6 What Was the Environment?

Environmental Archaeology

Environmental archaeology is now a well-developed discipline in its own right. It views the human animal as part of the natural world, interacting with other species in the ecological system or *ecosystem*. The environment governs human life: latitude and altitude, landforms and climate determine the vegetation, which in turn determines animal life. And all these things taken together determine how and where humans have lived – or at least they did until very recently.

With a few exceptions, little attention was paid by archaeologists to non-artifactual (ecofactual) evidence until recent decades. Sites were studied more or less as self-contained packages of evidence, rather than in their context within their surrounding landscape. It is now regarded as important to see sites in their setting, and to consider the geomorphological and biological processes occurring in and around them. The environment is seen now as a variable, not as something which is constant or homogeneous through space and time.

The reconstruction of the environment first requires an answer to very coarse-grade questions of chronology and climate. We need to know when the human activities under study took place in terms of the broad world climatic succession. This then is partly a matter of chronology. A reliable date allows us, for instance, to determine whether the context belongs to a glacial or an interglacial phase, and what the temperature is likely to have been in that part of the globe. Sea-level and other questions will be related to this one.

Finer-grade questions will follow, and these are particularly relevant for all postglacial contexts, after about 10,000 years ago. The archaeologist usually turns then to the evidence of the vegetation at the time. Whether from pollen or from other plant remains, information is gained about the vegetation cover, which also contributes yet further useful data about the climate.

The logical next step is to turn to the fauna (animal remains), in the first place to the microfauna, including insects, snails, and rodents, all of which are very sensitive indicators of climatic change. Like some of the plant remains, they are indicators also of the microenvironment – of specific conditions at the site. Some of these conditions, of course, resulted from human activity when people erected structures and otherwise influenced the immediate surroundings to ensure survival and comfort.

Owing to the poor preservation of many forms of evidence, and to the distorted samples we recover, we can never arrive at the "true" facts for past environments. One simply has to aim for the best approximation available. No single method will give an adequate picture – all are distorted in one way or another – and so as many methods as data and funds will allow need to be applied to build up a composite image.

Despite these difficulties, the task of environmental reconstruction is a fundamental one. For if we are to understand how human individuals functioned, and the community of which they formed a part, we have to know first what their world was like.

INVESTIGATING ENVIRONMENTS ON A GLOBAL SCALE

The first step in assessing previous environmental conditions is to look at them globally. Local changes make little sense unless seen against this broader climatic background. Since water covers almost three-quarters of the earth, we should begin by examining evidence about past climates that can be obtained from this area.

In the last few decades, thanks to developments in technology and scientific analysis, it has become possible not only to excavate shipwrecks and submerged sites, but also to extract data from the sea bed that are of great value in reconstructing past environments, particularly for earlier periods.

Evidence from the Oceans

The sediments of the ocean floor accumulate very slowly (a few centimeters every thousand years) and in some areas consist primarily of an ooze made up of microfossils such as the shells of planktonic foraminifera – tiny one-celled marine organisms that live in the surface water masses of the oceans and sink to the bottom when they die. As in an archaeological stratigraphy, one can trace changes in environmental conditions through time by studying cores extracted from the sea bed and fluctuations in the species represented and the morphology (physical form) of single species through the sequence (see box opposite).

Thousands of deep-sea cores have now been extracted and studied, and have produced consistent results that form an invaluable complement to data obtained from land (see below). For example, one 21-m (69-ft) core from the Pacific Ocean has given a climatic record of over 2 million years. In the eastern Mediterranean, analysis by Robert Thunell of foraminifera in sediment samples has enabled him to estimate sea-surface temperatures and salinities (salt levels) at different periods. He has established that about 18,000 years ago, at the height of the last Ice Age, the winter temperature was 6°C (11°F) cooler than now, and the summer temperature was 4°C (7°F) cooler. The Aegean was also 5 percent less saline than at present, probably because cool, low-salinity water was being diverted into the Aegean from the large freshwater lakes that then existed over parts of eastern Europe and western Siberia.

Sea cores also provide climatic information through the analysis of organic molecules in the sediment. Some of these molecules, and especially the so-called fatty lipids, can remain relatively intact, yielding climatic clues because cells adjust the fatty composition of their lipids according to temperature changes. In cold conditions the proportion of unsaturated lipids in marine organisms increases, with a corresponding rise in saturated lipids in warm conditions. Cores of deep-sea sediment have shown variations in the ratio of saturated to unsaturated fatty lipids through time which, according to the British chemist Simon Brassell and his German colleagues, seem to correlate well with changes in ocean temperature over the last half million years known from the oxygen isotope technique (explained in the sea cores box, opposite).

Using a similar technique, cores can also be obtained from stratified ice sheets, and here again the oxygen isotopic composition gives some guide to climatic oscillations. Results from cores in Greenland and the Antarctic, and Andean and Tibetan glaciers are consistent with, and add detail to, those from deep-sea cores. The Vostok ice-core in the Antarctic has reached a depth of (11,886 ft), and extends back to to 420,000 BP. Oxygen isotope data from GRIP (the Greenland Ice Core Project) and GISP2 (Greenland Ice Sheet Project 2) – two cores 28 km (17 miles) apart and about 3 km (1.9 miles) long, containing at least 200,000 annual growth layers – show that the last glaciation had several cold phases of between 500 and 200 years, all beginning abruptly, perhaps within a few decades, and ending gradually. At first it was thought that they were 12–13°C (21–24°F) colder than at present, but recent analysis of bubbles in ancient methane gas trapped in the ice (resulting from plant decomposition, which is sensitive to temperature and moisture variations) has revealed that the temperatures were twice as severe. A final swing back to glacial cold, in 12,900–11,600 BP (uncalibrated), was followed by a rapid, very abrupt warming – the temperature in Greenland rose by 7°C (13°F) in 50 years. There are some even more violent swings in the cores, when the temperature appears to have risen by up to 12°C (21°F) in only one or two years! The last 10,000 years have been stable apart from the Little Ice Age in the early Middle Ages. The results from the far north and south have been confirmed by the cores from the high Andes, as well as analyses of sediments and coral in other regions, which reveal how the tropics (with half the world's landmass and much of its population) reacted to worldwide climatic changes.

Ancient Winds. Isotopes can be used not merely for temperature studies but also for data on precipitation. And since it is the temperature differences between the equatorial and polar regions that largely determine the storminess of our weather, isotope studies can even tell us something about winds in different periods. As air moves from low latitudes to colder regions, the water it loses as rain or snow is enriched in the stable isotope oxygen 18 with respect to the remaining vapour which becomes correspondingly richer in the other stable isotope of oxygen, oxygen 16. Thus from the ratio between the two isotopes in precipitation at a particular place, one can calculate the temperature difference between that place and the equatorial region.

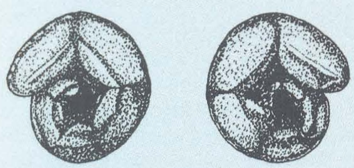
Using this technique, the changing ratios found over the last 100,000 years in ice cores from Greenland and the Antarctic have been studied. The results show that during glacial periods the temperature difference between equatorial and polar regions increased by 20–25 percent, and thus wind circulation must have been far more violent. Confirmation has come from a deep-sea core off the coast of West Africa, analysis of which led to estimates of wind strength over the last

RECONSTRUCTING CLIMATES FROM SEA AND ICE CORES

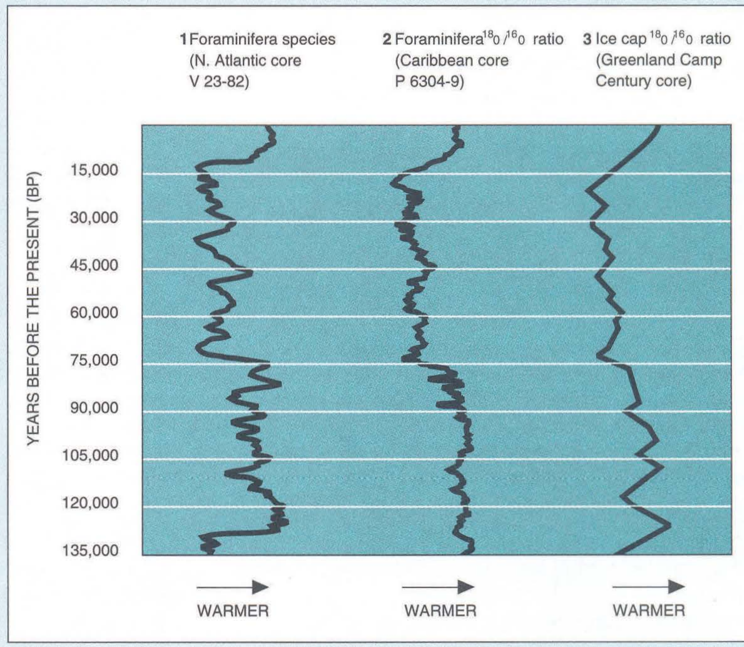
The stratigraphy of sediment on the ocean floor is obtained from cores taken out of the sea bed. Ships use a "piston-corer" to extract a thin column of sediment, usually about 10–30 m (33–98 ft) in length. The core can then be analyzed in the laboratory.

Dates for the different layers in the core are obtained by radiocarbon, paleomagnetism, or the uranium-series method (Chapter 4). Changing environmental conditions in the past are then deduced by two kinds of tests on microscopic fossils of tiny one-celled organisms called foraminifera found in the sediment. First, scientists study the simple presence, absence, and fluctuations of different foraminiferan species. Second, they analyze, by mass spectrometer, fluctuations in the ratio of the stable oxygen isotopes 18 and 16 in the calcium carbonate of the foraminiferan shells. Variations discernible by these two tests reflect not simply changes in temperature, but also oscillations in the continental glaciers. For example, as the glaciers grew, water was drawn up into them, reducing sea levels and increasing the density and salinity of the oceans, and thus causing changes in the depths at which certain foraminiferan species lived. At the same time the proportion of oxygen 18 in seawater increased. When the glaciers melted during periods of warmer climate, the proportion of oxygen 18 decreased.

A similar technique can be used to extract cores from present-day ice sheets in Greenland and Antarctica. Here, too, variations in oxygen isotopic composition at different depths of the cores provide some indication of past changes in climate. These results coincide well with those from the deep-sea cores.



Microscopic fossils of the foraminiferan species Globorotalia truncatulinoides, *which coils to the left during cold periods and to the right during warm ones.*



***Three climate records** compared. Left to right: proportions of different shell species in a deep-sea core; ratio of oxygen 18 to oxygen 16 in shells from a deep-sea core; and oxygen ratios from an ice core. The resemblance of the three records is good evidence that long-term climatic variation has been worldwide.*

700,000 years. Apparently wind "vigor" was greater by a factor of two during each glacial episode than at the present; and wind speeds were 50 percent greater during glacial than interglacial phases. In future, analysis of the minute plant debris in these cores may also add to the history of wind patterns.

Why should archaeologists be interested in ancient winds? The answer is that winds can have a great impact on human activity. For example, it is thought that increased storminess may have caused the Vikings to abandon their North Atlantic sea route at the onset of a cold period. Similarly, some of the great Polynesian migrations in the southwestern Pacific during the 12th and 13th centuries AD seem to have coincided with the onset of a short period of slightly warmer weather, when violent storms would have been rare. These migrations were brought to an end a few centuries later by the Little Ice Age, which may have caused a sharp increase in the frequency of storms. Had the Polynesians been able to continue, they would probably have gone on from New Zealand to colonize Tasmania and Australia.

CLIMATIC CYCLES: EL NIÑO

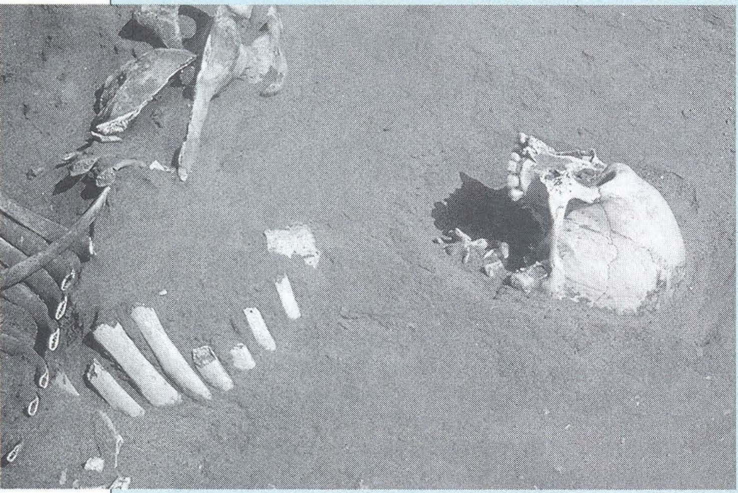
It has long been known that the earth's climate moves in cycles, from the annual seasons to the long-term growth and decline of the great ice sheets. Some climatic cycles span several millennia, thus escaping notice in human lifetimes but nevertheless affecting human affairs. Data from the Greenland ice core GISP2 and from marine sediments have exposed a whole range of such cycles, from those of 40,000 and 23,000 years, caused by the tilting and wobbling of the earth's axis, down to cycles of 11,100, 6100, and 1450 years. The 1450-year cycle corresponds with tree-ring records and seems to coincide with abrupt shifts in climate. It may be related to variations in the strength of the sun, though this is uncertain.

The most famous rapid shifts in climate are the tropical Pacific warmings known as El Niño events, named after the Christ child because they occur near Christmastime. They are signalled by a weakening of the trade winds that normally drive warm surface water west from South America's Pacific coast and pull a current of cold water up from the ocean depths to replace it. This incursion of warm tropical waters causes the cold-water fish to decline or head south, thus affecting resource abundance and distribution – tropical species of fish, crustaceans, and some molluscs invade the Peruvian coast for the duration of the event; the Western Pacific and the Andes undergo drought, while coastal Ecuador and Peru are inundated with rain. The monsoon fails in India, droughts occur in Australia and Africa, and storms hit the coasts of California and Mexico.

El Niño events (known as ENSO, or El Niño/Southern Oscillation) show that even a relatively subtle redistribution in sea surface temperature in the tropics can influence climate globally, and these seem to have occurred throughout history, affecting climate, ocean temperatures, and hence coastal species. Evidence has recently been obtained from geoarchaeology and faunal assemblages at sites on the west coast of tropical South America that the modern series of ENSO began with a major climatic change at about 5000 years ago, since sites dating back to 8000 BP contained predominantly warm-water species characteristic of stable, warm tropical water, whereas sites after 5000 BP included temperate species.

It is therefore thought that this onset of ENSO may have helped shape the emergence of civilizations around the Pacific, and notably on the South American coast, with the crop-nourishing rains sparking population increases, temple construction, and more complex societies.

Climate records were recently obtained from sediments at the bottom of Lake Pallcacocha, at an altitude of 4000 m (13,000 ft) in the Ecuadorian Andes. Light, organic-poor layers alternate with dark, organic-rich layers caused by the torrential rains associated with El Niño. The sediments confirm that ENSO was non-existent, or extremely weak, between about 12,000 and 5000 years ago: during the last 5000 years, the lake recorded extreme rains every 2 to 8 years, which is ENSO's current pattern, whereas the preceding seven millennia only had such rains every few decades, or even up to 75 years apart. However, climatic records for even earlier periods, obtained from western Pacific corals and sediments in the Great Lakes, again show ENSO operating much the same as today – hence this phenomenon clearly waxes and wanes over the millennia.



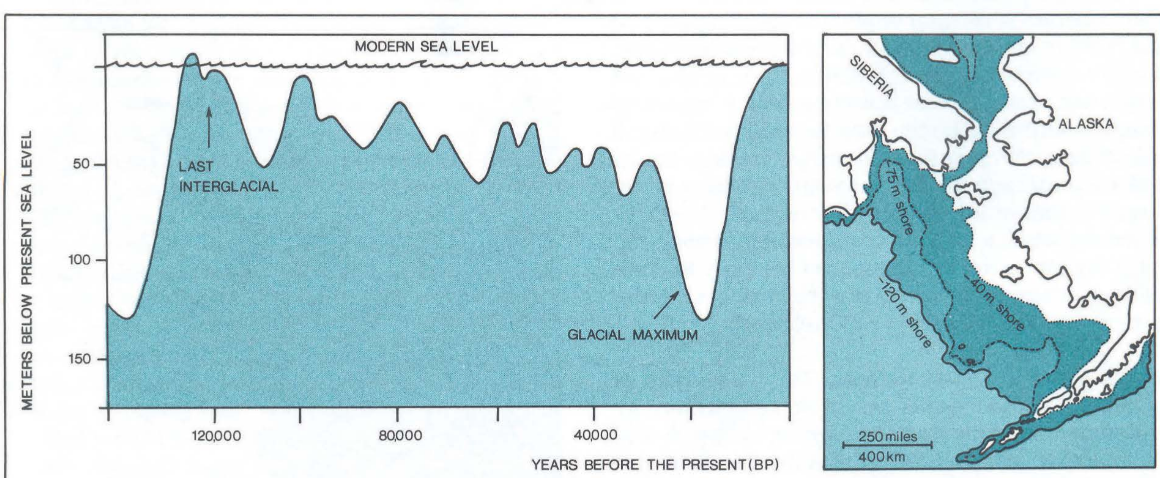
The skeletons of people sacrificed at the Huaca de la Luna, Moche, Peru, during an El Niño event that took place between the late 6th and early 8th century. They were then buried in the mud of the adobe walls of Plaza-3-A which were melted by the torrential rains associated with the event.

Ancient Coastlines

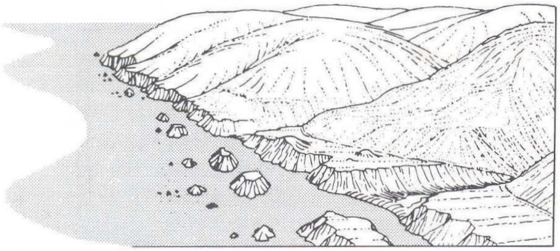
Ancient life at sea is certainly of archaeological interest, but information on past climates is primarily of relevance to archaeology because of what it tells us about the effects on the land, and on the resources that people needed to survive. The most crucial effect of climate was on the sheer quantity of land available in each period, measurable by studying ancient coastlines. These have changed constantly through time, even in relatively recent periods, as can be seen from the Neolithic stone circle of Er Lannic, Brittany, which now lies half submerged on an island (once an inland hill in the Neolithic), or medieval villages in east Yorkshire, England, that have tumbled into the sea in the last few centuries as the North Sea gnaws its way westward and erodes the cliffs. Conversely, silts deposited by rivers sometimes push the sea farther back, creating new land, as at Ephesus in western Turkey, a port on the coast in Roman times but today some 5 km (3 miles) inland.

Nevertheless, for archaeologists concerned with the long periods of time of the Paleolithic epoch there are variations in coastlines of much greater magnitude to consider. The expansion and contraction of the continental glaciers, mentioned above, caused huge and uneven rises and falls in sea levels worldwide. When the ice sheets grew, sea level would drop as water became locked up in the glaciers; when the ice melted, sea level would rise again. Falls in sea level often exposed a number of important ***land bridges***, such as those linking Alaska to northeast Asia, and Britain to northwest Europe, a phenomenon with far-reaching effects not only on human colonization of the globe, but also on the environment as a whole – the flora and fauna of isolated or insular areas were radically and often irreversibly affected. Between Alaska and Asia today there lies the Bering Strait, which is so shallow that a fall in sea level of only 46 m (150 ft) would turn it into a land bridge. When the ice sheets were at their greatest extent some 18,000 years ago (the "glacial maximum"), it is thought that the fall here was about 120 m (395 ft), which therefore created not merely a bridge but a vast plain, 1000 km (621 miles) from north to south, which has been called Beringia. The existence of Beringia (and the extent to which it could have supported human life) is one of the crucial pieces of evidence in the continuing debate about the likely route and date of human colonization of the New World (see Chapter 11).

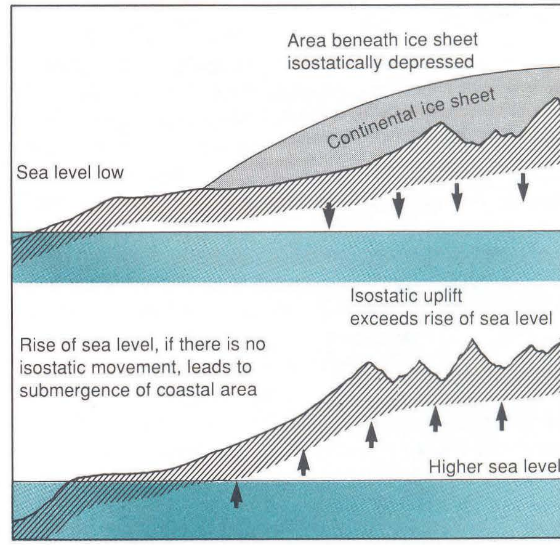
The assessment of past rises and falls in sea level requires study of submerged land surfaces off the coast and of raised or elevated beaches on land. Raised beaches are remnants of former coastlines at higher levels relative to the present shoreline and visible, for instance, along the California coast north of San Francisco (see illus. p. 230). The height of a raised beach above the present shoreline, however, does not generally give a straightforward indication of the height of a former sea level. In the majority of cases, the beaches



Sea levels and land bridges. (Left) Fluctuations in world sea levels over the last 140,000 years, based on evidence from uplifted coral reefs of the Huon Peninsula, New Guinea, correlated with the oxygen isotope record in deep-sea sediments (see p. 126). (Right) Falls in sea level created a land bridge between Siberia and Alaska known as Beringia. At the coldest period of the last glaciation ("glacial maximum"), some 18,000 years ago, the fall was as much as 120 m.



Raised beaches along the California coast north of San Francisco. Such beaches usually lie at a higher level because of isostatic uplift of the land (see right).



