Chapter 6

Time: Chronometric Dating

More effort has been devoted to inventing methods of chronometric dating in archaeology than to almost any other aspect of the subject (Bailey, 1983). The reason for this interest is that fundamental questions about the past are involved. How old is this tool? How long ago was that site occupied? Are these villages contemporary? These are probably the first questions asked by anyone curious about an artifact or a prehistoric village, as well as by the archaeologist. They remain among the most difficult to answer.

We now have an impressive array of chronological techniques for dating the past. Some have become well established and are reliable. Others, after a brief vogue, have been ejected into academic oblivion when someone discovers a fatal flaw. In practice, the huge span of human cultural history is dated by a number of scientific methods; the chronological span is shown in Figure 6.1. Potassium argon dating provides a somewhat generalized chronology for the first two-thirds of human history, its recent limits reaching up to some 20,000 years ago (it is less precise after 100,000 years). The other major radioactive technique, radiocarbon dating, covers a period from approximately 75,000 years ago up to as recently as A.D. 1500, when the standard errors become too large for the small time spans.

As for recent periods, historical documents provide a fairly accurate chronology for kings and political events going back more than five thousand years in the Near East and shorter periods elsewhere in the world. In the New World, prehistory ends with European settlement of the Americas in the fifteenth century. Frequently in these more recent periods, archaeology can be used in conjunction with historical

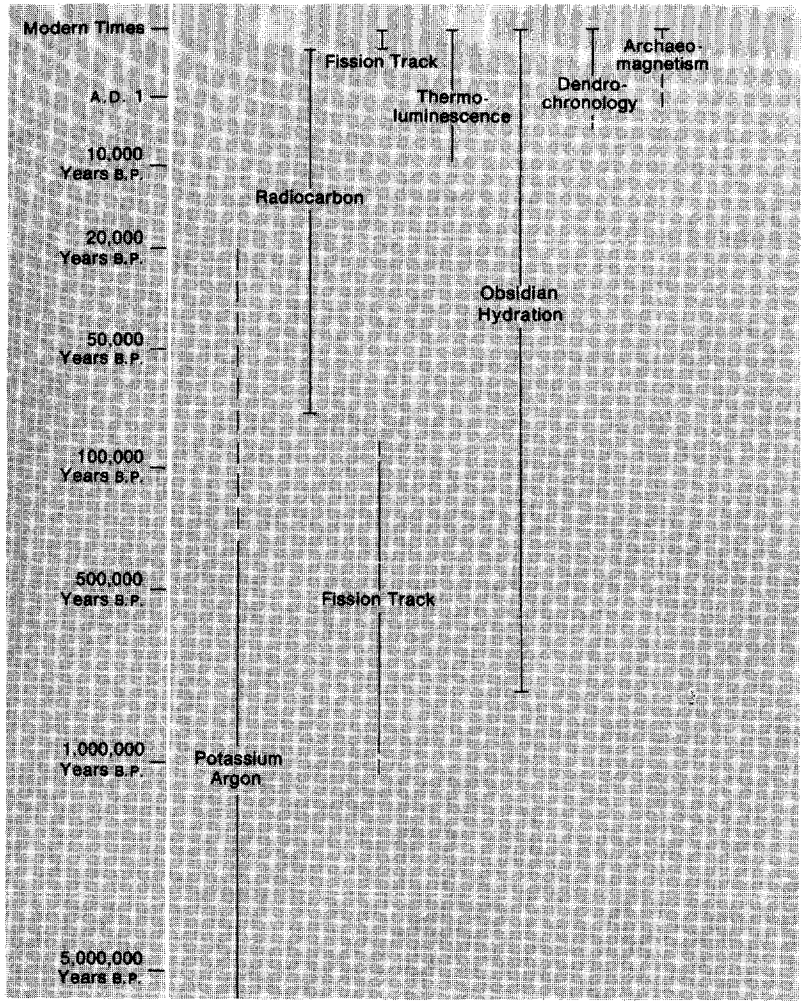

Figure 6.1 Chronological spans of major chronometric methods in archaeology. B.P.: "Before the present."

documents or oral records, which are covered by many other dating methods, including imported objects of known historical date and dendrochronology. Dates in years not only tell how old a site is but also illuminate the relationships among communities, cultures, or larger geographic or social units.

Let us now look at the principal methods of chronometric dating used to develop absolute chronologies for world prehistory. Our discussion starts with the chemical and physical methods used to date the earlier millennia of prehistory and ends in modern times with objects of known age.

POTASSIUM ARGON DATING

Principles

The only viable means of chronometrically dating the earliest archaeological sites is the potassium argon method (Dalrymple and Lamphere, 1970). Geologists use this radioactive counting technique to date rocks as much as 2 billion years old and as little as 10,000 years old. Potassium (K) is one of the most abundant elements in the earth's crust and is present in nearly every mineral. In its natural form, potassium contains a small proportion of radioactive potassium 40 atoms. For every hundred potassium 40 atoms that decay, eleven become argon 40, an inactive gas that can easily escape from its material by diffusion when lava and other igneous rocks are formed. As volcanic rock forms by crystallization, the concentration of argon 40 drops to almost nothing. But regular and reasonable decay of potassium 40 will continue, with a half-life of 1.3 billion years. It is possible, then, to measure with a spectrometer the concentration of argon 40 that has accumulated since the rock formed. Because many archaeological sites were occupied during a period when extensive volcanic activity occurred, especially in East Africa, it is possible to date them by associations of lava with human settlements.

Datable Materials and Procedures

Potassium argon dates have been obtained from many igneous minerals, of which the most resistant to later argon diffusion are biotite, muscovite, and sanidine. Microscopic examination of the rock is essential to eliminate the possibility of contamination by recrystallization and other processes. The samples are processed by crushing the rock, concentrating it, and treating it with hydrofluoric acid to remove any atmospheric argon from the sample. The various gases are then removed from the sample and the argon gas is isolated and subjected to mass spectrographic analysis. The age of the sample is then calculated using the argon 40 and potassium 40 content and a standard formula. The resulting date is quoted with a large standard deviation—for early Pleistocene sites, on the order of a quarter of a million years.

Archaeological Applications

Fortunately, many early human settlements in the Old World are found in volcanic areas, where such deposits as lava flows and tuffs are found in profusion.

The first archaeological date, and one of the most dramatic, obtained from this method came from Olduvai Gorge, Tanzania, where Louis and Mary Leakey found a long sequence of human culture extending over much of the Lower and Middle Pleistocene, associated with human fossils.

