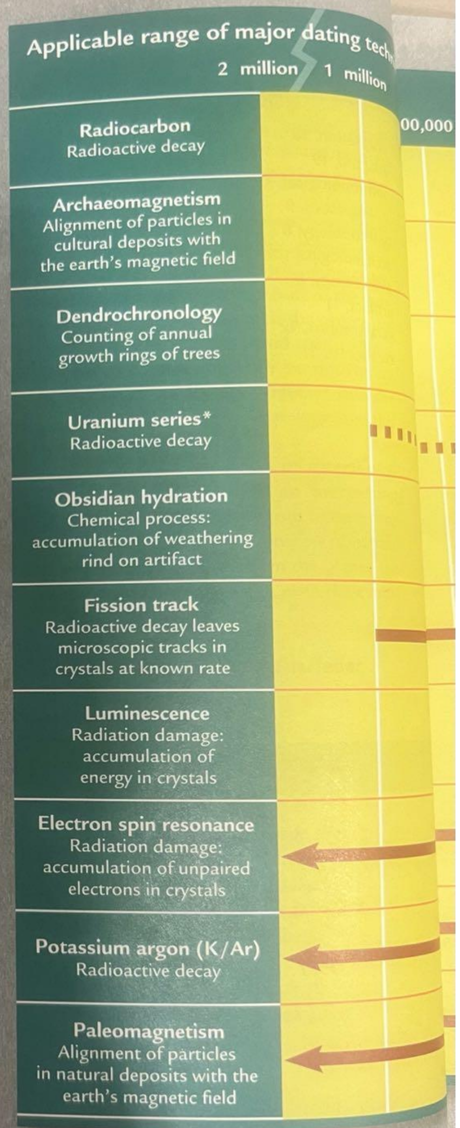
2

Probing the Past

CHAPTER OVERVIEW

Paleoanthropologists and archaeologists study the actual physical remains of human beings and those of our evolutionary ancestors. They also examine the material remains of the behavior of these ancient ancestors: the things that past humans made and used and then lost or discarded. By the investigation of the bones of humans and human ancestors as well as analysis of the objects they left behind—tools, weapons, items of adornment, works of art, structures, and so on—paleoanthropologists and archaeologists hope to better understand the ways in which our ancestors evolved and adapted. This chapter summarizes many of the most important and widely used techniques relied on by these scientists to paint a picture of the human past.



*Uranium series results older than 300,000 years are statistically questionable.

PRELUDE

ONE OF MY FAVORITE TELEVISION SHOWS when I was a kid was the cartoon series *Rocky and Bullwinkle*. Don't tell anybody, but actually it remains one of my favorite shows to this day. Smart, funny, and subversive, the cartoons were laced with adult humor, puns, and politically astute commentary, all from a smart-ass talking squirrel and a goofy moose. My favorite segment of the show was Peabody's Improbable History. Mr. Peabody was a bipedal, talking dog who happened to be a genius (you could tell by his glasses) and who, with his boy Sherman (whom he adopted from the local pound), would time travel in one of Mr. Peabody's inventions, the Way Back Machine. After setting a date and place on the machine's control panel, Peabody and Sherman would travel back, for example, to the sixteenth century to help Galileo figure out gravity, or they'd visit Columbus in the fifteenth century and point the way to the New World.

I bring this up because, as a prehistorian, I have to admit I'd love to have a Way Back Machine. It would render my profession so much easier. Instead of the slow and laborious process of looking for paleoanthropological and archaeological sites, excavating them, analyzing the artifacts we recover, and trying to come up with a comprehensible story of the biological evolution and cultural development of our species, we could simply travel back in time with Sherman and Peabody and be eyewitnesses to antiquity.

But we don't have a Way Back Machine. Instead, we must rely on some extremely cool real-world techniques to find archaeological sites and then extract information from the stones, bones, soils, and plant materials left behind. It can be a daunting process, but we rely on an approach that authors Michael Shermer and Alex Grobman (2000) characterize as "a convergence of evidence." In each historical discipline, including archaeology, paleoanthropology, historical geology, and history, we search for knowledge and meaning along different, independent pathways. We are confident in our conclusions when those different and independent streams of data point to the same conclusion, when they converge at the same point. It is, for example, difficult to figure out when the first people entered the New World and where they came from (see Chapter 7), but when geological data, archaeological investigations in the Old and New Worlds, and genetic information from both ancient bones and modern people separately and independently point to the same scenario, when they converge on the same story, we can be pretty confident that our reconstruction matches the way things really were. This chapter is a very brief summary of how we obtain the information necessary for that convergence.

EPISTEMOLOGY: HOW WE KNOW WHAT WE KNOW

Every field of scientific study presents its own set of challenges. Researchers in each branch of science must develop a specific set of methods for data collection as well as techniques of analysis and interpretation. Archaeology and paleoanthropology are no different. Our data are the objects that ancient humans and human ancestors made, used, lost, abandoned, or discarded; environmental data that inform us about the natural conditions our ancient forebears experienced and to which they adapted; and their actual biological remains. Archaeologists and paleoanthropologists have developed procedures for finding this ancient evidence along with techniques for extracting from it information about the lives of our ancient ancestors. This chapter summarizes some of the more significant methods used in archaeology and paleoanthropology for data collection and analysis.

The "Science" in the Study of the Past

Science often begins with objective observation of the world or universe. For example, biologists examine living things; astronomers focus on other planets, stars, and galaxies; and geologists observe the earth itself. Anthropologists, on the other hand, concentrate on humanity, with paleoanthropologists and archaeologists focusing more specifically on humanity's past.

All scientists observe the world and look for patterns or correlations, cause-and-effect relationships, trends, and trajectories in an attempt to puzzle out the rules that govern how the world works—how the earth was formed, how rivers flow, how life originated, how humanity evolved, or how people adapt through their cultures. To be sure, scientists are not blank slates or passive receptors of the data they encounter in research. Dominant perspectives called **paradigms**—think of a paradigm as a scientific worldview or conceptual framework—play a significant role in how we structure our research, in the kinds of research that receive funding, in what kinds of evidence we look for, and in how we interpret and interpolate what we do find. The hallmark of science, however, rests in its open-mindedness to new data and ideas, in its constant testing, probing, reassessment, and revision. New approaches and new interpretations, in archaeology, paleoanthropology, and all other sciences, are constantly being proposed and then tested. One of the great strengths of science rests in its ability to accept data—and explanations of these data—that are surprising and unexpected.

Paradigm: An overarching perspective, a broad view that underlies a scientific discipline.

From the things they observe and the patterns they perceive, scientists come up with general explanations, or **hypotheses**, for what they have observed. Scientists are not content, however, just to generalize about the world. They also need to test these hypotheses by predicting what additional data will be found if a hypothesis is valid, if it accurately explains how things work. Paleoanthropologists and archaeologists accomplish these tasks by applying the procedures outlined in this chapter and by a rigorous adherence to the scientific method.

Hypothesis: A proposed explanation for some phenomenon. A hypothesis may be derived initially from empirical observation of the phenomenon.

The fact that in archaeology and paleoanthropology we are examining our own human past and time periods enormously distant from our own poses a unique challenge. It is one thing for a chemist to examine a chemical reaction and suggest a rule that governs how those reactions progress; it is one thing for a microbiologist to focus on a colony of bacteria and suggest a hypothesis for how those bacteria react to heat or an overabundance of food. These chemical reactions and bacteria are of the here and now, and they are apart from us. It is quite another thing for paleoanthropologists and archaeologists to gaze back across the centuries, millennia, and eons of human history where the data are ancient, elusive, and rare and where our interpretations impinge on how we view ourselves. Did we humans begin our journey as "killer apes," and what does it mean to us if we did? Were the world's first civilizations dependent on

FIGURE 2.1
Artifacts are objects that human beings manufactured. The eight long stone blades shown here are part of a cluster of thirty such artifacts, found in an ancient site in southern New England (top). A feature is an archaeological deposit that reflects a human activity or series of activities that occurred at a specific place. Here (middle) are shown two "unharvested" soapstone bowl blanks from a 3,000-year-old site in Barkhamsted, Connecticut (see Figure 1.4, left, for the tools used to quarry the soapstone at this site). These two impressive stone towers (bottom) are among a series of such towers constructed by Native Americans in southeast Utah, at the Hovenweep site. *(K. L. Feder)*

retrieval that never takes place; human ancestors may be killed by animals and their remains dragged into a lair; and so forth. The study of how paleontological remains ended up in a particular place is called **taphonomy**; we can also apply this term to the study of how paleoanthropological or archaeological remains came to rest in their place of discovery. Recognition of how items became part of the paleoanthropological or archaeological record provides insights into the behavior of the human beings who left those artifacts behind.