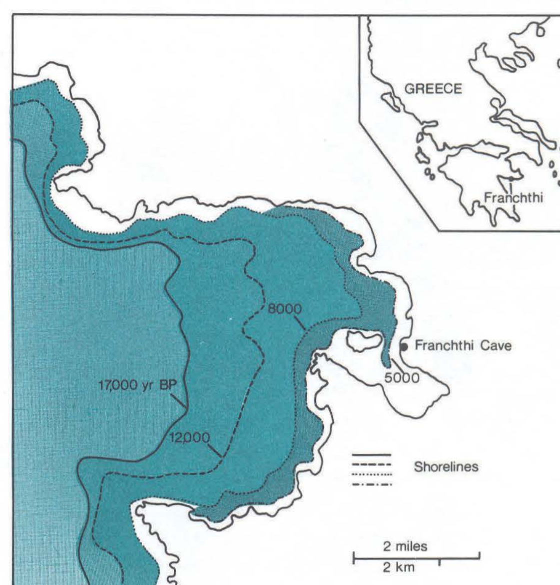
(Above) Principles of isostatic uplift. When sea levels are low and water is locked up in continental glaciers, land beneath the ice sheets is depressed by the weight of the ice. When the glaciers melt, sea level rises, but so too does the land in areas where once it was depressed.

lie at a higher level because the land has literally been raised up through ***isostatic uplift*** or ***tectonic movements***. Isostatic uplift of the land occurs when the weight of ice is removed as temperatures rise, as at the end of an ice age; it has affected coastlines for example in Scandinavia, Scotland, Alaska, and Newfoundland during the postglacial period. Tectonic movements involve displacements in the plates that make up the earth's crust; Middle and Late Pleistocene raised beaches in the Mediterranean are one instance of such movements. The interpretation of raised beaches in connection with past sea levels thus requires specialist expertise. For archaeologists they are equally if not more important as locations where early coastal sites may be readily accessible; coastal sites in more stable or subsiding areas will have been drowned by the rise in sea level.

In addition to the major importance of isostatic uplift and tectonic movements, volcanic eruptions can occasionally affect coastlines. It is thanks to the eruption of AD 79, for example, that the once coastal resorts of Pompeii and Herculaneum now lie some 1.5 km (0.9 miles) from the sea, their former shorelines buried under volcanic lava and mud. Along the coast of northeast Scotland, at an altitude of 8 or 9 m (26–29 ft) above sea level, a layer of coarse white marine sand overlying Mesolithic occupations of the early 8th millennium BP seems to indicate that the area was hit by a tsunami or tidal wave about 7000 years ago.

Tracing Submerged Land Surfaces. The topography of submerged coastal plains can be traced offshore by echo-sounding or the closely related technique of seismic reflection profiling, which in water depths of over 100 m (330 ft) can achieve penetration of more than 10 m (33 ft) into the sea floor. Such acoustic devices are analogous to those used in locating sites (Chapter 3). Using these techniques in the bay in front of the important prehistoric site of Franchthi Cave, Greece, geo-

(Below) Franchthi Cave, Greece. By plotting sea floor depths near Franchthi, and correlating these with known sea level fluctuations (see diagram, p. 229), van Andel and his colleagues produced this map of local changes in coastline.



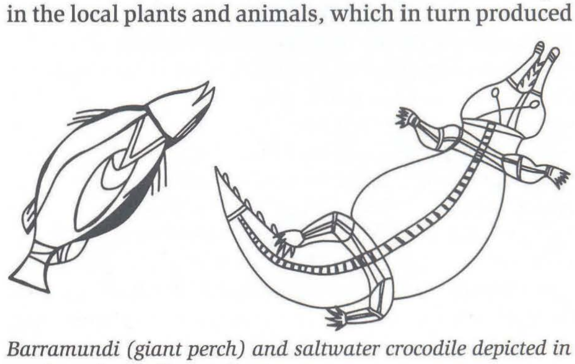
morphologists Tjeerd van Andel and Nikolaos Lianos found that the bay's central shelf is flat, with a series of small scarps (past shoreline positions) at various depths down to one at 118–120 m (387–394 ft) that marks the late glacial shoreline. From this survey it has been possible to reconstruct the coastline for the whole of the sequence represented by the cave's prehistoric occupation (23,000–5000 years ago). As will be seen later (Elands Bay Cave box, pp. 254–55), this kind of reconstruction also enables one to understand changes in the exploitation of marine resources, and to assess the marine molluscs that would have been available for food and ornamentation at different periods by seeing what is present in a range of environments in the Franchthi area today. The lack of seashells in the cave's deposits before 11,000 years ago reflects the distance to the shore at that time. Subsequently, the coast gradually approached the site, and shells accordingly become common in the occupation deposits. During the rise in sea level at the end of the Ice Age, almost half a kilometer of land would have been drowned every millennium, while after 8000 years ago this would have slowed to less than 100 m (330 ft) every millennium. At present, Franchthi is only a few meters from the sea.

Raised Beaches and Middens. Raised beaches often consist of areas of sand, pebbles, or dunes, sometimes containing seashells or middens comprising shells and bones of marine animals used by humans. Indeed, the location of middens can be an accurate indicator of earlier coastlines. In Tokyo Bay, for example, shell mounds of the Jomon period (dated by radiocarbon) mark the position of the shoreline at a time of maximum inundation by the sea (6500–5500 years ago), when, through tectonic movement, the sea was 3–5 m (10 ft–16 ft 5 in) higher in relation to the contemporary landmass of Japan than at present. Analysis of the shells by Hiroko Koike confirms the changes in marine topography, for it is only during this "maximum phase" that subtropical species of mollusc are present, indicating a higher water temperature.

Occasionally, beaches may occur not in a vertical but in a horizontal stratigraphy. At Cape Krusenstern, Alaska, a series of 114 minor relic beach terraces, up to 13 km (8 miles) long, form a peninsula extending into the Chukchi Sea. In 1958, American archaeologist J. Louis Giddings began work here, and his excavations beneath the frozen sod that now covers these ridges revealed settlements and burials dating from prehistoric to historic times. He found that people had abandoned successive beaches as the changing ocean conditions caused a new one to be formed in front of the old. The modern shoreline is Beach 1, while the oldest dune ridge (no. 114) is now about 4.8 km (3 miles) inland. In this way, six millennia of local occupation are stratified horizontally, with 19th-century AD occupation on Beach 1, Western Thule material (*c.* AD 1000) about five beaches inland, Ipiutak material (2000–1500 years ago) around Beach 35, an Old Whaling Culture village (*c.* 3700 years ago) at Beach 53, and so on.

Coral Reefs. In tropical areas, fossil coral reefs provide evidence similar to that of raised beaches. Since coral grows in the upper part of the water, and extends more or less up to sea level, it indicates the position of previous shorelines, and its organisms give information on the local marine environment. For example, the Huon Peninsula, on the northeast coast of Papua New Guinea, has a spectacular shoreline sequence, comprising a stepped series of raised coral terraces produced by an upward tilting of the coast together with falling sea levels during cold glacial periods. The scientists J.M.A. Chappell, Arthur Bloom, and others studied more than 20 reef complexes on the Huon Peninsula dating back over 250,000 years and calculated the sea level at different periods – for instance, 125,000 years ago it was 6 m (20 ft) higher than at present, while 82,000 years ago it was 13 m (43 ft) lower, and 28,000 years ago it was 41 m (134 ft) lower. Measurements of oxygen isotopes provide complementary information on glacial expansion and contraction. The New Guinea results have been found to be in substantial agreement with those from similar formations in Haiti and Barbados.

Rock Art and Shorelines. One interesting technique, useful not so much for accurate shoreline data as for clear indications of change in coastal environments, is the study of rock art devised by George Chaloupka for northern Australia. As the sea rose, it caused changes in the local plants and animals, which in turn produced



Barramundi (giant perch) and saltwater crocodile depicted in northern Australian rock art.

modifications in technology, all of which seem to be reflected in the region's art. The deduced variations in sea level are themselves important in providing a date for the art.

Chaloupka's Pre-Estuarine period, broadly coinciding with the height of the last glaciation, depicts non-marine species including several that have been interpreted as animals now extinct. In the Estuarine period (starting 6000 or 7000 years ago, by which time the postglacial rise in sea level had ceased) one finds images of new species such as the barramundi (giant perch) and the saltwater crocodile, whose presence can be explained by encroaching seawater that had partially filled the shallow valleys and creeks, creating a salt-marsh environment. Contemporaneously, other species, such as small marsupials, that had once occupied the pre-estuarine plains now moved further inland and disappeared from the coastal art, as did the boomerang, the human weapon used to hunt them. Finally, the Freshwater period (about 1000 years ago) brought another great environmental change when freshwater wetlands developed, supporting species of waterfowl and new food plants such as lilies and wild rice, all of which were depicted in the rock art.

All these sources of evidence – submerged land surfaces, raised beaches, coral reefs, rock art – give us an impressive amount of information about ancient coastlines. But it should be realized that most of this information applies to particular regions only: correlating the evidence over wider areas is difficult, because the dates lack consistency, and there are serious discrepancies in sea-level data worldwide.

This is a common problem in paleoclimatic studies: events do not always happen at the same moment in all areas. Nevertheless attempts have been made at producing paleoclimatic data for the world; one major example is the CLIMAP project, which has published maps showing sea-surface temperatures in different parts of the globe at various periods, based on results from many of the techniques mentioned here.

STUDYING THE LANDSCAPE

Having assessed roughly how much land was available for human occupation in different periods, we should now turn to methods for determining the effects of changing climate on the terrain itself.

Today it would be unthinkable to study any site without a thorough investigation of its sediments and the surrounding landscape. The aim is to achieve the fullest possible reconstruction of the local area (terrain, permanent or periodic availability of water, groundwater conditions, susceptibility to flooding, etc.) and set it in the context of the region, so that one can assess the environment faced by the site's inhabitants in different periods – and also gain some idea of the possible loss of sites through erosion, burial under sediment, or inundation.

Moreover, it is vital to know what happened to a landscape before one can begin to speculate about the possible reasons why it changed and how people adapted to the new conditions. Much of this work is best left to the earth scientist, but in the last few years a number of specialists have urged archaeologists to try to master some of these techniques themselves. Certain major changes in landscape are obvious even to the layman – for example, in cases where former irrigation channels can be seen in areas that are now desert; where well shafts are now exposed above ground through massive erosion of the surrounding sediment; or where volcanic eruptions have covered the land with layers of ash or lava.

Glaciated Landscapes

Some of the most dramatic and extensive effects of global climatic change on landscape were produced by the formation of glaciers. Study of the movements and extent of ancient glaciers rests on the traces they have left behind in areas such as the Great Lakes region in North America, and the Alps and the Pyrenees in Europe. Here one can see the characteristic U-shaped

Glaciated landscape: formerly glaciated valleys at Wasdale Head, Cumbria, northern England. The U-shaped valley in the middle distance is a typical glacial feature.

Glaciers today: like great rivers of ice, two glaciers in Alaska are seen converging and joining into one stream, with so-called moraine deposits at their edges that carry forward rocks and other debris.

valleys, polished and striated rocks, and, at the limits of glacier expansion, the so-called moraine deposits that often contain rocks foreign to the area but carried in by the ice (known as glacial erratics). In some areas the final glaciation obscured traces of its predecessors.

Examples of Ice Age glacial phenomena are readily observable in regions with glaciers today, such as Alaska and Switzerland, while the richness of modern periglacial areas (where part of the ground is permanently frozen in a permafrost layer) gives some idea of the potential resources in the regions at the edge of the ancient glaciers. The distribution of periglacial phenomena such as fossil ice wedges can be a guide to past conditions, since a mean annual temperature of -6°C to -9°C (21.2°F to 15.8°F) is required for ice wedges to form: they are caused when the ground freezes and contracts, opening up fissures in the permafrost that fill with the wedges of ice. The fossil wedges are proof of a past cooling of climate and of the depth of permafrost.

Varves

Among the most valuable periglacial phenomena for paleoclimatic information are varves, discussed as a method of dating in Chapter 4. Deep lakes around the edges of the Scandinavian glaciers received annual layers of sediment deposited after the spring thaw. Thick layers represent warm years with increased glacial melt, thin layers indicate cold conditions. As well as providing dating evidence, the varves often contain pollen which, as will be seen below, complements the climatic information inherent in the sediment. Unfortunately varves are of limited use outside Scandinavia, since most lakes are shallow, and their sediments can be disturbed and new varves created by other factors such as violent storms.

Rivers

So much for frozen water and stationary water: but what are the effects of *flowing* water on the landscape? The reconstruction of past landscapes around major rivers – which tend to be areas of rapid change, through erosion or deposition of sediments along courses and at river mouths – is particularly valuable to archaeology because these environments were frequently the focus of human occupation. In certain cases, such as the Nile, Tigris-Euphrates, and Indus, the floodplains proved crucial to the rise of irrigation agriculture and urban civilization.

Many rivers actually changed their course at different periods, through complex processes of erosion, silting, and varying gradients. The channel of the Indus in modern Pakistan is not incised into the plain like those of most rivers, and therefore has a tendency to change its course from time to time. The lower Indus is shallow, with a gentle gradient, and thus deposits large quantities of alluvial material in its channel, actually raising its bed above the level of the surrounding plain, and frequently breaking out and inundating large areas with fertile silt, vital to early agriculture and, for example, the ancient city of Mohenjodaro.

Similarly, the lower Mississippi Valley is covered with the traces of meander changes over a long period. These abandoned channels have been detected and plotted, by topographic survey and aerial photography (see Chapter 3), for the period AD 1765–1940. Using this information, a pattern of meander changes plotted

Aerial view of the deeply cut meander of the Colorado river, Utah. In some regions, abandoned meander channels have been used to build up a local chronology.

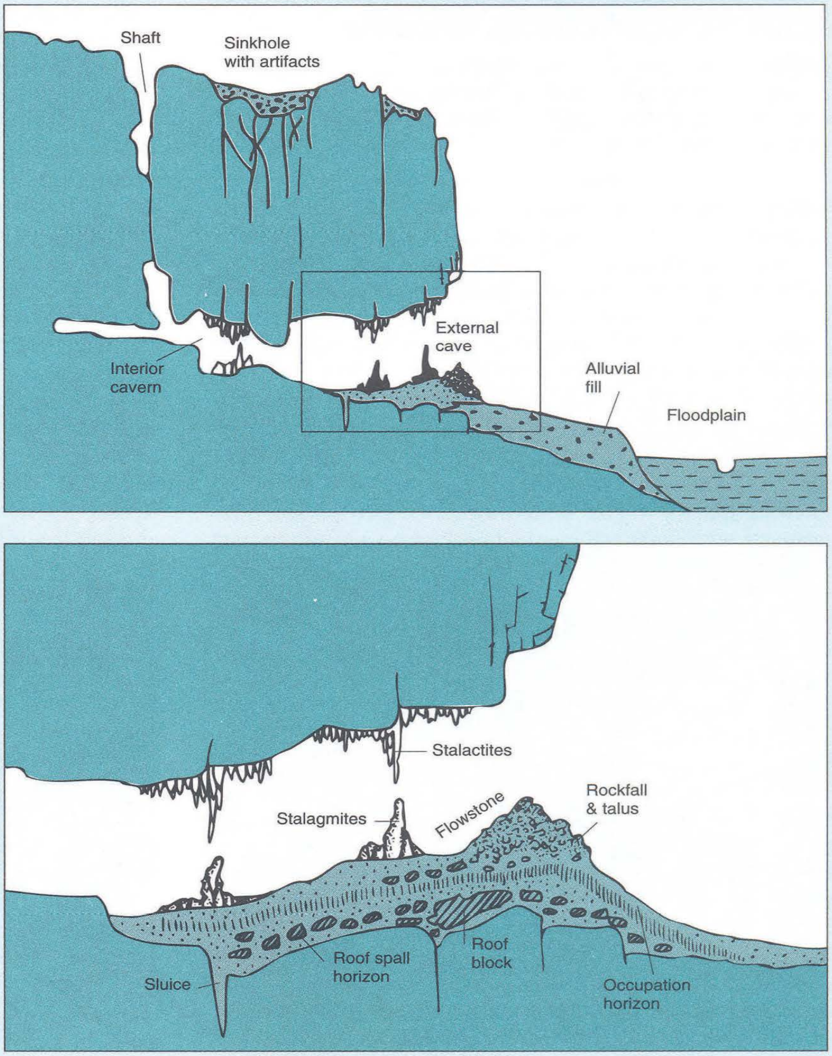
CAVE SEDIMENTS

The sediments that make up the floors of caves are composed of material brought in through entrances and holes in the roof by wind, water, animals, and people. A section through a cave or rockshelter floor usually shows a number of layers, often of differing textures and colors. The contents of these layers can indicate changing temperatures through time. For example, the percolation of water can loosen and break off rounded lumps from wall and roof, a type of weathering associated with a mild, humid climate. In cold conditions, water in rock fissures turns to ice, and this increase in volume puts pressure on the surface rock layer, which can disintegrate into angular, sharp-edged fragments, *c.* 4–10 cm (1½–4 in) long. Thus, after repeated phases of thawing and freezing, alternating layers of rounded and angular fragments ("rock spalls") will be produced near cave entrances and in rockshelters.

Although there are other potential causes of rubble layers, such as earthquakes, or attack by microbes, it is generally accepted that a study of changes in rubble size can provide information on environmental fluctuations. For example, in Cave Bay Cave, Tasmania, the Australian archaeologist Sandra Bowdler attributed the great accumulation of angular roof detritus between 18,000 and 15,000 years ago to the effects of frost wedging at the height of the last glacial. At the shallow cave of Colless Creek shelter, in tropical Queensland, on the other hand, the marked changes in sediments detectable through the 20 millennia of occupation seem to have been caused by fluctuations in rainfall. The Colless Creek sediments were studied in thin sections under the microscope for micromorphological differences; the lower layers (before 18,000 years ago) were compacted, and had clearly been modified by the movement of water, which suggested a wetter climate.

Analysis in Practice

In general, analysis is carried out initially by visual examination. Samples need to be taken from several parts of the cave, in view of the microclimates and horizontal variation (e.g. the presence of a large hearth may have had considerable influence on a wall's temperature in some periods). It is often hard to correlate sequences from within a single cave, let alone between caves and regions. Subsequent sieving and laboratory examination of grain size, and of color and texture of sediment, modifies or amplifies the initial assessment. Usually all blocks over 100 mm (4 in) are noted and removed; then the remainder is passed through a series of sieves and differentiated into blocks, granules, gravel, and sand/silt/clay. The more blocks and granules there are in a layer, the more severe the cold in that period.



General and detailed sections of a hypothetical cave site.

Scholars such as the French archaeologist Yves Guillien have stressed that it is necessary to do experiments on a cave's limestone before attempting to interpret the fill. Laboratory simulation of the natural freeze/thaw successions gives one some idea of the rock's friability under the kind of climatic conditions that caused the real breakage.

Stalagmites and Stalactites
Caves often have layers of stalagmite, and of flowstone (travertine), laid down by water that picks up calcium carbonate in solution as it passes through limestone. Such layers are generally indicative of fairly temperate climatic phases, and sometimes also of humid conditions. Stalagmites and stalactites (collectively known as speleothems) can even be used for accurate assessment of past climate through the oxygen isotope technique. In cross-section, speleothems have a series of concentric growth rings, which can be dated by radiocarbon. Each ring preserves the oxygen isotope composition of the water that formed it, and hence of the average atmospheric precipitation and temperature at which it was deposited. Since the ultimate source of rainwater is the surface of the ocean, this method is a potentially valuable complement to ocean cores.

Scientists have taken samples from speleothems in Soreq cave, Israel, and dated them by the uranium-thorium method. Isotopic analysis has provided a record of eastern Mediterranean rainfall over the past 25,000 years. From 25,000 to 17,000 years ago the region was dry and cool. After that there were some sharp climatic fluctuations until about 6000 years ago, when today's climatic pattern was established.

Since the rate of calcium carbonate deposition per square centimeter on speleothems can be much faster than the deposition of sediment on the ocean bed, this method may achieve more detailed temperature profiles than ocean cores: in fact, it is thought that temperature changes of only 0.2°C may be detectable.

at 100-year intervals has been extrapolated back for the last 2000 years. Like the work on fossil beach lines in Alaska (see above), this sequence has formed the basis for a rough chronology for sites located along particular abandoned channels.

Cave Sites

A different type of abandoned water-channel is represented by the limestone cave, a category of site that has been of tremendous importance to archaeology through its conservation of a wide variety of evidence, not only about human activities but also about local climate and environment.

Caves and rockshelters, although of enormous archaeological interest, are nevertheless special cases. Their importance as places of habitation has always been exaggerated in prehistoric studies at the expense of less well-preserved open sites. What can we learn from the great outdoors where people have spent most of their time?

Sediments and Soils

Investigation of sediments (the global term for material deposited on the earth's surface) and soils (the life-supporting, biologically and physically weathered upper layers of those sediments) can reveal much about the conditions that prevailed when they were formed. The organic remains they may contain will be examined in subsequent sections on plants and animals, but the soil matrix itself yields a wealth of information on weathering, and hence on past soil types and land-use.

Geomorphology (the study of the form and development of the landscape) incorporates specializations such as sedimentology, which itself includes sedimentary petrography and granulometry. These combine to produce a detailed analysis of the composition and texture of sediments, ranging from freely draining gravel and sand to water-retentive clay; the size of constituent particles in sediments, ranging from pebbles to sand or silt; and the degree of consolidation, ranging from loose to cemented. In some cases, the orientation of the pebbles gives some indication of the direction of stream-flow, of slope, or of glacial deposits. As we will see in Chapters 8 and 9, the X-ray diffraction technique can be used to identify specific clay minerals and thus the specific source from which a sediment is derived.

Soil micromorphology – the use of microscopic techniques to study the nature and organization of the components of soils – is becoming an increasingly important part of excavation and site analysis. An intact block sample from a known context is first consolidated with resin and then a thin section is taken from it. This is examined using a polarizing microscope. The observed sequence of soil development may reveal many aspects of a site's or landscape's history not otherwise visible. Three main categories of features can be discerned: those related to the source of the sediment; those which reveal something of the processes of soil formation; and those which are humanly produced or modified, whether deliberately or accidentally. As the environmental archaeologist Karl Butzer recognized, humans have affected soils and sediments found at archaeological sites at a microscopic level.

Butzer has distinguished three groups of cultural deposits. ***Primary cultural deposits*** are those which accumulate on the surface from human activity, for instance many ash layers or living floors. ***Secondary cultural deposits*** are primary deposits which have undergone modification, either by physical displacement or because of a change of use of the activity area. ***Tertiary cultural deposits*** are those which have been completely removed from their original context and may have been reused (for instance to build terracing).

Soil micromorphology can achieve results in two crucial areas. First, it can assist in an environmental reconstruction of ancient human landscapes, both on a regional scale and also at site level. Human effects on soils produced by deforestation and by farming practices are one area of study. Second, it can be used in contextual archaeology – when combined with the traditional approach of the study of artifacts, a much more comprehensive picture of a site and its past activities can be obtained.