Olduvai, a jagged slash in the Serengeti Plains, was formed by movement and erosion of earth, exposing the beds of a long-forgotten Pleistocene lake overlying a layer of volcanic tuff. Early humans wandered around the shores of the lake; places they visited are preserved in the sides of the gorge, and their implements and broken animal bones lie where they were dropped by their owners, to be preserved under layers of fine lake silt. The remains of early humans have been found on these sites, associated with the tools and bones, together with lumps of lava. Some layers overlying the underlying sites have been dated by the potassium argon technique. Samples from the location where the first cranium of *Australopithecus boisei* was discovered were dated to about 1.75 million years (Figure 6.2) (Tobias, 1971). At the time, these and other nearly contemporary dates were a sensation, for most people had imagined that the Pleistocene began about a million years ago. With one discovery, humanity had almost doubled its antiquity. Even earlier dates have come from the Omo Valley in southern Ethiopia, where American, French, and Kenyan expeditions have investigated extensive Lower Pleistocene deposits long known for their rich fossil beds. Fragmentary australopithecines were found at several localities, but no trace of tools; potassium argon dates gave readings between two and four million years for deposits yielding hominid fossils. Tools were found in levels dated to about two million years. Stone flakes and chopping tools of undoubted human manufacture have come

Figure 6.2 Skull of *Australopithecus boisei*, with reconstructed jaw, from Bed I of Olduvai Gorge, Tanzania, potassium argon–dated to about 1.75 million years ago.

from Koobi Fora in northern Kenya, dated to about 1.85 million years, one of the earliest dates for human artifacts (Curtis, 1975).

Limitations

Potassium argon dates can be taken only from volcanic rocks, preferably from actual volcanic flows. The laboratory technique is so specialized that only a trained geologist should take the samples in the field. Archaeologically, it is obviously vital that the relationship between the lava being dated and the human settlement it purports to date be worked out carefully. The standard deviations for potassium argon dates are so large that greater accuracy is almost impossible to achieve.

Chronological Limits

Potassium argon dating is accurate from the origins of the earth up to about 100,000 years before the present.

RADIOCARBON DATING

Principles

Radiocarbon dating is the best known and most widely used of all chronometric dating methods. J. R. Arnold and W. F. Libby (1949) published a paper in *Science* describing the dating of organic samples from objects of known age by their radiocarbon content. The paper caused an archaeological furor, but once checked, it was soon applied to organic materials from prehistoric sites hitherto undatable by any reliable chronometric method. More than forty years have elapsed since the radiocarbon dating method became a regular part of the archaeologist's tool kit. For the first time we begin to have a world chronology for prehistory, based almost entirely on dates obtained by Libby's technique.

The radiocarbon dating method is based on the fact that cosmic radiation produces neutrons that enter the earth's atmosphere and react with nitrogen. They produce carbon 14, a carbon isotope with eight rather than the usual six neutrons in the nucleus. With these additional neutrons, the nucleus is unstable and is subject to gradual radioactive decay. Willard Libby calculated that it took 5,568 years for half the carbon 14 in any sample to decay, its so-called half-life. (The half-life is now more accurately measured to be 5,730 years.) He found that the neutrons emitted radioactive particles when they left the nucleus, and he arrived at a method for counting the number of emissions in a gram of carbon.

Carbon 14 is believed to behave exactly like ordinary carbon from a chemical standpoint, and together with ordinary carbon it enters into the carbon dioxide of the atmosphere. The tempo of the process corresponds

to the rates of supply and disintegration. Because living vegetation builds up its own organic matter by photosynthesis and by using atmospheric carbon dioxide, the proportion of radiocarbon present in it is equal to that in the atmosphere. As soon as an organism dies, no further radiocarbon is incorporated into it. The radiocarbon present in the dead organism will continue to disintegrate slowly, so that after 5,730 years only half the original amount will be left; after about 11,100 years, only a quarter; and so on. Thus if you measure the rate of disintegration of carbon 14 to nitrogen, you can get an idea of the age of the specimen being measured. The initial amount of radiocarbon in a sample is so small that the limit of detectability is soon reached. Samples earlier than 75,000 years contain only minuscule quantities of carbon 14 (Grootes, 1978).

Datable Materials and Procedures

Radiocarbon dates can be taken from samples of many organic materials. About a handful of charcoal, burnt bone, shell, hair, skin, wood, or other organic substance is needed. The samples themselves are collected with meticulous care during excavation from particular stratigraphic contexts so that an exact location, specific structure, or even a hearth is dated. Several dates must be taken from each level, because one or more may have been contaminated by a variety of factors. Modern rootlets, disturbances in the stratigraphy, and even packing with cotton wool or newspaper can introduce younger carbon into an ancient sample, although some of the more obvious contaminations are eliminated by careful laboratory treatment.

The first stage in the dating procedure is physical examination of the sample. The material is then converted into gas, purified to remove radioactive contaminants, and then piped into a proportional counter (Figure 6.3). The counter itself is sheltered from background radiation by massive iron shields. The sample is counted at least twice at intervals of about a week. The results of the count are then compared with a modern count sample, and the age of the sample is computed by a formula to produce the radiocarbon date and its statistical limit of error.

A date received from a radiocarbon dating laboratory is in this form:

3,621 ± 180 radiocarbon years before the present (B.P.)

The figure 3,621 is the age of the sample (in radiocarbon years) before the present. With all radiocarbon dates, A.D. 1950 is taken as the present by international agreement. Notice that the sample reads in *radiocarbon years,* not calendar years. Corrections must be applied to make this an absolute date.

The radiocarbon age has the reading ± 180 attached to it. This is the *standard deviation,* an estimate of the amount of probable error. The figure 180 years is an estimate of the 360-year range within which the date falls. Statistical theory provides that there is a 2 out of 3 chance that the

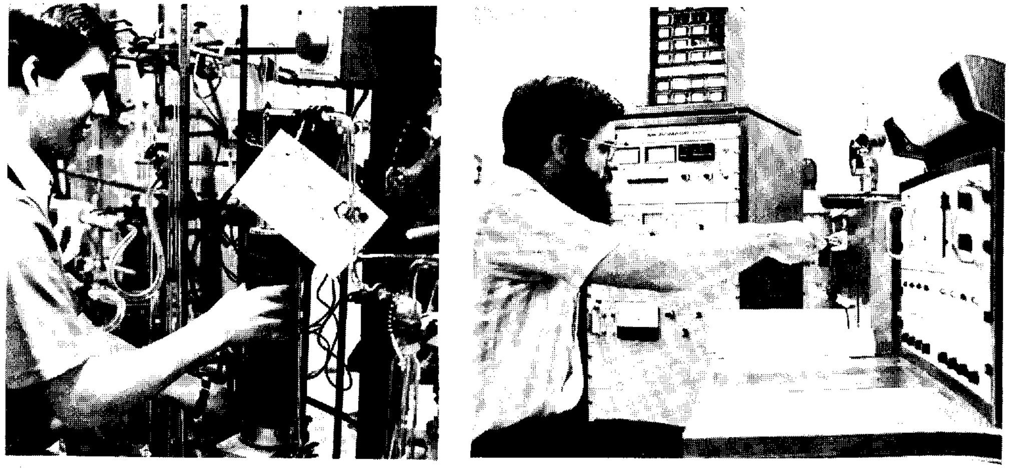

Figure 6.3 A radiocarbon laboratory at the University Museum, University of Pennsylvania. Left: The equipment used to purify the sample and convert it to gas. Right: The equipment used for measuring radioactivity.

correct date is between the span of one standard deviation (3,441 and 3,801). If we double the deviation, chances are 19 out of 20 that the span (3,261 and 3,981) is correct. Most dates in this book are derived from carbon 14–dated samples and should be recognized for what they are—statistical approximations.