Taphonomy: How materials become part of the paleontological or archaeological record.

Archaeological artifacts and ecofacts used or produced together to accomplish a task—to make stone tools, to prepare food, to carry out a ceremony—often are deposited together on the ground in a pattern that reflects the spatial arrangement of the activity. These clusters of archaeological material are called **features** and can be analyzed in our attempt to reconstruct a particular activity or set of behaviors. When **activity areas** are intact—in other words, where the items used together and deposited together are left exactly where they fell by ancient people—we use the term **primary refuse**. The next time you see inconsiderate folks leave the remnants of their picnic lunch behind on the ground, don't think of it as a gross mess; think of it as primary refuse. The remnants of that lunch, the waste flakes resulting from the production of stone tools left where they fell, and the skeletal elements of an animal left where it was butchered are examples of primary refuse.

Feature: Combination of artifacts and/or ecofacts at a site, reflecting a location where some human activity took place.

Activity Area: A place where an activity or group of activities were carried out in the past. The activity area is transformed into an archaeological feature by the loss or discard of material items used in the activity.

Primary Refuse: Archaeological artifacts and ecofacts left at the place they were used or produced.

The trash dump in my town, now called the Barkhamsted-New Hartford Landfill, was used as the collective garbage disposal point for residents of my town for more than 40 years. The landfill began as a deep, broad depression where, beginning in 1974, residents would simply haul their trash for disposal. The Barkhamsted-New Hartford landfill and countless others throughout the world represent **secondary refuse** accumulations, places where members of a community collectively dispose of their trash. Just like us in the modern world, ancient people also often cleaned up the places where they carried out tasks, removing the objects used and produced from their primary contexts to a designated refuse area or areas. Just as we use refuse dumps and recycling facilities in our towns and cities, people in the past often took their trash to a pile or pit, removing from the immediate vicinity of their living quarters material that might be dangerous, that might attract wild animals or noxious insects, or that might simply otherwise be a nuisance (perhaps because of its smell).

Secondary Refuse: Archaeological artifacts and ecofacts that were removed by the people who made, used, or produced them from the place where they were made, used, or produced, to a designated refuse area or areas.

Understand that archaeological sites are, essentially, repositories of the material remnants of people living out their lives. Sites are, in a sense, unintentional time capsules. "Material remnants" is the key part of the site definition. As such, it must be admitted that the archaeological record is an imperfect and incomplete record of a way of life; behaviors or activities that don't involve any material objects may not leave behind any direct evidence. An elder sitting under a tree, telling children a story about creation; two men bragging about their sexual prowess; a woman speaking a silent prayer for the life growing within her: these may leave no traces in the archaeological record, though they are vitally important. But written history is no different; the written record is no more inclusive than the archaeological record. The lives of poor people, of slaves, and, for much of Western history, of women get short shrift in the historical record, no matter how detailed that record may seem. Such deficiencies are not a reason to reject the study of history. Similarly, we can admit to the incomplete nature of the archaeological record while still asserting that, imperfect

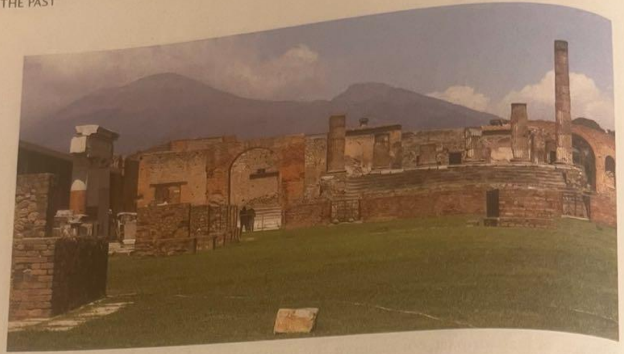


FIGURE 2.2
Volcanic ash was long ago removed by archaeologists from around the columns, arches, walls, and stairways of Pompeii, here dramatically framed by the jagged caldera of Vesuvius, the volcano that destroyed the city and killed many of its residents. *(K. L. Feder)*

The initial fall of pumice had killed hundreds and destroyed most of the homes of Pompeii's residents, but it also protected the walls of those homes from the destructive force of the pyroclastic flow on the following day. Sealed in pumice, these walls—as well as the boulevards, avenues, and back alleys of Pompeii—were neither burned nor crushed but preserved, insulated from the elements and looters. Then, in A.D. 1594, a bit more than 1,500 years after its tragic destruction, the city was rediscovered by workers digging a drainage channel. It wasn't until about 1740 that researchers began the arduous task of removing the hardened ash and pumice layer, revealing the homes, theaters, and civic buildings of Pompeii, with their sometimes well-preserved wall paintings and tiled mosaics. Though the roofs are gone, today the city is a strange place, a ghost town that appears to have been abandoned months or only a few years ago (Figure 2.2).

Even some of the inhabitants of Pompeii were preserved, in a way, when their bodies were entombed by the ash deposited by the pyroclastic surges on August 25. Entombed in a hard crust of ash, the bodies decayed away, leaving a hollow in the shape of the deceased (Dwyer 2010). When discovered, these hollows were filled with plaster and the ash chipped away, revealing a series of extraordinary phantasms—crudely cast, three-dimensional images of human tragedies (Figure 2.3).

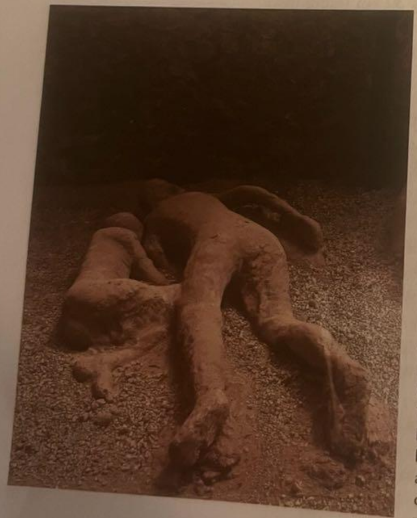


FIGURE 2.3
Eerie images like these were made when archaeologists found cavities in the volcanic ash that covered Pompeii, which they then filled with plaster. The casts of an adult and child (perhaps a mother and her own offspring) seen here were victims of the A.D. 79 eruption of Mt. Vesuvius (see Figure 2.2). The falling ash killed them and then hardened around them before their bodies decomposed, leaving hollow molds. About 100 such body casts have been created from the hollows in Pompeii's ash. These casts represent an instant frozen in time, desperately sad shadows of lives snuffed out in a catastrophe that occurred more than 1,900 years ago. *(K. L. Feder)*

FIGURE 2.4
Some archaeological sites are revealed by chance through the agency of natural processes. Here at Skara Brae, at the Orkney Mountains north of Scotland, an ancient site a few thousand years old was exposed by the winds and waves of a North Atlantic storm. *(K. L. Feder)*

How Sites Are Found

Archaeological sites are found in a number of ways. While some natural processes may preserve sites, other such processes may expose them. Rivers cutting into their banks, wind blowing sand away from an area, or waves eroding a beach may bring to light ancient, buried remains (Figure 2.4). Many of the sites related to the earliest history of humanity have been exposed by these processes of erosion. Places such as Olduvai Gorge in Tanzania and the Hadar region of Ethiopia (see Chapters 3 and 4) present naturally exposed layers of ancient geological deposits (Figure 2.5). By walking over these places systematically in a procedure called **pedestrian survey**, paleoanthropologists and archaeologists found many

Pedestrian Survey: A systematic walkover of an area in the search for archaeological remains.

