Figure 10.1 Decapitated human sacrifice victims, Huaca de la Luna, Peru. (National Geographic Image Collection / Alamy)

The Moche state controlled at least ten coastal valleys along the north coast of what is now Peru during the mid-first millennium A.D. A small elite of fierce warrior-priests built on the political and religious traditions of earlier Andean societies to create a complex and very wealthy society based on irrigation agriculture and far-flung trade with highland neighbors. The nobility, probably a network of princely families, ruled from imposing temple complexes based on adobe pyramids built by thousands of commoners, who paid tribute to the state by compulsory labor, known in later centuries as *mi'ta*, an ancient Andean tradition. Much of what we know about Moche society comes not from written texts – theirs was a civilization without writing – but from their flamboyant visual culture expressed in ceramics, metal artifacts, wooden sculptures, textiles, and wall paintings. A great deal of this visual culture is concerned with warfare, captured prisoners, and human sacrifice.

The greatest Moche center lay at the Huacas de Moche site, dominated by two huge pyramids named after the sun and moon. Huaca de la Luna, the Temple of the Moon, has been under continual investigation since 1991 by Peruvian archaeologists Santiago Uceda and Ricardo Morales (see Figure 10.9 on p. 252). While excavating a plaza in a secluded area of the temple, Steve Bourget uncovered a precinct surrounded by high adobe walls, built in the sixth or seventh century A.D., where about seventy male warriors were sacrificed. Many of them were subsequently dismembered in the course of at least five different ritual events. After their sacrifice, the body parts of the victims were scattered around the ritual area, some of them accompanied by deliberately broken clay statuettes of named men, their bodies covered with elaborate symbols (see Figure 10.1). These were three-dimensional representations of individuals depicted in fine paintings.

What do these sacrifices mean? They may be ritual killings of prisoners of war, a frequent motif in Moche art, and one well documented by the burials of the lords of Sipán, dating to about A.D. 400 (see Figure 3.4 on p. 64). Bourget originally believed that the dead men were indeed casualties of a ritual battle, staged to placate the unknown forces that unleashed strong El Niños on Moche domains. But after further study, he realized that El Niños were, in fact, already fully integrated into Moche religion and ideology. The pectorals, bracelets, and other ornaments worn by the Sipán lords, and looted from other tombs, prominently depict exotic animals like the Peruvian eagle ray and swimming crabs that only arrived off the north coast when the El Niño counter-current was flowing. The elite also wore depictions of local species affected by El Niño events such as octopuses, catfish, seabirds, and sea lions. The temple walls of Huaca de la Luna and other shrines also bear painted reliefs of animals associated with El Niños. Bourget theorizes that Moche rulers responded to the threat of El Niños by associating their authority with the awesome power of such events, which could transform the marine environment. When an El Niño event brought torrential rains that washed away entire irrigation systems and decimated the anchovy fisheries, the rulers used the occasion to reinforce their authority at times of crisis. They already wore the iconography of such events on their bodies and caused it to be displayed on temples and on ritual vessels (see Figure 2.6 on p. 43). Their authority came from their perceived unique relationship with the powers of the supernatural, reinforced by human sacrifice. So they used the immolation of the seventy sacrificial victims in this particular plaza, and probably in others, to reinforce their power and to maintain social solidarity in such times of crisis.

Short-Term and Long-Term Climatic Change

Climatic change comes in many forms. The long cycles of cold and warm associated with the Ice Age occur on a millennial scale and have little more than long-term effects on human existence. For example, the existence of a low-lying land bridge between Siberia and Alaska during much of the late Ice Age may have allowed humans to forage their way from Asia into the Americas before 15,000 years ago, but the actual formation of the shelf that linked the two continents would have taken many centuries and human generations. Short-term climatic change, such as the floods or droughts caused by El Niño episodes or volcanic eruptions dumping ash into the atmosphere, are another matter. Memories of catastrophic famines and other events associated with such events would have endured for generations, for they had immediate impact on hundreds, if not thousands, of people. Through human history, people have developed strategies to deal with sudden climatic shifts bringing drought, hunger, or unexpected food shortages. Humans have always been brilliant opportunists, capable of improvising solutions to unexpected problems caused by environmental change. Thus environmental reconstruction and climatic change are two major concerns for archaeologists wherever they work.

Long-Term Climatic Change: The Great Ice Age

About 1.8 million years ago, global cooling marked the beginning of the **Pleistocene** epoch, more popularly called the Great Ice Age. Together with the **Holocene**, which began about 15,000 years ago, it forms part of the **Quaternary** epoch. The Pleistocene was remarkable for dramatic swings in world climate. On numerous occasions during the Pleistocene, great ice sheets covered much of western Europe and North America, bringing arctic climate to vast areas of the Northern Hemisphere. Scientists have identified at least eight major glacial episodes over the past 780,000 years, alternating with shorter warm periods when the world's climate was sometimes warmer than today. The general pattern is cyclical, with slow coolings culminating in a relatively short period of intense cold, followed by rapid warming. For 75 percent of the past three-quarters of a million years, the world's climate has been in transition from one extreme to another. We ourselves still live in the Ice Age, in a warm interglacial period. If the current scientific estimates are correct and humanly caused global warming does not interfere, we will probably begin to enter another cold phase in about 23,000 years.

No one knows exactly what causes the climatic fluctuations of the Ice Age, but they are connected with oscillations in the intensity of solar radiation and the trajectory of the earth around the sun. But such climatic changes are of great importance to archaeologists, for they form a long-term environmental backdrop for the early chapters of our past. Although almost no human beings lived on, or very close to, the great ice sheets that covered so much of the Northern Hemisphere, they did live in regions affected by geological phenomena associated with the ice sheets: coastal areas, lakes, and river flood-plains. When human artifacts are found in direct association with Pleistocene geological features of this type, it is sometimes possible to tie in archaeological sites with the relative chronology of Pleistocene events derived from geological strata.

Deep-Sea Cores and Ice Cores

Our knowledge of Ice Age climatic change comes from many sources, including geological strata such as glacial deposits and ancient high beach levels, and fossil animal bones from environmentally sensitive mammals as large as elephants and as small as mice. Such approaches have long provided a crude outline of Ice Age glaciations. But in recent years the study of deep-sea and ice cores has revolutionized our understanding of the Pleistocene by providing long sequences of constantly changing Ice Age climate from deep below the ocean floor and the heart of the Greenland ice sheet.

The world's ocean floors are a priceless archive of ancient climatic change. Deep-sea cores produce long columns of ocean-floor sediments that include skeletons of small marine organisms that once lived close to the ocean's surface. These planktonic foraminifera (protozoa) consist largely of calcium carbonate. When alive, their minute skeletons absorb organic isotopes. The ratio of two of these isotopes – oxygen 16 and oxygen 18 – varies as a result of evaporation. When evaporation is high, more of the lighter oxygen 16 is extracted from the ocean, leaving the plankton to be enriched by more of the heavier oxygen 18. When great ice sheets formed on land during glacial episodes, sea levels fell as moisture was drawn off for continental ice caps. During such periods, the world's oceans contained more oxygen 18 in proportion to oxygen 16, a ratio reflected in millions of foraminifera. A mass spectrometer is used to measure this ratio, which does not reflect ancient temperature changes but is merely a statement about the size of the oceans and about contemporary events on land.