The conventional radiocarbon method relies on measurements of a beta-ray decay rate to date the sample. A number of laboratories are now experimenting with an ultrasensitive mass spectrometer to count the individual carbon 14 atoms in a sample instead. This exciting new approach has numerous advantages and promises to overcome many disadvantages in the traditional method. One can date much smaller samples—as small as a fragment of straw in a potsherd—and the results will be more accurate than conventional readings. It takes only a few minutes to measure samples that hitherto took hours to study. The practical limits of radiocarbon dating with beta decay approaches are between 40,000 and 60,000 years.

Accelerator mass spectrometry allows radiocarbon dating to be carried out by direct counting of carbon 14 atoms, rather than by counting radioactive disintegrations (Gowlett, 1987). This has the advantage that samples up to 1/1,000 the size can be dated, especially for the time span between 10,000 and 30,000 years ago. Accelerator dating distinguishes between carbon 14 and carbon 12 and other ions through its mass and energy characteristics, requiring far smaller samples to do so. Even more important, the problem of background radiation is eliminated, and the sample sizes are the same for all time periods, the small quantity of organic material required allowing retesting if this proves necessary. The samples needed are so small that it is possible, for example, to date an individual tree ring or an actual artifact. The method is much faster, for relatively

modern samples can be dated within thirty minutes or so, as opposed to the many hours required for the conventional system.

Accelerator dating is especially useful for dating the amino acids from bone collagen, but almost any material can be dated, even tiny wood fragments preserved in the haft sockets of metal spearheads, for example. The technique has been used for dating Upper Paleolithic sites in Europe, where charcoal is rare, and is especially useful as a method for dating series of burials from mass graves and other circumstances where great precision is required. At present, about a third of all radiocarbon dates are coming from this new approach (Gillespie and others, 1984).

Archaeological Applications

Radiocarbon dates have been obtained from African hunter-gatherers' settlements as long as 50,000 years before the present, from Paleo-Indian bison kills in the American Plains, from early farming villages in the Near East and the Americas, and from cities and spectacular temples associated with early civilizations. The method can be applied to sites of almost any type where organic materials are found, provided that they date to between about 40,000 years ago and A.D. 1500.

Limitations

Radiocarbon dates can be obtained only from organic materials, which means that relatively few artifacts can be dated. But associated hearths with abundant charcoal, broken animal bones, and burnt wooden structures can be dated. Artifacts contemporary with such phenomena are obviously of the same age as the dated samples. The context of any dated sample has to be established beyond all doubt, and having a block of samples from the same division is preferable so that they can be treated statistically and tested for probable degree of accuracy. It is the moment of death of an organism that is dated. All radiocarbon dates are, of course, statistical computations and if uncalibrated, merely the radiocarbon age that is statistically most likely.

Calibration of Radiocarbon Dates

Just when archaeologists thought they had found an accurate and reliable means for dating the past, radiocarbon dates for tree rings of the California bristlecone pine were published. The readings were consistently younger for trees before 1200 B.C. because Libby made a false assumption when he originally formulated the radiocarbon method. He had argued that the concentration of radiocarbon in the atmosphere remained constant as time passed, so that prehistoric samples, when alive, would have contained the same amount of radiocarbon as living things today.

In fact, changes in the strength of the earth's magnetic field and alterations in solar activity have considerably varied the concentration of radiocarbon in the atmosphere and in living things. Thus samples of six thousand years ago were exposed to a much higher concentration than are living things today. It is possible, fortunately, to correct radiocarbon dates by using accurate dates from tree rings. Since 1966, dendrochronology experts have been systematically applying radiocarbon analysis to tree-ring samples of known age and have plotted calibration curves, which are used for converting radiocarbon dates into actual dates in years. A task force of radiocarbon experts has recently produced tables that match radiocarbon ages with calibrated dates (Klein and others, 1982). This tool is likely to receive universal acceptance in coming years; it calibrates dates between A.D. 1950 and 6500 B.C. The discrepancies between radiocarbon and calibrated dates are wide. Here is an example: 10 B.C. ± 30 has a calibrated interval of 145 B.C. to A.D. 210. British archaeologist Colin Renfrew calibrated radiocarbon dates for European prehistory some years ago. He claimed that, as a result, many long-accepted chronological relationships are now reversed (Renfrew, 1971). According to him, the famous megalithic stonebuilt tombs of western Europe are older than the pyramids of Egypt, supposedly their predecessors. The final layout of Stonehenge (the complex of prehistoric stone circles in southern Britain) constructed in 1600 B.C., was originally thought to have been inspired by Mycenaean designs. When the calibrated dates were released, it was found that the earliest stages of Stonehenge dated to before 1800 B.C., much older than the Mycenaean civilization in question. The new, calibrated radiocarbon chronology for Europe, argues Renfrew, allows us to think of distinctive European societies that developed their own institutions without the Oriental influence favored by so many archaeologists. Few prehistorians jumped so whole-heartedly into the new chronologies as Renfrew, but widespread calibration of radiocarbon dates is certain to be a reality within a few years. In the meantime, most people think of radiocarbon dates as nothing more than *radiocarbon ages,* not dates in actual years. Earlier dates are still uncalibrated, but recently scientists have used a new, highly accurate technique based on the decay of uranium into thorium to date fossil coral near Barbados in the Caribbean. They compared these dates to radiocarbon results, and found that dates between 10,000 and 30,000 years ago may be as much as 3,500 years too recent. Earlier radiocarbon ages, then, are of unknown accuracy, but the new coral researches may provide more accurate chronologies for much of the late Ice Age in the future.

Chronological Limits

Carbon 14 dating is accurate from around 40,000 years B.P. to A.D. 1500.

FISSION TRACK DATING

Principles

Fission track dating is a new chronometric method that promises to have important archaeological applications in the future. The principle of the

method is that many minerals and natural glasses, such as obsidian, contain very small quantities of uranium that undergo slow, spontaneous decay. Most uranium atoms decay by emitting alpha particles, but spontaneous fission causes the decay of about one atom in every two million, the fission decay rate and its extent are constant, and the date of any mineral containing uranium can be obtained by measuring the amount of uranium in the sample, which is done by counting the *fission tracks* in the material. These tracks are narrow trails of damage in the material caused by fragmentation of massive, energy-charged particles. The older the sample, the more tracks it has. It is possible to examine fission tracks under high magnification and to calculate the sample's age by establishing the ratio between the density of the tracks and the uranium content of the sample.

Datable Materials and Procedures

Two counts of fission tracks are needed for each sample. The materials used, which must have a high uranium content, can be either volcanic rock, as in lava flows that originated more recently than the beginnings of prehistory, or manufactured materials, such as certain types of artificial glass. In rocks, it is the time of origin of the rocks that is being dated, not the time of their utilization. An optical microscope is used to examine the tracks in the sample, which have first been etched with hydrofluoric acid. This procedure enlarges the tracks to make them more visible. The first count establishes the density of the tracks; the second, by inducing fission of uranium 235 through neutron irradiation, makes a count of the uranium content in the sample. The age of the sample is the ratio of the number of observed tracks resulting from natural fission to those resulting from induced fission.