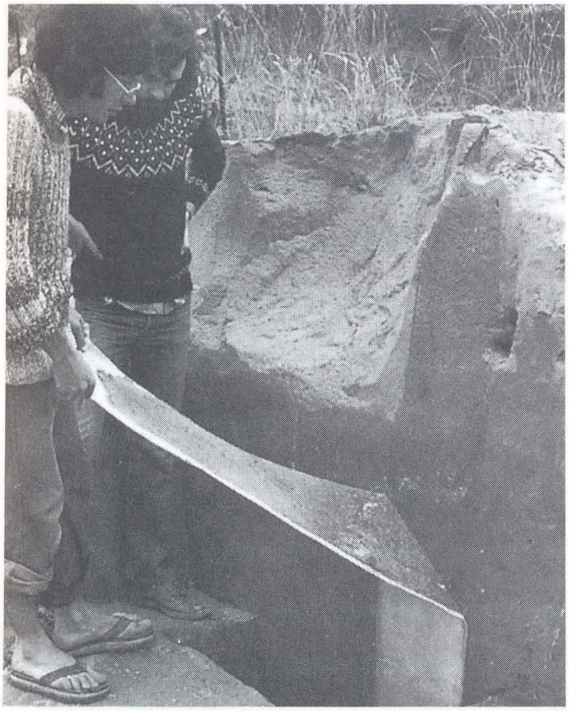
Micromorphological investigations have been shown to be highly useful in distinguishing between sediments that are still *in situ* from ones which are no longer in their original situation, and also between human and natural influences on soils and sediments. Study of thin sections has, for example, been able to distinguish natural from man-made accumulations in cave deposits which otherwise look very similar. The absence of evidence of human interference is also very informative – for instance it could demonstrate that artifacts are not in their primary context. Throughout, a comprehensive reference collection of samples is required to allow comparisons to be made between real, experimental, and archaeological situations.

A large range of human activities can now often be recognized from their micromorphological signals in soils and sediments. For instance, it should theoretically be possible when studying a settlement site to identify and distinguish outdoor and indoor fires, cooking and eating zones, activity areas, storage, and passage zones from the examination of thin sections. British environmental archaeologist Wendy Matthews is conducting detailed micromorphological investigations of floor deposits within structures in four Neolithic sites in the Near East. These have indicated the use of space in certain buildings, both before and after their abandonment. Obviously it is not possible to study an entire site in this way and it is necessary for the excavator to make choices as to which soils to sample and which contexts are the most representative for the purposes of analysis. Soil micromorphology is now an integral part of the excavation process.

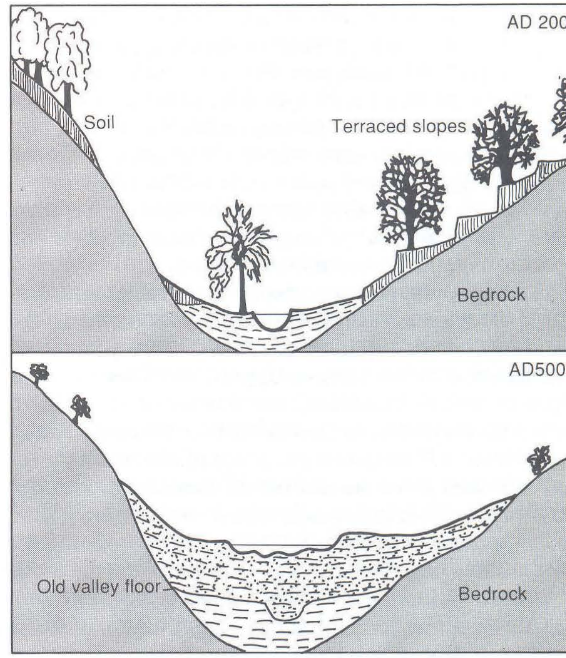
Soil micromorphology requires a laboratory environment and specialized equipment, but a growing number of archaeologists have gained sufficient field experience to undertake a basic assessment of sediments in the field – simply by rubbing a little of the dry sediment between their fingers, and then testing its plasticity by making it damp and rolling it in the palm. However, for a more accurate assessment the expertise of a specialist is essential. Accurate and standardized descriptions of soil color are also vital, and are usually accomplished by means of the widely adopted Munsell Soil Color Charts (also used for describing archaeological layers).

Accurate analysis of the texture of a soil entails the use of a series of sieves, with mesh sizes decreasing from 2 mm to 0.06 mm for the separation of the sand fraction, and the use of hydrometer or sediograph techniques (for determining the density of liquids) to quantify the proportions of silt and clay fractions comprising the soil/sediment. Similar information may be obtained using micromorphological or thin section techniques. Soil textural analysis provides information on soil type, land-use potential, and susceptibility to erosion, especially when allied with micromorphological and hydrological information. These studies all contribute to the investigation of landscape history.

One technique for close study of sediments, developed before World War II, involved the application of a film of rubber or "lacquer" to the stratigraphy, but modern materials have improved the method enormously. At the open-air Upper Paleolithic camp of Pincevent, near Paris, Michel Orliac has used a thin film of synthetic latex (about 1.5 kg per sq. m or 0.3 lb per sq. ft) painted onto a flat, carefully cleaned section. When dry, the latex preserves an image of the stratigraphy that is far easier than the original to examine in detail. Indeed, the imprint, composed of a very thin film of sediment that adheres to the latex, reveals much more than can be distinguished in the original section. After it has been peeled off, the imprint can be stored



Studying sediments: at Pincevent, France, a film of latex was painted onto a stratigraphic section and peeled off when dry, with an image of the soil profile attached.



Sediments, erosion, and changing patterns of settlement. A typical Italian valley during the Roman period suffered erosion of hillslope soils under the combined effects of deforestation, intensive agriculture, and overgrazing. Human settlement eventually shifted from hillside to valley bottom.

flat or rolled up, and thus enables the archaeologist to keep or display a faithful record of a soil profile.

Analyses of soils and sediments can provide data on long-term processes of deposition and erosion. For example, the way in which sediments have eroded from hillslopes down into valley bottoms has been widely studied in Mediterranean countries, where the process is associated with shifts in settlement. Hillside farms were abandoned in the face of soil loss, while settlement increased in valley bottoms. Sediment analyses suggest that misuse of the landscape in some Mediterranean areas dates back five millennia, to at least the Early Bronze Age. In Cyprus, for instance, a combination of deforestation, intensive agriculture, and pastoralism destabilized the fragile soil-cover on hillslopes in the Early Bronze Age and led to rapid infilling of sediment along coastal valleys. In the southern Argolid, Greece, a major project conducted by Tjeerd van Andel, Curtis Runnels, and their colleagues has revealed at least four phases of settlement, erosion, and abandonment between 2000 BC and the Middle Ages. At times here, careless land clearance seems to have been to blame, without suitable conservation measures; and on other occasions it was the partial abandonment or neglect of terracing, and hence of soil conservation, that led to soil erosion.

Loess Sediments. A pedologist (soil specialist) can examine a sediment profile, and from its composition and its changing textures and colors can tell whether it was laid down by water, wind, or human action, and can obtain some idea of the weathering it has undergone, and hence of the climatic conditions that existed locally throughout its history. One important wind-blown sediment encountered in certain parts of the world is loess, a yellowish dust of silt-sized particles blown in by the wind and redeposited on land newly deglaciated or on sheltered areas. Loess has been found on about 10 percent of the world's land surface, in Alaska, the Mississippi and Ohio valleys, in northwest and central Europe, and particularly in China, where it covers over 440,000 sq. km (170,000 sq. miles) or about 40 percent of arable land there. It is important to the Paleolithic specialist as an indicator of ancient climate, while all students of Neolithic farming learn to associate it with the first agricultural settlements.

Loess works as a climatic indicator because it was only deposited during periods of relatively cold, dry climate when the fine silt particles were blown off a periglacial steppe-like landscape, with little vegetation or moisture to consolidate the sediment. The loess "rain" stopped in warmer and wetter conditions. Sediment sections taken in areas such as central Europe therefore show loess layers alternating with so-called "forest soils," themselves indicators of climatic improvement and the temporary return of vegetation.

Classic sequences are known at Paudorf and Göttweig in Austria, the former giving its name to the Paudorf Loess Formation (27,000–23,000 years ago) associated with the famous Upper Paleolithic open-air sites of Dolní Věstonice and Pavlov in the Czech Republic. Similarly, in the Paris Basin, François Bordes established a Pleistocene sequence of alternating loess and warmer, more humid levels, associated with different Paleolithic industries, which could be correlated with the known glacial sequence. Studies of climatic oscillations detectable in the extensive sequence available from China have shown a good correlation with the fluctuations of cold-water foraminifera and the oxygen isotope record from deep-sea sediments.

As well as being a good indicator of ancient climate (often containing land snails that provide confirmatory data), loess also played a crucial role in Neolithic farming. Rich in minerals, uniform in structure, and well drained, soils formed in loess provided fertile and easily worked land ideal for the simple technology of the first farming communities. The *Linearbandkeramik* (LBK, i.e. Early Neolithic) sites of central and western Europe have an extremely close association with soils formed in loess: at least 70 percent of LBK sites in a given area are found to be located on loess.

Buried Land Surfaces. Entire land surfaces can sometimes be preserved intact beneath certain kinds of sediment. For example, ancient soils and landscapes have been discovered beneath the peat of the English Fenlands, while at Behy, in Ireland, a Neolithic farming landscape with stone-built banks has emerged from the peat. We shall return to the subject of buried land surfaces below (evidence for plowing section).

By far the most spectacular occurrences of this type are those brought about by volcanic eruptions. The buried cities of Pompeii and Herculaneum in southern Italy, and Akrotiri on the Greek island of Thera, have been referred to in earlier chapters. But, from the point of view of environmental data, volcanically preserved natural landscapes are even more revealing. In 1984, the remains of a prehistoric forest were found at Miesenheim, western Germany. It was already known that an eruption about 11,000 years ago had buried the nearby late Upper Paleolithic open-air sites of Gönnersdorf and Andernach under several meters of ash, but the discovery of a contemporaneous forest was a special bonus for the archaeologists. Trees (including willow), mosses, and fungi had been preserved by the ash in a waterlogged layer, 30 cm (11.8 in) thick; mollusc shells, large and small mammals, and even a bird's egg were also present. The forest seems to have been relatively dense, with a thick undergrowth, and this was confirmed by pollen analysis (see box, pp. 240–41); study of the tree-rings will also add information on climatic fluctuations in this period.

Prehistoric trees and other plant material preserved in a waterlogged layer by a volcanic ash fall some 11,000 years ago at Miesenheim, western Germany. Rare finds such as this give important insights into the character of ancient landscapes.

Other engulfed trees are also providing climatic information: in California and Patagonia, Scott Stine has examined drowned tree stumps around the edges of lakes, swamps, and rivers. They indicate that water levels in the past were lower, but were followed by flooding. Radiocarbon dating of the trees' outer rings tells him when flooding occurred, and the preceding dry interval can be calculated by counting the earlier rings. His results reveal some sustained droughts, for example in AD 892–1112 and 1209–1350; the latter may be linked with the decline of the Anasazi cliff-dwellers in *c.* 1300 (see below, p. 265).

Tree-Rings and Climate

Tree-rings, like varves (see above), have a growth that varies with the climate, being strong in the spring and then declining to nothing in the winter; the more moisture available, the wider the annual ring. As we saw in

Chapter 4, these variations in ring width have formed the basis of a major dating technique. However, study of a particular set of rings can also reveal important environmental data, for example whether growth was slow (implying dense local forest cover) or fast (implying light forest). Tree growth is complex, and many other external and internal factors may affect it, but temperature and soil moisture do tend to be dominant. For example, a 3620-year temperature record has been obtained from tree-rings in southern Chile, which reveals intervals with above-average and below-average temperatures for the region.

Annual and decade-to-decade variations show up far more clearly in tree-rings than in ice cores, and tree-rings can also record sudden and dramatic shocks to the climate. For example, data from Virginia indicate that the alarming mortality and near abandonment of Jamestown Colony, the first permanent settlement in America, occurred during an extraordinary drought, the driest 7-year episode in 770 years (AD 1606–1612).

The study of tree-rings and climate (dendroclimatology) has also progressed by using X-ray measurements of cell-size and density as an indication of environmental productivity. More recently, ancient temperatures have been derived from tree-rings by means of the stable carbon isotope ($^{13}C/^{12}C$) ratios preserved in their cellulose. A 1000-year-old kauri tree in New Zealand has been analyzed in this way, and the results – confirmed by data from New Zealand speleothems – revealed a series of fluctuations in mean annual temperature, with the warmest phase in the 14th century, followed by a decline and then a recovery to present conditions. Isotopes of carbon and oxygen in the cellulose of timbers of the tamarisk tree, contained in the ramp which the Romans used to overcome the besieged Jewish citadel of Masada in AD 73, have revealed to Israeli archaeologists that the climate at that time was wetter and more amenable to agriculture than it is today.

The importance of tree-rings makes it clear that it is organic remains above all that provide the richest source of evidence for environmental reconstruction. We must now take a detailed look at the surviving traces of plants and animals.

RECONSTRUCTING THE PLANT ENVIRONMENT

Our prime environmental interest in plant studies is to try to reconstruct the vegetation that people in the past will have encountered at a particular time and in a particular place. But we should not forget that plants lie at the base of the food chain. The plant communities of a given area and period will therefore provide clues to local animal and human life, and will also reflect soil conditions and climate. Some types of vegetation react relatively quickly to changes in climate (though less quickly than insects, for instance), and the shifts of plant communities in both latitude and altitude are the most direct link between climatic change and the terrestrial human environment, for example in the Ice Age.

Plant studies in archaeology have always been overshadowed by faunal analysis, simply because bones are more conspicuous than plant remains in excavation. Bones may sometimes survive better, but usually plant remains are present in greater numbers than bones. In the last few decades plants have at last come to the fore, thanks to the discovery that some of their constituent parts are much more resistant to decomposition than was believed, and that a huge amount of data survives which can tell us something about long-dead vegetation. As with so many of the specializations on which archaeology can call, these analyses require a great deal of time and funds.

Some of the most informative techniques for making an overall assessment of plant communities in a particular period involve analysis not of the biggest remains but of the tiniest, especially pollen.

Microbotanical Remains

Pollen Analysis. Palynology, or the study of pollen grains (see box overleaf), was developed by a Norwegian geologist, Lennart von Post, at the beginning of the 20th century. It has proved invaluable to archaeology, since it can be applied to a wide range of sites and provides information on chronology as well as environment – indeed, until the arrival of isotopic chronological methods, pollen analysis was used primarily for dating purposes (Chapter 4).

While palynology cannot produce an exact picture of past environments, it does give some idea of fluctuations in vegetation through time, whatever their causes may be, which can be compared with results from other methods. The best known application of pollen analysis is for the postglacial or Holocene epoch (after 12,000 years ago), for which palynologists have delineated a series of *pollen zones* through time, each characterized by different plant communities (especially trees), although there is little agreement on the numbering system to be used or the total number of zones.

POLLEN ANALYSIS

All hayfever sufferers will be aware of the pollen "rain" that can afflict them in the spring and summer. Pollen grains – the tiny male reproductive bodies of flowering plants – have an almost indestructible outer shell (exine) that can survive in certain sediments for tens of thousands of years. In pollen analysis the exines are extracted from the soil, studied under the microscope, and identified according to the distinctive exine shape and surface ornamentation of different families and genera of plants. Once quantified, these identifications are plotted as curves on a pollen diagram. Fluctuations in the curve for each plant category may then be studied for signs of climatic fluctuation, or forest clearance and crop-planting by humans.

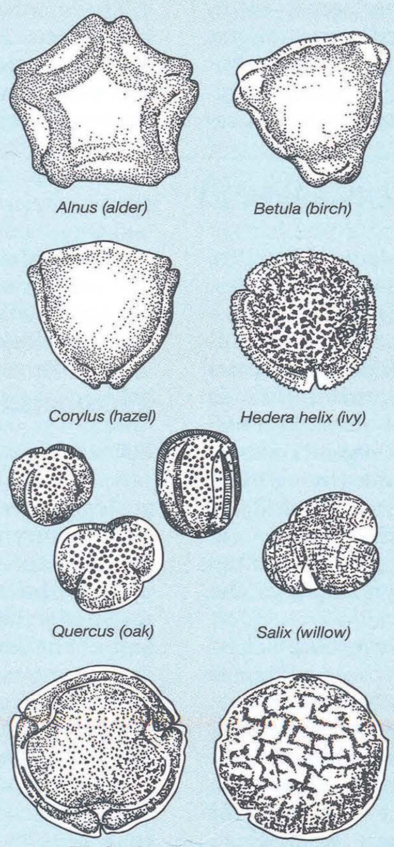
Preservation

The most favorable sediments for preservation of pollen are acidic and poorly aerated peat bogs and lake beds, where biological decay is impeded and grains undergo rapid burial. Cave sediments are also usually suitable because of their humidity and constant temperature. Other contexts, such as sandy sediments or open sites exposed to weathering, preserve pollen poorly.

In wet sites, or unexcavated areas, samples are extracted in long cores, but in dry sites a series of separate samples can be removed from the sections. On an archaeological excavation, small samples are usually extracted at regular stratified intervals. Great care must be taken to avoid contamination from the tools used or from the atmosphere. Pollen can also be found in mud bricks, vessels, tombs, mummy wrappings, the guts of preserved bodies, coprolites (Chapter 7), and many other contexts.

Examination and Counting

The sealed tubes containing the samples are examined in the laboratory, where a small portion of each sample is studied under the microscope in an attempt to identify a few hundred grains in that sample. Each family and almost every genus of plant produce pollen grains distinctive in shape and surface ornamentation, but it is difficult to go further and pinpoint the species. This imposes certain limits on environmental reconstruction, since different species within the same genus can have markedly different requirements in terms of soil, climate, etc.



***Morphology** of a selection of pollen grains, as seen under the microscope.*

Slow and laborious manual counting and identification will probably be replaced in the next few years by an automated technique, in which pollen grains are identified through analysis in the scanning electron microscope of digitized images of the exine's shape and texture.

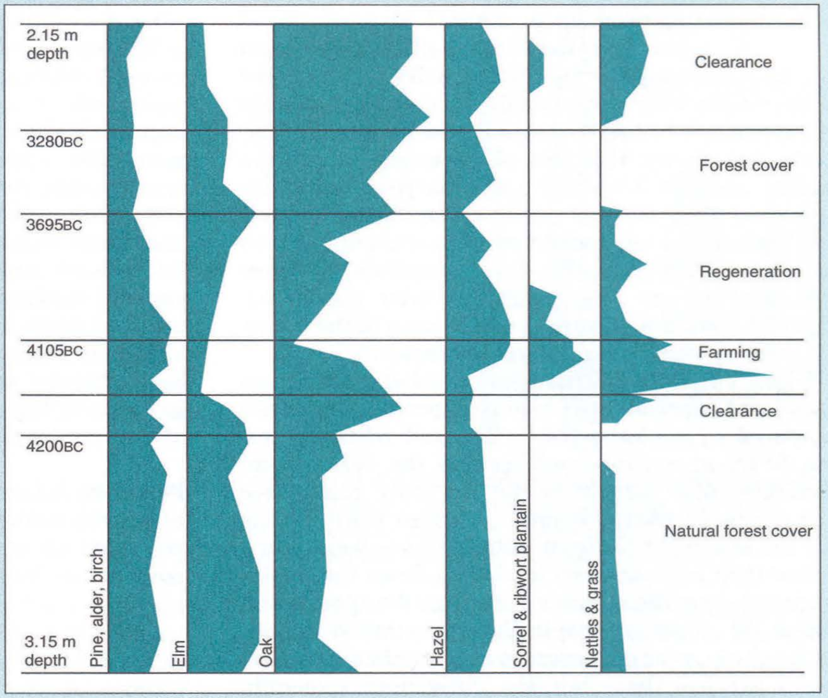
After identification, the quantity of pollen for each plant-type is calculated for each layer – usually as a percentage of the total number of grains in that layer – and then plotted as a curve. The curves are seen as a reflection of climatic fluctuations through the sequence, using the present-day tolerances of these plants as a guide.

However, adjustments need to be made. Different species produce differing amounts of pollen (pines, for example, produce many times more than oaks), and so may be over- or under-represented in the sample. The mode of pollination also needs to be taken into account. Pollen of lime, transported by insect, is probably from trees that grew nearby, whereas pine pollen, transported by the wind, could be from hundreds of kilometers away. The orientation of sites (and especially of cave-mouths) will also have a considerable effect on their pollen content, as will site location, and length/type of occupation.

It is necessary to ensure there has been no mixing of layers (intrusion is now known to be a common problem), and to assess human impact – samples should be taken from outside the archaeological site as well as within it. In urban archaeological deposits, for instance, pollen from well-fills or buried soils are mostly present through natural transport and deposition, and hence reflect the surrounding countryside. Pollen from urban living areas, on the other hand, derive primarily from food preparation and the many other human uses of plants.

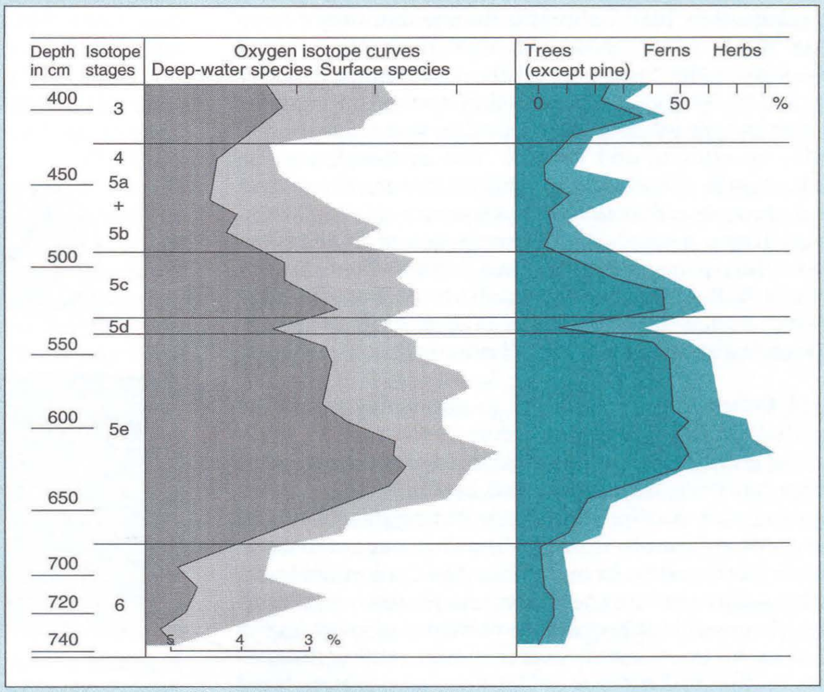
In a study of pollen assemblages from a series of Roman and medieval towns in Britain, James Greig found that the Roman sites were rich in grasses but poor in cereals, whereas the medieval deposits produced the opposite result. The reason is not economic but hygienic – the Romans had a sewerage system for their towns, which were kept clean and, apparently, were surrounded by short grassland which dominates the pollen assemblages. In medieval times, however, garbage was allowed to accumulate in the towns, so that the food refuse remained for the archaeologist to find, and dominated the pollen samples.