One can confirm climatic fluctuations by using other lines of evidence as well, such as the changing frequencies of foraminifera and other groups of marine microfossils in the cores. By using statistical techniques, and assuming that relationships between different species and sea conditions have not changed, climatologists have been able to turn these frequencies into numerical estimates of sea surface temperatures and ocean salinity over the past few hundred thousand years and thus produce a climatic profile of much of the Ice Age (see Figure 10.2). These events have been fixed at key points by radiocarbon dates (see Chapter 5) and by studies of paleomagnetism (ancient magnetism). The **Matuyama–Brunhes event**, a magnetic reversal of 780,000 years ago (when the world's magnetic field suddenly reversed), is a key stratigraphic marker, which can

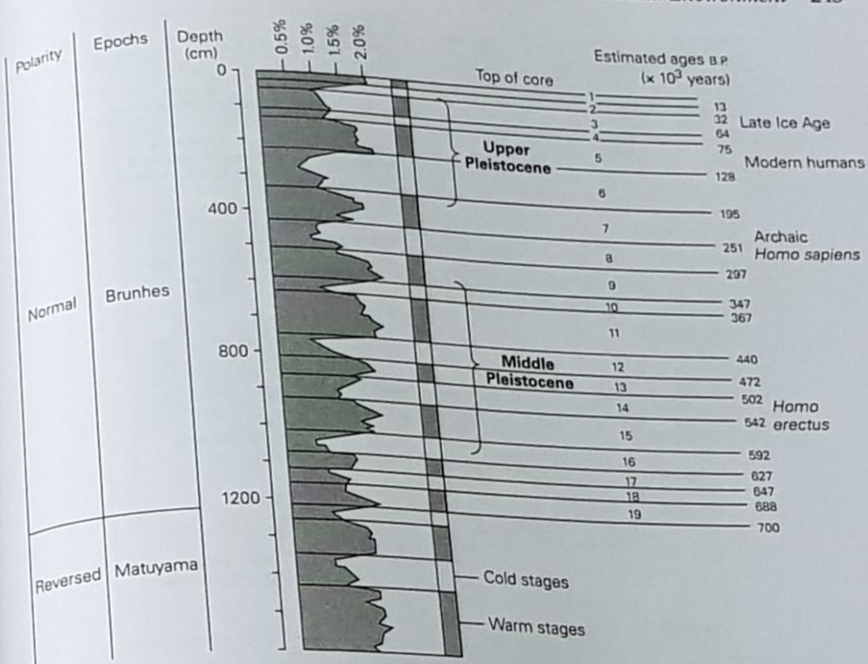


Figure 10.2 The deep-sea core that serves as the standard reference for the past 780,000 years comes from the Solomon Plateau in the southwestern Pacific Ocean. The Matuyama–Brunhes event occurs at a depth of 39.3 feet (11.9 meters). Above it a sawtooth-like curve identifies at least eight complete glacial and interglacial cycles.

be identified both in sea cores and in volcanic strata ashore, where it can be dated precisely with potassium-argon samples.

Ice-core studies are a comparatively recent development but are now yielding increasingly accurate climatic portraits, especially of the later Ice Age and the past 10,000 years. They preserve records of annual snowfall going back far into the past. As the snow layers are buried deeper and deeper in a glacier, they are compressed into ice. The ice for winter and summer has a different texture. Once researchers realized this, they were able to read ice cores like tree-ring samples, with very good resolution back for 12,000 years and improving accuracy back to 40,000 years. One ice core from Antarctica extends back over 400,000 years and shows that the past 10,000 years since the Ice Age have been some of the most climatically stable in human history. Ice cores have been especially useful for studying not so much the long-term fluctuations of Ice Age climatic change but the short-term episodes of warmer and colder conditions that occurred in the middle of glaciations, which had a profound effect on humanity. For example, scientists now suspect that there were bursts of human activity in late Ice Age western Europe about 35,000 and 25,000 years ago, when conditions were relatively warm for short periods of time.

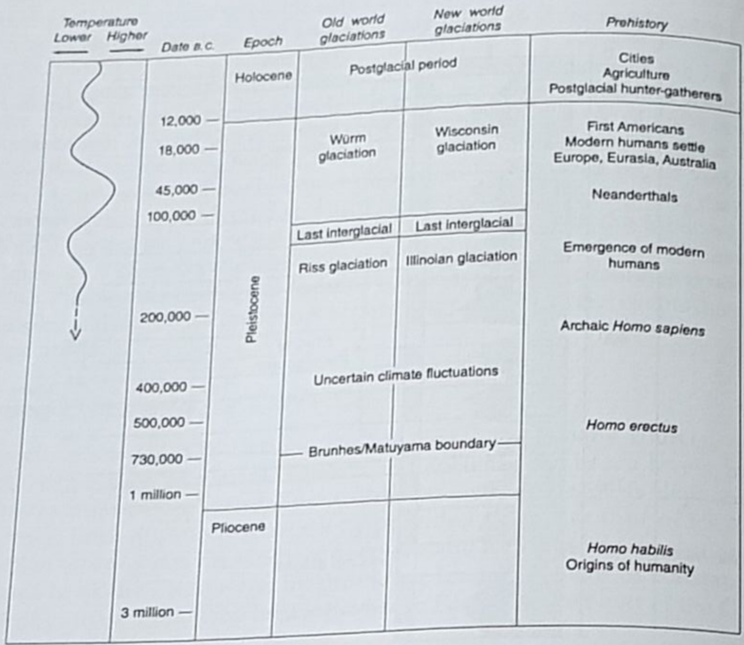


Figure 10.3 Provisional chronology and subdivisions of the Ice Age.

Ice and sea cores, combined with pollen analysis, have provided a broad framework for the Pleistocene, which is in wide use by archaeologists and is worth summarizing here (see Figure 10.3).

The Pleistocene Framework

The Pleistocene began about 1.8 million years ago, during a long-term cooling trend in the world's oceans. These millennia have been ones of constant climatic change. The Pleistocene is conventionally divided into long subdivisions.

Lower Pleistocene times lasted from the beginning of the Ice Age until about 780,000 years ago. Deep-sea cores tell us that climatic fluctuations between warmer and colder regimens were still relatively minor. These were critical millennia, for it was during this long period that humans emerged in Africa and spread from tropical regions into temperate latitudes in Europe and Asia.

The *Middle Pleistocene* began with the Matuyama–Brunhes reversal in the earth's magnetic polarity about 780,000 years ago, a change that has been recognized geologically not only in deep-sea cores but in volcanic rocks ashore, where it can be dated by potassium-argon samples.

