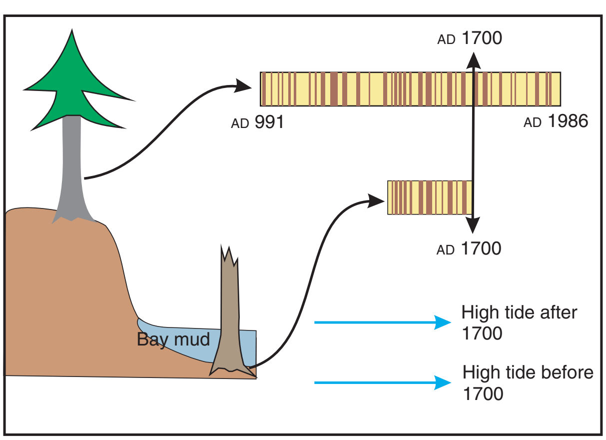

Figure 11 Tree-ring dating of the 1700 Cascadia earthquake. The dead tree on the right was drowned in salt water due to subsidence during the earthquake. The outermost tree-rings from a number of dead snags in regional salt marshes correspond to the year AD 1700 in tree-ring sequences from living (upland) trees in the region.

Biosphere History

Our knowledge of how ecosystems function has been greatly aided by Quaternary paleontological studies. In the absence of such studies, modern ecologists would have little or no idea about the longevity of ecosystems and their resistance to change in the face of large-scale environmental variations.

Longevity, Resistance and Resilience of Ecosystems

Studies of plant and animal remains from the Quaternary have shown that the current ecosystems are not composed of species that are inherently the best suited to their environments. Rather, modern ecosystems represent the latest reshuffling of species, and the mixture of species in biological communities at any given time has been shaped by many forces. In the middle and high latitudes, the catalyst for changes in ecosystems has been large-scale climatic fluctuations of the Pleistocene, accompanied by the waxing and waning of continental ice sheets and mountain glaciers (*see* Evidence of Glacier and Ice Sheet Extent). There have been hundreds of these large-scale fluctuations in climate during the last 2.4 million years. Amazingly, some groups of organisms (notably beetles) have remained intact throughout this interval, shifting their ranges in response to climatic change (*see* Overview). Other groups, such as mammals, have undergone waves of speciation during the Quaternary (*see* Vertebrate Overview). This includes, of course, the hominid lineage that gave rise to our species (*see* Overview). Towards the end of the last glaciation, a large number of megafaunal mammals (species with adult weight greater than 40 kg) became extinct. During the middle of the last glaciation, more than 150 genera of megafauna were alive on the planet. By 10,000 years ago, that number was reduced to just over 50 genera (*see* Late Pleistocene Megafaunal Extinctions). Thus approximately two-thirds of the large mammal gr-oups became extinct during this interval (**Fig. 12**). This extinction event has been the subject of hot scientific debate for the last 40 years.

Pleistocene Megafaunal Extinctions

The nature of the debate over the megafaunal mammal extinctions at the end of the Pleistocene rests in determining its cause. Paleontological evidence has shown that previous glacial-to-interglacial transitions in the Pleistocene did not bring about wholesale extinctions of species. This evidence has led some scientists to conclude that human predation was what dealt the final blow to the Pleistocene megafauna, at the end of the last ice age (Martin, 1989; Flannery, 1994). Others believe that changing

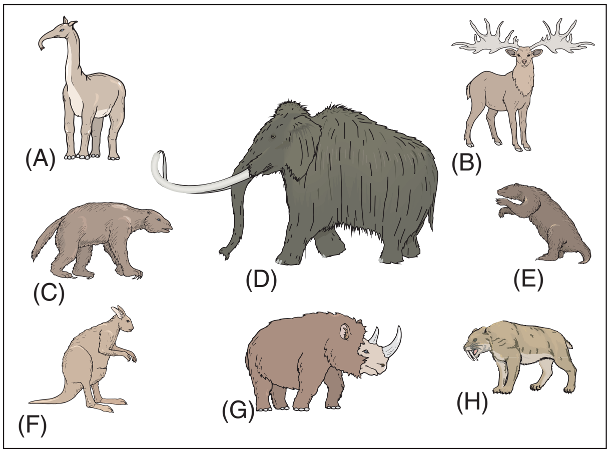

Figure 12 Megafaunal mammals that became extinct towards the end of the last glaciation. A) *Macrauchenia* (South American browser – no living relatives); B) *Megaloceros* (Giant deer); C) *Eremotherium* (Ground sloth); D) *Mammuthus* (Woolly mammoth); E) *Megatherium* (Giant ground sloth); F) *Procoptodon* (Giant short-faced kangaroo); G) *Coelodonta* (Woolly rhinoceros); H) *Smilidon* (sabre-tooth cat). Drawings courtesy of Corel Corp.