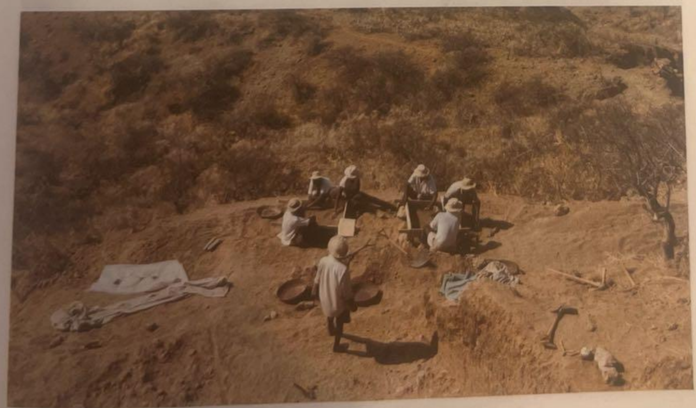


FIGURE 2.5
Researchers are shown here at Olduvai Gorge, searching for remnants of early hominin occupation of one of the most important fossil localities on Earth (see Chapter 3). *(© Rick Ergenbright/CORBIS)*

FIGURE 2.6
In areas of the world where natural processes have not exposed ancient sites, archaeologists must dig to reveal buried cultural deposits. Test pits are often excavated to explore an area for buried archaeological material. Here you are looking up a line of test pits—a test pit "transect." The pits are 10 meters apart and all soil is passed through ⅛-inch hardware cloth in the search for artifacts and ecofacts. *(K. L. Feder)*

of the important ancestral human fossils discussed in this book.

In other cases, archaeologists do not have the luxury of naturally exposed ancient layers in which to search for artifacts, ecofacts, or human skeletons. In these areas, scientists search for sites through a process of subsurface sampling, placing **test pits** at regular intervals in an attempt to locate ancient material buried by natural processes (Figure 2.6). In some cases aerial photography can help identify large-scale land modifications or buried remains that affect the growth of vegetation.

How Information Is Recovered

Test Pit: A hole or boring into soil in the search for archaeological evidence.

Once a site has been found, the arduous task of extracting the physical evidence from the ground begins. Paleoanthropological and archaeological evidence is rare, precious, and often fragile, so the methods used to unearth it have been designed accordingly.

We must recover our data with great care. Though we may use power equipment and picks and shovels to remove the culturally sterile overburden, once within the zone of a site we ordinarily rely on handheld trowels, dental picks, and brushes to remove the soil enclosing site materials (Figure 2.7). Material may be

FIGURE 2.7
Once a site has been found, it must be excavated in a regular and ordered way. Not only must artifacts and ecofacts be preserved, the spatial relationships among the materials found at a site must also be maintained. Excavation in square units by slowly peeling away soil layers aids in this task. *(K. L. Feder)*

left exactly where found in order to expose the possible **associations** among the remains. For example, a single stone, found and then tossed in a bag, is not nearly as informative as a series of stones, each one left in place, that together denote a platform hearth. Even better, when the weapon used to killed the animal cooked on the platform is found in place, precisely where it was left, more than 4,000 years ago (Figure 2.8; see inset).

Context is the key here. A single artifact, devoid of any context—where it was found, what items it was found in proximity to—provides the archaeologist or paleoanthropologist with only a fraction of the information provided by an object for which context has been preserved and recorded. Consider the various possible contexts of a spearpoint in Figure 2.9. In 2.9b the spearpoint is found embedded in an animal bone. In 2.9c the same artifact is depicted as part of a **cache**, or collection, of other spearpoints. In 2.9d, again the same artifact is shown, this time stuck in the eye orbit of a human being. Finally, in 2.9e the spearpoint is shown as one of two next to the skeletal remains of a person. In each case the spearpoint is exactly the same, but its setting and spatial associations differ, suggesting different uses or meanings of the object, respectively: (b) a hunting weapon, (c) part of a tool kit, (d) a weapon of war, or (e) an offering to a deceased member of the group.

Though it might be an exaggeration to say that in archaeology spatial context is everything, it certainly is crucial. Have you ever watched one of the many crime shows on television that show how the police investigate the scene of a crime? They're always careful to record and recover all evidence in order to solve a crime. Archaeological field methods are analogous, except a site isn't usually the scene of a crime; it's the scene of a life. This should explain in part why

Association: Term relating to the spatial relationships among archaeological artifacts, ecofacts, and features. Objects found in proximity to each other are said to be in association.

Cache: A stash of stuff placed away for safekeeping by ancient people.

FIGURE 2.8
This platform of stones served in the manner of a grill. Under the stones was a burning fire, as evidenced by charcoal, and the butchered remains of an animal—in this case, a deer, as evidenced by the bone fragments recovered. The meat was cooked on the surface of the stones. Immediately adjacent to the roasting platform, in the location indicated by the white arrow, we recovered the spear point seen in the inset. Perfect except for a broken tip, this weapon likely was one of those used to kill one of the animals cooked on the platform. The charcoal left behind by the fire has been radiocarbon dated to about 4,200 years ago (see the discussion of dating methods later in this chapter). *(K. L. Feder)*

slavery and warfare, and if so what does this knowledge tell us about our twenty-first-century civilization?

As scientists, we must always be aware of and try to transcend our own preconceptions of what we think the past *should* tell us—or what we would like it to tell us—about ourselves. Our constructs of the past should be objective and free of our own temporal and cultural biases. This ideal is not easy to achieve, and we archaeologists and paleoanthropologists have sometimes fallen short of these goals. Further, we must recognize that our interpretations of the human past are approximations subject to continual refinement, major overhaul, or even complete abandonment as new data and new ways of looking at the same data come to the fore.

PALEOANTHROPOLOGICAL AND ARCHAEOLOGICAL SITES

I use the term "site" quite frequently in this book. Paleoanthropological and archaeological **sites** are places where physical evidence of a past human presence can be recovered. Such evidence consists of (1) the skeletal remains of human beings or human ancestors, (2) **artifacts**—objects made and used by past peoples (Figure 2.1), and (3) **ecofacts**—environmental elements that exhibit traces of human use or activity, such as the bones of butchered animals. I began this book talking about the physical remains of Pilfershire, a nineteenth-century village in northwestern Connecticut. Those remains constitute the archaeological "site" of that community.

Site: A place where people lived and/or worked and where the physical evidence of their existence in the form of artifacts, ecofacts, and features can be or has been recovered.

Artifact: Any object manufactured by a human being or human ancestor. Usually defined further as a portable object like a stone spearpoint or clay pot to distinguish it from larger more complex archaeological features.

Ecofact: Element found in archaeological contexts that exhibits human activity, but was not made by people and so is not, strictly speaking, an artifact.

Wherever people lived or worked, they used material from the surrounding environment: stone, clay, metal, wood, bone, plant fiber, seeds, antler, animal hides, and so on. They built things and made things and those things ultimately were lost, used up and discarded, abandoned, or hidden away for future use. Where conditions in the soil allow for their preservation, these items can be found and recovered for analysis by scientists who study the human past. Together, these physical remnants make up the archaeological site. A site was once a home, a community, a place of work. It now is a place where data can be collected that will enable us to tell the story of that home, that community, and that workplace.

Sites are defined not only by the recovered objects themselves but also by the physical arrangement of the remains. The preserved spatial context of archaeological remains—where things were used and left by an ancient people—allows us to reconstruct the activities that took place at a site. Most reconstructions of past times are based on analysis of human remains, artifacts, and ecofacts, as well as their spatial arrangement at sites where people lived or performed special tasks. Sites can be small and short-term, like hunting camps, or large and permanent, like the sites of the world's first cities in Mesopotamia (see Chapter 10).

How Sites Are Formed

Sites come into existence through a series of site formation processes (Schiffer 1976). Tools can be discarded or lost; food remains can be thrown in a trash pit or pile; dead bodies may be casually abandoned or intentionally and ceremonially buried; valuable objects may be "cached," or hidden away, for a future