Since then, there have been at least eight cold (glacial) and warm (interglacial) cycles, the last cycle ending about 12,000 years ago. (Strictly speaking, we are still in an interglacial today.) Typically, cold cycles have begun gradually, with vast continental ice sheets forming on land – in Scandinavia, on the Alps, and over the northern parts of North America (see Figure 10.4). These expanded ice sheets locked up enormous quantities of water, causing world sea levels to fall by several hundred feet during glacial episodes. The geography of the world changed dramatically, and large continental shelves were opened up for human settlement. When a warming trend began, deglaciation occurred very rapidly, and rising sea levels flooded low-lying coastal areas within a few millennia. During glacial periods, glaciers covered a full one-third of the earth's land surface, and during interglacials their extent was comparable to what it is today.

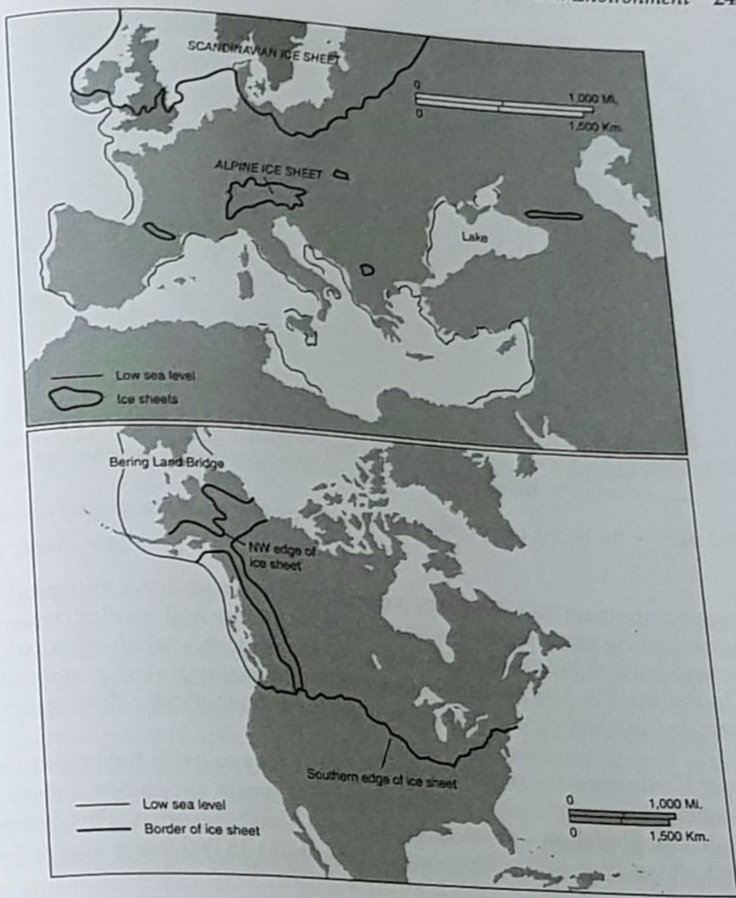


Figure 10.4 Distribution of major ice sheets in Europe and North America during the last Ice Age glaciation and the extent of land exposed by low sea levels.

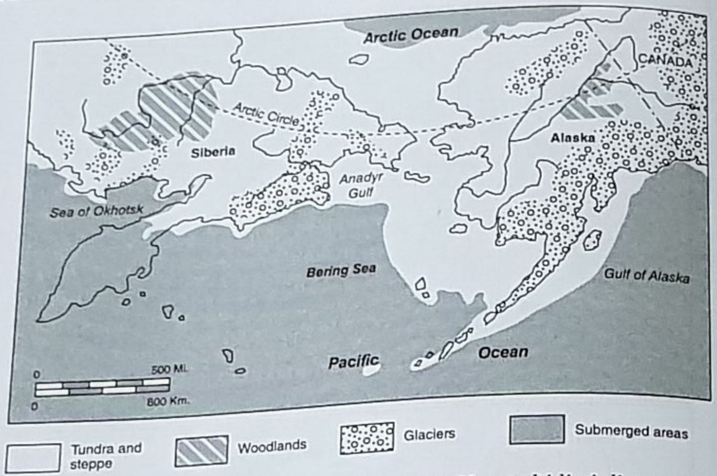


Figure 10.5 Map of the Bering Land Bridge, as reconstructed by multidisciplinary research.

Throughout the past 730,000 years, vegetational changes have mirrored climatic fluctuations. During glacial episodes, treeless arctic steppe and tundra covered much of Europe and parts of North America, but gave way to temperate forest during interglacials. In the tropics, Africa's Sahara Desert may have supported grassland during interglacials, but ice and desert landscape expanded dramatically during dry, colder spells.

The *Upper Pleistocene* stage began about 128,000 years ago, with the beginning of the last interglacial. This period lasted until about 118,000 years ago, when a slow cooling trend brought full glacial conditions to Europe and North America. This Würm glaciation, named after a river in the Alps, lasted until about 15,000 years ago, when there was a rapid return to more temperate conditions.

The Würm glaciation was a period of constantly fluctuating climatic change, with several episodes of more temperate climate in northern latitudes (see Figure 10.2 on p. 243). It served as the backdrop for some of the most important developments in human prehistory, notably the spread of anatomically modern *Homo sapiens* from the tropics to all parts of the Old World and into the Americas. Between about 25,000 and 15,000 years ago, northern Eurasia's climate was intensely cold but highly variable. A series of brilliant Stone Age hunter-gatherer cultures evolved both on the open tundra of central Europe and Eurasia and in the sheltered river valleys of southwestern France and northern Spain, cultures famous for their fine antler and bone artifacts and exceptional artwork.

The world's geography was dramatically different 18,000 years ago. These differences had a major impact on human prehistory – one could walk from Siberia to Alaska across a flat, low-lying plain, the Bering Land Bridge (see Figure 10.5). This was the route by which humans first reached the Americas some time around 15,000 years ago.

Britain was joined to the Continent in the area of the English Channel and the southern North Sea. The low-lying coastal zones of Southeast Asia were far more extensive

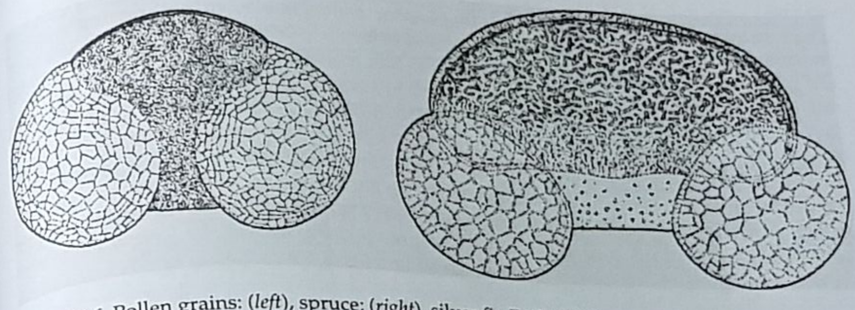


Figure 10.6 Pollen grains: (*left*), spruce; (*right*), silver fir. Both 340 times actual size.

15,000 years ago than they are now, and they supported a thriving population of Stone Age foragers. The fluctuating distributions of vegetational zones also affected the pattern of human settlement and the course of human history.