As a rule, pollen in soils away from human settlement tends to reflect the local vegetation, while peat bogs preserve pollen from a much wider area. Results from pollen in deep peat-bog successions usefully confirm the long-term climatic fluctuations deduced from deep-sea and ice cores mentioned earlier in the main text.



Postglacial pollen core from Fallahogy, Northern Ireland (above right), reveals the impact of the first farmers in the region. Forest clearance is indicated c.4150 BC with a fall in tree pollen and a marked increase in open-country and field species such as grass, sorrel, and ribwort-plantain. The subsequent regeneration of forest cover, followed by a second period of clearance, shows the non-intensive nature of early farming in the area.

Long-term sequences for the Ice Age (right) show the good correlation between a terrestrial pollen core from the Iberian peninsula (at right) and oxygen-isotope curves (at left) derived from deep-sea core SU 8132 extracted in the Bay of Biscay.



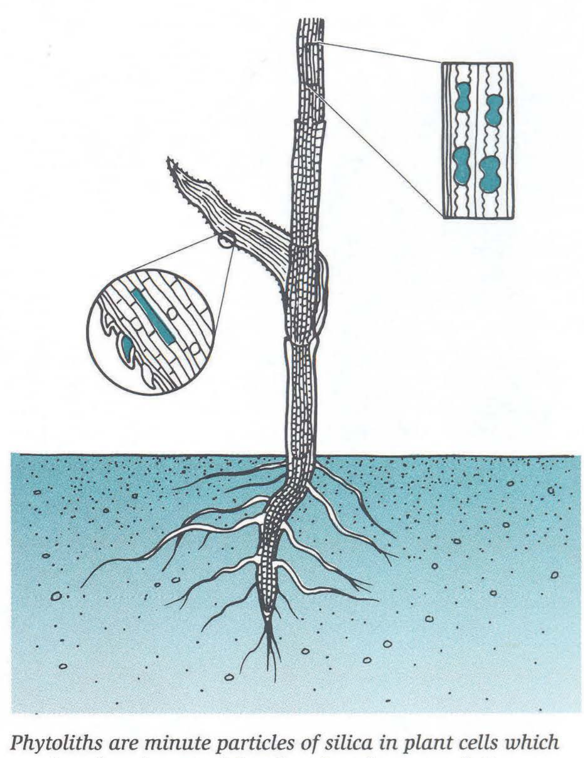
But pollen studies can also supply much-needed information for environments as ancient as those of the Hadar sediments and the Omo valley in Ethiopia around 3 million years ago. It is usually assumed that these regions were always as dry as they are now, but pollen analysis by the French scientist Raymonde Bonnefille has shown that they were much wetter and greener between 3.5 and 2.5 million years ago, with even some tropical plants present. The Hadar, which is now semi-desert with scattered trees and shrubs, was rich, open grassland, with dense woodland by lakes and along rivers. The change to drier conditions, around 2.5 million years ago, can be seen in the reduction of tree pollen in favor of more grasses.

By and large, the fluctuations recorded for the postglacial and especially the historical periods are minor compared with what went before, and where regression of forest is concerned there is the ever-present possibility that climate is not the only cause (see human impact section below). It is also worth noting that the British hydrologist Robert Raikes went much further than most scholars in playing down the significance of climatic changes during the postglacial period. He points out that in Europe variation in rainfall from one year or season to the next is almost certainly greater than rainfall differences generally deduced (though without quantification) from pollen diagrams. Any major climatic change that might have taken place would probably have been ecologically less significant than short-term variation of greater amplitude. Raikes concluded that ecological changes should more probably be ascribed to year-to-year variability of climate and rainfall. The archaeologist, he said, should therefore investigate minor, short-term local changes rather than try to squeeze all the sites in a region into a standardized succession of fixed pollen zones. Most specialists disagree with Raikes' line of argument, but his emphasis on the importance of local environmental reconstruction makes good sense for archaeologists working on individual sites.

Fossil Cuticles. Palynology is particularly useful for forested regions, but the reconstruction of past vegetation in grassy environments such as those of tropical Africa has been much hindered by the fact that grass pollen grains can be virtually indistinguishable from one another, even in the scanning electron microscope (SEM). Fortunately, help is at hand in the form of fossil cuticles. Cuticles are the outermost protective layer of the skin or epidermis of leaves or blades of grass, made of cutin, a very resistant material that retains the pattern of the underlying epidermal cells which have characteristic shapes. The cuticles thus have silica cells of different shapes and patterns, as well as hairs and other diagnostic features.

The scientist Patricia Palmer has found abundant charred cuticular fragments in core samples from lake sediments in East Africa. The fragments were deposited there as a result of the recurrent natural grass fires common during the dry season, and her samples date back at least 28,000 years. Many of the fragments are large enough to present well-preserved diagnostic features that, under the light microscope or in the SEM, have enabled her to identify them to the level of subfamily or even genus, and hence reconstruct changes in vegetation during this long period. Cuticular analysis is a useful complement to palynology wherever grass material, whole or fragmentary, is to be identified, and it is worth noting that cuticles can also be removed from stomachs or feces.

Phytoliths. A better-known and fast-developing branch of microbotanical studies concerns phytoliths, which were first recognized as components in archaeological contexts as long ago as 1908, but have only been



Phytoliths are minute particles of silica in plant cells which survive after the rest of the plant has decomposed. Some are specific to certain parts of the plant (e.g. stem or leaf).

studied systematically in the last few decades. These are minute particles of silica (plant opal) derived from the cells of plants, and they survive after the rest of the organism has decomposed or been burned. They are common in hearths and ash layers, but are also found inside pottery, plaster, and even on stone tools and the teeth of herbivorous animals: grass phytoliths have been found adhering to ungulate teeth from Bronze Age, Iron Age, and medieval sites in Europe.

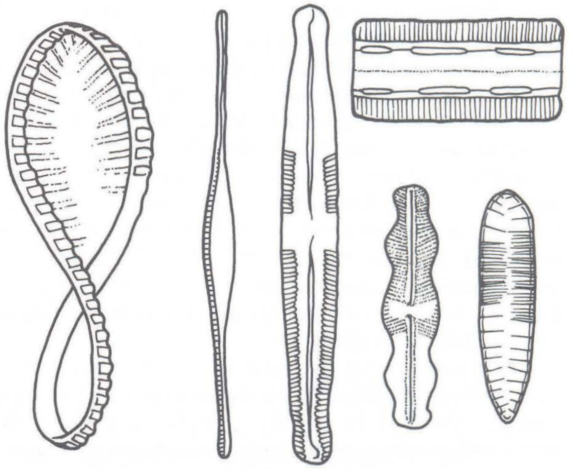
These crystals are useful because, like pollen grains, they are produced in large numbers, they survive well in ancient sediments, and they have myriad distinctive shapes and sizes that vary according to type, though it is usually difficult to identify their genus or species, even with a SEM. They inform us primarily about the use people made of particular plants, but their simple presence adds to the picture of the environment built up from other sources.

In particular, a combination of phytolith and pollen analysis can be a powerful tool for environmental reconstruction, since the two methods have complementary strengths and weaknesses. The American scholar Dolores Piperno has studied cores from the Gatun Basin, Panama, whose pollen content had already revealed a sequence of vegetation change from 11,300 years ago to the present – from mature tropical forest to mangrove, freshwater swamp, and finally to clearance through swidden (slash-and-burn) agriculture. She found that the phytoliths in the cores confirmed the pollen sequence, with the exception that evidence for agriculture and forest clearance (i.e. the appearance of maize, and an increase in grass at the expense of trees) appeared around 4850 years ago in the phytoliths, about 1000 years earlier than in the pollen. This early evidence is probably attributable to small clearings which do not show up in pollen diagrams because grains from the surrounding forest infiltrate the samples, as well as to the relatively poor production and dispersal of non-arboreal pollen.

Pollen analysis will nevertheless remain the more important technique, if only because of difficulties in phytolith identification.

Diatom Analysis. Another method of environmental reconstruction using plant microfossils is diatom analysis. Diatoms are unicellular algae that have cell walls of silica instead of cellulose, and these silica cell walls survive after the algae die. They accumulate in great numbers at the bottom of any body of water in which the algae live; a few are found in peat, but most come from lake and shore sediments.

Diatoms have been recorded, identified, and classified for over 200 years. The process of identifying and counting them is much like that used in palynology, as is the collection of samples in the field. Their well-defined shapes and ornamentations permit identification to a high level, and their assemblages directly reflect the floristic composition and the productivity of the water's diatom communities, and, indirectly, the water's salinity, alkalinity, and nutrient status. From the environmental requirements of different species (in terms of habitat, salinity, and nutrients), one can determine what their immediate environment was at different periods.



A variety of diatoms, the microscopic single-cell algae, whose silica cell walls survive in many sediments after death. Study of the changing species in a deposit can help scientists reconstruct fluctuations in past environments.

The botanist J.P. Bradbury looked at diatoms from nine lakes in Minnesota and Dakota, and was able to show that the quality of their water had become "eutrophic" (more nutrient) since the onset of European settlement around the lakes in the last century, thanks to the influxes caused by deforestation and logging, soil erosion, permanent agriculture, and the increase in human and animal wastes.

Since diatom assemblages can also denote whether water was fresh, brackish, or salt, they have been used to identify the period when lakes became isolated from the sea in areas of tectonic uplift, to locate the positions of past shorelines, to indicate marine transgressions, and to reveal water pollution. For instance, the diatom sequence in sediments at the site of the former Lake Wevershoof, Medemblick (the Netherlands) suggests that a marine transgression occurred here around AD 800, taking over what had been a freshwater lake and causing a hiatus in human occupation of the immediate area.

Rock Varnishes. Even tinier fragments of plant material can provide environmental evidence. Rock varnishes, which have been formed on late Pleistocene desert landforms in many areas such as North America, the Middle East, and Australia, are natural accretions of manganese and iron oxides, together with clay minerals and organic matter. The organic matter comes from micrometer-sized airborne plant debris that accumulates on rock surfaces and is thus metabolized and cemented into the varnish by bacterial action. Less than 1 percent of the varnish is organic matter, however, so thousands of square centimeters are required for adequate analysis.

The reason for the analysis is that a strong correlation has been found between the ratio of stable carbon isotopes ($^{12}C/^{13}C$) in modern samples and their different local environments (desert, semi-arid, montane-humid, etc.). Therefore, the stable carbon isotope ratios of the organic matter preserved in the different layers of varnish on rocks can provide information about changing conditions, and especially about the abundance of different types of plant in the adjacent vegetation. The American scholars Ronald Dorn and Michael DeNiro have sampled surface and subsurface layers of varnish on late Pleistocene deposits in eastern California, and found that the basal layers formed under more humid conditions than those on the surface, which supports the view that the Southwest of the United States was less arid in the last Ice Age than during the succeeding Holocene. Similarly, samples from the Timna Valley in Israel's Negev Desert revealed a sequence of arid, humid, and arid periods. However, there are difficulties with the technique, primarily because the layers are so thin that distinguishing stratification is not simple. Future work may resolve these problems.

Plant DNA. The tiniest possible fragments of plants are their DNA, and these can now be detected and identified in some contexts: for example, fossilized dung from an extinct ground sloth of about 20,000 years ago, recovered from Gypsum Cave, Nevada, has been chemically analyzed and found to contain a wide variety of plant DNA. This gave clues not only to the sloth's diet (grasses, yucca, grapes, mint, etc.), but also to the vegetation available at that time and place.

All these microbotanical techniques – studies of pollen, cuticles, phytoliths, diatoms, rock varnish, and DNA – are clearly the realm of the specialist. For archaeologists, however, a far more direct contact with environmental evidence comes from the larger plant remains that they can actually see and conserve in the course of excavation.

Macrobotanical Remains

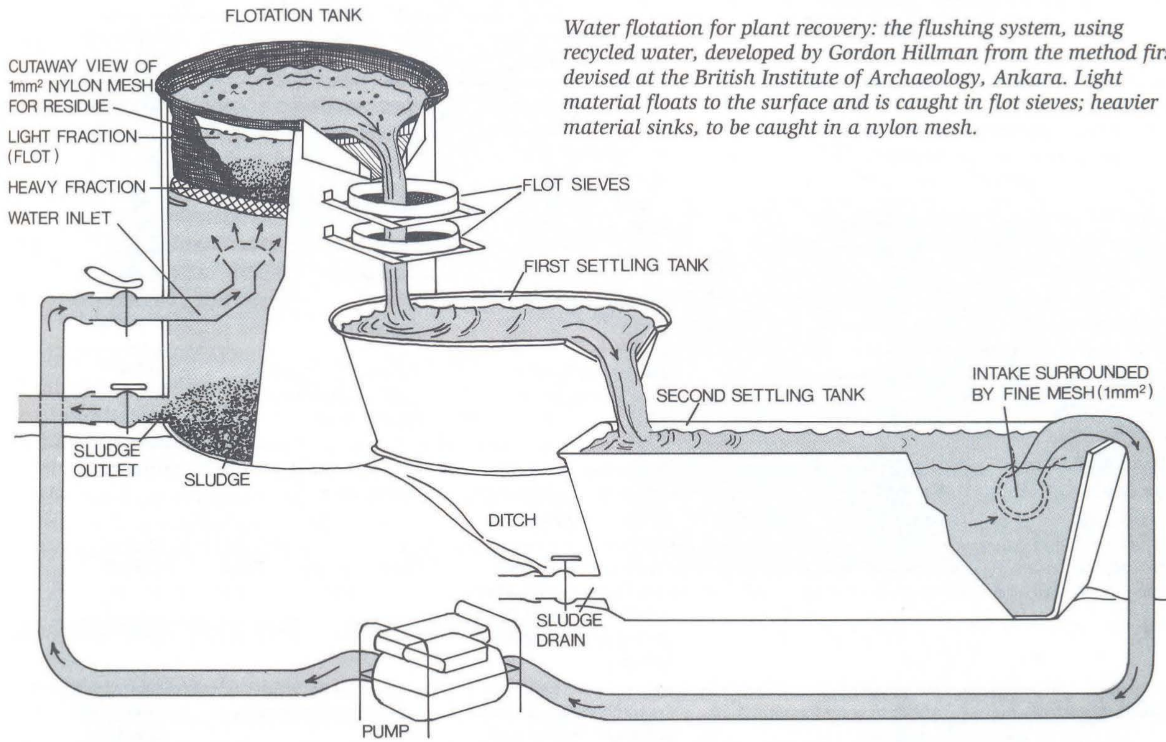
A variety of bigger types of plant remains are potentially retrievable, and provide important information about which plants grew near sites, which were used or consumed by people, and so on. We shall discuss human use in the next chapter; here we shall focus on the crucial contribution of macrobotanical remains to environmental reconstruction. As with microbotanical remains, they cannot assist us in quantifying the vegetation cover except in the most relative fashion, but some of them do provide valuable clues to local environmental conditions.

Retrieval in the Field. Retrieval of vegetation from sediments has been made simpler by the development of screening (sieving) and flotation techniques able to separate mineral grains from organic materials because of their different sizes (screening) and densities (flotation). Archaeologists need to choose from a wide range of available devices in accordance with the excavation's location, budget, and objectives.

Sediments are by no means the only source of plant remains, which have also been found in the stomachs of frozen mammoths and preserved bog bodies; in the coprolites (fossilized feces) of humans, hyenas, giant sloths, etc.; on the teeth of mammoths, etc.; on stone tools; and in residues inside vessels. The remains themselves are varied:

Seeds and Fruits. Ancient seeds and fruits can usually be identified to species, despite changes in their shape caused by charring or waterlogging. In some cases, the remains have disintegrated but have left their imprint behind – grain impressions are fairly common on pottery, leaf impressions are also known, and imprints exist on materials ranging from plaster and tufa to leather and corroded bronze. Identification, of course, depends on type and quality of the traces. Not all such finds necessarily mean that a plant grew locally: grape pips, for example, may come from imported fruit, while impressions on potsherds may mislead since pottery can travel far from its place of manufacture.

Plant Residues. Chemical analysis of plant residues in vessels – primarily by means of chromatograms – will be dealt with in the context of human diet in Chapter 7, but the results can give some idea of what species were available. Pottery vessels themselves may incorporate plant fibers (not to mention shell, feathers, or blood) as a tempering material, and microscopic analysis can sometimes identify these remains – for example, study of early pots from South Carolina and Georgia in the



Water flotation for plant recovery: the flushing system, using recycled water, developed by Gordon Hillman from the method first devised at the British Institute of Archaeology, Ankara. Light material floats to the surface and is caught in flot sieves; heavier material sinks, to be caught in a nylon mesh.

United States revealed the presence of shredded stems of Spanish Moss, a member of the pineapple family.

Remains of Wood. Study of *charcoal* (wood that has been burnt for some reason) is making a growing contribution to archaeological reconstruction of environments and of human use of timber. A very durable material, charcoal is usually found and extracted by the archaeologist. Once the fragments have been sieved, sorted, and dried, they can be examined by the specialist under the microscope, and identified (thanks to the anatomy of the wood) normally at the genus level, and sometimes to species. Since no chemicals need to be used, charcoal and charred seeds have also proved the most reliable material from which to take samples for radiocarbon dating (Chapter 4).

Many charcoal samples derive from firewood, but others may come from wooden structures, furniture, and implements burnt at some point in a site's history. Samples therefore inevitably tend to reflect human selection of wood rather than the full range of species growing around the site. Nevertheless, the totals for each species provide some idea of one part of the vegetation at a given time. Quantification is tricky, since charcoal fragments do not come in standard sizes. Should one compare the number of fragments for each species, or the total mass of each?

Occasionally, charcoal analysis can be combined with other evidence to reveal something not only of local environment but also of human adaptation to it. At Boomplaas Cave, in southern Cape Province (South Africa), excavation of the deep deposits by Hilary Deacon and his team has uncovered traces of human occupation stretching back to about 70,000 years. There is a clear difference between all Ice Age charcoals and those postdating 12,000–14,000 years ago at the site. At times of extreme cold when conditions were also drier, as between 22,000 and *c.* 14,000 years ago, the species diversity both in the charcoals and the pollen was low, whereas at times of higher rainfall and/or temperature the species diversity increased. A similar pattern of species diversity is seen also in the small mammals.

The vegetation around Boomplaas Cave at the time of maximum cold and drought was composed mainly of shrubs and grass with few fruits and corms that could be used by people. The charcoal samples are dominated by the so-called rhinoceros bush, a small shrub that grows today in relatively dry areas. The larger mammal fauna during the Ice Age was dominated by grazers that included "giant" species of buffalo, horse, and

COLLECTION OF PLANT REMAINS

Kind of remains	*Sediment type*	*Information available from investigation*	*Method of extraction and examination*	*Volume to be collected*
Soil	All	Detailed description of how the deposit formed and under what conditions	(Best examined *in situ* by environmental staff)	(Column sample)
Pollen	Buried soils, waterlogged deposits	Vegetation, land use	Laboratory extraction and high power (x400) microscopy	0.05 ltr or column sample
Phytoliths	All sediments	As above	As above	As above
Diatoms	Waterlain deposits	Salinity and levels of water pollution	Laboratory extraction and high power (x400) microscopy	0.10 ltr
Uncharred plant remains (seeds, mosses, leaves)	Wet to waterlogged	Vegetation, diet, plant materials used in building crafts, technology, fuel	Laboratory sieving to 300 microns	10–20 ltr
Charred plant remains (grain, chaff, charcoal)	All sediments	Vegetation, diet, plant materials used in building crafts, technology, fuel processing of crops and behavior	Flotation to 300 microns	40–80 ltr
Wood (charcoal)	Wet to waterlogged, charred	Dendrochronology, climate, building materials and technology	Low power microscopy (x10)	Hand or lab. collection

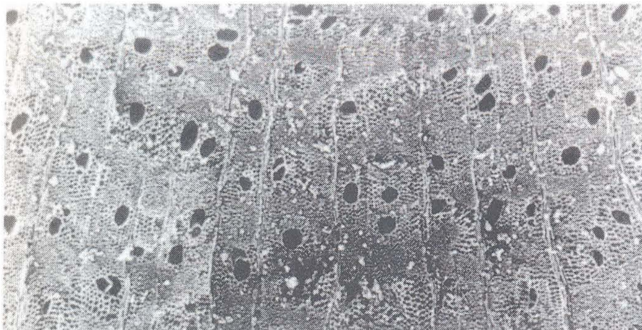
Table summarizing collection methods for microbotanical and macrobotanical plant remains, with an indication of the range of information to be gained for each category.

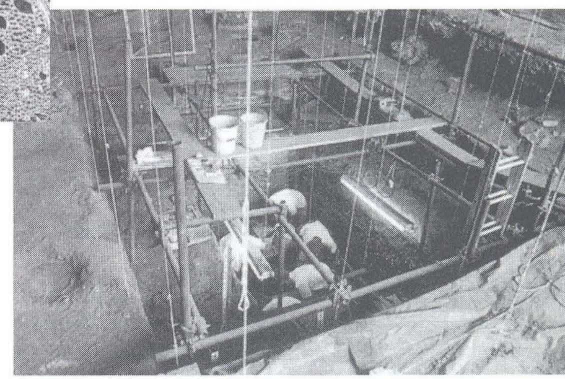
hartebeest. These became extinct by about 10,000 years ago (the worldwide extinction of big-game is discussed in a later section).