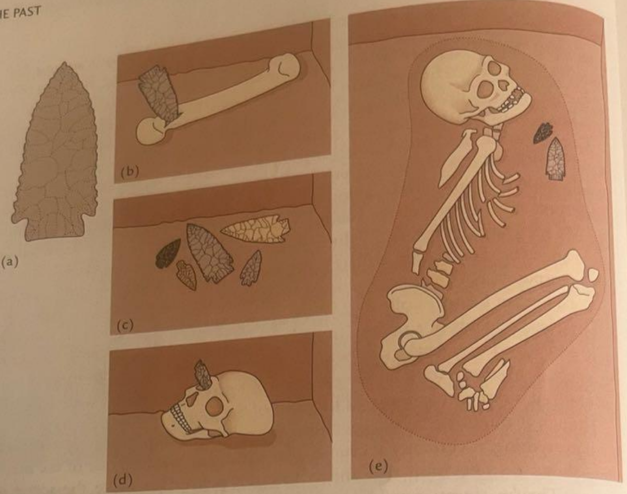


FIGURE 2.9
An isolated artifact may tell us about an ancient technology, but to determine the use and meaning an object had to an ancient people, context is crucial. Consider the same artifact (a) recovered archaeologically from very different contexts: (b) embedded in an animal bone; (c) as one in a cluster of spearpoints found in an ancient hiding place; (d) stuck in the skull of a human being; (e) as a grave offering to a deceased hunter. In each case the artifact looks exactly the same, but its context—and, therefore, its deduced use and meaning—is different. *(From Kenneth Feder and Michael Park, Human Antiquity: An Introduction to Physical Anthropology and Archaeology, Fourth Edition, © McGraw Hill Education)*

archaeologists and paleoanthropologists are meticulous in excavating sites. A site is much more than just the sum of its individual parts (artifacts and ecofacts). Objects need to be carefully exposed, leaving them, at least initially, in place in order to preserve their spatial contexts and associations. This also explains why detailed and time-consuming record keeping is important before specimens are removed from the ground and returned to the lab for analysis. As careful as we are in excavating a site, we can miss small fragmentary remains. All excavated soil ordinarily is sifted through wire screening of ¼-inch, ⅛-inch, or even smaller mesh to ensure 100% recovery. In some cases the soil matrix may be taken to an on- or off-site lab, where standing water may be used to help in separating artifacts, ecofacts, or human bone from the surrounding soil.

Archaeology at a Distance: Noninvasive Methods of Data Collection

Beyond the ordinary probings that accompany regular health screenings, twice in my 60 or so years doctors have wanted to get a peek inside of me. Throughout most of the history of medicine there was really only one way for them to accomplish this: exploratory surgery. For example, if a patient experienced chronic pain at a particular spot—like the back—a doctor might have to anesthetize and then cut him or her open for a look around to see what was going on.

I am grateful, indeed, that this wasn't my fate. Doctors now have at their disposal all manner of technologies for examining the inside of a patient's body without recourse to the surgical knife. X-rays, computed tomography (CT) scans, magnetic resonance imaging (MRI), and the like allow a doctor to explore what's going on inside of you without the dangers of general anesthesia, the risk of infection, or the and challenging as it may be, the archaeological record is all we have for the vast amount of time human beings and our ancestors have been on this planet.

How Sites Are Preserved

Once material objects are laid on or in the earth, natural processes may cover, protect, and preserve them. Ash or lava spewed from a volcano, silt from a flooding river, sand blown by the wind, a collapsed cave roof, an avalanche—all may cover the objects left behind by people, preserving them until nature or archaeologists uncover them many years later. Some of the materials used by people, especially stone tools and pottery, preserve very well under most circumstances. Other materials, like bone and plant remains, require particular conditions for preservation. When archaeologists and paleoanthropologists are lucky, an archaeological site is itself like a fossil, a preserved physical representation of a past people and way of life.

In certain cases, the catastrophic agency of a community's destruction ironically acts, at least in part, to preserve the archaeological site left behind. There is no better example of this than what occurred at the beautiful Roman harbor town of Pompeii (Cooley 2003).

Nestled between the Bay of Naples and the foot of a towering volcanic mountain named Vesuvius, the residents of Pompeii had long been subject to the rumblings of their looming neighbor. We know that an enormous earthquake rocked Pompeii in A.D. 62, causing significant damage. In the years following this, numerous smaller tremors were felt by the city's residents, who likely became inured to the bad behavior of the volcano. Those tremors increased in frequency and amplitude in the early summer of A.D. 79 and then, on August 24, Vesuvius erupted catastrophically, hurling what is estimated to have been about 4 cubic km (a cubic mile) of ash into the atmosphere, some of it reaching an altitude of as much as 30 km (more than 18 mi; that's three times higher than the cruising altitude of a standard commercial jet). The prevailing wind, along with gravity, brought the plume of **ejecta** over the city, resulting in a shower of **pumice** that accumulated like an eerie, ashy snow on the streets and rooftops. Falling at an estimated rate of 15 cm (about 6 in) per hour (faster, by far, than any snowfall you have experienced), the weight of the accumulating pumice eventually collapsed roofs and filled the streets and houses of Pompeii, attaining a height of about 2.8 m (9 ft; Cooley 2003:40).

It is believed that the accumulating pumice killed only a few hundred residents of Pompeii, but it was a series of **pyroclastic** surges—what amounts to a sequence of devastatingly hot avalanches—on August 25 racing down the slopes of Vesuvius at speeds approaching 200 km (almost 125 mi) per hour that killed thousands more and, essentially, killed the city as well (Cooley 2003:42). If you were in Pompeii at the time and saw the surge coming, it was already too late for you to escape; you were a dead man—or a dead woman—walking. Pompeii had succumbed to one of the most awesome forces in nature and lay as a great sepulcher, undisturbed, for more than 1,500 years.

After its destruction, Pompeii and the area surrounding the city were abandoned by any who had survived the eruption of Vesuvius, and no attempt was made to rebuild. Blanketed in ash, Pompeii slowly faded from memory until it was all but forgotten.

Ejecta: All the material thrown out of a volcano during an eruption.

Pumice: A light and porous volcanic rock. Pumice forms when a glassy molten froth cools and solidifies quickly.

Pyroclastic: A swiftly flowing mass of ash, molten rock, and gas spewing from an erupting volcano.

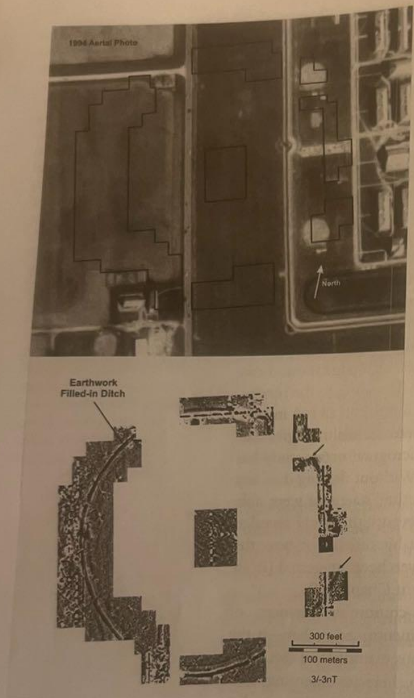


FIGURE 2.10
Sometimes science produces magic. The top image is an aerial photograph of an area that is currently the location of an Ohio prison. There doesn't appear to be anything in the photo that suggests that this was the location of an ancient monument. The application of a remote sensing technique produced the image on the bottom, clearly outlining the location of a buried soil signature marking the location of an enormous circular earthwork built by the aboriginal inhabitants of Ohio about 2,000 years ago. *(Jarrod Burks and Robert Cook)*

of radar, the bounced-back signal can indicate something about the nature of whatever it has encountered. Lawrence Conyers (http://www.gpr-archaeology.com) has used GPR very successfully to locate ancient kivas in the American southwest (see Chapter 14); the remains of buried building foundations in Petra, Jordan; and the unmarked burials of a small group of African slaves killed in a shipwreck along Florida's Key West coast just before the Civil War. GPR and similar technologies can't replace the need to dig, but they certainly can help in determining where we ought to be digging.

In some cases, an ancient, large-scale monument may have been completely obscured by modern activity including agriculture and construction, but its magnetic ghost can still be seen by the application of remote sensing devices. For example, historical records indicated the approximate location of what was historically labeled the Shriver Circle, an earthwork built by the indigenous people of Ohio—in this case, a circular mound of earth with an accompanying ditch circumscribing a vast space (Burks 2010; and see Chapter 14). All we have today is a sketch made in the early nineteenth century and a surveyor's map made in 1848. Though huge—the diameter of the circular embankment is about 400 m (1,300 ft), circumscribing an area of more than 20 acres—the entire area was leveled as a military camp during World War I. There is hardly any remaining surface indication of the earthwork. If you could walk over the entire site today—you can't because it's now on the grounds of a prison—you'd be hard pressed to recognize that there was a significant archaeological monument under your feet. Much of the site had, in essence, been erased, at least from the surface. Then, in 2008, by using a **fluxate gradiometer**, a device that measures minor fluctuations in the earth's magnetic field that may result from alterations in the soil, archaeologists Jarrod Burks (2010) and Robert Cook (Burks and Cook 2011) were able to identify the buried and mostly hidden remains of the 2,000-year-old earthwork. The gradiometer's readout is stunning, almost magical (Figure 2.10). The lost earthwork has been recovered, at least as a magnetometer image. Through remote sensing, a part of America's ancient legacy, long thought destroyed, was revealed.