Pollen Analysis

As long ago as 1916, Swedish botanist Lennart von Post used fossil pollen grains from familiar trees like birches, oaks, and pines to develop a sequence of vegetation change for northern Europe after the Ice Age. He showed how arctic, treeless tundra gave way to birch forest, then mixed oak woodland in a dramatic sequence of change that survived in pollen samples from marshes and swamps all over Scandinavia. Since then, pollen analysis (palynology) has become a highly sophisticated way of studying both the ancient environment and human impacts on natural vegetation.

The principle is simple. Large numbers of pollen grains are dispersed in the atmosphere and have remarkable preservative properties if deposited in an unaerated geological horizon. The pollen grains can be identified microscopically (see Figure 10.6) with great accuracy and used to reconstruct a picture of the vegetation, right down to humble grasses and weeds that grow near the spot where they are found.

Pollen analysis begins in the field. The botanist visits the excavation and collects a series of closely spaced pollen samples from the stratigraphic sections at the site. Back in the laboratory, the samples are examined under a very powerful microscope. The grains of each genus or species present are counted, and the resulting figures subjected to statistical analysis. These counts are then correlated with the stratigraphic layers of the excavation and data from natural vegetational sequences to provide a sequence of vegetational change for the site. Typically, this vegetational sequence lasts a few centuries or even millennia (see Figure 10.7). It forms part of a much longer pollen sequence for the area that has been assembled from hundreds of samples from many different sites. In northern Europe, for example, botanists have worked out a complicated series of vegetational time zones that cover the past 12,000 years. By comparing the pollen sequences from individual sites with the overall chronology, they can give a relative date for the site.

Palynology has obvious applications to prehistory, for sites are often found in swampy deposits where pollen is preserved, especially fishing or fowling camps and

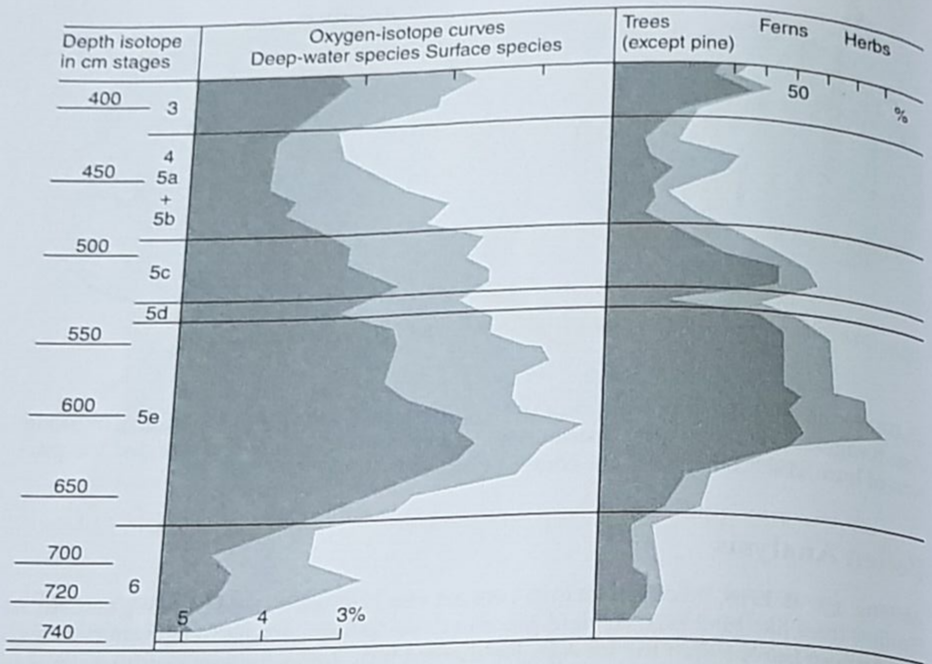


Figure 10.7 A long-term pollen sequence for the Ice Age from Spain (*left*) compared to oxygen-isotope curves taken from a deep-sea core in the nearby Bay of Biscay, showing the close correlation between the two.

settlements near water. Isolated artifacts, or even human corpses such as that of Tollund Man found in a Danish bog (see Figure 9.6 on p. 226), have also been discovered in these deposits; pollen is sometimes obtained from small peat lumps adhering to crevices in such finds. Thus botanists can assign relative dates even to isolated finds that would otherwise remain undated.

Until recently, pollen analysts dealt in centuries. Now, thanks to much more refined methods and AMS radiocarbon dating, they can study even transitory episodes, such as the brief farming incident described at the beginning of this chapter. For example, dramatic falls in forest tree pollens at many locations in Europe chronicle the first clearance of farming cultures with almost decade-long accuracy – at a moment when characteristic cultivation weeds like *Plantago lanceolata*, already mentioned, appear for the first time. Southwestern archaeologists now have a regional pollen sequence that provides not only climatic information but also valuable facts about the functions of different pueblo rooms and different foods eaten by the inhabitants.

Identifying cultural activities from pollen sites can be extremely tricky, for the tiny grains can be transported to a site in many ways – by wind, water, rodents, even people bringing ripe fruit home. Sometimes, too, people use surface soil from neighboring areas, complete with its pollen content, to make a house floor. Some species, like the sunflower, have heavy pollen that can cling to ripe fruit. Such factors are likely to contaminate the pollen samples from many sites unless one has other plant evidence such as, say, squash rind or seeds to confirm the palynological data.

Pollen analysis is providing new perceptions of Stone Age life at the height of the last glaciation in southwestern France, some 15,000 to 20,000 years ago (see Figure 10.7). This was, we are told, a period of extreme arctic cold, when Europe was in a deep freeze, people subsisting off arctic animals and taking refuge in deep river valleys like the Dordogne and the Vezère, where some of the earliest cave art in the world has been discovered. In fact, pollen grains from the rockshelters and open camps used by Stone Age hunter-gatherers of this period paint a very different picture of the late Ice Age climate in this area. It is a portrait of a favored arctic environment in which the climate fluctuated constantly, with surprisingly temperate conditions, especially on the south-facing slopes of deep river valleys. Here, people used rockshelters that faced the winter sun, where snow melted earlier in the spring, within easy reach of key reindeer migration routes and of arctic game that wintered in the valleys. The vegetational cover was not treeless, as is commonly assumed, but included pine, birch, and sometimes deciduous trees, with lush summer meadows in the valley.

The late Ice Age was a period of continual and often dramatic short- and long-term climatic change. Some of these changes lasted millennia, bringing intervals of near-modern conditions to temperate Europe interspersed with much colder winters. Other cold and warm snaps extended over a few centuries, causing human populations to adapt to dramatically new conditions. Just as today, there were much shorter climatic episodes, which endured for a year or more, bringing unusually warm summers, floods, droughts, and other short-term events.