The Boomplaas charcoal directly reflects the gradual change in climate and vegetation which led to the disappearance of the large grazers, and to a corresponding shift in subsistence practices by the cave's occupants. The charcoal analysis also highlights more subtle changes that reflect a shift in the season of maximum rainfall. The woody vegetation in the Cango Valley today is dominated by the thorn tree, *Acacia karroo*, characteristic of large areas in southern Africa where it is relatively dry and rain falls mostly in summer. Thorn tree charcoal is absent in the Ice Age samples at Boomplaas but here and at the nearby site of Buffelskloof it appears from about 5000 years ago and by 2000 years ago is the dominant species. This shift to hot, relatively moist summers after about 5000 years ago in the Cango Valley is traceable also in the carbon isotope analysis of a stalagmite (see box, pp. 234–35) from the nearby Cango Caves. With encroachment of summer rainfall species the inhabitants of the cave were able to make more use of a new range of fruits; the seeds of some of these are preserved in deposits that postdate 2000 years ago.

By no means all wood subjected to this kind of analysis is charred. Increasing quantities of ***waterlogged*** wood are being recovered from wet sites in many parts of the world (see below, and Chapters 2 and 8). And in some conditions, such as extreme cold or dryness, ***desiccated wood*** may survive without either burning or waterlogging; examination of a small slice (less than 1 mm (0.04 in) thick) under the light microscope and in the SEM permits identification of wood in pristine condition.

Other Sources of Evidence. A great deal of information on vegetation in the less remote periods studied by archaeologists can be obtained from art, from texts (e.g. the writings of Pliny the Elder, Roman farming texts, accounts and illustrations by early explorers such as Captain Cook), and even from photographs.





Boomplaas Cave, Cape Province, South Africa. (Left) Scanning electron microscope photograph (×50) of charcoal from the thorn tree Acacia karroo. *The appearance of this species at Boomplaas after 5000 years ago indicates a shift to hot, relatively moist summers. (Below) Excavations in progress at the cave in 1978. Compare the photograph on p. 110 taken at an earlier stage of the work.*

No single category of evidence can provide us with a total picture of local or regional vegetation, of small-scale trends or long-term changes: each produces a partial version of past realities. Input is needed from every source available, and, as will be seen below, these must be combined with results from the other forms of data studied in this chapter in order to reconstruct the best approximation of a past environment.

RECONSTRUCTING THE ANIMAL ENVIRONMENT

Animal remains were the first evidence used by 19th-century archaeologists to characterize the climate of the prehistoric periods encountered in their excavations. Thus, concepts such as the Mammoth Age, the Aurochs Age, and the Reindeer Age were in common use until the classification of stone tools replaced them. Underlying these terms was the realization that different species were absent, present, or particularly abundant in certain layers and hence also in certain periods, and the assumption that this reflected changing climatic conditions.

Today, in order to use faunal remains as a guide to environment, we need to look more critically at the evidence than did the 19th-century pioneers. We need to understand the complex relationship between modern animals and their environment. We also need to investigate how animal remains arrived at a site – either naturally, or through the activities of carnivores or people (see taphonomy box, pp. 284–85) – and thus how representative they may be of the variety of animals in their period.

Microfauna

Just as tiny plant remains tend to be of greater importance to environmental studies than large ones, so small animals (microfauna) are better indicators of climate and environmental change than are large species, because they are sensitive to oscillations and adapt relatively quickly, whereas large animals have a relatively wide range of tolerance. In addition, since microfauna tend to accumulate naturally on a site, they reflect the immediate environment more accurately than the larger animals whose remains are often accumulated through human or animal predation. Like pollen, small animals, and especially insects, are also usually found in far greater numbers than larger ones, which improves the statistical significance of their analysis. It is essential to extract a good sample by means of dry and/or wet screening or sieving; huge quantities are otherwise missed in the course of excavation.

A wide variety of microfauna is found on archaeological sites:

Insectivores, Rodents, and Bats. These are the species most commonly encountered. A specialist can obtain a great deal of environmental information from the associations and fluctuations of these seemingly insignificant creatures, since most of them are present in archaeological sites naturally rather than through human exploitation.

It is necessary to ensure as far as possible that the bones are contemporaneous with the layer, and that burrowing has not occurred. One should also bear in mind that, even if the remains are not intrusive, they will not always indicate the *immediate* environment –

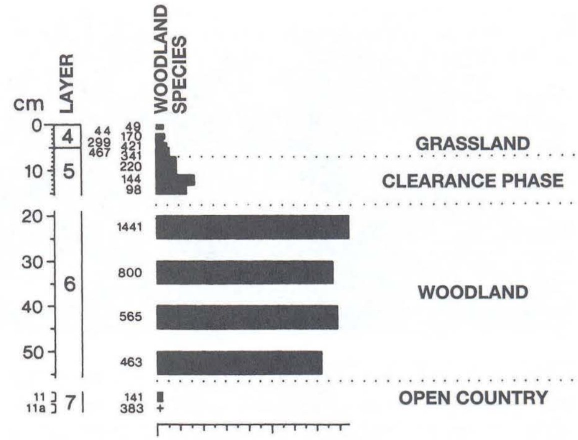
if they come from owl pellets, for example, they may have been caught up to a few kilometers from the site (the contents of bird pellets can nevertheless be of great value in assessing local environments).

As with large mammals, certain small species can be indicative of fairly specific environmental conditions. Richard Klein of Stanford University has noted a strong correlation between rainfall and the size of the modern dune mole rat of South Africa – the rats seem to grow larger in response to a general increase in vegetation density brought about by higher rainfall. His analysis of the fauna from Elands Bay Cave, South Africa (see box, pp. 254–55), revealed that the rats from layers dating to between 11,000 and 9000 years ago were distinctly bigger than those of the preceding seven millennia, and this has been taken as evidence of a rise in precipitation at the end of the Pleistocene.

Birds and Fish. Bones of birds and fish are particularly fragile, but are well worth studying. They can for example be used to determine the seasons in which particular sites were occupied (Chapter 7). Birds are sensitive to climatic change, and the alternation of "cold" and "warm" species in the last Ice Age has been of great help in assessing environment, though it is sometimes difficult to decide whether a bird is present naturally or has been brought in by a human or animal predator.

Land Molluscs. The calcium carbonate shells of land molluscs are preserved in many types of sediment, but especially in alkaline contexts where pollen analysis is constrained. They reflect local conditions, and can be responsive to changes in microclimate. But one needs to take into account that many species have a very broad tolerance, and their reaction to change is relatively slow, so that they "hang on" in adverse areas, and disperse slowly into newly acceptable areas.

As usual, it is necessary to establish whether the shells were deposited *in situ*, or washed or blown in from elsewhere. The sample of shells needs to be unbiased – sieving should ensure that not merely the large or colorful specimens that catch an excavator's eye are kept, but the whole assemblage. Quality of preservation is important since shell shape and ornamentation are key elements in identifying species. Once the assemblages have been determined, one can trace changes through time, and hence how the molluscan population has altered in response to environmental oscillations. Temperature and rainfall are the dominant factors; where a species is near the limit of its normal range, it can be a very sensitive indicator of change.



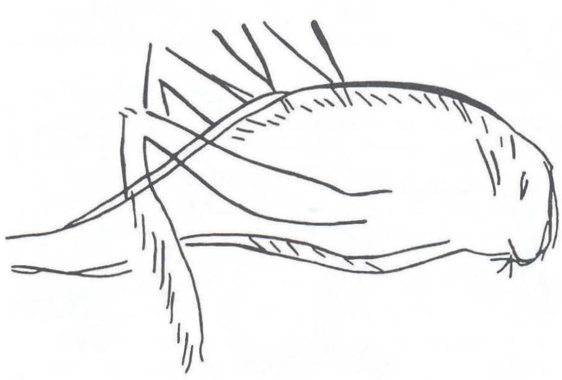
Land mollusc histogram based on excavations at Avebury, southern England. Fluctuating percentages of woodland species of snails reveal a change from open country (tundra) c. 10,000 years ago to woodland and eventually to grassland.

A great deal of work has been done on this topic by the British specialist John Evans and others at a number of prehistoric sites in Britain. For example, snails from sections at the Neolithic monuments of Woodhenge and Durrington Walls show that the area was wooded in that period. At Avebury nearby, the relative percentages of species found in successive layers of soil beneath the site's bank indicate a tundra environment about 10,000 years ago, open woodland 8000–6000 years ago, closed woodland 6000–3000 years ago, followed by a phase of clearance and plowing, and finally grassland.

Marine Molluscs. As we have already seen earlier in this chapter, middens of marine molluscs can sometimes help to delineate ancient shorelines, and their changing percentages of species through time can reveal something of the nature of the coastal microenvironment – such as whether it was sandy or rocky – through study of the modern preferences of the species represented. The climatic change suggested by these alterations in the presence or abundance of different species can be matched with the results of oxygen isotope analysis of the shells – a strong correlation between the two methods has been found by Hiroko Koike in her work on Jomon middens in Tokyo Bay where, for example, the disappearance of tropical species implied a cold phase at 5000 or 6000 years ago, confirmed by an increase in oxygen 18 (and hence a decrease of water temperature) around 5000 years ago. In Chapter 7 we shall see how changes in mollusc shell growth can establish seasonality.

Worms and Insects. Besides molluscs, a narrow range of nematodes (unsegmented worms) and annelids (such as earthworms represented by egg-cases) may be found, especially in waterlogged deposits including cesspits, as well as a wide range of arthropods such as mites and insects, the latter in the form of adults, larvae, and (in the case of flies) puparia. Analyses of fossil assemblages of aquatic midge larvae in cores from lakes in northern North America have shown changes in lake summer surface water temperature over several millennia at the end of the Ice Age. The study of ***insects*** (paleoentomology) was rather neglected in archaeology until about 30 years ago, since when a great deal of pioneering work has been done, particularly in Britain. Insect exoskeletons can be quite resistant to decomposition, and some assemblages comprise thousands of individuals.

Since we know the distribution and environmental requirements of their modern descendants, it is often possible to use insect remains as accurate indicators of the likely climatic conditions (and to some extent of the vegetation) prevailing in particular periods and local areas. Some species have very precise requirements in terms of where they like to breed and the kinds of food their larvae need. However, rather than use single "indicator species" to reconstruct a microenvironment, it is safer to consider associations of species, as with mammals or plant communities. Hence, the so-called mutual climatic range method is employed: this assumes that the present-day climatic tolerance of each species is the same as in the past, and therefore where several species are found together, the ancient climate must lie within the area of overlap of their tolerance ranges. It follows that the more species present, the more precisely can this area of overlap be determined. Although insects reflect microclimates, it should be remembered that these are in turn largely governed by the overall climate.



Grasshopper engraved on a bone fragment from the late Ice Age (Magdalenian) site of Enlène, Ariège, France. Insects respond rapidly to climatic change, and are sensitive indicators of the timing and scale of environmental variations.

In view of their rapid response to climatic changes, insects are useful indicators of the timing and scale of these events, and of seasonal and mean annual temperatures. A few depictions of insects even exist from the Ice Age, and reveal some of the types that managed to survive in periglacial areas.

Coleoptera (beetles and weevils) are particularly useful insects for microenvironmental studies. Their head and thorax are often found well preserved; almost all those known from the Pleistocene still exist; they are sensitive indicators of past climates, responding quickly to environmental change (especially temperature); and they form a varied group with well-defined tolerance ranges – some species are very selective in terms of vegetal environment, and live exclusively on particular plants, such as oak, or on certain fungi.

In one study, the climatic tolerance ranges of 350 coleopteran species that occur as Pleistocene fossils were plotted; the mutual climatic range method was then applied to 57 coleopteran faunas from 26 sites in Britain. It was found that there had been very rapid major warmings at 13,000 and 10,000 years ago, and a prolonged cooling trend from 12,500 years ago (when conditions were the same as now, with average July temperatures around 17°C, 62.6°F) to 10,500 years ago, together with a number of minor oscillations.

Occasionally the discovery of insects in archaeological deposits can have important ramifications. To take a major example, the remains of the beetle *Scolytus scolytus*, found in Neolithic deposits in Hampstead, London, occur in a layer before the sharp decline in elm pollen known just before 5000 years ago in cores from the lake sediments and peats of northwest Europe. This archaeologically famous and abrupt decline was originally attributed to climatic change or degrading soils, and later to clearance by early farmers requiring fodder (see Chapter 12). However, *Scolytus scolytus* is the beetle that spreads the pathogenic fungus causing Dutch elm disease, and thus provides an alternative, natural explanation for the elm decline of 5000 years ago. The recent outbreak of elm disease in Europe has allowed scientists to monitor the disease's effects on the modern pollen record. They have indeed found that the decline in elm pollen is of similar proportions to that in the Neolithic; not only that, but the accompanying increase in weed pollen caused by the opening of the woodland canopy is the same in both cases. This fact, together with the known presence of the beetle in Neolithic times, makes a strong case for the existence of elm disease in that period.

Insects have also come to the fore in excavations at York, where some Viking timbers seem to have been riddled with woodworm. A 3rd-century AD Roman sewer in the city was found filled with sludge, which had concentrations of sewer flies in two side channels leading to lavatories. The sewer was known from its position to have drained a military bath-house but remains of grain beetles and golden spider beetles showed that it must also have drained a granary.

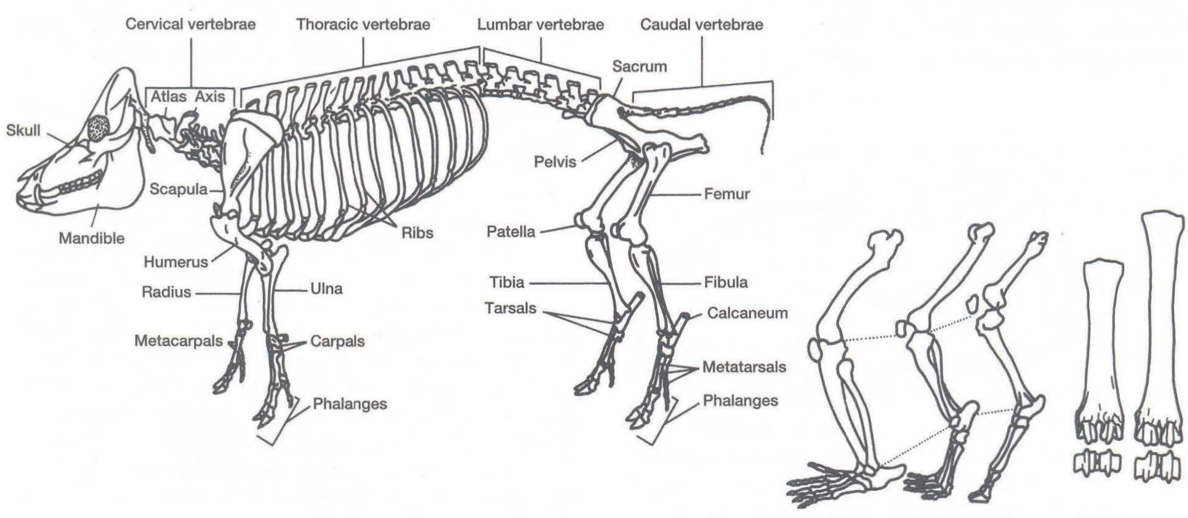
Clearly, insects are proving invaluable for the quantity and quality of information they can give archaeologists, not just about climate and vegetation, but about living conditions in and around archaeological sites as well.

Macrofauna

Remains of large animals found on archaeological sites mainly help us build up a picture of past human diet (Chapter 7). As environmental indicators they have proved less reliable than was once assumed, primarily because they are not so sensitive to environmental changes as small animals, but also because their remains will very likely have been deposited in an archaeological context through human or animal action. Bones from animals killed by people or by carnivores have been selected, and so cannot accurately reflect the full range of fauna present in the environment. The ideal is therefore to find accumulations of animal remains brought about by natural accident or catastrophe – animals caught in a flash flood perhaps, or buried by volcanic eruption, or mired (as in the case of the wide range of Pleistocene fauna found in the famous tarpits of Rancho La Brea, Los Angeles), or which became frozen in permafrost. But these are by any standards exceptional finds – very different from the usual accumulations of animal bones encountered by archaeologists.

Bone Collection and Identification in the Field. Bones are usually only preserved in situations where they have been buried quickly, thus avoiding the effects of weathering and the activities of scavenging animals. They also survive well, in a softened condition, in non-acidic waterlogged sites. In some cases, they may require treatment in the field before it is safe to remove them without damage. In sediments, they slowly become impregnated with minerals, and their weight and hardness increase, and thus also their durability.

After collection, the first step is to identify as many fragments as possible, both as part of the body and as a species. This is the work of a zoologist or one of the growing number of zooarchaeologists, although every archaeologist should be able to recognize a basic range of bones and species. Identification is made by compar-



Identifying animal bones. (Left) Bones in the skeleton of a typical domesticated animal, the pig. (Center) Structural comparison of mammal limb bones. In bears (and humans), the whole foot touches the ground, whereas among carnivores such as the dog only the toes do so. Herbivores such as cattle walk on "tiptoe," with only the final phalanges on the ground. (Right) Sheep and goat bones are notoriously difficult to distinguish, although there are subtle differences as in these metacarpals.

COLLECTION OF ANIMAL REMAINS

Kind of remains	*Sediment type*	*Information available from investigation*	*Method of extraction and examination*	*Volume to be collected*
Small mammal bone	All but very acidic	Natural fauna, ecology	Sieving to 1 mm	75 ltr
Bird bone	As above	See large and small mammal bone	As above	As above
Fish bone, scales, and otoliths	As above	Diet, fishing technology, and seasonal activity	As above	As above
Land molluscs	Alkaline	Past vegetation, soil type, depositional history	Laboratory sieving to 500 microns	10 ltr
Marine molluscs (shellfish)	Alkaline and neutral	Diet, trade, season of collection, shellfish farming	Hand sorting, troweled sediment and sieving	75 ltr
Insect remains (charred)	All sediments	Climate, vegetation, living conditions, trade, human diet	Laboratory sieving and paraffin flotation to 300 microns	10–20 ltr
Insect remains (uncharred)	Wet to waterlogged	As above	As above	As above
Large mammal bone	All but very acidic	Natural fauna, diet, husbandry, butchery, disease, social status, craft techniques	Hand sorting, troweled sediment, and sieving	Whole context troweled except when bulk samples are taken

Table summarizing collection methods for microfauna and macrofauna, with an indication of the variety of information to be gained for each category.

ison with a reference collection. The resulting lists and associations of species can also sometimes help to date Paleolithic sites (see Chapter 4).

Once quantification of the bone assemblage has been completed (see box, pp. 288–89), what can the results tell us about the contemporary environment?

Assumptions and Limitations. The anatomy and especially the teeth of large animals tell us something about their diet and hence, in the case of herbivores, of the type of vegetation they prefer. However, most information about range and habitat comes from studies of modern species, on the assumption that behavior has not changed substantially since the period in question. These studies show that large animals will tolerate – i.e. have the potential to withstand or exploit – a much wider range of temperatures and environments than was once thought. Thus species characteristic today of arctic and temperate regions in fact show a marked overlap in their habitats, and share a very similar minimum-temperature tolerance. This means that we can no longer assume, as archaeologists once did, that Pleistocene species such as the woolly rhinoceros or cave bear necessarily indicate cold climate – the presence of these species should be regarded merely as proof of their ability to tolerate low temperatures.

If it is therefore difficult to link fluctuations in a site's macrofaunal assemblage with changes in ***temperature***, we can at least say that changes in ***precipitation*** may sometimes be reflected quite directly in variations in faunal remains. For example, species differ as to the depth of snow they can tolerate, and this affects winter faunal assemblages in those parts of the world that endure thick snow-cover for much of the winter.

Large mammals are not generally good indicators of ***vegetation***, since herbivores can thrive in a wide range of environments and eat a variety of plants. Thus, individual species cannot usually be regarded as characteristic of one particular habitat, but there are exceptions. Ibex, which today are restricted to the higher reaches of mountains, were forced by glaciations to live at lower altitudes, and there were similar latitudinal shifts by other animals and birds. For example, reindeer reached northern Spain in the last Ice Age, as shown not only by bones but also by cave art. Such major shifts clearly reflect environmental change. In the rock art of the Sahara, too, one can see clear evidence for the presence of species such as giraffe and elephant that could not survive in the area today, and thus for dramatic environmental modification.

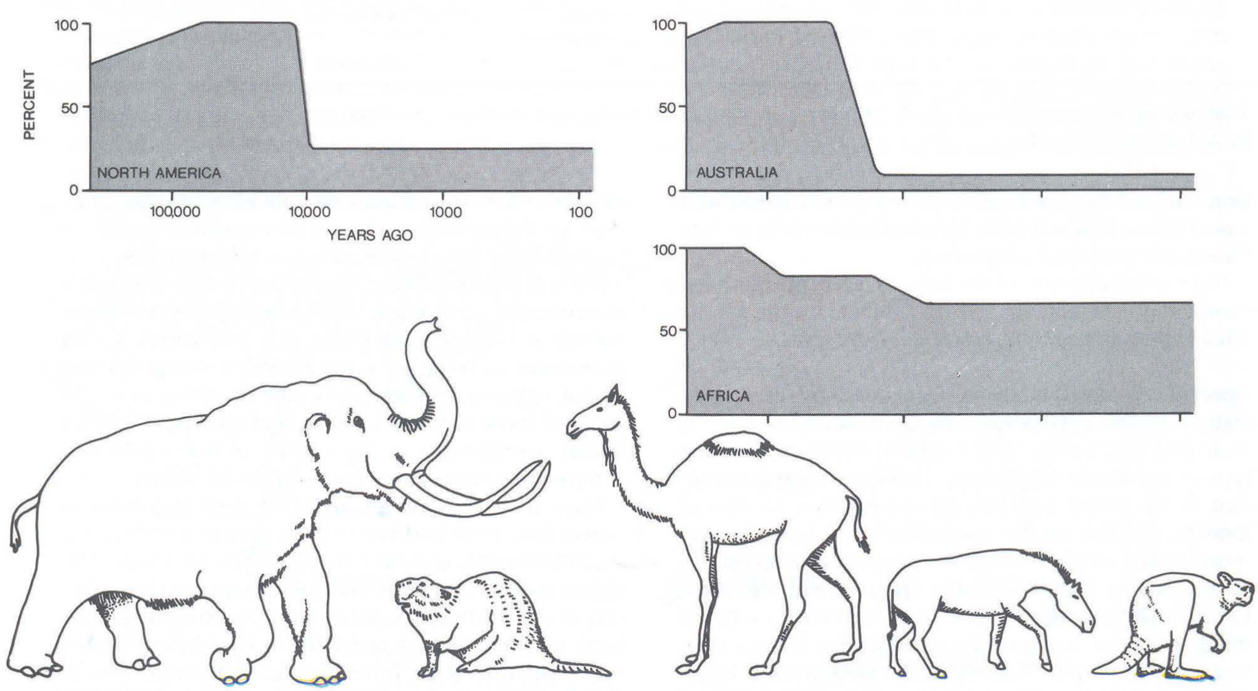
As will be seen in Chapter 7, fauna can also be used to determine in which seasons of the year a site was occupied. The techniques described there can go some way toward showing how the local environment changed from season to season. It is possible as well to correlate macrofauna and other types of evidence. Many faunal sequences in areas such as Europe or southern Africa display changes of species that are independent of culture change, span thousands of years, and can be correlated with sequences derived from sediment or plant studies.