Archaeological Applications

The fission track dating technique is still new to archaeology, but it promises to become a fairly precise means of dating samples between 100,000 and one million years old. The method can be used to date many mineralogical materials, but in archaeology it is applicable only to sites that were subjected to volcanic activity just before, during, or shortly after occupation. Sites overlain or underlain by lava can be given upper or lower age limits by dating the lava. Because many early sites are found in volcanic areas, such as the Great Rift Valley of East Africa, the method has obvious applications.

Few results from the fission track method have been published, but volcanic pumice from Bed I at Olduvai Gorge, where the early hominid fossils were found, was dated to 2.03 ± 0.28 million by the fission track method. This reading was in reasonably close agreement with Leakey's original date of about 1.8 million years, obtained from potassium argon readings for the same stratum. Modern manufactured glass with high uranium content, used to make a nineteenth-century candlestick, has been dated accurately to the last century (Brill, 1964; Fleischer, 1975).

Limitations

The limitations of fission track dating are much the same as those of potassium argon dating. Only volcanic rocks contemporary with a human settlement and formed at the time the site was occupied can be used.

Chronological Limits

Fission track dating is accurate from one million to 100,000 years before the present. Some limited application to historic artifacts is possible as well.

OBSIDIAN HYDRATION

Principles

Obsidian is a natural glass substance formed by volcanic activity. It has long been prized for its sharp edges and other excellent qualities for toolmaking. Projectile heads, hand axes, blades, and even mirrors were made from this widely traded material in both the New World and the Old. A new dating method makes use of the fact that a freshly made surface of obsidian (and no other known artifact material) will absorb water from its surroundings, forming a measurable *hydration layer* that is invisible to the naked eye. Because the freshly exposed surface has a strong affinity for water, it keeps absorbing until it is saturated with a layer of water molecules. These molecules then slowly diffuse into the body of the obsidian. This hydration zone contains about 3.5 percent water, increasing the density of the layer and allowing it to be measured accurately under polarized light. Each time a freshly fractured surface is prepared, as when a tool is being made, the hydration begins again from scratch. Thus the depth of hydration achieved represents the time since the object was manufactured or used (Leute, 1987).

Hydration is observed with microscopically thin sections of obsidian sliced from artifacts and ground down to about .003 inch. The thickness of the layer is measured through the microscope at eight spots, the mean value being calibrated into units of microns (micrometers). These thickness readings can be used in both absolute and relative chronologies (Taylor and Meighan, 1978; Friedman and Trembour, 1983). Unfortunately, this promising dating method has some problems, mostly because we still do not fully understand hydration. Little is known about how temperature changes or chemical composition affect hydration, and so it is impossible to use the method without calibrating it against tree-ring dates or some other established archaeological procedure. Researchers are working hard to solve these problems so that obsidian hydration can become an economical and widely applicable dating method in the future.

Archaeological Applications

Obsidian hydration is a useful way of ordering large numbers of artifacts in relative series, simply by positioning each in the series according to its micron reading, such as 1.5 or 2.0. Provided one has control over such constants as chemical composition, one can place artifacts in order with great precision. This approach was first tried at the Mammoth Junction site in Colorado, which served not only as a quarry site but also as a residential settlement and hunting station. By assigning some 450 artifacts such as projectile heads and scrapers positions in a series, the investigators were able to find the order in which 37 types of projectile point came into fashion and disappeared. The chronological data could be linked to attributes like weight or length: all six of the latest styles weighed less than a gram, as if they had been used not for spears but for much lighter arrows.

Obsidian hydration is extremely useful for sorting out the cultural content of sites like shell middens, in which the stratigraphic layers are often indistinct and the site is excavated in arbitrary levels. By plotting the hydration values from obsidian artifacts against the excavated layers on a three-dimensional scatter diagram, you can sometimes identify how much the arbitrary excavation has mixed artifacts from different levels. Another possible application has researchers using hydration readings to associate artifacts found on a living surface with one another in groups. Using arbitrary ranges of hydration readings, say, 1.5 to 1.9, one can group obsidian tools into units useful for analysis, with little or no possibility of contamination with other tools. This technique is particularly useful on surface sites.

Applications of obsidian hydration to chronometric chronology are still in their infancy (Meighan, 1983). If one can determine the rate of hydration in a population of artifacts, there is a chance that one can assign each artifact a date in years. More than two thousand obsidian dates were obtained from 520 test trenches at the city of Kaminaljuyu in Guatemala. These, and a further two thousand samples from surrounding sites, were used to piece together dozens of phases in the complicated residential history of the site and its satellite communities. Many of the dated artifacts came from surface sites, where they were the only possible source of chronological information. The same approach was used at the Aztec site of Chiconautla in the Basin of Mexico. This was known to be an important Aztec community. But the excavators were able to use obsidian hydration to show that the large numbers of rasp-ended scrapers found at Chiconautla were in fact used for maguey cactus cultivation long before the Aztec community flourished on the site (Michels and Tsong, 1980).

Limitations

Obsidian hydration is potentially as useful as radiocarbon dating, but it still suffers from grave limitations, especially when dealing with very early sites. Obsidian itself is of very limited distribution. Hydration layers more than 50 microns thick are known to "peel off," and reaching this thickness may take longer in some areas than others. Many of the world's earliest archaeological sites have yielded obsidian, and the method has been tried experimentally with East African settlements 300,000 to 780,000 years old. Should the method be validated for sites this old, it will have far wider application than potassium argon and radiocarbon dating.

Chronological Limits

The reach of hydration dating is from recent times to perhaps 800,000 years ago. Until such chronometric dating methods as potassium argon, fission track, and radiocarbon were available, the chronology of major events in the Pleistocene epoch was mostly uncertain, despite many efforts to develop viable time scales.

THERMOLUMINESCENCE

Principles, Datable Materials, and Procedures

Thermoluminescence, a method with a formidable-sounding name for dating pottery, is still in the developmental stage (Aitken, 1984; Fleming, 1976, 1979). It has much promise and may one day provide absolute dating even for isolated potsherds. The principle is simple. The materials from which pottery is made have the property of storing energy by trapping electrons as atomic defects or impurity sites. This stored energy can be released by heating the pottery, at which time visible light rays, known as thermoluminescence, are emitted. All pottery and ceramics contain some radioactive impurities at a concentration of several parts per million. These materials emit alpha particles at a known rate, depending on how densely concentrated they are in the sample. When an alpha particle is absorbed by the pottery minerals around the radioactive impurities, it causes mineral atoms to ionize. Electrons are then released from their binding to the nuclei and later settle at a metastable (relatively unstable) stage of higher energy. This energy is stored, unless the parent material is heated—as when the pot is being fired—when the trapped electrons are released and thermoluminescence occurs. After the pot is fired, alpha particles are again absorbed by the material, and the thermoluminescene potential increases until the pot is heated again. Thus a clay vessel is dated by measuring the thermoluminescence of the sample, as well as its alpha-radioactivity and its potential susceptibility to producing thermoluminescence. In the laboratory, the trapped electrons are released from a powdered pottery fragment by sudden and violent heating under controlled conditions.