environments brought about this extinction, and express the view that humans had little or nothing to do with it (Grayson and Meltzer, 2003). A third group of scientists holds a middle view, that perhaps people played a part in megafaunal extinction, but the degree of human impact has yet to be determined (Barnowsky *et al.*, 2004).

Modern Extinction Rates

We may never find the 'smoking gun' for the end-of-Pleistocene extinction event, but the fossil record demonstrates that such large-scale extinction events have been rare in Earth's history. There have been at least five well-documented mass extinctions in the planet's history. Some, such as the dinosaur extinction, 65 million years ago, are thought to have been caused by meteor impacts. The causes of other extinction events remain unknown. However, the causes of the modern extinction of species are all too obvious. As human populations swell and human land use alters once-pristine ecosystems, the biodiversity of the planet has been plummeting. For the past 300 years, recorded extinctions for some groups of organisms have shown rates of extinction at least several hundred times the rate expected on the basis of the geological record (Dirzo and Raven, 2003).

Human 'Coming of Age' in the Quaternary

As we have seen, the study of Quaternary environments and organisms forms the basis for gauging much of what is happening in the modern world. Quaternary science provides the necessary information for assessing potential impacts of future global warming, recurrence rates for geologic hazards, modern species extinction rates, and a host of other topics of vital interest to humanity. Our own species, *Homo sapiens*, first appeared only about 160,000 years ago (Clark *et al.*, 2003). Although modern societies are quite capable of shaping their immediate environment to suit their needs, for more than 90% of human history, the environment has been shaping us. Our species, and its immediate ancestors, were all products of the Pleistocene, first shaped by environmental changes in Africa, followed by Eurasia, finally colonizing most of the globe within the last 12,000 years (since the end of the last glaciation) (*see* Human Migrations During the Late Pleistocene). *Homo sapiens* means 'wise man.' Will our species live up to its scientific name?

See also: **Introduction**: History of Quaternary Science. **Archaeological Records**: Overview. **Beetle Records**: Overview; Late Pleistocene of Europe. **Dendrochronology**. **Glacial Landforms, Ice Sheets**: Evidence of Glacier and Ice Sheet Extent. **Ice Core Records**: Africa; South America; Antarctic Stable Isotopes. **Ice Cores**: Dynamics of the Greenland Ice Sheet; Dynamics of the West Antarctic Ice Sheet. **Paleoceanography**; **Paleoclimate Relevance to Global Warming**. **Paleoclimate**: Introduction. **Paleosols and Wind-Blown Sediments**: Overview. **Quaternary Stratigraphy**: Tephrochronology. **Sea Level Studies**: High Energy Coasts Sedimentary Indicators. **SEA Level Studies**: Eustatic Sea-Level Changes, Glacial-Interglacial Cycles. **Vertebrate Overview**. **Vertebrate Records**: Late Pleistocene Megafaunal Extinctions.

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History of Quaternary Science

S A Elias, Royal Holloway, University of London, Surrey, UK

Introduction

The Quaternary sciences represent the systematic study of the Quaternary, or most recent geologic period. This period is generally characterized by a series of glaciations, or ice ages, interspersed with relatively warm, interglacial intervals, such as the current interglacial, the Holocene. The study of Quaternary environments began in the late eighteenth century. Quaternary geology and paleontology came of age in the nineteenth century, and other important aspects of Quaternary science, such as paleoceanography (*see* Paleoceanography), paleoecology, and paleoclimatology (*see* Introduction), developed to a much greater extent in the twentieth century. As with many branches of science, the pioneers in Quaternary studies had to work hard to overcome many widely held, erroneous ideas from previous generations of scholars.

At the beginning of the nineteenth century, science itself was rapidly changing. Up until that time, university professors and other scholars who performed scientific research were mostly generalists who dabbled in many different fields. They looked upon themselves as natural historians, studying the workings of the