Fluxate Gradiometer: A noninvasive device used to investigate the subsurface.

ANALYZING ARCHAEOLOGICAL DATA

We can break archaeological evidence down into the following categories: artifacts, ecofacts, and human skeletons. Each category requires its own forms of analysis.

How Artifacts Are Analyzed

In analyzing artifacts, at a minimum we want to know where the raw materials for the objects came from, how the items were manufactured, how they were used, and the social context in which they were made and used.

THE SOURCES OF RAW MATERIALS

We can attempt to figure out where ancient people obtained their raw materials through a process called **trace element analysis**, in which impurities present in tiny or "trace" amounts are scanned for. Essentially, this involves a precise determination of the chemical makeup of artifacts and of potential geographic sources for the raw materials from which artifacts were made by any one of a number of procedures such as **neutron activation analysis** and **X-ray fluorescence**. The percentages of particular impurities often are unique and diagnostic of specific geographic sources and can serve as a fingerprint for place of origin. In other words, two pieces of turquoise (or obsidian or copper, etc.) may look entirely alike but have distinctive chemical compositions traceable to different sources. Artifacts are examined for their particular percentages of these trace elements. Possible sources for the raw material from which the artifact was made are also examined for their trace element percentages. If a raw material source and the artifact have matching trace element profiles, a scientist can suggest that the raw material for the artifact derived from that source.

For example, it has been conservatively estimated that a million turquoise artifacts have been found in Mesoamerica (E. Powell 2005), but there is an interesting problem; there aren't any known, extensive turquoise sources in central Mexico where most of the artifacts have been found. Archaeologists and geologists have long known, however, that there are significant sources of extremely high-quality turquoise in the American Southwest, in Arizona and New Mexico especially, not all that far away from central Mexico. Could the Southwest turquoise have been the raw material from which the artisans of ancient Mexico made their often spectacular works of art, and what might we conclude about trade and contact between the ancient inhabitants of the regions (Figure 2.11)? Archaeologist

Trace Element Analysis: Determining the geographic source of the materials used by an ancient people through the analysis of small or "trace" concentrations of elements or chemicals in those raw materials

Neutron Activation Analysis: Form of trace element analysis. When the artifact's chemistry matches that of a source area, it is concluded that the ancient people obtained the material from the chemically matching source.

X-Ray Fluorescence: A technique for identifying the chemical makeup of a raw material.

FIGURE 2.11
The raw materials from which artifacts were made can sometimes be traced to their geographic sources through the analysis of their trace element chemistry. In this way, for example, archaeologist Phil Weigand has been able to show that much of the turquoise used to produce jewelry and other items of adornment in ancient Mexico was obtained by their artisans from sources in Arizona and New Mexico. *(© Werner Forman/Werner Forman/Corbis)*

possibility of surgical error. It really is pretty great to avoid all that drama and have your doctor tell you, on the basis of your MRI, that "there's nothing interesting going on inside of you" and send you home with back exercises and a bottle of aspirin.

Archaeologists are in a situation analogous to your doctor. We are interested in what's going on inside a mummy, inside the ground, or inside a stone structure. While we are not nearly as far along as the modern medical profession in this regard, we do have a number of imaging technologies at our disposal that, like CT scans or MRIs, allow us to peer inside without digging holes or damaging precious remains.

For example, it seems obvious that human remains might present us with information concerning the health of ancient people. Avoiding a potentially damaging, invasive procedure by using the same kind of CT scanner available at your local hospital, researchers recently examined the hearts of 52 Egyptian mummies. The result: Though the average age of death was only 40, nearly half already exhibited evidence of atherosclerosis, in other words, hardening of the arteries (Pringle 2011a).

Monuments like earth mounds or stone pyramids present another challenge to the archaeologist. Perhaps there is a tomb secreted at the base of the mound, hidden chambers in the pyramid, or internal clues within that might enable us to determine how an edifice was constructed. Excavating to the base of a large mound can be a daunting and dangerous exercise, as well as potentially damaging to the monument. Peering into the internal structure of a stone building can be all but impossible without doing violence to its integrity. However, there are technologies that provide ways to accomplish these tasks. For example, a microgravimetric study has been conducted on the Great Pyramid at Giza, in Egypt. Without drilling into any pyramid blocks or dismantling any elements of the structure, scientists were able to peer inside the pyramid. In a fascinating sequence of events, the study revealed evidence of the pyramid's construction that supported a hypothesis for how the pyramid had been built, long before the hypothesis had even been suggested (Brier and Houdin 2008). I'll reveal the particulars of this study in Chapter 10.

Finally, it is probably true that the most time-consuming element of archaeology—and the thing that led me to the MRI I mentioned earlier—is the literally back-breaking labor involved in moving enormous quantities of dirt in an attempt to reveal buried archaeological material. Here, too, there are emerging noninvasive technologies that allow us to look into the ground without moving any dirt.

For example, electrical resistivity survey involves sending an electrical current through the ground. The current is affected by the medium through which it passes. A buried brick wall, an in-filled irrigation canal, or a hollow tomb each has a different level of resistance to the current, and this can be read by the operator of the survey instrument, alerting archaeologists to the presence of hidden features invisible from the surface.

You've probably witnessed scenes in movies or documentaries where air traffic controllers or military personnel use radar to track commercial and private planes, enemy fighter jets, or incoming missiles. In this application of radar, an electromagnetic pulse is aimed at the sky, encounters objects (planes, a flock of birds, etc.), and then bounces back to be gathered by a receiving dish. The nature of the reflected signal indicates the kind of object the radar pulse encountered and its size, location, altitude, and speed.

In **ground-penetrating radar (GPR)**, an electromagnetic pulse is aimed not at the sky but into the ground (Conyers 2004). Just as in the aeronautical use

Ground-Penetrating Radar (GPR): A noninvasive device used investigate the subsurfa

Experimental Replication: The reproduction, under laboratory conditions, of facsimiles of archaeological artifacts.

Phil Weigand tested that hypothesis for more than 30 years through the application of trace element chemistry, specifically through neutron activation analysis (NAA).

NAA produces a chemical signature for a raw material by bombarding it with neutrons. Weigand collected samples of raw turquoise from 44 sources in the American Southwest and California. When I was an undergraduate anthropology major at the State University of New York at Stonybrook, I was one of several students who prepared turquoise samples from these sources for NAA, which established the chemical signatures of each of these sources. With Brookhaven Lab physicist Garman Harbottle, Weigand was able to determine the chemical composition of finished artifacts excavated from sites in Mexico whose trace element signatures matched those determined from sources in the Southwest. Many of the artifacts found in Mexico, thus, had been manufactured from turquoise that originated in the American Southwest.

TOOL MANUFACTURE AND USE

Through **experimental replication**, the process of attempting to authentically re-create ancient artifacts, researchers can assess how an item was made

FIGURE 2.12
Archaeologists can gain insights about making and using tools by attempting to replicate their manufacture and use. Here, archaeology students are shown with some of their replicated tools: a bow and arrow, a fire-starting kit, a metate (grindstone), and a spear thrower or "atlatl" (see Chapter 6 for a detailed description of this weapon). *(K. L. Feder)*

(Figure 2.12). They also examine historically described groups that possessed a technology analogous to that of the ancient people being studied. Scientists can deduce the use an artifact served from its **morphology**—its form, what it looked like—and by the evidence of **wear patterns**. Different actions (piercing, cutting, scraping, engraving, chopping) performed by different tools on different raw materials (stone, wood, leather, bone, antler) leave distinctive and diagnostic wear traces, or "edge damage" (striations, polish, scars), that can be assessed through replication (Shea 1992). In an experiment conducted by archaeologist Lawrence Keeley (1980), researchers used stone-tool replicas to perform different tasks on particular raw materials. For example, some tools were used to cut animal hide, some were used to saw wood, some were used to scrape meat off of bone, while others were used to drill in antler. Each tool used was then examined carefully under a microscope, and the particular kinds of resulting polish, damage, or wear on each were catalogued. This experiment essentially defined the damage or wear that accompanies each kind of use so that these tools and those from subsequent experiments and experimenters can serve as models for stone-tool wear patterns in the analysis of ancient specimens. If the ancient wear patterns match those seen on a particular experimental tool, researchers can conclude that the archaeological implement was used in much the same way.