Archaeological Applications and Limitations

Thermoluminescence has been used with reasonable success to date heat-altered stone tools, burned hearths, and pottery. As with other dating methods, results have been obtained initially from vessels of known age; because of these results, several investigators claim accuracies of ±10 percent for prehistoric dates; other proponents of the method are more cautious, however. Exciting possibilities are emerging from experiments with dating Ice Age sediments such as loess (Chapter 5), some in contexts where there are associations with Stone Age artifacts.

DENDROCHRONOLOGY

Principles

Dendrochronology, or tree-ring dating, was originated in Arizona by A. E. Douglass in about 1913 (Bannister, 1969). The idea of using tree rings as a method for dating archaeological sites is much older, however. As early as 1788, the Reverend Manasseh Cutler was counting the rings in trees growing on archaeological sites near Marietta, Ohio, and suggested that the site he was studying was about a thousand years old. But the prehistoric time scale established from tree rings goes back much further into the past, especially in the Southwest, where it has been applied successfully to wooden beams in ancient pueblos preserved by dry desert conditions. Both the slow-growing sequoia and the California bristlecone pine *(Pinus aristata)* provide long tree-ring sequences, the latter a continuous chronology of 8,200 years. One pine tree 4,900 years old has been reported.

Everyone is familiar with tree rings, the concentric circles, each circle representing annual growth, visible on the cross-section of a felled trunk. These rings are formed on all trees but especially where seasonal changes in weather are marked, with either a wet and dry season or a definite alternation of summer and winter temperatures. As a rule, trees produce growth rings each year, formed by the cambium, or growth layer, lying between the wood and the bark. When the growing season starts, large cells are added to the wood. These cells become thicker-walled and smaller as the growing season progresses; by the end of the growth season, cell production has ceased altogether. This process occurs every growing year, and a distinct line is formed between the wood of the previous season, with its small cells, and the wood of the next, with its new, large cells. The thickness of each ring may vary according to the tree's age and annual climatic variations, thick rings being characteristic of good growth years.

Weather variations within a circumscribed area tend to run in cycles.

A decade of wet years may be followed by five dry decades. One season may bring a forty-year rainfall record. These cycles of climate are reflected in patterns of thicker or thinner rings, which are repeated from tree to tree within a limited area. Dendrochronologists have invented sophisticated methods of correlating rings from different trees so that they build up long sequences of rings from a number of trunks that may extend over many centuries (Figure 6.4). By using modern trees, whose date of felling is known, they are able to reconstruct accurate dating as far back as 8,200 years. Actual applications to archaeological wood are much harder, but archaeological chronology for the American Southwest now goes back to 322 B.C.

Datable Materials and Procedures

The most common dated tree is the Douglas fir. It has consistent rings that are easy to read and was much used in prehistoric buildings. Piñon and sagebrush are usable, too. Because the latter was commonly used as firewood, its charred remains are of special archaeological interest. The location of the sample tree is important. Trees growing on well-drained, gently sloping soils are best, for their rings display sufficient annual variation to make them more easily datable. The rings of trees in places with permanently abundant water supplies are too regular to be usable.

Samples are normally collected by cutting a full cross-section from an old beam no longer in a structure, by using a special core borer to obtain samples from beams still in a building, or by V-cutting exceptionally large logs. Delicate or brittle samples are impregnated with paraffin or coated with shellac before examination.

Once in the laboratory, the surface of the sample is leveled to a precise plane. Analyzing tree rings consists of recording individual ring series and then comparing them against other series. Comparisons can be made by eye or by plotting the rings on a uniform scale so that one series can be compared with another. The series so plotted can then be matched with the master tree-ring chronology for the region. Measuring the tree rings accurately can also add precision to the plottings.

Archaeological Applications

Extremely accurate chronologies for southwestern sites have been achieved by correlating a master tree-ring sequence from felled trees and dated structures with beams from Indian pueblos. The beams in many such structures have been used again and again, and thus some are very much older than the houses in which they were most recently used for support. The earliest tree rings obtained from such settlements date to the first century B.C., but most timbers were in use between A.D. 1000 and historic times.

One of the most remarkable applications of tree-ring dating was car-

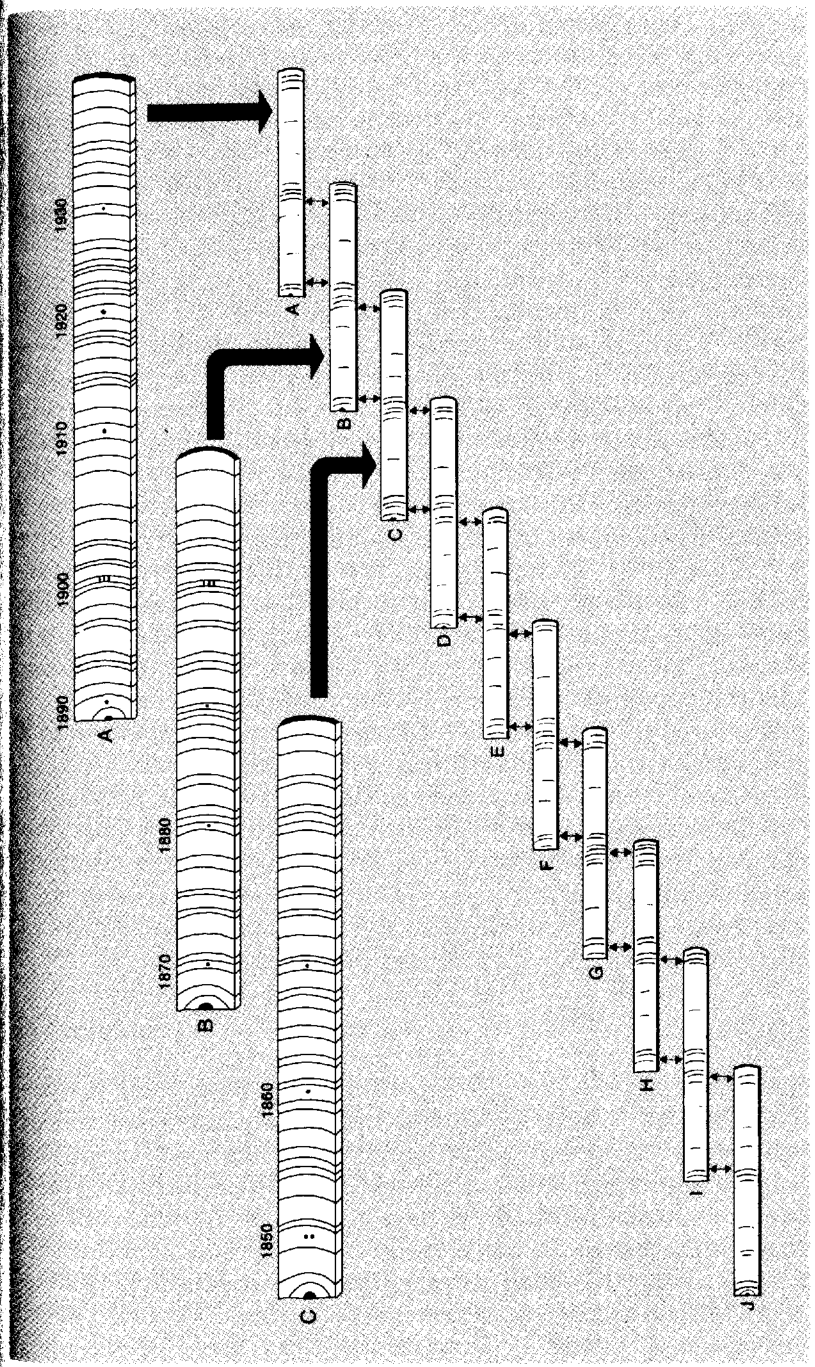

Figure 6.4 Building a tree-ring chronology: A shows a boring taken from a living tree after the 1939 growing season; B through J are specimens taken from old houses and progressively older ruins. The ring patterns match and overlap back into the past.