Short-Term Climatic Change: The Holocene

The last prolonged Ice Age glaciation ended about 15,000 years ago when North American and European ice sheets retreated and the world entered a period of pronounced global warming. Then the great glaciers retreated, sea levels rose from 300 feet (91 meters) below today's levels to near-modern heights, and vegetation patterns throughout the world changed considerably. Thus dawned the Holocene period (from the Greek *holos*, "whole," and *kainos*, "new," thus meaning "entirely recent"), which saw massive global warming, sudden cold snaps, and periods of warmer climate than today, with the appearance of both food production and civilization and eventually of the Industrial Revolution. Many people believe this warming has been continuous and is reflected in the record warm temperatures of today. In fact, the world's climate has fluctuated just as dramatically as it did during the late Ice Age. Recent research is revolutionizing our knowledge of these changes, which started new chapters in human history, overthrew civilizations, and caused widespread disruption. (It should be stressed that the Holocene is a purely arbitrary scientific term, used to distinguish post-Ice Age times. We are, in fact, in a warmer interval of the Pleistocene, and the earth will become colder again – subject, of course, to the effects of humanly caused global warming.)

We can identify Holocene climatic changes from ice cores, sedimentary records in caves, tree rings, and pollen samples, with a chronological resolution that improves every year as analytical methods become ever more refined.

Centuries-Long Changes: The Younger Dryas and the Black Sea

At least three major cold snaps have cooled global temperatures over the past 11,000 years. The last of these was the so-called Little Ice Age, which lasted from about A.D. 1300 to 1850. The earlier two of these cold intervals had major effects on the course of human history, which we can now assess thanks to new deep-sea core, ice-core, and pollen researches.

The *Younger Dryas* lasted from about 11,000 to 10,000 B.C. For some still little-understood reason, global warming ceased abruptly, perhaps as a result of sudden changes in the warm water circulation in the Atlantic Ocean. Within a century or so, Europe again shivered under near-Ice Age conditions as forests retreated and widespread drought affected areas like southwestern Asia. This catastrophic drought after centuries of ample rainfall may have been a major factor in the appearance of agriculture and animal domestication in areas like the Euphrates and Jordan River valleys, where dense forager populations had long subsisted off abundant food resources. What happened next has been documented by botanist Gordon Hillman with plant remains at the Abu Hureyra site (see Chapter 11). When the drought came, nut harvest yields plummeted, game populations crashed, and wild cereal grasses were unable to support a dense human population. So the foragers turned to cultivation to supplement their food supplies. Within a few generations, they became full-time farmers. The Younger Dryas-induced drought was not the only cause of agriculture, but the sudden climate change was of great importance.

The Black Sea was an enormous freshwater lake (often called the Euxine Lake) isolated from the Mediterranean by a huge natural earthen levee in the Bosphorus Valley between Turkey and Bulgaria during the early Holocene. Four centuries of colder conditions and drought again settled over Europe and southwestern Asia between 6200 and 5800 B.C. Many farmers abandoned long-established villages and settled near the great lake and other permanent water sources. Deep-sea cores and pollen diagrams chronicle what happened next as the climate warmed up again after 5800 B.C. Sea levels resumed their inexorable rise toward modern high levels. Salt Mediterranean waters climbed ever higher on the Bosphorus levee. Then, in about 5500 B.C., the rising water breached the barrier. Torrents of salt water cascaded into the Euxine Lake 500 feet (152 meters) below. Within weeks, the great waterfall had carved a deep gully and formed the narrow strait that now links the Black Sea to the Mediterranean. The former lake not only became a brackish ocean but rose sharply, flooding hundreds of agricultural settlements on its shores, perhaps with great loss of life. This long-forgotten event has recently been reconstructed from deep-sea cores taken in the Mediterranean, also in the Black Sea, which chronicle not only the cold snap and drought but the sudden change in the now-drowned lake. (It should be noted that this interpretation is somewhat controversial as paleoclimatologists disagree as to the severity of the flood.)

The Black Sea discoveries are so new that archaeologists still have to assess their full consequences. The flooding of the huge lake does coincide with the spread of farmers across temperate Europe from the Balkans. Some experts believe the environmental catastrophe and the spread of farming were connected, as people fled their once-fertile homelands, but the true impact of the inundation remains controversial.

Short-Term Climatic Change: El Niño

We look back at the past through obscure mirrors, which become increasingly easy to use as we approach recent times. Our knowledge of Ice Age climatic change is necessarily on a grand scale, for, until recently, even ice cores did not attain the year-by-year resolution needed to track short-term shifts. Yet such sudden changes are the most important of all to human populations, who have to adjust constantly to unusual weather conditions – to droughts and floods, to unusual heat and cold. The Younger Dryas and Black Sea drought and flood are centuries-long events that are short by geological and early prehistoric standards. We are only now beginning to understand their profound impact on ancient societies. As research into these and other centuries-long events has intensified, more scholars have paid increasing attention to violent year-long episodes such as monsoon failures, volcanic eruptions, and, most important of all, El Niños.

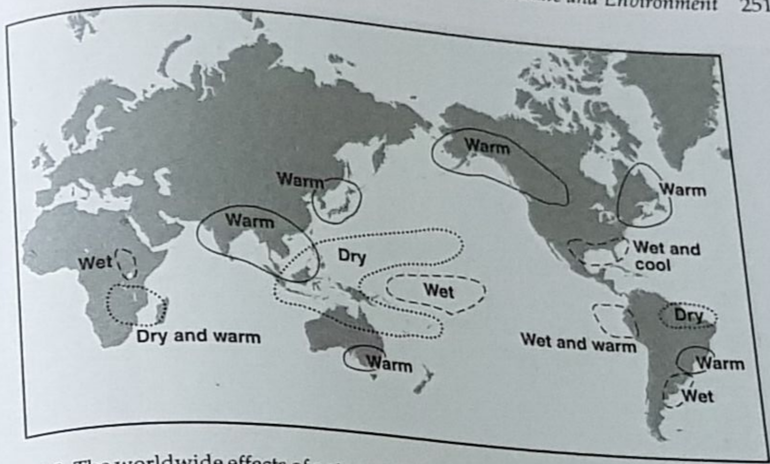


Figure 10.8 The worldwide effects of a strong El Niño, reconstructed on the basis of the 1982–1983 event. We can assume that generally similar effects were experienced over the past 5,000 years.

Identifying ancient short-term climatic change requires extremely precise and sophisticated environmental and climatic evidence, much of it obtained from ice cores, pollen diagrams, and tree rings. Ice cores in particular are revolutionizing our knowledge of ancient climatic shifts, for they are now achieving a resolution of five years or less, which really allows the study of drought cycles and major El Niño events of the past.

El Niños like those in 1982–1983 and 1997–1998 grabbed world headlines, and with good reason. Billions of dollars of damage came from drought and flood. California enjoyed record rains, Australia and northeast Brazil suffered through brutal drought, and enormous wildfires devastated rain forests in Southeast Asia and Mexico. Once thought to be a purely local phenomenon off the Peruvian coast, El Niños are now known to be global events that ripple across the entire tropics as a result of a breakdown in the atmospheric and ocean circulation in the western Pacific. From the archaeologist's point of view, El Niños are of compelling interest, for they had drastic effects on many early civilizations living in normally dry environments, where flooding could wipe out years of irrigation agriculture in hours. Humanity was not that vulnerable to El Niños until people settled in permanent villages, then cities, when the realities of farming and growing population densities made it harder for them to move away from drought or flood (see Figure 10.8).