In coastal sites, including many caves in Cantabrian Spain, or around the shores of the Mediterranean (see Franchthi Cave above), or on the Cape coast of South Africa (see box overleaf), marine resources and herbivore remains may come and go through the archaeological sequence as changes in sea level extended or drowned the coastal plain, thus changing the sites' proximity to the shore and the availability of grazing.

One always has to bear in mind that faunal fluctuations can have causes other than climate or people; additional factors may include competition, epidemics, or fluctuations in numbers of predators. Moreover, small-scale local variations in climate and weather can have enormous effects on the numbers and distribution of wild animals, so that despite its high powers of resistance a species may decline from extreme abundance to virtual extinction within a few years.

Big-game Extinctions. There is clear evidence from many Polynesian islands, as will be seen below, that the first human settlers devastated the indigenous fauna and flora. But in other parts of the world the question of animal extinctions, and whether and how people were involved, still forms a major topic of debate in archaeology. This is particularly true of the big-game extinctions in the New World and Australia at the end of the Ice Age, where losses were far heavier than in Asia and Africa, and included not just the mammoth and mastodon, but species such as the horse in the Americas.

There are two main sides in the big-game extinction debate. One group of scholars, led by the American



Big-game extinctions. (Top) Diagrams by Paul Martin illustrate the sudden decline of large animal species in North America and Australia around the time of human colonization, by comparison with Africa, where big game had longer to adapt to human predation. Other scholars emphasize the importance of environmental factors as well in the demise of megafauna such as (above, left to right) the mastodon, giant beaver, camel, and horse (all North American), and the Australian giant kangaroo, Sthenurus.

scientist Paul Martin, believes that the arrival of people in the New World and Australia, followed by overexploitation of prey, caused the extinctions. New data from Australia have provided some support for this view, since dates obtained by amino acid racemization from eggshells of the large flightless bird *Genyornis* from three different climate regions show that it disappeared suddenly, around 50,000 years ago, the time when humans may have arrived in this continent. The simultaneous extinction of *Genyornis* at all sites during a period of modest climate change points to human impact as the major cause of its extinction. This view, however, does not account for the extinction at about the same time of mammal and bird species that were not obvious human prey, or that would not have been vulnerable to hunting. In any case, the precise date of each extinction is not yet known, while the dates of human entry into both continents are still uncertain (Chapter 11) and constantly being pushed back well beyond the extinctions.

The other view, presented by the geologist Ernest Lundelius and others, is that climatic change is the primary cause. But this interpretation does not explain why the many similar changes of earlier periods had no such effect, and in any case many of the species that disappeared had a broad geographic distribution and climatic tolerance.

Extinctions caused by climatic change had occurred previously, but always tended to affect all size classes of mammal equally, and those that disappeared were replaced by migration or the development of new species – this did not happen in the Pleistocene extinctions. All big-game species weighing over 1000 kg (1 ton) as adults (the megaherbivores) disappeared from the New World, Europe, and Australia, as did about 75 percent of the herbivore genera weighing 100–1000 kg (0.1–1 ton), but only 41 percent of species weighing 5–100 kg (11–220 lb), and under 2 percent of the smaller creatures.

A compromise theory that takes these factors into account and links the two main hypotheses has been put forward by the South African scholar Norman Owen-Smith. He believes that it was in the first place human overexploitation that led to the disappearance of the megaherbivores, which in turn caused a change in vegetation that led to the extinction of some medium-sized herbivores.

In view of the tremendous effects that modern elephants in eastern and southern Africa have on vegetation – by felling or damaging trees, opening up clearings for smaller animals, and transforming wooded savanna into grassland – it is certain that the removal of megaherbivores must have radically affected the Pleistocene environment. In one game reserve in Natal Province, South Africa, which has had no elephants for the last 100 years, three species of antelope have also become locally extinct, and open-country grazers such as wildebeest and waterbuck are much reduced in numbers.

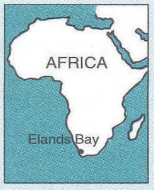
Owen-Smith's hypothesis has the merit that it can be tested through a more detailed analysis of vegetation changes and the order in which extinctions took place. Recently, an old notion has been revived – that some kind of epidemic, a mysterious and still totally hypothetical "hyperdisease," wiped out a range of animals. It remains to be seen what evidence can be mustered for this explanation.

Promising New Techniques. Eventually we may be able to extract more specific environmental data from bones using new techniques – for example, information on temperature and moisture histories from isotopic analysis of tooth-enamel and bones of the type described in Chapter 4, or from analysis of the amino acids in bone collagen. Work by M.A. Zeder on trace elements in the bones of sheep and goat from Iran has established that calcium, magnesium, and zinc are found in significantly different concentrations in animals from different environments; it should therefore be possible to obtain information on past environments through similar analyses of ancient bones.

In the same way, Tim Heaton and his colleagues in South Africa have found that the ratio of nitrogen isotopes in bone may be a useful tool for studying past variations in climate. Samples from prehistoric and early historic skeletons of humans and wild herbivores from a variety of habitats and climatic zones in South Africa and Namibia were tested for their $^{15}N/^{14}N$ values. They discovered variations that could not be ascribed to diet: specimens from far inland, or that reflected consumption only of terrestrial plants, produced results similar to those from the coast. In short, the $^{15}N/^{14}N$ ratio seems to be linked to climatic variation, especially in areas such as this where big changes in precipitation have occurred, with increasing aridity being reflected in a rise in ^{15}N.

Other Sources of Animal Evidence. Bones are not the only source of information about macrofauna. Frozen carcasses have already been mentioned, as has art. In some sites, *tracks* have been found. Examples range from the early hominid and animal prints – over 10,000 of them, including birds and insects – at Laetoli in Tanzania; tracks on Bronze Age soils (Chapter 7); and paw-prints on Roman tiles (Chapter 7). Caves are particularly rich in such traces, and the tracks of hyenas

ELANDS BAY CAVE



The Verlorenvlei estuary today (above). Elands Bay Cave lies just around the tip of the peninsula seen in the distance.

Located near the mouth of the Verlorenvlei estuary on the southwest coast of Cape Province, South Africa, Elands Bay Cave was occupied for thousands of years and is particularly important for the documentation of changes in coastline and subsistence at the end of the Ice Age. Work at the cave by John Parkington and his associates has demonstrated clearly how, within 6000 or 7000 years, the rise in sea level transformed the site's territory from being inland riverine to estuarine and coastal.

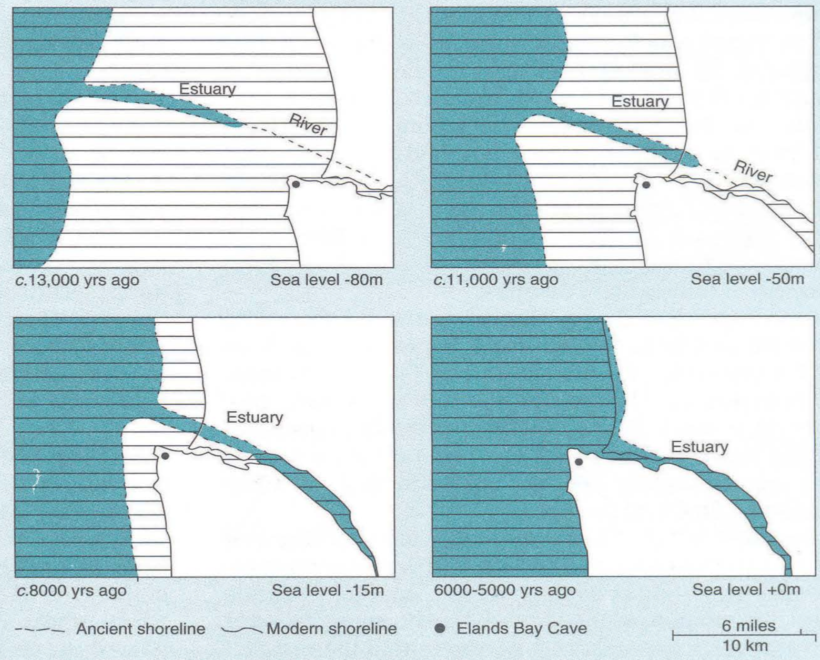
During the period *c.* 13,600–12,000 years ago, subsistence practices remained relatively stable, although the coastline must have approached to about 12 km ($7^1/_2$ miles) from the site according to present-day offshore sea-bed contours. The faunal remains left by the cave's occupants are dominated by an assemblage of large grazers such as rhinoceroses, equids, buffalo, and eland, suggesting that the local environment was one of fairly open grassland. The very low marine component in the remains reflects the considerable distance to the coast – still beyond the 2-hour distance considered normal for most hunter-gatherers (see box, pp. 258–59), and too far to make it economical to carry shellfish. The birds found are of riverine species, primarily ducks.

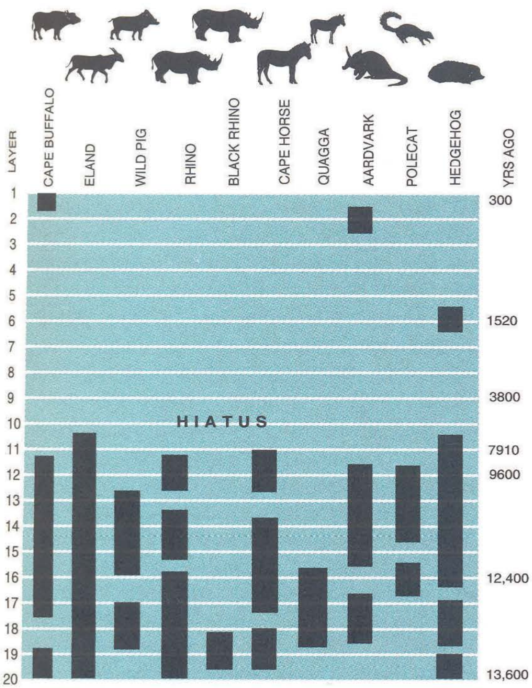
By about 11,000 years ago, the coast had approached to some 5–6 km (3.1–3.7 miles) west from the site, well within striking distance for hunter-gatherers. The first thin layers of shellfish now appear in the cave's sequence. In the following three millennia the sea encroached to 2 km ($1^1/_4$ miles) or so from the site, and gradually drowned the lower reaches of the Verlorenvlei valley, turning them into estuary and then into coastline.

The disappearance of the habitats suited to the large grazers had radical effects on the faunal environment. At least two animals (the giant horse and giant buffalo) became extinct, and other large animals such as the rhinoceros and Cape buffalo are absent or extremely rare in the cave's deposits after 9000 years ago. They are replaced at this site and in other parts of the region by smaller herbivores such as grysbok – browsers rather than grazers, a fact that implies a different plant environment, probably linked to a change in precipitation.

At the same time, there is a clear rise to dominance of marine animals between 11,000 and 9000 years ago, and the cave's sequence changes from a series of brown loams containing thin

Rising sea levels (below) at the end of the Ice Age drowned the coastal plain that once lay to the west of Elands Bay Cave.





Decline of the grassland animals (above) as reflected in the faunal remains recovered from Elands Bay Cave. By 9000 years ago, when the sea had encroached to within 3 km (1.9 miles) of the site, these animals had virtually ceased to be exploited from the cave.

shell layers to a sequence of true shell middens. In addition there are very high frequencies (in relation to terrestrial species) of cormorants, marine fish, rock lobsters, and seals after 9500 years ago, by which period the coast was a little more than 3 km (1.9 miles) away. The drowning of the valley after 11,000 years ago is reflected in the abundance of hippopotamuses and shallow-water birds such as flamingos and pelicans. At this time the estuary was certainly within exploitable distance. Some 9000–8500 years ago the cave was roughly equidistant between coast and estuary, but after 8000 the coast was nearer, reaching its present position about 6000 years ago.

and cave bears are well known in Europe; one can also find the claw-marks and nest-hollows of the cave bear. Toothmarks of beaver have been found on Neolithic wood from the Somerset Levels, England.

Fossil dung (coprolites) has also survived in many dry caves, and can contain much information about fauna and flora (see above p. 244). Bechan Cave in southeast Utah, for instance, has about 300 cu. m (392 cu. yd) of dehydrated mammoth dung, while many other species left their coprolites in other American caves. Quite apart from revealing which animals were present in different periods, the dung also shows what they ate, and even contributes to the debate on Pleistocene extinctions (see above). Paul Martin, a pioneer of fossil dung analysis, has shown that the contents of the coprolites of the extinct Shasta ground sloth do not change up to the time of its disappearance, and Jim Mead has reached the same conclusion with the dung of mammoths and the extinct mountain goat. These findings therefore suggest that these New World extinctions, at least, were not caused by a change in vegetation or diet. The decline in frequency and the eventual disappearance of the dung of certain species such as the ground sloth provide further (datable) evidence of extinctions even in the complete absence of skeletal material.

Other sources of evidence include horse and reindeer fat identified chemically from residues in sediment, and blood residues of various animals (Chapter 7) found on stone tools. Information can also be extracted from the writings and illustrations of early explorers, or the geographies of Roman writers. Even bone artifacts can sometimes be clear climatic indicators: large numbers of worn and polished bone skates, for instance, have been found in deposits of Anglo-Scandinavian date in York, England, suggesting that winters were harsh enough to freeze the Ouse river.

RECONSTRUCTING THE HUMAN ENVIRONMENT

All human groups have an impact on their environment, both locally and on a wider scale. One of the most important effects of human interference, the domestication of plants and animals, will be examined in Chapter 7. Here we shall concentrate on how people exploited and managed the landscape and natural resources.

The basic feature of the human environment is the site and the factors influencing the selection of a location. Many of these factors are readily detectable, either visually (proximity to water, strategic position, orientation) or by some method of measurement. The climates of caves and rockshelters, for example, can be assessed through the study of temperatures, shade and exposure to sunlight, and exposure to winds in different seasons, since these are the factors that determine their habitability. Site exploitation territory analysis (box overleaf) is one recognized procedure for assessing a site's location and the land around it.

Archaeologists should never forget that sometimes the choice of site will have been dictated by factors that we cannot assess: malevolent spirits, "good" or "bad" places – what Ernest Burch, in his study of the Alaskan Eskimo, has called the Nonempirical Environment.

The Immediate Environment: Human Modification of the Living Area

One of the first ways in which people modified their living places was by the controlled use of fire. Archaeologists have debated for decades just how early fire was introduced. Until recently the earliest contender was Zhoukoudian cave in China at some half a million years ago. In 1988, C.K. Brain and Andrew Sillen discovered pieces of apparently burnt animal bone at the Swartkrans Cave, South Africa, in layers dating to *c.* 1.5 million years ago. Since simple visual analysis cannot reliably differentiate burning from mineral staining on bones, Brain and Sillen carried out experiments with fresh bones, examining the cell structure and chemical changes that occurred when the bones were heated to various temperatures and then cooled slowly. Microscopic analysis showed that the changes were very similar to those in the fossil bones, suggesting that the latter were probably cooked on a wood fire at temperatures of less than 300°C (572°F) up to 500°C (932°F). The bones came from antelope, warthog, zebra, and baboon. Remains of early hominids found in the cave layers give a strong indication as to who tended those fires.

Evidence of actual hearths in early prehistoric campsites has always been hard to find and recognize, but recently, a new technique has been developed for detecting ash in sediments, because different minerals emit characteristic spectra when illuminated with infrared radiation. Hence, ancient hearths can now be detected after they have disintegrated almost completely. Most ash minerals change over time, but about 2 percent stays relatively stable. In this way, fireplaces have been identified in the Israeli cave of Hayonim (250,000 BP) through comparison with clearly defined hearths in the nearby cave of Kebara (70,000 BP). When the technique was applied to Zhoukoudian cave in China, long considered to have the world's earliest evidence of controlled fire, at 500,000 years ago, the chemical "signature" of ash was not found in the part of the cave that was analyzed. Some bones from the cave are definitely burned, but it remains uncertain whether this was a case of natural or controlled fire.

The presence of fire in a cave is important not only for cooking and human comfort, but also because it affects the cave's microclimates and can accelerate weathering of the walls, as was mentioned in the box on cave sediments on pp. 234–35.

Archaeologists can show that people adapted to cave life in the Upper Paleolithic in other ways too. Visual examination has found evidence for scaffolding in some decorated caves such as Lascaux in France. Excavations elsewhere have unearthed traces of pavements of slabs, and of shelters. Specialized analysis of cave sediments can even unearth proof of bedding and the use of animal skins as floor coverings. Arlette Leroi-Gourhan, for example, has used pollen analysis to show the presence of clusters of grasses in Lascaux, and armfuls of unburnt grasses around a hearth at Fontanet, France, both of which probably indicate bedding. Cave sediments analyzed by Rolf Rottländer at the Upper Paleolithic cave of Geissenklösterle in western Germany showed such a huge proportion of fat that it suggests the floor was probably covered in the skins of large mammals.

Besides caves, archaeologists can investigate evidence from open sites for tents, wind-breaks, and other architectural remains as indicators of the way in which people modified their own immediate environment during the Paleolithic. For later periods, of course, this evidence multiplies enormously and we move into the realm of full-scale architecture and town planning discussed elsewhere in the book (Chapters 5 and 10).

Modification of the immediate environment is certainly fundamental to human culture. But how can we learn something about the varied ways in which people manipulated the world beyond?

Human Exploitation of the Wider Environment

Methods for Investigating Land Use. Examination of the soils around human habitations can be carried out where sections are exposed, or where an original land surface is laid bare beneath a monument. Specialists can go some way to reconstructing human use of the land by a combination of all the methods outlined in earlier sections. However, a different method is needed for cases where the area around the site has to be assessed on the surface.

This kind of off-site analysis was first developed systematically by Claudio Vita-Finzi and Eric Higgs in their work in Israel, and has been widely adopted, albeit with modifications and variations. Two distinct types of investigation are involved – site catchment analysis and site exploitation territory analysis – together with combinations and variations, and these methods are discussed in the box overleaf. Geographic Information Systems (GIS) are now also proving useful in investigating and mapping ancient environments, as, for instance, in George Milner's project at Cahokia, in the United States (see box, pp. 260–61).

Gardens. The archaeology of gardens, whether decorative or food-producing, is a subdiscipline that has only recently come to the fore, devoted to the accurate study, and in some cases the reconstruction, of ancient gardens. Examples include the complexes of mounds, terraces, and walls that constituted the Maori gardens of New Zealand; the formal garden of the 8th-century AD imperial villa at Nara in Japan; and especially those of Roman villas like that at Fishbourne, southern England. The best known are probably those preserved by the volcanic debris at Pompeii and its adjacent settlements. In most cases, as at Nara, a combination of excavation and analysis of plant remains has led to an accurate reconstruction; but at Pompeii, identification of species comes not only from pollen, seeds, and charred wood, but also from the hollows left by tree-roots, casts of which can be taken in the same way as for corpses (see Chapter 11). Such casts can even provide details about gardening techniques: for instance, the base of a lemon tree in a garden of Poppaea's villa at Oplontis, near Pompeii, showed clearly that it had been grafted, a method still used in the region to obtain new lemon trees. Similarly, at the "Mesoamerican Pompeii," the site of Cerén in El Salvador, engulfed by volcanic ash in *c.* AD 595 (see p. 63), liquid plaster poured into cavities has produced remarkable casts of plants, including corn stalks planted in fields, maize cobs stored in a crib, chili pepper bushes, and an entire household garden of 70 agave plants.

Pollution of Air and Water. Human effects on water resources have not yet received much attention from archaeologists, but recent evidence shows clearly that pollution of rivers is by no means confined to our own epoch. Excavations in the city of York, northeast England, have revealed changes in the composition of freshwater fish over the past 1900 years, with a marked shift from clean-water species such as shad and grayling to species more tolerant of polluted water (such as perch and roach). This change occurs around the 10th century AD, when the Viking town underwent rapid development, apparently intensifying pollution of the river Ouse in the process. The shift is mirrored in remains of freshwater molluscs, which change from species requiring well-oxygenated (i.e. clean) water to others that are less demanding. Air pollution is not a modern phenomenon either: cores from lakes in Sweden and a peat bog in the Swiss Jura Mountains have revealed that lead levels first increased 5500 years ago, when farming increased wind-blown soil, and then far more sharply 3000 years ago, when the Phoenicians started trading in lead mined in Spain, and metal smelting began. Lead pollution continued to increase as the Greeks began releasing lead into the atmosphere through the extraction of silver from ores; and even more so during Roman times, when 80,000 tons of lead were produced every year from European mines. Greenland ice cores not only confirm these data about lead, but also record marked pollution from ancient copper smelting in Roman and medieval times, especially in Europe and China.

Land Management Using Field Systems. Management of land is detectable in several ways. The clearest evidence comprises the various traces visible on the land surface, such as the 300 ha (741 acres) of Maya ridged fields at Pulltrouser Swamp, Belize, linked by a network of canals; the spectacular mountain terraces of the Incas; the *chinampas* (fertile reclaimed land, made of mud dredged from canals) of the Aztecs; or the similar but very much older drainage ditches and fertile garden lands of Kuk Swamp, New Guinea (see box pp. 262–63). Similarly, in Britain archaeologists have discovered Bronze Age stone boundary walls, known as reaves, on Dartmoor, and field systems and lynchets (small banks that build up against field boundaries on slopes) in many areas. In Japan, about 500 ancient rice paddy fields have been discovered, especially from the Yayoi period (400 BC–AD 300), together with their irrigation systems – wooden dams, drainage ditches, and baulks. For example, 10 ha (25 acres) of the 40-ha (100-acre) site of Ikejima-Fukumanji site near Osaka have been excavated, sealed by sandy sediments laid down by floods.