ried out by Jeffrey Dean (1970), who collected numerous samples from wooden beams at Betatakin, a cliff dwelling in northeastern Arizona dating to A.D. 1270. Dean ended up with no fewer than 292 samples, which he used to reconstruct a history of the cliff dwelling, room by room. He found that three room clusters were built in 1267, and a fourth was added a year later. In 1269 the inhabitants trimmed and stockpiled beams for later use. These beams were not actually used until 1275, when ten more room clusters were added to Betatakin. Dean also found that the site was abandoned between 1286 and 1300. Such intrasite datings are possible only when a large number of samples can be found.

Dendrochronology has been used widely in Alaska, the Mississippi Valley, northern Mexico, Canada, Scandinavia, Ireland, the British Isles, Greece, and Germany (Bannister and Robinson, 1975; Baillie, 1982). Recent European research has been especially successful. What the bristlecone pine is to the Southwest, oaks are to Europe. European tree-ring experts have collected large numbers of tree-ring records from oaks that have lived for 150 years or so. By visual and statistical comparison, they have linked living trees to ancient ones from bogs and prehistoric sites and also to farmhouse and church beams, providing a tree-ring sequence that goes back 7,272 years in Northern Ireland and six thousand years in Germany (Pitcher and others, 1984). This means that radiocarbon dates throughout Europe can now be calibrated to as early as 5200 B.C. Dutch tree-ring experts have even tried dating the oak panels used by old masters for their oil paintings as a way of authenticating works of art!

Arizona tree-ring laboratories are trying to analyze data on annual variability in rainfall from the many trees encompassed by their chronologies. A network of archaeological and modern chronologies provides a basis for reconstructing changing climatic conditions over the past two thousand years. These conditions will be compared with the complex events in southwestern prehistory over the same period (Fritts, 1976). And as mentioned earlier, radiocarbon dates are calibrated with the aid of dendrochronology.

Limitations

Dendrochronology has traditionally been limited to areas with well-defined seasonal rainfall. Where the climate is generally humid or cold or where trees enjoy a constant water supply, the difference in annual growth rings is either blurred or insignificant. Again, the context in which the archaeological tree-ring sample is found affects the usefulness of the sample. Many house beams have been reused several times, and the outside surface of the log has been trimmed repeatedly. The felling date cannot be established accurately without carefully observing the context and archaeological association of the beam. For this reason, several dates must be obtained from each site. Artifacts found in a structure whose beams are dated do not necessarily belong to the same period, for the house may have been used over several generations. Like any other chronometric dating method, dendrochronology requires meticulous on-site observations and very careful collection of samples.

Chronological Range

Dendrochronology is accurate from approximately seven thousand years ago to the present, with wider application possible. Nonarchaeological tree-ring dates extend back 8,200 years.

ARCHAEOMAGNETIC DATING

The study of paleomagnetism has revolutionized geology in recent years, confirming theories of continental drift and showing that the earth's geomagnetic field has reversed its polarity many times in the past. By dating unoriented samples of fired clay, it may one day be possible to date sites at least 10,000 years old, perhaps much earlier. This type of *paleointensity dating* has the potential for dating potsherds, among the most common of all archaeological finds (Wolfman, 1984), but has not yet been widely used.

In the past twenty-five years, information on polarity has been recorded from stratified rocks up to a billion years old. These igneous (volcanic) rocks are independently dated by potassium argon methods, providing a relatively accurate polarity scale for the world over the past five million years. The current epoch of normal polarity is called the Brunhes and began about 700,000 years ago. As research into archaeological applications of paleointensity dating accelerates, we can expect some dramatic results, especially from more recent sites where pottery is to be found.

Archaeomagnetic dating has a much shorter time frame and is based on measurements of secular variation in fired clays.

Principles

We know that the direction and intensity of the earth's magnetic field varied throughout prehistoric time. Many clays and clay soils contain magnetic minerals, which when heated to a dull red heat will assume the direction and intensity of the earth's magnetic field at the moment of heating. Thus if the changes in the earth's magnetic field have been recorded over centuries, or even millennia, it is possible to date any suitable sample of clay material known to have been heated by correlating the thermoremanent magnetism of the heated clay with records of the earth's magnetic field (Figure 6.5) (Traling, 1983; Wolfman, 1984). Archaeologists frequently discover structures with well-baked clay floors—ovens, kilns, and iron-smelting furnaces, to name only a few—whose burned clay can

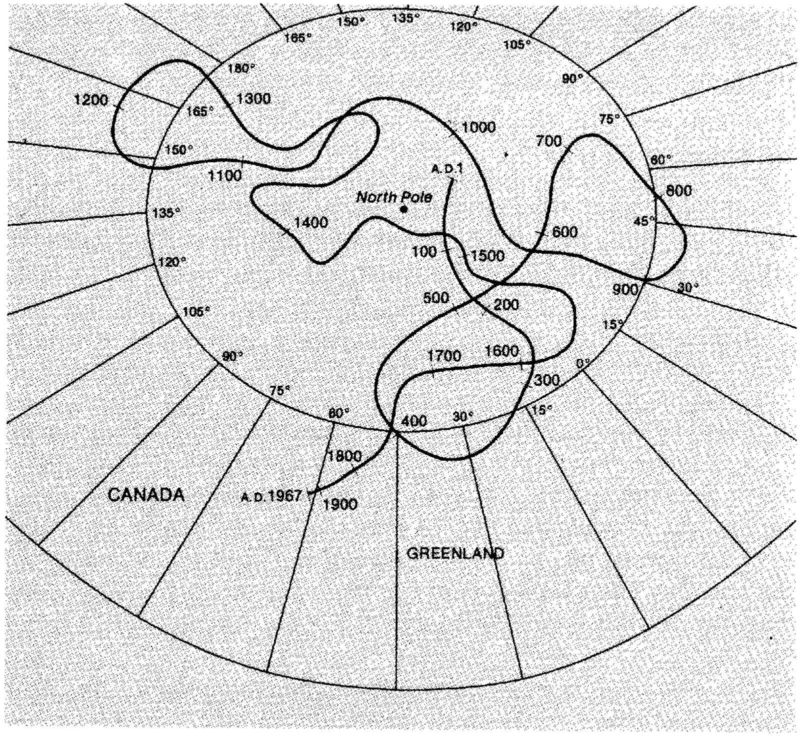

Figure 6.5 Meandering of the geomagnetic North Pole, worked out over a period of two thousand years.

be used for archaeomagnetic dating. Of course, reheated clays (clays used again after their original heating) will change their magnetic readings and are thus useless for archaeomagnetic dating.