The Moche Civilization

A classic example of such vulnerability comes from the north coast of Peru, where Moche civilization flourished around A.D. 400, overseen by powerful, authorita

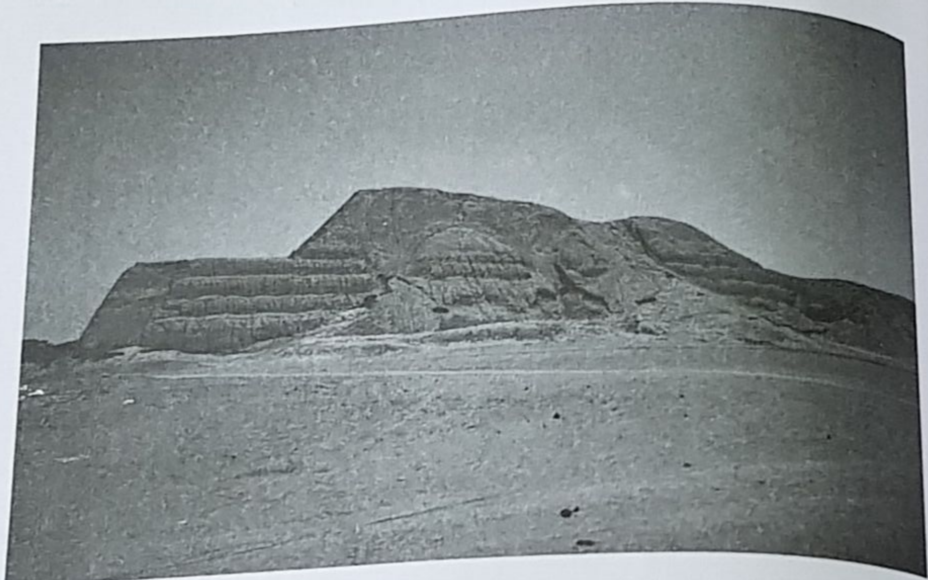


Figure 10.9 The Moche pyramid known as *Huaca del Sol*, capital of powerful Moche lords in the fifth century A.D. The pyramid was extensively damaged by powerful El Niño events. (James Brunker / Alamy)

warrior-priests who ruled from great pyramid centers (see Figure 10.9; see also Figure 2.6 on p. 43). The Moche survived in one of the driest environments on earth by using elaborate irrigation schemes to harness spring runoff from the Andes in coastal river valleys. Everything depended on ample mountain floodwaters. When drought occurred, the Moche suffered.

The Quelccaya ice cap in the Cordillera Occidental of the southern Peruvian highlands lies in the same zone of seasonal rainfall as the mountains above Moche country. Two ice cores drilled in the summit of the ice cap in 1983 provide a record of variations in rainfall over 1,500 years, and, indirectly, an impression of the amount of runoff that would have reached lowland river valleys during cycles of wet and dry years (see chapter opener photo for an Iceland example on p. 238). In the southern highlands, El Niño episodes have been tied to intense short-term droughts in the region, also on the nearby *altiplano*, the high-altitude plains around Lake Titicaca. The appearance of such drought events in the ice cores may reflect strong El Niño episodes in the remote past. However, it is more productive to look at long-term dry and wet cycles.

The two ice cores, 508 and 537 feet (155 and 164 meters) long, each yielded clear layering and annual dust layers that reflected the yearly cycle of wet and dry seasons, the latter bringing dust particles from the arid lands to the west to the high Andes, accurate to within about twenty years. The cores show clear indications of long-term rainfall variations. A short drought occurred between A.D. 534 and 540. Then, between A.D. 563 and 594, a three-decade drought cycle settled over the mountains and lowlands, with

annual rainfall as much as 30 percent below normal. Abundant rainfall resumed in 602, giving way to another drought between A.D. 636 and 645.

The thirty-year drought of A.D. 563 to 594 drastically reduced the amount of runoff reaching coastal communities. The effect of a 25 or 30 percent reduction in the water supply would be catastrophic, especially on farmers near the coast, well downstream from the mountains. Moche society apparently prospered until the mid-sixth-century's severe drought cycle. As the drought intensified, the diminished runoff barely watered the rich farming land far downstream. Miles of laboriously maintained irrigation canals remained dry. Blowing sand cascaded into empty ditches. By the third or fourth year, as the drought lowered the water table far below normal, thousands of acres of farmland received so weak a river flow that unflushed salt accumulated in the soil. Crops withered. Fortunately, the coastal fisheries still provided ample fish meal – until a strong El Niño came along without warning, bringing warmer waters and torrential rains to the desert and mountains.

We do not know the exact years during the long drought when strong El Niños struck, but we can be certain that they did. We can also be sure they hit at a moment when Moche civilization was in crisis, grain supplies running low, irrigation systems sadly depleted, malnutrition widespread, and confidence in the rulers' divine powers much diminished. This was the time of the human sacrifices at Huaca de la Luna (see the Discovery box on pp. 239–240). The warmer waters of the El Niño reduced anchovy harvests in many places, decimating a staple both of the coastal diet and highland trade. Torrential rains swamped the Andes and coastal plain. The arid rivers became raging torrents, carrying everything before them. Levees and canals overflowed and collapsed. The arduous labors of years vanished in a few weeks. Dozens of villages disappeared under mud and debris as the farmers' cane and adobe houses collapsed and their occupants drowned. The floods polluted springs and streams, overwhelmed sanitation systems, and stripped thousands of acres of fertile soil. As the water receded and the rivers went down, typhoid and other epidemics must have swept through the valleys, wiping out entire communities. Infant mortality undoubtedly soared.

The Moche's elaborate irrigation systems created an artificial landscape that supported dense farming populations in the midst of one of the driest deserts on earth, where farming would be impossible without technological ingenuity. The farmers were well aware of the hazards of droughts and El Niños, but technology and irrigation could not guarantee the survival of a highly centralized society driven as much by ideology as by pragmatic concerns. There were limits to the climatic shifts Moche civilization could absorb. Ultimately, the Moche ran out of options and their civilization collapsed.

We do not know how long El Niños have oscillated across the globe, but they have descended on Peru for at least 5,000 years. A new generation of climatic researches from ice cores and other data show that short-term climatic shifts played a far more important role in the fate of early civilizations than once realized.