Artifacts and art can also be a valuable source of information about ancient land management. Han dynasty sites in China, for example, have yielded pottery models of paddy fields, some of them with irrigation ponds with a movable gate at the center of a dam, used to regulate the flow of water into the field.

Evidence for Plowing. Investigation of mounds, including their mollusc and pollen content, and especially the

SITE CATCHMENT ANALYSIS

People are geomorphic agents and bring a great deal of varied material into their sites – not just food but also tools, fuel, raw materials, etc. Indeed, the human contribution to a sediment can range from less than 1 percent to almost 100 percent. The catchment of a site is the total area from which the site's contents have been derived. At its simplest, therefore, **site catchment analysis** (SCA) is the attempt to work out the full inventory of a site's contents and their sources.

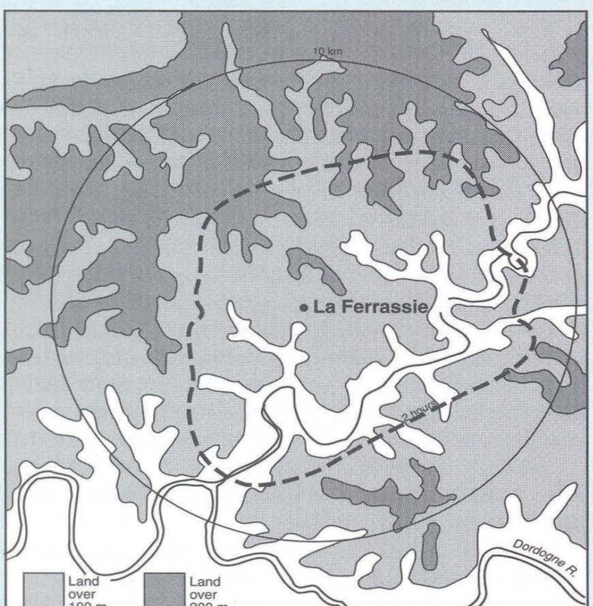
Site catchment analysis as more widely understood, however, is the technique devised by Eric Higgs and Claudio Vita-Finzi for studying the area around a site that would have been exploited by the site's occupants – hence its more accurate name, analysis of **site exploitation territory** (SET). The aim is to calculate the proportions within the territory of such resources as arable or pastoral land, so that conclusions can be drawn about the site's nature and function.

The SET technique rests on the assumption that the further the resource area is from the site, the less likely will be its exploitation (the costs in terms of time and effort would simply be too great). Using ethnographic data, it was estimated that hunter-gatherers normally exploit an area of roughly 10 km radius around their base – or, since time rather than distance is the limiting factor, a radius of 2 hours' walk. Most farming communities, on the other hand, normally use an area of 5 km radius, or 1 hour's walk. Thus, modern investigators would walk for either 1 or 2 hours outward from the site in question, and study various aspects of the landscape and soils. The information was drawn up in map form, usually as a circle around the site, distorted by the effects of topography on the distances covered in the set time, and with different categories of land-use or soil-quality inserted.

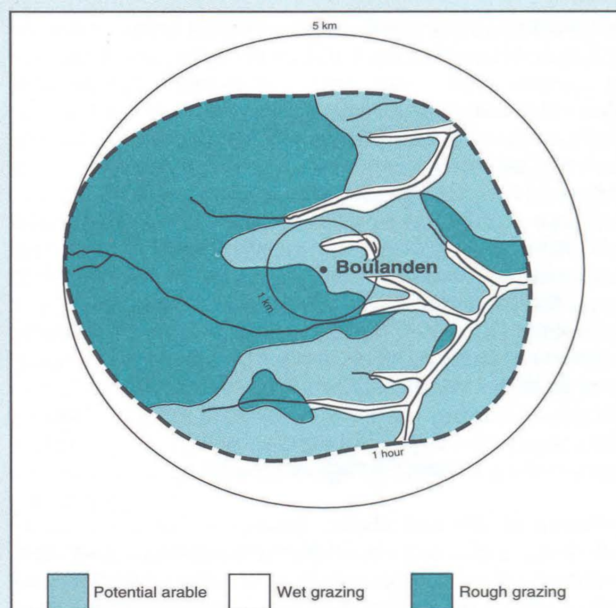
Modifications and Assessment

Modifications have been made to the original method, primarily because it took a great deal of time. Some scholars simply draw circles around sites, or take shorter walks (on the assumption that the immediate surroundings of a site were the most crucial to its existence). Others assess the land from a high vantage point, or estimate the shape of the site's territory from detailed contour maps.

When a digital elevation map is available, it is possible to use a GIS (Geographic Information System) to produce a more accurate mapped estimation of the territory within a 1 or 2 hour walk of a particular site using cost-surface analysis (see Chapter 3). These GIS maps are sometimes "calibrated" from the known times taken to walk



***Hunter-gatherer** site exploitation territory: the Middle Paleolithic site of La Ferrassie, Périgord, France. The area within 2-hours' walking distance from the site is considerably smaller than the circle of 10 km radius, because of the distortions imposed by hills around the site.*

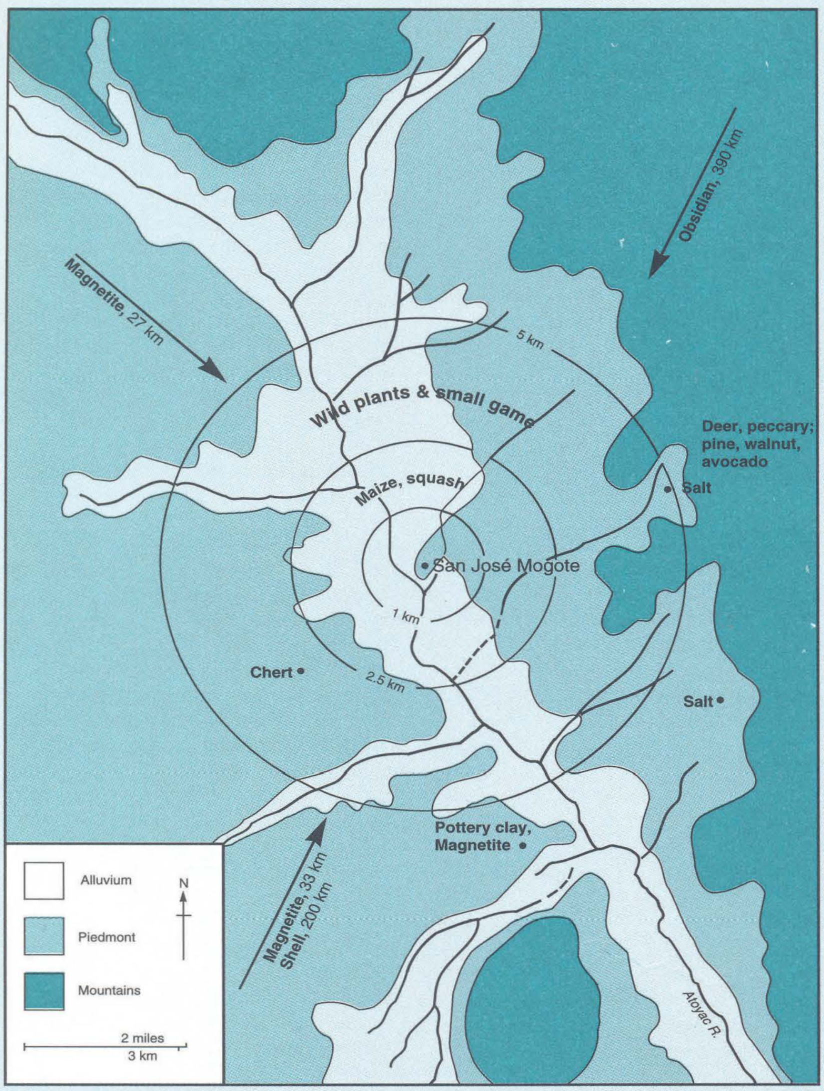


***Farming** site exploitation territory: the Early Neolithic (Linear pottery) site of Boulanden, Upper Rhine Valley, Germany. The area within 1 hour's walk from the site has been subdivided into three categories of potential land-use (an attempt having been made to reconstruct the likely Neolithic environment).*

within the area. This method can be used to generate exploitation territories which take account of the slope of the terrain, and of obstacles such as rivers or walls. GIS can also be used to calculate the proportions of resources which fall within the territory.

Assessment of the area around hunter-gatherer sites is relatively easy, involving a study of the landscape, and the location of water supply, fords, raw materials, natural passages for game, and natural traps and corrals for herds, etc. However, assessment of the area around farming sites is more complex, since it tries to reconstruct the exploitable land in different periods, using different farming technologies. The effects of erosion, irrigation, or terracing need to be taken into account.

Analysis of the soil (see main text) can provide a rough guide to its workability – how much energy is needed to disturb it. Heavy clays, for example, need stronger equipment than loose or sandy soil. Soil potential and fertility are harder to evaluate, and will have altered considerably through time as farming practices changed. Thus, the qualitative assessments from SET analysis tend to be deliberately vague (good arable, potentially arable, good grazing), and geomorphological expertise is required to obtain more detail. As much information as possible needs to be gathered about the area's history of land-use, both from documentation and from what the land and soils can reveal to an expert.



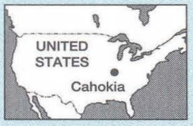
Flannery's Combined Method

A combination of catchment area and exploitation territory analysis has sometimes been employed, most notably by Kent Flannery and his colleagues in Oaxaca (see Chapter 13). Here the starting point is the resources actually found in the site. Investigation then focuses on where the resources probably came from, a task requiring knowledge of resource distribution. The result is a possible zonation of resource use around the site, together with the delineation of a catchment area which is usually larger than the exploitation territory.

This quantitative approach – which enables one to calculate the potential yield of the surrounding area and hence estimate the carrying capacity (the number of people who could live off the land) – avoids the artificiality of a predetermined area of study, but runs the risk of ignoring resources the area could have provided and that have not survived archaeologically. Both methods therefore have advantages and drawbacks. Ultimately it is always wise to combine detailed analyses of the area around particular sites with the more general techniques of regional survey (see Chapter 3), in order to assess how representative the conditions at individual sites really are.

Flannery's analysis *of the catchment and exploitation territory around the village of San José Mogote, Oaxaca, Mexico. He concluded that most of the village's agricultural needs would have been satisfied within a 2.5-km radius of the site.*

MAPPING THE ANCIENT ENVIRONMENT: CAHOKIA AND GIS



Reconstructing prehistoric human environments requires a detailed knowledge of the natural setting, especially the distribution, productivity, and reliability of edible resources. To handle such complex data, archaeologists are increasingly turning to computer-based mapping systems – Geographic Information Systems (GIS) – when looking at how settlements were distributed in relation to each other and to environmental features such as rivers, topography, soils, and vegetation cover.

The development of GIS makes it possible to organize complex spatial data arranged as a series of separate layers, one for each kind of information – sites, soils, elevation, and so on (see Chapter 3). Relationships between data in various layers can then be analyzed, allowing archaeologists to address questions about human land-use with large numbers of sites and many environmental details.

Mapping Cahokia

One place where such work is underway is the central Mississippi river valley in the United States. This area is uncommonly rich in prehistoric sites, the most impressive of which is Cahokia. Almost a millennium ago, Cahokia was the principal settlement of one of the most complex societies that ever existed in prehistoric North America. The site once encompassed more than 100 earthen mounds, including an immense 30-m (100-ft) high mound that towered over the surrounding community. Many of these mounds and the remnants of extensive residential areas have survived to modern times. Although a great deal of archaeological work has been undertaken near Cahokia, many questions remain. How many people lived in the area? How was this society organized? Why did people favor some locations but avoid others? How has human land-use changed over time?

Recently George Milner of Pennsylvania State University began a research project in the area. The project has three main objectives:

1 to identify changes in the valley floor that would have caused the destruction or burial of sites;

2 to assess the availability of different resources in different areas;

3 to determine why sites were located where they were.

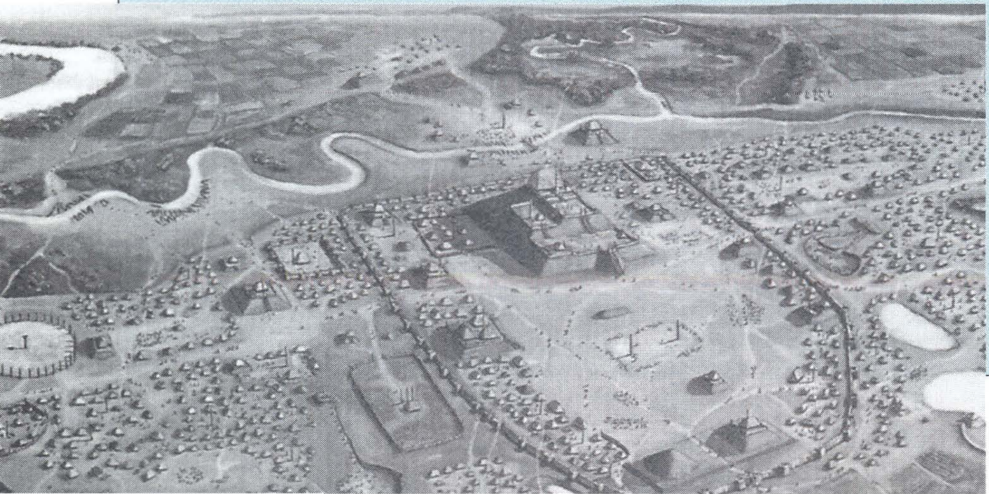
Work started with the systematic examination of existing site records to determine the locations of known settlements. Diagnostic artifacts in museum collections were studied to identify when these places were occupied. Maps and land surveys up to almost 200 years old were used to document the movements of the river and the locations of the wetlands that once covered much of the valley floor.

The earliest detailed maps of the river and surrounding landscape were produced by the General Land Office (GLO) surveyors in the early years of the 19th century. The locations of rivers, creeks, and swamps in the GLO notes and maps were plotted, checked against other information about valley landforms, and converted to an electronic GIS format. The paths of later river channels were taken from Corps of Engineers navigation charts.

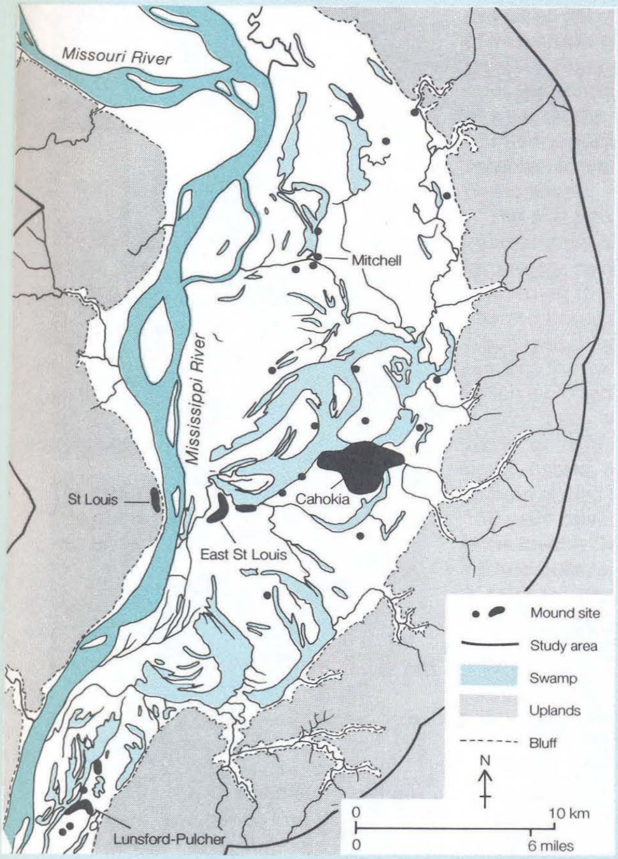
The natural landscape during Cahokia's heyday is being modeled by focusing first on one of the most important characteristics of the floodplain – the extent, disposition, and nature of the wetlands. By using various sources of information – GLO survey records, other early historical maps and descriptions of the valley, and modern maps and aerial photographs – it is possible to estimate the distribution of resources, and hence the attractiveness of different places.

The spatial arrangement of large and small settlements is being analyzed to identify the natural and social determinants of site positioning. The ecological settings of settlements can be studied by looking at the relative amounts of different kinds of land – dry ground, occasionally inundated areas, and permanent wetlands – within several kilometers of where people lived. For example, the largest sites are for the most part located on well-drained land adjacent to steep banks alongside permanent wetlands. People were therefore able to take advantage of dry land for farming and lakes for fishing. Settlement data complement information on subsistence practices: crops, particularly maize, and fish were mainstays of the diet.

The locations of prehistoric sites in relation to old channel scars indicate that in many places the river has remained within a relatively narrow corridor for the last thousand or more



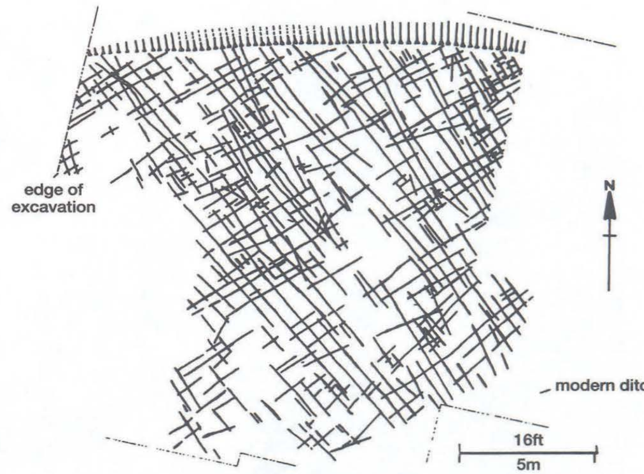
***Reconstruction** of the site of Cahokia and its environs, c. AD 1100.*



years. Elsewhere, however, the river has taken great bites out of the floodplain, destroying any possible evidence of prehistoric sites. So some gaps in settlement distribution may be nothing more than places where river movement has destroyed sites.

The GIS project has thus helped recreate the landscape of a thousand years ago and indicated the strong wetlands orientation of the settlement pattern of Cahokia's heyday – to be explained by the dietary importance of fish. The initial work is sufficiently encouraging to warrant further systematic study, including new archaeological and geomorphological fieldwork, to gain a better perspective on how the face of the land and the human use of this area changed over many thousands of years.

Cahokia was one of many mound centers scattered across part of the Mississippi floodplain known as the American Bottom. In the past it was covered by water for part or all of the year, the wetlands providing a valuable source of food.



A buried land surface revealed beneath the Neolithic burial mound at South Street, southern England. The criss-cross grooves in the soil were made by an ard, an early form of plow that does not turn the soil.

original soils and land surfaces beneath them, can reveal whether there was any cultivation before they were erected. Occasionally, archaeologists are even fortunate enough to uncover buried land surfaces that preserve marks made by plows or ards (ards score a furrow but do not turn the soil). The marks found beneath the Neolithic burial mound at South Street, England, are a good example. Although evidence from prehistoric Danish burial mounds suggest that these marks are not in fact functional (that is, produced in the course of soil cultivation) but are part of the mound-building ritual, they nevertheless provide an indication of the land management techniques available in different periods and on different soils.

Management of Woodland and Vegetation. Many of the techniques for analyzing plant remains, outlined earlier in the chapter, can be used to demonstrate human manipulation of woodland and vegetation generally.

Waterlogged wood, found abundantly in archaeological deposits in the Somerset Levels, England, by John and Bryony Coles, has been used by them to demonstrate the earliest known examples of systematic pollarding and coppicing, dating from about 4000 BC. The evidence consists of remains of thin poles of regular size, produced by cutting trees down to stumps and thus stimulating rapid growth of spring shoots and rods that could be harvested repeatedly. In coppicing, the poles are grown near the ground, while in pollarding the trunks are left some meters high to avoid the effects of grazing animals.

ANCIENT GARDENS AT KUK SWAMP

Kuk Swamp is a 283-ha (700-acre) property in the Wahgi Valley, near Mount Hagen, at an altitude of 1550 m (5084 ft) in the highlands of New Guinea. It contains features that have been interpreted as evidence of some of the world's oldest gardening practices.

The area lay underwater until drainage was begun for a Tea Research Station, giving opportunity in 1972 for a study to begin, led by Jack Golson and his colleagues. Air photographs had revealed that old ditch systems covered virtually the whole swamp. The widely spaced ditches dug for the new plantation, then and in later years, provided the researchers with many kilometers of cross-sections for stratigraphic study. Layers of ash found intermittently in the profiles from volcanic eruptions along the New Guinea north coast could be dated to provide the basis of a chronology. Swamp grasses were also cleared to reveal surface features such as 40 houses (some of which were excavated), and the filled outlines of old channels.

The investigations were seen as providing unequivocal evidence of five separate periods of agricultural use of the swamp back to *c.* 6000 years ago, in the form of large (up to 2 x 2 m or 6.5 x 6.5 ft wide) and long (over 750 m or 2450 ft) drainage channels and of distinctive gardening systems on each of the drained surfaces.

These five drainage episodes lay above a gray clay deposited between *c.* 9000 and *c.* 6000 years ago, which formed part of a fan deposit of sediments washed in from the southern catchment of the swamp. Beneath this clay was a set of features consisting of hollows, basins, and stakeholes associated with an undeniably artificial channel, which, by analogy, were seen as representing a sixth, older, phase of swamp gardening. Moreover, compared with the previous history of the swamp, the gray clay represented such a dramatic increase in the deposition of eroded materials that it was interpreted as marking the practice of a new dryland subsistence mode, that of shifting agriculture. The appearance of these innovations in the immediate wake of the climatic amelioration after the end of the Ice Age suggested that they were introduced fully formed from lower altitude, with a set of tropical cultigens – taro, some kinds of yam, and some of banana – which other evidence indicates were present in the New Guinea region.

Ul, a native New Guinean, displays a paddle-shaped wooden spade excavated from a drainage ditch.