Morphology: Literally, the study of form. An analysis of the shape and form of skeletons or artifacts.

Wear Patterns: Characteristic and diagnostic traces of damage or polish left on stone tools as a result of their use.

SOCIAL PATTERNS

Along with providing insights into technology and use, artifacts can sometimes help illuminate less concrete aspects of ancient lifeways. The particular style of an artifact made by an individual may tell us something about who taught the maker. How people learn to make objects within a culture is a social decision. For example, they may learn from a parent who is passing down a family tradition of spearpoint or ceramic styles. The style seen in the archaeological remains, therefore, embodies this aspect of an ancient social system. Some archaeological features even more directly reveal the nonmaterial practices of a people. Most obvious here are burials, which often directly reflect a group's religious ideology as it relates to recognition of the significance of death as well as possible belief in an afterlife. Neandertals (see Chapter 5) interred their dead with tools and food 60,000 years ago, and what we uncover may tell us much about their perspective on life and death. Egyptian pharaohs were laid to rest in sumptuous splendor (see Chapter 10), and what we unearth in their pyramids informs us of their beliefs about the meaning of death.

How Ecofacts Are Analyzed

Animal bones, charred seeds, nut fragments, the shells of marine organisms, and fruit pits recovered at sites may represent the food remains of past people. Because diet is an important part of a culture, scientists would like to reconstruct the subsistence practices of prehistoric people. Because the skeletons of different animal species are usually distinctive, the kinds of animals present in an archaeological deposit can often be identified if remains are not too fragmented. Many archaeology labs possess **osteological comparative collections**, or bone libraries, where ancient specimens can be compared to known, labeled specimens

Osteological Comparative Collection: A collection of bones used as models to aid in identifying the bones (species, sex, anatomical part) recovered in a paleontological or archaeological excavation.

FIGURE 2.13
Bones from an osteological comparative collection; from top to bottom, the scapula (shoulder blade), the left side of the mandible (lower jaw), and a rib bone of a white-tailed deer (*Odocoileus virginianus*). (K. L. Feder)

Faunal Assemblage: The animal bones found at a site and the species represented by those bones.

Sexual Dimorphism: Differences in the form and size of the two sexes.

Osteological: Related to bones.

Artificial Selection: The process used in the domestication and refinement of plants and animals whereby human beings select which members of a species will live and produce offspring.

to help identify the species recovered in excavation (Figure 2.13). The minimum number of animals represented in the **faunal assemblage** at a site can also be reconstructed. Because most animals exhibit two distinct forms on the basis of sex—that is, **sexual dimorphism**—scientists often can distinguish male from female animals. In addition, because animals go through a number of **osteological** developmental stages—changes in their bones as they grow and mature—it is also often possible to determine the age at death of an animal hunted, killed, cooked, and eaten by a prehistoric people. Furthermore, scientists can differentiate the bones of wild animals from those of domesticated animals: Domesticated animals frequently are smaller than their wild ancestors; the teeth of domesticated dogs are more crowded than those of their wolf progenitors; and the bones of wild animals are often denser than those of their domesticated descendants. We can learn much about the subsistence strategies of an ancient people if we can determine the species of an animal and its sex and age, whether the people hunted only older animals, and whether they avoided killing females or killed most of the young males but allowed females to survive to adulthood (a common pattern for domesticated animals).

Plant remains, including seeds, nuts, and wood, can be recovered and analyzed, and the contribution of plant foods to the diet can be assessed. Because plants are available seasonally, the yearly schedule of a people can be reconstructed based on which plant foods are present at a site and which are absent. We usually can differentiate the seeds, grains, or fruits of wild species from those that have been altered by humans through **artificial selection** (see Chapter 8) in the process of domestication.

Plant and animal communities often rely on a particular, sometimes rather narrow, range of climatic variables including amount of rainfall, length of the growing season, and high and low temperatures. By identifying the existence of particular plant and animal communities in the past, we can deduce the presence of climatic conditions such communities required for their survival. For example, caribou are not currently native to southern New York State, yet their remains have been found there—apparently they were on the menu—at the Dutchess

Quarry Cave site, a more than 10,000-year-old occupation of the Hudson River valley near the modern town of Athens in Orange County. Today, caribou live far to the north in Canada and require a much colder climate than the one that currently characterizes southern New York. Their presence there 10,000 years ago implies a much colder climate then. This, in turn, provides archaeologists with important information about the environment to which human beings living in this same place adapted.

The human body is not entirely efficient when it comes to digestion. That is to say, not everything we swallow is digested and available to provide energy for our bodies. Some materials are exceptionally difficult for us to break down and digest and often are passed through our bodies and end up in our feces. When these fecal deposits are preserved, as can happen, for example, in cave environments, they are called **coprolites**. When coprolites can be recovered, fragmentary remains of undigested food are collected and identified. Analysis of coprolites has aided in tracing the first Americans (Chapter 7) and the origins of agriculture (Chapter 8). Although it certainly would not be characterized by anyone as the most romantic part of archaeology—I'm guessing that the next installment of the Indiana Jones franchise, if there is one, will not have Indy tracking down the mystical coprolites of the Aztecs or whomever—coprolites are a valuable ecofact in the study of an ancient diet.

Coprolites: Fossilized feces, useful in the reconstruction of an ancient diet.

PALYNOLOGY

One of the most important sources of information about past plant communities is **pollen**, the male gamete in plant sexual reproduction. Pollen grains tend to be rather durable and can preserve for thousands and even tens of thousands of years. Beyond this, pollen morphology is species specific: The pollen produced by each species is unique and distinguishable from the pollen produced by other kinds of plants. In other words, each species produces pollen that can serve in the manner of a fingerprint by which the presence of a species at a particular place in the past can be verified (Figure 2.14). Upon recovery of pollen from an ancient soil layer at or nearby an archaeological site, researchers can calculate the percentages of the various kinds of pollen falling on a site when it was occupied. Next, they attempt to locate modern locations where the **pollen rain**—the percentages of the pollen of different plant species that rains down in the spring today—is a close

Pollen: Pollen grains are the male gametes in plant sexual reproduction.

Pollen Rain: The overall count or percentage of pollens of different plant species falling at a particular place and time.

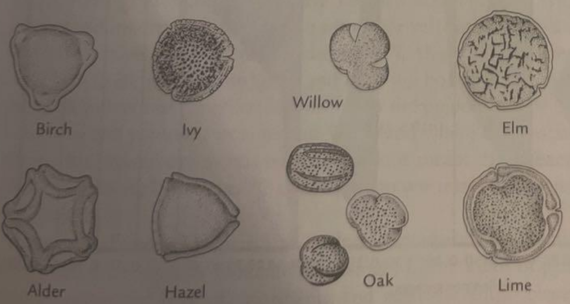


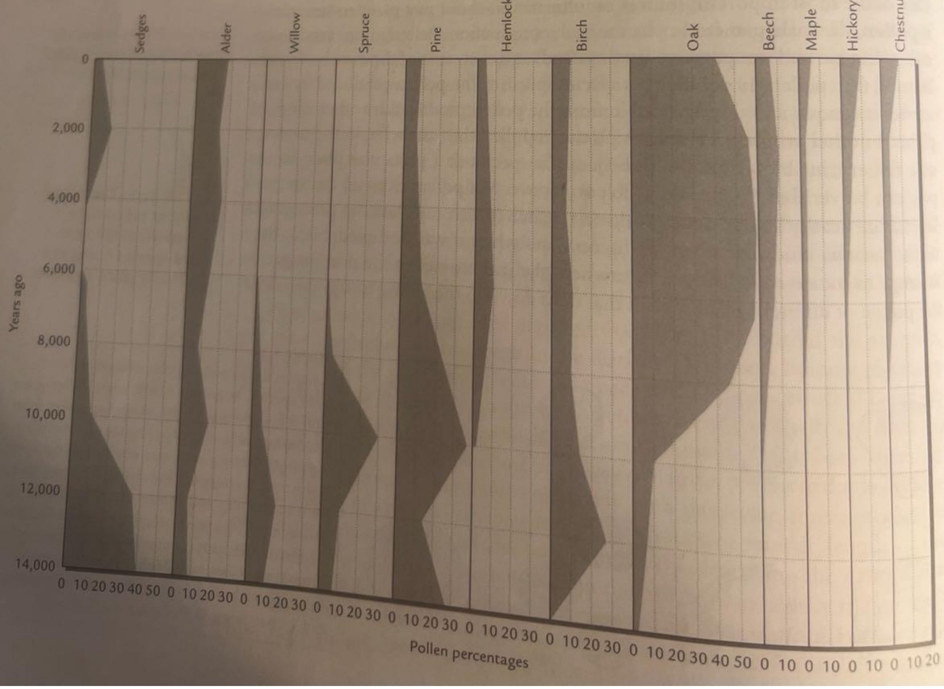
FIGURE 2.14
Examples of the pollen grains of eight different plant species, magnified 5,000 times. Pollen grain form is species specific. By recovering pollen from archaeological levels, palynologists can identify the plants growing in an area when it was occupied in the past, reconstruct the makeup of a previous plant community, and deduce the nature of the environment that must have been in place for the reconstructed plant community to have survived. *(From Kenneth Feder and Michael Park,* Human Antiquity: An Introduction to Physical Anthropology and Archaeology, *© McGraw Hill Education.)*

match for the percentages derived for an ancient time and place. When a good match can be found, it is reasonable to conclude that the ancient climate in which the site's inhabitants found themselves was similar to the climate of the modern location with a similar pollen rain.