Tree Rings: Studying Southwestern Drought

Many ancient societies lived in environments with unpredictable rainfall where agriculture was, at best, a chancy enterprise. The ancient peoples of the southwestern United States farmed their semiarid environment with brilliant skill for more than 3,000 years, developing an extraordinary expertise in water management and plant breeding. One central philosophy of modern-day Pueblo Indian groups encompasses movement – the notion that people have to move to escape drought and survive. Until recently, archaeologists did not fully appreciate the importance of movement in southwestern life and

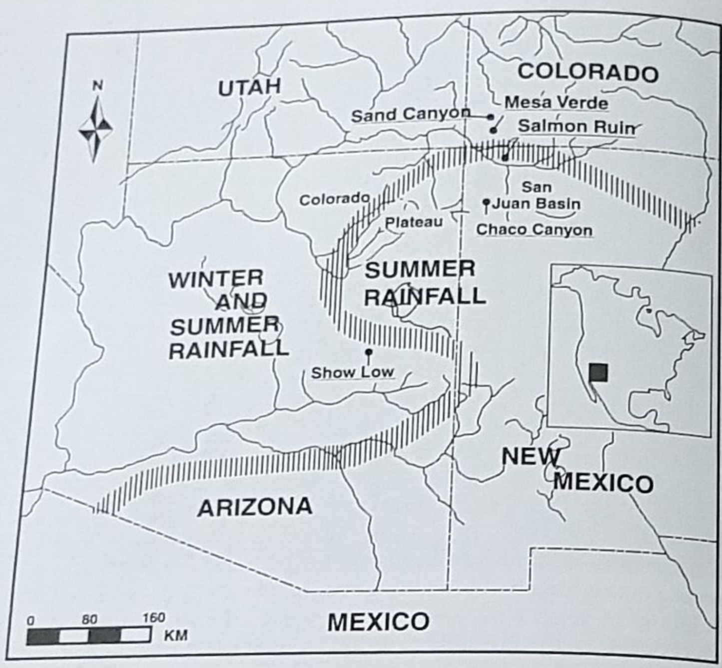


Figure 10.10 The climatic regimens of the American Southwest, showing the general configuration of rainfall across the region reconstructed with tree rings. The northwestern area receives both summer and winter rainfall, the southeastern area only predictable summer rainfall.

were at a loss to explain the sudden dispersal of the Ancestral Pueblo people of Chaco Canyon and the Four Corners region in the twelfth and thirteenth centuries A.D. New studies have shown that climate played an important role in the dispersal.

Dendrochronologies for the Ancestral Pueblo are now accurate to within a year, giving us the most precise time scale for any early human society anywhere. In recent years, the Laboratory of Tree-Ring Research at the University of Arizona has undertaken a massive dendroclimatic study that has yielded a reconstruction of relative climatic variability in the Southwest from A.D. 680 to 1970. The same scientists, headed by Jeffrey Dean, are now producing the first quantitative reconstructions of annual and seasonal rainfall, also of temperature, drought, and stream flow for the region. Such research involves not only tree-ring sequences but also intricate mathematical expressions of the relationships between tree growth and such variables as rainfall, temperature, and crop yields. These calculations yield statistical estimations of the fluctuations in these variables on an annual and seasonal basis.

By using a spatial grid of twenty-seven long tree-ring sequences from throughout the Southwest, Dean and his colleagues have compiled maps that plot the different station values and their fluctuations like contour maps, one for each decade. This enables them to study such phenomena as the progress of what Dean sometimes calls the "Great

Drought" of A.D. 1276 to 1299 from northwest to southeast across the region. In 1276, the beginnings of the drought appear as negative standard deviations from average rainfall in the northwest while the remainder of the region enjoys above-average rainfall. During the next ten years, very dry conditions expand over the entire Southwest before improved rainfall arrives after 1299. This form of mapping allows close correlation of vacated large and small pueblos with short-term climatic fluctuations (see Figure 10.10).

When the researchers looked at the entire period from A.D. 966 to 1988, they found that the tree-ring stations in the northwestern region accounted for no less than 60 percent of the rainfall variance. In contrast, stations in the southeastern part of the Southwest accounted for only 10 percent. This general configuration, which persisted for centuries, coincides with the modern distribution of seasonal rainfall in the Southwest: predictable summer rainfall dominates the southeastern areas, while the northwest receives both winter and summer precipitation. Winter rains are much more uncertain. When the scientists examined this general rainfall pattern at 100-year intervals from 539 to 1988, they observed that it persisted most of the time, even though the boundary between the two zones moved backward and forward slightly.

But this long-term pattern broke down completely from A.D. 1250 to 1450, when a totally aberrant pattern prevailed in the northwest. The southeast remained stable, but there was major disruption elsewhere. For nearly two centuries, the relatively simple long-term pattern of summer and winter rains gave way to complex, unpredictable precipitation and severe droughts, especially on the Colorado Plateau. The change to an unstable pattern would have had a severe impact on Ancestral Pueblo farmers, especially as it coincided with the Great Drought of A.D. 1250 to 1299.

Why did this breakdown occur? Dean divides the relationship between climatic change and human behavior into three broad categories. Certain obvious stable elements in the Ancestral Pueblo environment have not changed over the past 2,000 years, such as bedrock geology and climate type. Then there are low-frequency environmental changes – those that occur on cycles longer than a human generation of twenty-five years. Few people witnessed these changes during their lifetimes. Changes in hydrological conditions such as cycles of erosion and deposition along stream courses, fluctuations in water table levels in river floodplains, and changes in plant distributions transcend generations, but they could affect the environment drastically, especially in drought cycles.

Shorter-term, high-frequency changes were readily apparent to every Ancestral Pueblo person: year-to-year rainfall shifts, decade-long drought cycles, seasonal changes, and so on. Over the centuries, they were probably barely aware of long-term change, for the present generation and their ancestors enjoyed the same basic adaptation, which one could call a form of "stability." Cycles of drought, unusually heavy rains, and other high-frequency changes required temporary and flexible adjustments, such as farming more land, relying more heavily on wild plant foods, and, above all, movement across the terrain.

Such strategies worked well for centuries, as long as the Ancestral Pueblo people farmed their land at well below its carrying capacity. When the population increased to near carrying capacity, however, as it did at Chaco Canyon in the twelfth century, people became increasingly vulnerable to brief events like El Niños or droughts, which could stretch the supportive capacity of a local environment within months, even weeks. Their vulnerability was even more extreme when long-term changes – such as a half century or more of much drier conditions – descended on farming land already pushed to its carrying limits. Under these circumstances, a year-long drought or torrential rains could quickly destroy a local population's ability to support itself. So the people dispersed into other areas where there were ample soil and better water supplies. Climate change and drought did not, of course, cause the Ancestral Pueblo dispersal by themselves, for other significant political and social factors came into play. Without question, however, the Ancestral Pueblo people dispersed from Mesa Verde and Chaco Canyon in part because drought forced them to do so. Unlike the Moche in distant Peru, they had the flexibility to move away.

The coming decades will see a revolution in our understanding of ancient environments and short-term climatic change as scientists acquire a closer knowledge both of climates in the past and of the still little-known forces that drive the global weather machine. Like our predecessors, we still live in the Ice Age, which, some estimates calculate, will bring renewed glacial conditions in about 23,000 years' time. So it is hardly surprising that, like our forebears, we have had to adjust to constant short-term climatic changes. And, as humanly induced global warming accelerates, these changes may become more frequent and violent, spelling danger for an overpopulated world.

Geoarchaeology

Sediments and soils contain a record of climate change, for climate helps drive geomorphic and landscape changes on earth. **Geoarchaeology**, the study of archaeology using the methods and concepts of the earth sciences, plays a major role in reconstructing ancient environments and landscapes. This is a far wider enterprise than geology and involves at least four major approaches:

1. Geochemical, electromagnetic, and other remote-sensing devices to locate sites and environmental features (see Chapter 6).
2. Studies of site-formation processes and of the spatial contexts of archaeological sites (see Chapters 5 and 9), a process that includes distinguishing humanly caused phenomena from natural features.
3. Reconstructing the ancient landscape by a variety of paleogeographic and biological methods, including pollen analysis.
4. Relative and chronometric dating of sites and their geological contexts.