Thermoremanent magnetism results from the ferromagnetism of magnetite and hematite, minerals found in significant quantities in most soils. When the soil containing these minerals is heated, the magnetic particles in magnetite and hematite change from a random alignment to one that conforms with that of the earth's magnetic field. In effect, the heated lump of clay becomes a very weak magnet that can be measured by a parastatic magnetometer. A record of the magnetic declination and dip similar to that of the earth's actual magnetic field at the time of heating is preserved in the clay lump. The alignment of the magnetic particles fixed by heating is called thermoremanent magnetism.

Datable Materials and Procedures

Selecting a kiln or other baked structure for magnetic dating is far from straightforward. Substantial floors of well-baked clay are best for the pur-

pose. Tiny pillars of burnt clay that will fit into a brass-framed extraction jig are extracted from the floor. The jig is oriented to present-day north-south and fitted over the pillars, which are then encapsulated in melted dental plaster. The jig and pillar are carefully removed from the floor, and then the other side of the jig is covered with dental plaster as well. The clay sample is placed under suspended magnets and rotated. The scale will record the declination and dip of the remanent magnetism in the clay.

An absolute date for the sample can then be obtained if the long-term, or *secular,* variation of the earth's field for the region is known.

Archaeological Applications and Limitations

From the archaeological point of view, archaeomagnetism has but limited application because systematic records of the secular variation in the earth's magnetic field have been kept for only a few areas. Declination and dip have been recorded in London for four hundred years, and a very accurate record of variations covers the period from A.D. 1600. France, Germany, Japan, and the southwestern United States have received some attention. From the last, clay samples associated directly with dendrochronological or radiocarbon samples have been tested, with one set of readings from sixteen pre-Columbian villages extending back almost two thousand years. At the moment the method is limited, but as local variation curves are recorded from more areas, archaeomagnetism is likely to be far more useful for the more recent periods of prehistory, when kilns and other burned-clay features were in use.

Chronological Range

Archaeomagnetic dating is potentially useful from two thousand years ago to the present. (For a detailed analysis, see Wolfman, 1984.)

CALENDARS AND OBJECTS OF KNOWN AGE

Calendars

A calendar developed by an ancient civilization provides an excellent way of dating archaeological sites, if the calendar can be linked to our own chronology (Aveni and Brotherston, 1983). The Mesopotamians and the ancient Egyptians fashioned sophisticated calendars, and the Maya of the Yucatán had a calendric system that is justly admired (Hammond, 1982). Calendars were used to regulate the agricultural and religious year in Egypt and Mesopotamia and were vital in organizing secular and religious life in the Yucatán.

The Maya used both a 365-day secular calendar and a 260-day religious calendar for timing religious ceremonies (Figure 6.6). Their system of

Figure 6.6 Many Mayan *stelae* (carved stone monuments) record important dates in the lives of their rulers. This stela carries a date equivalent to A.D. 771.

dating their own civilization in years started from a mythical date long before their own society was in being. Known as the Long Count, the system is recorded on many stelae, along with inscriptions that signal important events or transfer of priestly power. Attempts that have been made to link the Long Count and the Christian calendar place the span of the Mayan calendar from about 3113 B.C. to A.D. 889. Much of this time is, of course, long before the Maya themselves were a fully fledged state. But the Long Count stelae are a useful check on the dates of such well-known Mayan sites as Tikal and Palenque.

The most reliable chronometric dates are, of course, those obtained from historical documentation of archaeological sites. We know that King Henry VIII began to build his palace at Nonsuch, England, in A.D. 1538, as well as the chronology of Plimoth Plantation in Massachusetts, from contemporary records, and our primary interest lies in discovering details of settlement layout or day-to-day life. Many later sites yield easily dated artifacts, such as coins dropped by the inhabitants on the floors of buildings or elsewhere in the settlement's strata. Such objects can provide accurate dates for the earliest age of the archaeological sites being investigated.

Objects of Known Age

Objects of known age found in African, North American, and European prehistoric sites include a bewildering array of artifacts, from dated coins and glass bottles to Chinese porcelain and all manner of imported ceramics. The latter include American domestic tableware, English imported china, and Spanish majolica vessels in historic sites in North America. Ivor Noël Hume (1969) has compiled an extremely valuable compendium of artifacts from Colonial America that is a useful source book for anyone interested in such objects. Some of these types of finds can act as artifacts for cross-dating prehistoric sites.

One of the most useful Colonial American artifacts is the imported English kaolin pipe (Figure 6.7). Not only were pipes manufactured, imported, smoked, and thrown away within a very short time, but also the shape of the pipe body changed in an easily recognizable evolutionary chain. Clay pipes were so cheap that everyone, however poor, used and discarded them almost like cigarettes. Not only the bowl but the length of the stem and the diameter of the hole changed between A.D. 1620 and 1800, and these characteristics have been used to date these artifacts and the sites associated with them with considerable precision.

Stanley South and others have used statistical techniques to study the relationships between eighteenth-century English imported pottery and historic sites in North Carolina. They argued that once enough percentage relationships had been worked out, they would be able to date sites of unknown age by using the frequencies of imported pottery types (South, 1972). Surprisingly good correspondence was found between the calculated median dates and the known historical dates of the pottery forms.

Roger Grange (1972, 1981) has taken this method a step further and applied the ceramic dating formula to the Pawnee and Loup Loup ceramic tradition of the Great Plains. This tradition was estimated, from historical data and archaeological cross-dating, to date from the period A.D. 1825 to 1846, when Pawnee potmaking died out, back to about A.D. 1500. Grange calculated median dates with archaeological data derived

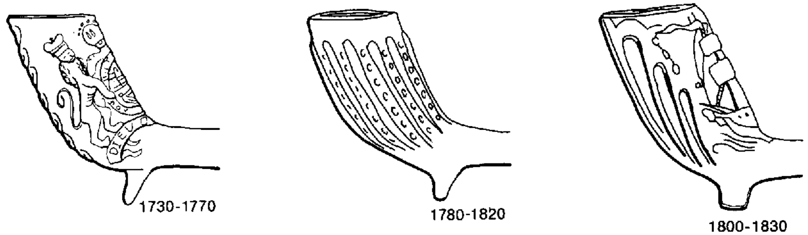

Figure 6.7 Representative evolutionary changes in the designs on the bowls of English tobacco pipes dating to between 1730 and 1830.

from seriation, which gave the range of types. He found fair correspondence between the median dates and those obtained by more conventional analyses, especially when the greatest peaks of popularity for different pottery types were used as the basis for calculations. Formula dating of this type may have much potential in areas where tree-ring chronologies or calibrated radiocarbon dates provide a basis for accurate calculations of median age. And the advantages for cross-dating of newly discovered sites are obvious.