***Intersecting drainage** ditches of various prehistoric periods.*

Interpreting the Evidence

These interpretations of Kuk must be evaluated in the light of recent results from pollen analysis in the highlands indicating widespread forest disturbance toward the end of the Ice Age associated with fire, and at one archaeological site, Kosipe, with a distinctive type of flake axe designed to be hafted. Together, this evidence is interpreted as indicating the opening up of rainforest to promote the growth of light-demanding plants, particularly the nut-producing *Pandanus*. It has been argued from this that the innovations at Kuk may be seen, not as the result of importations from lower altitudes, but rather as the product of the "forcing" of established strategies because of the rapidly changing climate at the very end of the Ice Age. There are uncertainties about exactly which plants were involved, and at what stage certain cultigens, like taro, yams, and bananas, would have appeared.

Similar uncertainties attach to another proposition – that the Kuk evidence for landscape modification through forest clearance and for swamp use through drainage is consistent with subsistence systems that have reached the stage of agriculture. Such systems include cultivation involving systematic environmental management and possibly domesticated plants, and even

Air view, looking north, showing large prehistoric drainage ditches together with smaller trenches defining a grid of gardens. All these features belong to the most recent systems at Kuk, ending in the 19th century. Two modern parallel drains of the Tea Research Station cut across the landscape from east to west.

***Clearing swamp** vegetation to expose surface features, such as houses and the outlines of old ditches.*

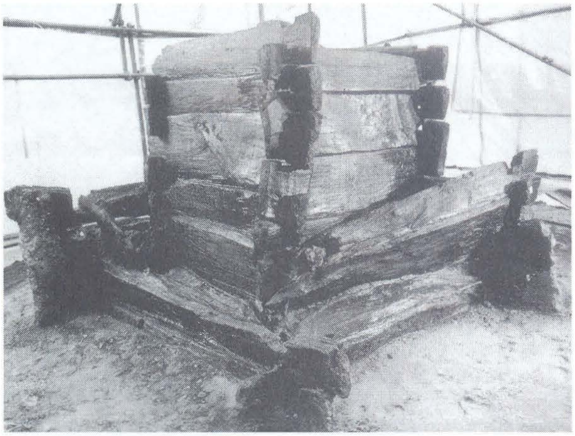
wild-food production involving environmental modification.

The standard interpretation of the evidence from the Kuk project is in fact built around the concept of such an environmental transformation, from forest to grassland. This transformation is seen as having been achieved about 2000 years ago as the result of the progressive deforestation revealed in the pollen record, which put at increasing risk a system of shifting cultivation dependent on forest fallow, with staple crops, assumed to be taro and yams, intolerant of degraded soils. This situation led to a series of innovations in agricultural technology designed to sustain the productivity of dryland cultivation in grassland environments, together with more continuous and intensive use of the swamp itself, which provided land of sustainable fertility at higher costs in labor. Agricultural production was required not only for humans but also now for pigs, which with deforestation and the loss of forest fauna became important as the major source of protein at the same time that their forest foraging ground was disappearing.

Recent results suggest that there were no pigs in the highlands 6000 years ago as originally thought and that they may have only arrived there following their Lapita-associated introduction into the Bismarck Archipelago *c.* 3500 years ago.

The agricultural sequence at Kuk ends with the arrival of the tropical American sweet potato in the New Guinea region a few hundred years ago as a result of Iberian explorations in island Southeast Asia. Today it is the dominant staple of most highland communities since it produces better at altitude than older crops, more readily tolerates poorer soils, and is prime pig fodder. It must be implicated, at least in part, in the abandonment of swamp cultivation at Kuk about a hundred years ago.

It was the recent tea-plantation ditches that helped initiate the project, but swamp drainage undertaken for commercial projects of this kind is now threatening the survival – both at Kuk and at similar sites in the region – of some of the world's oldest agricultural remains.



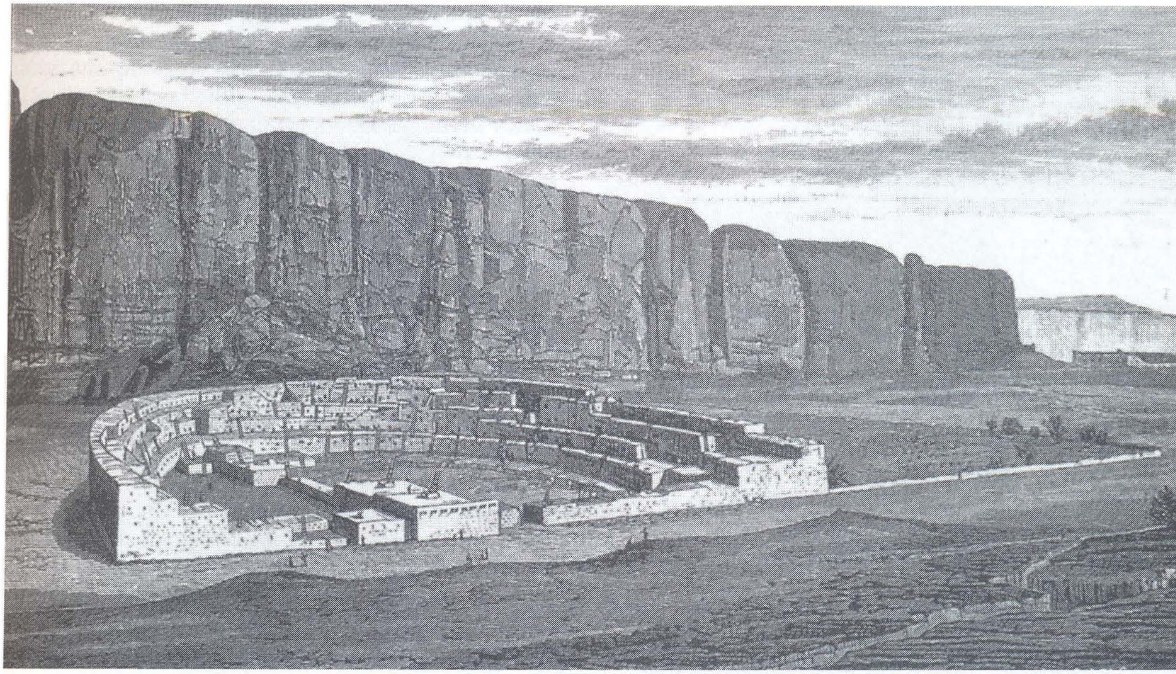
One important aspect of environmental management is the artificial provision of water, whether by storage cisterns, aqueducts, or simple wells. The wooden well-shaft of Kückhoven, Germany, was found on an LBK (Neolithic) site. This box frame of split oak planks, caulked with moss, was dated by dendrochronology to 5090 BC *(outer frame) and 5050* BC *(inner frame).*

Charcoal fragments have been discovered in turves used by Neolithic builders to construct a burial mound at Dalladies in Scotland. The presence of the charcoal indicated that the turves had been cut from grassland formed just after the burning of forest. It is also interesting to reflect on the fact that the farmers could sacrifice 7300 sq. m (8730 sq. yd) of this rich turf in order to build their monument.

Pollen analysis is another highly important method for demonstrating deliberate woodland clearance. The American scholar David Rue has analyzed pollen from cores taken near the Maya city of Copán, Honduras, and managed to trace the process of forest clearance and cultivation in the area. Since there is no evidence for any significant climatic change in the late postglacial of Central America, he could safely attribute the shifts in the pollen record to human activity. Clearings had been made in the forest using swidden (slash-and-burn) techniques and maize agriculture had begun apparently in the preceramic phase at least 4500 years ago. Forest clearance was intensified 1500 years later, and then maintained on a large scale until Copán was abandoned in AD 1200. These findings support not only the early dates from phytolith work (see earlier section) but also the view that ecological stress and soil degradation were probably important in the downfall of cities such as this. (In Chapter 12 we consider more generally the possible reasons for the collapse of cities and civilizations.)

It is known that the vegetation of much of Australia has been changed by the controlled burning practices of the Aborigines, who have managed the landscape in ways that prevent out-of-control bushfires, and create new environments that attract grazing animals with new shoots – although some scholars suspect that this destruction of vegetation could have stopped monsoon rains from penetrating inland, turning much of Australia's heartland into desert. Nevertheless, these techniques – dubbed "fire-stick farming" by the archaeologist Rhys Jones – are being reintroduced in Australian National Parks to prevent uncontrolled fires. There is controversial evidence from pollen that such practices may perhaps be traced back 130,000 years, whereas the earliest archaeological evidence for people in Australia is only about 50,000 years old. Gurdip Singh's studies of sediment cores from Lake George, New South Wales, revealed a period when there was a sudden increase in destructive bush fires, reflected in greatly increased quantities of charcoal, and coinciding with a sudden and dramatic change in vegetation, the first in 750,000 years, when fire-sensitive forests began to be replaced by the fire-tolerant eucalyptus, together with grasses. Singh placed the event at around 130,000 years ago from pollen diagrams in conjunction with results from deep-sea cores. Many scholars find the date – though not the event – archaeologically unacceptable. The archaeologist Richard Wright, for instance, through a simple correlation of age with depth in the lake cores, assigned the vegetation change to 60,000–54,000 years ago, a date far closer to the archaeologically agreed date for the earliest human presence in Australia. However, support for Singh has come from work by Peter Kershaw, who has found similar pollen and charcoal evidence dated to about 140,000 years ago in a 400-m (1300-ft) marine core on the continental shelf off the Queensland coast; the core spans 1.5 million years, and, unlike Lake George, its upper part is well dated. The decline of forest and rise of charcoal particles form the most dramatic change in the whole core, and have been tentatively attributed to human colonization.

Plant macroremains have also been used successfully together with other evidence to indicate woodland clearance. The Anasazi, one of the most advanced pre-Columbian societies in North America, erected buildings in Chaco Canyon, New Mexico, which were the largest and highest in that continent until the advent of the skyscraper. Construction began in the early 10th century AD, and it has been estimated that more than 200,000 pines and firs were needed for the timber. Recently, Julio Betancourt and his colleagues have examined plant macroremains at Chaco cemented into



Human impact on the environment at Chaco Canyon: the large number of trees cut down to build this Anasazi town of Pueblo Bonito brought about the transformation of the local environment and may have contributed to its eventual abandonment.

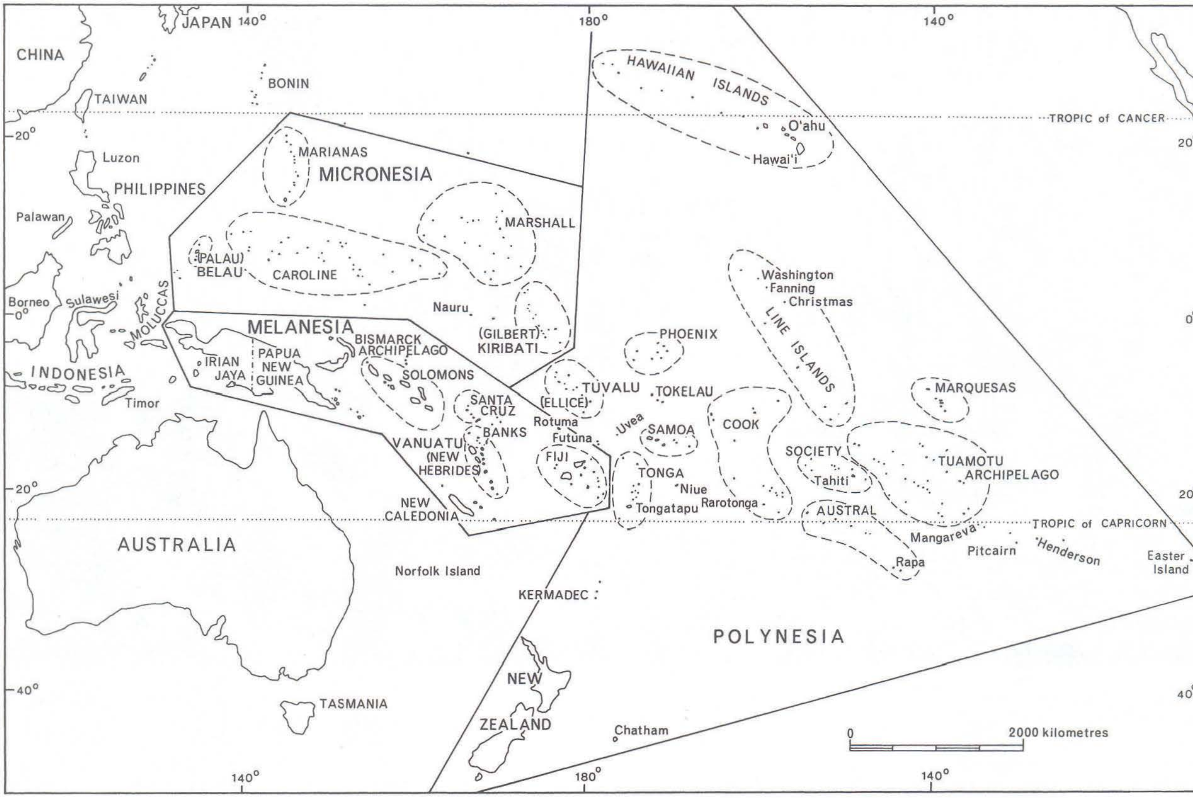
crystallized urine in ancient packrat middens that can be radiocarbon dated. Since packrats are known to gather plant materials from within 30 m (98 ft) of their dens, these fragments and their associated pollen have permitted the reconstruction of Chaco's vegetational history for the last 11,000 years.

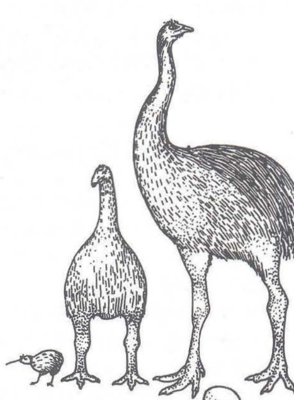
It appears that during the first two centuries of human occupation in Chaco Canyon, the piñon and juniper woodland of the surrounding clifftops was cleared for firewood for a radius of 20 km (12.5 miles). Only relentless woodcutting to meet the fuel demands of a growing population can explain this drastic reduction, because any climatic change in this period was within the range of climatic extremes of earlier millennia, when no such reduction occurred. Study of the timber in the buildings was also instructive: some of the ponderosa pine logs for construction had to be hauled from distances exceeding 40 km (25 miles); and, as the pines declined, the inhabitants began, in AD 1030, to fetch spruce and fir logs from over 75 km (46 miles) away. The environmental damage caused by all this activity was irreversible, and though tree-ring studies have suggested that a drought struck the final blow to the Chaco settlements, the inhabitants were clearly to blame to a large extent. Middens made by hyraxes (rodents found in Africa and the Middle East) have provided similar evidence that the ancient Byzantine city of Petra, Jordan, collapsed suddenly in AD 900 after centuries of drastic clearance of forests and shrubbery by the inhabitants.

Human Impact on Island Environments

The most devastating human impact on environments can be seen on islands to which settlers introduced new animals and plants. While some of these "transported landscapes" became exactly what the colonists required, others went tragically wrong.

The most notable examples are to be found in Polynesia. The first European explorers who came to these islands assumed that the environments they saw there had remained unchanged, despite the earlier colonization by Polynesians. This view was due in large measure to their paternalistic view of the natives as noble savages, innocents living in harmony with their surroundings like other animals. However, archaeologists can never assume that "what is must always have been so," and work over the last few decades has proved that the Polynesian settlers were only too human in their environmental depredations.





(Top) Human impact on island environments is particularly evident in the Pacific region, where human colonization came relatively late (map pp. 164–65), but often with devastating effect on indigenous plants and animals. Botanical and faunal evidence shows that human predation, deforestation, and newly introduced competitor species caused widespread destruction. (Above) In New Zealand, 13 species of the great flightless moa became extinct (two are shown, right, with the much smaller kiwi that still survives).

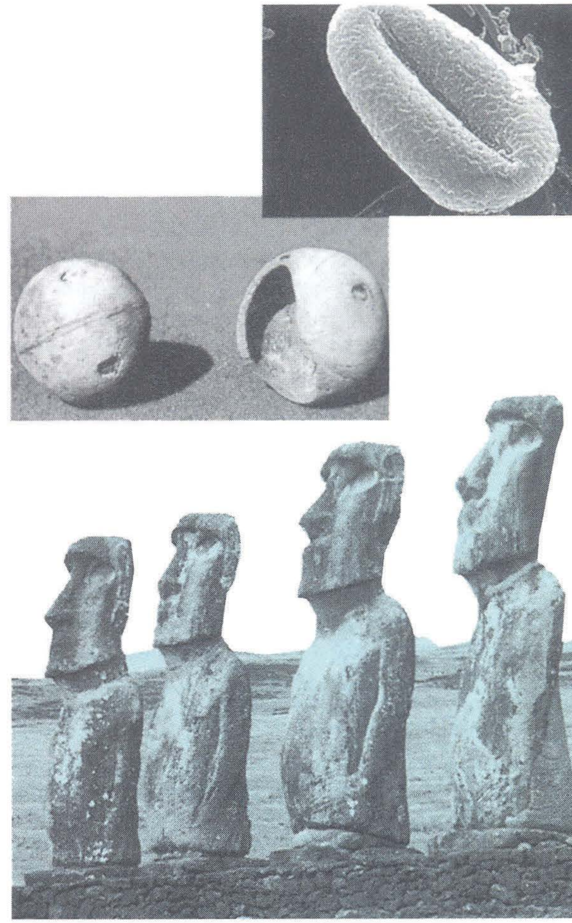
A combination of palynology, analysis of plant and animal macro- and micro-remains, and many of the other techniques outlined above has produced a dramatic picture of change. The first arrivals exploited the indigenous resources very heavily during their settling-in phase: the faunal record generally shows an immediate massive reduction in usable meat. For example, Patrick Kirch found that the remains of shellfish and turtle on Tikopia (Solomon Islands) quickly declined in both size and abundance. Most of these resources never recovered, and many were completely wiped out.

The chief cause of extinction was the range of new species introduced to the islands by the settlers. It was certainly necessary for them to bring some, since the islands generally had very few indigenous edible plants and animals. But in addition to the domestic pigs, dogs, and fowl, and the crop plants, they inadvertently brought stowaways such as the Polynesian rat, geckos, and all kinds of weeds and invertebrates (the rat may even have been brought intentionally). These new and highly competitive predators and weeds had drastic effects on the vulnerable island environments.

Rats, for example, must have killed native birds and their eggs, which, combined with human predation for meat and plumage, led to large-scale extinction. In Hawaii, dozens of indigenous bird species were wiped out very rapidly, while in New Zealand about 13 species of the great flightless moa disappeared, together with 16 other kinds of birds.

However, predation was only part of the picture; destruction of habitat was probably the major killer. Pollen, phytoliths, charcoal, and landsnails in Hawaii, New Zealand, and elsewhere combine to reveal a rapid and massive deforestation in the lowlands, producing open grassland in a few centuries. Not only did this have a drastic effect on vegetation and birds, it also eliminated hundreds of molluscan species. In addition, the clearing of vegetation from hillsides to make gardens led to greater erosion: some early sites are covered with meters of alluvium and slopewash.

In other words, people brought their own "landscapes" to these islands, and rapidly altered them both dramatically and irrevocably, both intentionally and accidentally. Analysis of the environmental history of this part of the world makes it plain that (apart from volcanic eruptions) natural catastrophes such as hurricanes, earthquakes, and tidal waves have not affected vegetation to any extent. The changes in landscape and resources have occurred only since the arrival of humans – less than 1000 years ago in New Zealand, 2000 years ago in Hawaii, 3000 years ago in Western Polynesia.



Human impact on Easter Island. This remote Pacific island has long been famous for its giant statues (above), but palynologists have only recently discovered that this now treeless environment had forests of large palms before human arrival (top right: palm pollen; top left: palm endocarps).

Easter Island. The ultimate example of this process of devastation occurred on Easter Island, the most isolated piece of inhabited land in the world. Here, the settlers wrought environmental damage that is perhaps unique both in its extent and in its cultural and social consequences. Analysis by the British palynologist John Flenley and his colleagues of pollen from cores taken from lakes in the volcanic craters of the island has revealed much of its vegetational history, and in particular the fact that until the arrival of humans in about AD 400 the island was covered with forest. The vegetation was probably dominated by a large palm tree, now extinct but closely related to the Chilean wine palm; not only has its pollen been identified, but a number of ancient endocarps (palm fruits, 820 years old) of this species have been recovered from caves on the island, and its root channels detected in the subsoil.

By the last century, every tree on Easter Island had been cut down, and grassland prevailed. The pollen record shows the decline of forest over the course of a millennium, and since nothing similar had occurred in the pollen record before AD 400 it is clear that people were responsible, even if a local drought or the Little Ice Age may have been contributing factors. It is likely that much of the wood was used for transporting the hundreds of giant statues on the island. In addition, people probably ate the palm fruits; and since those found have all been gnawed by rodents, it is certain that the Polynesian rat, introduced here as elsewhere by the settlers, also ate them. This will have prevented regeneration and thus aided the decline of the tree.

The total loss of timber had several effects. It was probably one of the major reasons for the relatively abrupt termination of statue carving in about AD 1680, because they could no longer be moved. In addition, it was no longer possible to make good canoes, which must have caused a radical decline in exploitation of fish, the main protein source apart from chickens. Deforestation also led to soil erosion (detectable in chemical analysis of the lake-cores) and lower crop yields through the loss of fertile forest soils. The most clearcut case of deforestation in the archaeological record led to starvation and cultural collapse, culminating after AD 1500 in slavery and constant warfare.

SUMMARY

To sum up, humankind has developed from being an inconsequential species at the mercy of the environment to one with a huge influence over its surroundings. The environment is of crucial importance to archaeology. During every period of the past it has played a vital role in determining where and how people could live. Archaeologists now have a battery of techniques to help reconstruct such past environments.

Environmental analysis is no longer undertaken simply to set the scene for particular periods of past human activity, to give some indication of the climate or a site's surroundings. Archaeology now strives to understand former environments in order to assess the key variables that might have influenced the operation of cultural systems. With early farming communities in riverine or estuarine environments, for instance, we need to ascertain not only the basic climate and soil types but also potentially crucial factors such as the extent of the arable area, the frequency of droughts, the pattern of flooding, the rate of silting, and any problems of drainage. The emphasis is no longer on individual sites in isolation, but on site systems, and on changing patterns of land-use through time.

Our present techniques may grant us only a partial and imperfect view of environmental change, but we are steadily developing improved methods, such as the use of Geographic Information Systems, and already we know far more than the early archaeologists could ever have dreamed possible.

FURTHER READING

General introductions to environmental archaeology can be found in the following:

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