Geoarchaeology plays a major role in the study of early Egyptian and Mesopotamian civilizations. Both lay in fertile lands transected by great rivers. The annual inundations of the Nile brought silt to the floodplain from far upstream, fertilizing the fields. In drought years, when the flood failed, crops failed and people went hungry. In about 2180 B.C., the Nile experienced poor floods for generations. The pharaohs were powerless, and Egypt fell apart into its nine provinces, each ruled by powerful warlords. More than a century passed before powerful leaders from Upper Egypt reunited the kingdom. The pharaohs learned their lesson and invested heavily in centralized storage and irrigation. In Mesopotamia, Sumerian cities were at the mercy of flood and drought, especially when high floods caused river courses to change or when sluggish waters failed, leading to a rapid rise in the salinity of the soil and much lower crop yields.

On a smaller scale, people are geomorphic agents, just like the wind. Accidentally or deliberately, they carry inorganic and organic materials to their homes. They remove rubbish, make tools, build houses, abandon tools. These mineral and organic materials are subjected to all manner of mechanical and biochemical processes while people live on a site and after they abandon it. The controlling geomorphic system at a site, whatever its size, is made up not only of natural elements but of a vital cultural component as well. The geoarchaeologist is involved with archaeological investigations from the very beginning and deals not only with formation of sites and with the changes they underwent during occupation but also with what happened to them after abandonment.

In the field, the geoarchaeologist is part of the multidisciplinary research team, recording stratigraphic profiles within the excavation and in special pits close by in order to obtain information on soil sediment sequences. At the same time, he or she takes soil samples for pollen and sediment analyses and relates the site to its landscape by topographic survey. Working closely with survey archaeologists, geoarchaeologists locate sites and other cultural features on the natural landscape using aerial photographs, satellite images, and even geophysical prospecting on individual sites. As part of this process, they examine dozens of natural geological exposures, where they study the stratigraphic and sedimentary history of the entire region as a wider context for the sites found within it. The ultimate objective is to identify not only the microenvironment of the site but also that of the region as a whole – to establish ecological and spatial frameworks for the socioeconomic and settlement patterns that are revealed by archaeological excavations and surveys.

SUMMARY

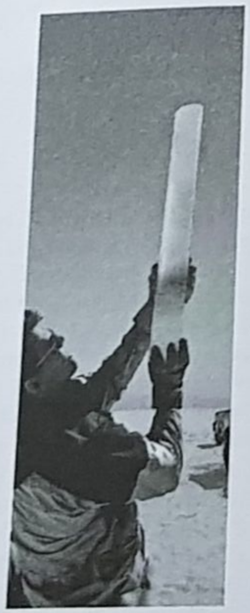
1. The study of long- and short-term climatic and environmental change is of vital importance to archaeologists concerned with human societies' changing relationships with their surroundings.
2. This chapter describes ways of studying such changes. Deep-sea cores and ice drillings provide us with a broad framework of climatic change during the Pleistocene (Ice Age) that chronicles at least eight glacial periods during the past 780,000 years.
3. The Pleistocene itself is divided into three broad subdivisions, the last of which coincides with the spread of modern humans across the world from Africa. The Holocene covers postglacial times and witnessed not only global warming but at least three short periods of much colder conditions.
4. The Younger Dryas brought drought and cold conditions and may have helped trigger agriculture in southwestern Asia.
5. The catastrophic flooding of the Black Sea lake in about 5500 B.C. by salt water from the Mediterranean caused major population movements in Europe.
6. Short-term events such as El Niños and droughts in the southwestern United States are studied with the aid of ice cores, geological observations, and tree rings – methods achieving increasing precision.
7. We are now beginning to realize that short-term climatic change played a vital role in the rise and fall of many human societies.
8. Geoarchaeology is a multidisciplinary approach to the study of human adaptations that reconstructs ancient landscapes using such techniques as remote sensing and paleographic and biological methods such as pollen analysis.

QUESTIONS FOR DISCUSSION

1. What are the differences between centuries-long and shorter climatic events in th context of human history?

10 Ancient Climate and Environment

CHAPTER OUTLINE



An ice-core sample from the Langjokull Ice Cap, Iceland. (ARCTIC IMAGES / Alamy)

PREVIEW

Human societies have adapted to changing environments and long- and short-term climate change since before the Ice Age began some 1.5 million years ago. In recent years, a revolution in the study of ancient climate change using deep-sea cores and ice cores, as well as tree-ring and pollen analysis, has made it possible to look at ancient human societies in the context of such changes on a much more detailed scale. Chapter 10 describes the major events of the Ice Age, then the Holocene, and also the major climatological approaches for studying them. We discuss the impacts of El Niños and droughts on societies like the Moche of the Andes and the Ancestral Pueblo of the Southwest. The multidisciplinary science of geoarchaeology is of central importance in studying climatic change in the past.

In 4500 B.C., a patch of woodland in northern England boasted mature oak, ash, and elm trees interspersed with occasional patches of open grassland and swamp. In 3820 B.C., some foragers set fire to the forest to encourage fresh green shoots for feeding deer. Birch and bracken now appeared. About thirty years passed before the landscape was cleared even more. Judging from numerous charcoal fragments, fire swept through the undergrowth, leaving fine ash to fertilize the soil. Now wheat pollen and that of a cultivation weed named *Plantago lanceolata* appeared. Fifty years of wheat farming ensued. These years saw only two fires, one after six years, the other nineteen years after that. Then seventy years passed, during which agriculture ceased and the land stood vacant. Hazel, birch, and alder became more common and oak resurged as woodland rapidly gained ground.

This scenario of brief clearance, slash-and-burn agriculture, then abandonment and regeneration was repeated at thousands of locations in ancient Europe in the early years of Stone Age farming. Over a few centuries, the natural environment of mixed oak forest was transformed beyond recognition by gardens and domesticated animals. Until a few years ago, we could only have guessed at these environmental changes. Today, fine-grained pollen analysis and other highly sophisticated methods allow the reconstruction of even short-lived climatic and environmental changes in the remote past.

Archaeology is unique in its ability to study culture change over very long periods of time. By the same token, it is a multidisciplinary science that also studies human interactions with the natural environment over centuries and millennia. Chapter 10 describes some of the ways archaeologists study long- and short-term environmental change from a multidisciplinary perspective.

Discovery

Moche Human Sacrifice and El Niño, Huaca de la Luna, Peru, Sixth to Seventh Century A.D.

Human sacrifice was commonplace in pre-Columbian states, among them the Aztecs and the Inka. Early Spanish accounts of these societies abound with stories of people being burned alive, flayed, decapitated, or having their hearts ripped out. Archaeological evidence for such practices is fairly rare, which makes a dramatic find of a Moche sacrifice of 1,400 years ago of unusual importance.