The potential range of historic objects that can be dated to within surprisingly narrow chronological limits is enormous. Many people collect beer cans, bottle caps and openers, barbed wire, firearms, uniform buttons, even horseshoes. All these artifacts, to say nothing of such prosaic objects as forks, electrical switch plates, and scissors, can be dated to within a few years with mail order catalogs, U.S. patent records, and a great deal of patient detective work. Bernard Fontana (1968) points out that bottles, buckets, and horseshoes may be the unrespectable artifacts of archaeology but, unlike many of their prehistoric equivalents, they can be dated with great accuracy. What better way to learn about archaeology than to study and date our own material culture!

SUMMARY

- Although historical records provide a fairly accurate chronology for much of the past five thousand years, archaeologists rely heavily on chemical and physical chronometric dating methods.
- Potassium argon methods are used for dating the earliest human beings. These can be used to determine dates from the origins of the earth up to about 400,000 years ago. This radioactive counting method is based on measuring accumulations of argon 40 in volcanic rocks. It has been used to date Olduvai Gorge and other early sites to between one and three million years ago.
- Radiocarbon dating is the most widely used method. It can be applied at sites from between 75,000 and four hundred years ago. Based on the rate at which carbon 14 decays to nitrogen in organic objects, it can be used to date many such materials as charcoal and bone and even skin and leather. The accuracy of radiocarbon dating is subject to statistical errors, owing to past variations in the carbon 14 content of the atmosphere, and thus has to be calibrated against tree-ring chronologies.
- Fission track dating is done by measuring the uranium content of many minerals and volcanic glasses and examining the fission tracks left in the material by fragmentation of massive concentration of energy-charged particles. It can be applied in sites between a million and 100,000 years old, where volcanic rocks are found in human-occupied levels.

- Thermoluminescence may prove to be a method for dating potsherds, in which the baked clay has trapped electrons; these are released for measurement by sudden and intense heating under controlled conditions. The visible light rays emitted during heating are known as thermoluminescence. This method is still highly experimental.
- Dendrochronology (tree-ring dating) has its principal application in the American Southwest. It provides an accurate chronology for about two thousand years of southwestern prehistory and has many uses on more recent sites in Europe and elsewhere. Dendrochronologists count the annual growth rings in trees such as the bristlecone pine and correlate them into long sequences of growth years that are joined to a master chronology. Wooden beams and other archaeological wood fragments are correlated with this master chronology to provide accurate dates for pueblos and other sites.
- Archaeomagnetic dating can be used to date clay samples from furnaces and other features by measuring the thermoremanent magnetism of the clay and correlating it with records of changes in the earth's magnetic field.
- Historical records and calendars developed by such people as the Ancient Egyptians and the Maya are of immense value for dating their literate civilizations. A great deal of valuable chronological information can also be obtained from objects of known age, such as clay pipe or coins. But again, these objects are confined to the most recent periods of human history.

GUIDE TO FURTHER READING

The literature on chronometric dating is enormous, but these volumes can be of great use to the student.

Fleming, Stuart J. *Dating in Archaeology*. New York: St. Martin's Press, 1976. An introduction to archaeological chronology that is good on basic principles.

Leute, Ulrich. *Archaeometry*. Weinheim, West Germany: VCH, 1987. A useful summary of dating techniques and science in archaeology. Quite technical in orientation.

Michels, J. W. *Dating Methods in Archaeology*. New York: Science Press, 1973. Probably the most widely read book on dating presently available. A good follow-up to this chapter.

Taylor, R. E., and C. W. Meighan, eds. *Chronologies in New World Archaeology*. Orlando, Fla.: Academic Press, 1978. Essays on New World chronological problems.

Chapter 7

The Archaeological Record

The archaeological record is incomplete, for complex and still little understood processes have transformed the abandoned artifacts, structures, and sites of our forebears. Our interpretations of the archaeological record depend, ultimately, not only on how representative the surviving stone implements, pottery, or other objects are of past human behavior; they also depend on our knowledge of the complex processes that formed the remains of human behavior *after they were abandoned to the elements.*

There was a time when archaeologists assumed that their knowledge of the past would always be incomplete. Many argued that the reliability of our statements about the past depended on how strongly we can believe that the nonmaterial elements of society and culture are reflected in the incomplete archaeological record that has come down to us.

In this chapter, we examine the nature of the archaeological record, site formation processes, and the nature of archaeological data.

ARCHAEOLOGICAL DATA

The traditional cautionary arguments have been challenged by American archaeologist Lewis Binford and other prehistorians, who refuse to accept the assumption that archaeology yields information only on material culture. The distinction between material culture (artifacts, houses, and the products of human culture) and nonmaterial culture (kinship, social organization) is regarded as totally artificial, for every aspect of a human sociocultural system interacts with many other complex variables. According to Binford (1968), "Data relevant to most, if not all, the components of past

sociocultural systems *are* preserved in the archaeological record." The archaeologist's task, then, as he sees it, is to develop means for extracting such information from the data recovered from excavations and archaeological surveys.

This school of thought refuses to attribute the limitations in our knowledge about the past to the quality of the archaeological record and the state of its preservation in the soil. The limitations, they say, lie in our methodological naiveté, in the various methodologies that many archaeologists are seeking to improve by means described at intervals in this book.

Archaeological data result from two processes. The first is human behavior, the results of human activity. The other is what are often called transformational processes. As we have seen, the archaeologist is concerned to identify and reconstruct ancient human behavior, such as the occupation of a hunting camp. The hunting band decides on a location, gathers building materials—sticks, brush or sod, mammoth bones—erects a dwelling, occupies it, then destroys or just abandons the settlement. Archaeologists reconstruct sequences of ancient human behavior not only from archaeological data itself but also from the circumstances under which they are found.

Human behavior is the first stage in the formation of the archaeological record. But what happens when the site is abandoned? The remains of brush shelters, a scatter of stone tools, the remains of a ceremony are abandoned as being of no further use to their owners. All manner of natural processes take hold. The bodies of the buried dead decay; toppled brush shelters rot away in the sun. Subsequently, a nearby lake may rise and cover the remains, or windblown sand may accumulate over the stone artifacts. Another group may come and build a farming village on the same spot or may simply pick up and reuse some of the artifacts left by the earlier occupants. All of these cultural and noncultural developments are transformational processes—continuous, dynamic, and unique processes that vary with each archaeological site. Of course, there are wide differences in the preservation of various artifacts, raw materials, and other finds. Thus the archaeologist's data are always biased and incomplete, altered by a variety of transformational, or site transformation, processes. It follows that anyone investigating an archaeological site has to look closely at both natural and human agents of transformation. For example, World Wars I and II destroyed thousands of archaeological sites, whereas wet conditions in Scandinavian bogs have preserved prehistoric corpses in excellent condition.

SITE FORMATION PROCESSES

"The time machine, which has enchanted generations of readers and moviegoers, is a fictional artifact for transporting people through time. Although archaeologists would welcome a time machine, we are satisfied by the remarkable fact that objects made, used, and deposited in the past