Palynology: The identification of plants through the remains of their pollen grains.

The modern pollen profile of my own state of Connecticut, for example, contains an abundance of pollen from cold-loving trees like pine and birch, but there also is plenty from temperate-climate species like oak, maple, and hickory. Fourteen thousand years ago, however, the pollen falling on the state included only one of these species, pine; 60% of the pollen in that period came from bushes that don't even grow in Connecticut today but can be found thriving only in the Canadian Arctic (Davis 1969). The pollen species percentages as a whole falling on Connecticut 14,000 years ago look nothing like the modern breakdown but are a reasonably good match for what falls in northeastern Canada today (Figure 2.15). From this we can deduce that the climate of Connecticut 14,000 years ago was probably quite similar to what we find in the modern Canadian Arctic. **Palynology** provides a vital, direct link to the plant communities that characterized given places and times. This, in turn, allows us to suggest what the overall climate was like at those times and places.

FIGURE 2.15
The pollen profile from Rogers Lake, southeastern Connecticut, showing a dramatic change in plant communities over the last 14,000 years. *(Based on Davis 1969)*



BLOOD RESIDUE

Modern forensic scientists regularly look for and find blood residue on weapons used in the commission of a crime. If the knife or ice pick found in a suspect's garage, for example, exhibits residue of the precise blood type of a murder victim, investigators may reasonably assume that they have identified the weapon used to commit the crime and recovered evidence, therefore, that implicates the suspect.

It turns out that under the right circumstances blood residue can preserve for decades, centuries, and even millennia. In a recent test, for example, blood residue was recovered from quartz spear points dating to 62,000 years ago and found in the Sibudu Cave in southern Africa (Lombard 2014). The existence of cracks and crevices along the edge of a stone tool, may in fact, provide tiny, protected pockets where such residue can be preserved.

Once recovered, the species wounded or killed by the weapon can be identified from its blood by immunological assay based on antibody–antigen reactions in the sample. For example, in an examination of 25 stone tools from two ancient Alaskan sites, remnants of blood were recovered and identified, including that of deer, rabbit, cat, sturgeon, bear, and mouse (Gerlach et al. 1996). Though not found very frequently, in those rare cases where conditions are right for its preservation, blood residue can be recovered and used to directly identify the species of animals killed and likely butchered and eaten by an ancient people.

CARBON ISOTOPES

All plants conduct photosynthesis, but not all photosynthesis is the same. In fact, there are a number of different **photosynthesis pathways**. For example, the **C3 pathway** characterizes most trees, and the **C4 pathway** typifies most grasses. These two pathways do essentially the same thing: They are the processes by which plants extract carbon from the carbon dioxide they respire and then use that carbon to produce leaves, stems, roots, bark, wood, and so on. These two pathways differ, however, in how they treat the different varieties (**isotopes**) of carbon in the atmosphere. We will see later in this chapter that one carbon variety, ^{14}C, is valuable in dating archaeological material. Here, an analysis of the concentration of another version of carbon, ^{13}C, provides data that can be useful in environmental reconstruction. C3 pathway plants, the trees, select against ^{13}C during photosynthesis. After trees extract carbon atoms from carbon dioxide, those atoms that happen to be ^{13}C are filtered out to a degree. C4 pathway plants, most grasses and sedges, have no such bias. They use whatever ^{13}C they take in and incorporate this carbon into their various parts. As a result, C4 pathway plants have a higher concentration of ^{13}C than do C3 pathway plants.

The soil in which plants grow and even the bones of the animals that eat the plants all reflect the concentration of ^{13}C in the preponderance of plants growing in an area at a particular time period. When and where **carbon isotope analysis** shows that concentration was relatively high, it means that grasses dominated the plant community. When the ^{13}C concentration was relatively low, it means that trees dominated.

As we will see in Chapter 3, an analysis of dramatic changes in ^{13}C concentrations over time suggests fundamental changes in the kinds of plant communities that characterized regions, continents, and even the entire planet. For example,

Photosynthesis Pathways: Different specific modes of photosynthesis various plant groups employ in the production of energy from sunlight.

C3 Pathway: The photosynthetic process employed by most trees. In the C3 pathway, a radioactive isotope of carbon, ^{13}C, is differentially filtered out.

C4 Pathway: The photosynthetic process employed by most grasses and sedges. In the C4 pathway, a radioactive isotope of carbon, ^{13}C, is more readily used than in plants that follow the C3 pathway.

Isotope: Variety of an element's atomic form.

Carbon Isotope Analysis: Analysis of the proportion of ^{12}C and ^{13}C in a bone or soil sample. Useful in dietary and environmental reconstruction because different groupings of plants use carbon compounds containing ^{12}C and ^{13}C differentially.

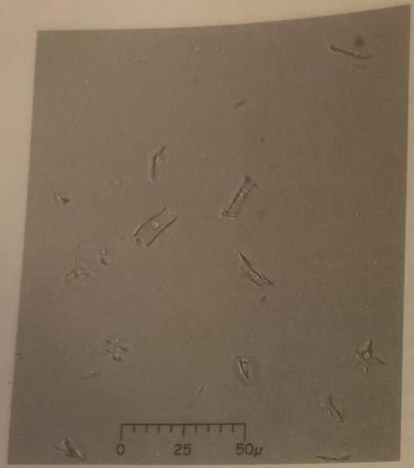


FIGURE 2.16
Phytoliths are inorganic silica bodies produced by plants. Phytoliths are useful to archaeologists because they are durable and each species produces distinct forms; specialists can identify the plant from the phytolith. Pictured here are maize phytoliths. *(Courtesy Deborah Pearsall/University of Missouri Paleoethnobotany Lab)*

^{13}C measurements made at multiple locations indicate a worldwide contraction of forests and their replacement by grasslands beginning about 7 million years ago. The time of these shrinking forests is also characterized by a wave of extinction of forest-dwelling ape species and may have helped set the stage for the success of an ape-like creature that could thrive in grasslands. That creature may very well have been our ancestor.

PHYTOLITHS

Plants also produce a nonorganic residue consisting of microscopic mineral particles called **phytoliths** (Figure 2.16). Phytoliths are quite durable and can last in soil deposits or, when we are lucky, on the edges of tools used to process the plants that produced them. Phytolith form is unique to each plant species, so, when phytoliths are recovered at an archaeological site, specialists can determine the species of plants growing in the area when the site was occupied and might even be able to tell the species of plants cut, pounded, or ground with the tool. We'll see how important phytoliths have been in assessing the development of agricultural economies in Chapter 8.

OXYGEN ISOTOPES

Planetwide changes in climate can also be read in the oxygen isotope record preserved in the fossil shells of ancient marine microorganisms called **foraminifera** ("forams" to those in the know). Foram shells reflect the ratio of two isotopes of oxygen, ^{16}O and ^{18}O, in seawater when these organisms were alive. Because ^{16}O is lighter than ^{18}O, water molecules (H_2O) with the lighter oxygen isotope evaporate more readily than do those with the heavier variety. Ordinarily, this makes little difference because the water that evaporates from the ocean returns as rain or as meltwater from frozen precipitation. However, during cold periods, water evaporates from the ocean and some of it falls as snow on land in higher elevations and upper latitudes. During periods of worldwide temperature decline, an increasing amount of that frozen precipitation remains locked in as ice, not returning to the ocean. As a result, a disproportionate amount of lighter oxygen water is removed from the evaporation-precipitation cycle during these cold periods. The oceans, therefore, become depleted of ^{16}O relative to ^{18}O. Foram shells reflect this depletion as they incorporate oxygen in the surrounding seawater into their shells. Therefore, when the proportion of ^{16}O in foram shells exhibits a drop, it's a good bet that worldwide temperature was experiencing a decline as well. When later foram shells show a return of higher ^{16}O levels, this indicates a change toward warmer temperatures. The oxygen isotope proportion curve (see Figure 4.11) has been worked out for the past 780,000 years or so based on ancient dated submarine strata in which foram shells have been recovered and analyzed (Shackleton and Opdyke 1973, 1976). Scientists have used this curve to figure out changes in worldwide temperature and glacial ice coverage during the Pleistocene epoch, or the Ice Age.

Phytoliths: Microscopic, inorganic particles produced by plants.

Foraminifera: By measuring the ratio of ^{16}O:^{18}O in foraminifera fossils, the amount of the earth's surface covered in ice at any given point of time can be indirectly determined.

Although the environment cannot cause a particular adaptation to develop, and a change in the environment does not guarantee any specific evolutionary change or behavioral adjustment, it does serve as the stage on which adaptations, evolutionary developments, and behavioral adjustments are played out. Clearly, to understand human adaptation, archaeologists and paleoanthropologists need to understand the nature of the ancient environments to which humans adapted. Reconstructing animal communities through the identification of their bones and reconstructing plant communities on the basis of their macroscopic remains, through palynology, and by carbon isotope analysis contribute to our understanding of the environments that played a crucial role in shaping the human story.

How Human and Prehuman Skeletal Remains Are Analyzed

The bones of human ancestors are an invaluable resource to paleoanthropologists and archaeologists. To begin with, the fact that archaic forms of human beings existed is shown most clearly by the presence of their bones, which are different from those of either apes or modern humans. (See the many photographs in Chapters 3 through 5 of creatures who were ancestral to us but, at the same time, were not quite us.) These bones can inform us about how human ancestors walked, the kinds of climates to which they were adapted, the foods they ate, their general level of nutrition, and the diseases and traumas from which they suffered. Comparing the bones of ancient human ancestors to those of modern people can help us place these specimens accurately in the human evolutionary line.

THE SPECIES REPRESENTED BY A BONE

Ordinarily, the first question scientists ask about a bone concerns its species. When bones are complete, species identification is relatively straightforward because the precise form of each bone in an animal's body is unique to its species. For example, each of the 206 bones of the adult human body is uniquely human and cannot be mistaken for the bones of any other animal species. As a result, for the most part, the species of an intact bone found at an ancient archaeological site can be identified with great accuracy.

The identification of species can be tricky, however, when we deal with the remains of possible human ancestors. A first step is to compare the excavated bones with those of modern people. When the recovered bones exhibit features or landmarks that are uniquely human—for example, the position of the point of connection between the top of the spinal column and the base of the cranium reflecting the diagnostically human pattern of walking on two feet rather than four—we can confidently conclude at least that the bones being examined belonged to an individual in the human family. Also, very detailed and careful measurements can be taken of the bones and teeth of excavated specimens. Ordinarily, if those measurements—for example, the thickness of tooth enamel or the proportions of the bones in the hands—fall outside the range of those same measurements taken on human beings, we may conclude that the bones do not belong to a modern human being.

What happens when the bones being examined fall outside the range of variation of any living species, as do many of the bones discussed in Chapters

3 through 5? Sometimes, a new designation is created—for example, *Ardipithecus, Sahelanthropus*, or *Australopithecus*—to reflect the fact that the bones do not belong to any known, living creature but rather to an extinct variety that had not been recognized previously (Chapter 3). The next problem that may arise, however, concerns the interpretation of subsequent discoveries. Does a new fossil with features that indicate it did not belong to any living species belong to an already defined fossil species, or should we invent a new species designation for the newly discovered bones?

Remember, when judging whether or not a bone belonged to an animal of a known, living species, we need to determine whether its various measurements fall within the ranges of variation calculated for the living group. These ranges are very well known for modern human beings. A bone's identity as human or not can be determined. But how do we determine if a newly discovered bone whose measurements fall outside the human range belonged to an extinct species that has already been defined? Here we don't have nearly as good an idea of what the range of variation is for the bones of an extinct species. You cannot figure out a range of variation when there is only one specimen. The accuracy of a range cannot be meaningful when there are only a few examples. So it can be extremely difficult to figure out if the new bone's statistics fall within or outside that poorly known range. Beyond this, perhaps instead of placing a new specimen in a new species, we should expand the metrical definition of our own species to include it as well.

As a result, there is an element of subjectivity in inserting a fossil into a given extinct species or using the fossil to name a new species. Some paleoanthropologists are "lumpers," accepting a wide range of variation in ancient species and lumping most new finds into one of the already existing categories. Others are "splitters," assuming a narrow range of acceptable variation and naming new species with nearly every new discovery on the basis of rather small differences between the new find and already defined groups.

I admit this can be confusing, even to experienced researchers, but there is no right and wrong here. Naming new species and categorizing new finds cannot be absolutely objective, and there is much disagreement about the number of ancient, extinct species in the human evolutionary line. Keep this in mind when reading Chapters 3 through 5.

THE SEX OF A SKELETON

Many of the police dramas currently on television include forensic analysis of human remains (*Bones* is likely the most obvious example, but *CSI* and assorted versions of *Law and Order* also come to mind) with medical examiners attempting to identify people—their sex, age at death, geographic origin, and pathology—on the basis of incomplete skeletal remains. The techniques employed by these television scientists are based on those actually employed in the analysis of ancient skeletal remains.

For example, this book will refer to specific fossils as being male or female. This identification is possible because of the recognition of sexual dimorphism. Human and ape males, for example, have skeletons that often are readily distinguishable from those of females of the same species. Among humans and apes, males tend to be larger, with heavier, denser, and rougher bones than females.

In addition, males tend to have larger, heavier skulls, with larger and rougher areas for muscle attachment. In some ape species, males have a bony crest on the top of their skulls, whereas females lack this feature. Also, in some species, males have a large ridge of bone above the eye orbits (sockets). Females either lack this feature or have a smaller bony ridge. Among human beings, all of the various angles of the pelvis that control the overall size of the birth canal are, of necessity, larger in the vast majority of females than in males. With enough skeletal elements recovered, modern forensic scientists as well as paleoanthropologists can correctly distinguish males and females more than 95% of the time (Krogman 1973).

THE AGE AT DEATH

Our discussion of human skeletons will occasionally mention an individual's approximate age at death. The bones of human children go through a series of developmental changes during the course of their lives. For example, tooth eruption and replacement provide developmental time-posts in human maturation. The **deciduous dentition**—the baby teeth—erupt above the gum line in a regular order and at fairly well-established times (Figure 2.17). The permanent teeth then replace the baby teeth, also in a regular pattern, at reasonably well-fixed ages until, finally, the wisdom teeth—the 18-year molars—come in. Using a chart like that shown in Figure 2.17, one can estimate the age of a child under 18 based on which teeth have already erupted above the gum line and which teeth have yet to appear.

Another developmental time-post can be found on the long bones—the various bones of the arms, legs, hands, and feet. When we are born, each of the long bones is in three sections: a shaft, or **diaphysis**, and two endcaps, or **epiphyses** (*sing.*, epiphysis). In a process called **epiphyseal fusion**, the shafts and endcaps fuse to one another during growth at more or less set times during our teen years; this fusion reflects maturity and full growth (see Figure 2.17). Once again, by reference to the time range when each of the individual epiphyses fuses to its respective diaphysis, the age at death of an immature individual can be estimated fairly accurately.

Later in life, changes are less regularly timed, reflecting gradual deterioration of our bones rather than consistent time-posts. This deterioration, while inevitable, is subject to great variability depending on the life and work history of the individual, so determining a person's age based on his or her state of deterioration can be problematic. There are, however, some changes in the adult skeleton that are more consistently timed. For example, **cranial sutures**—the places where the different cranial plates come together—fuse through time. Young adults usually exhibit well-defined sutures, whereas aged people may have had their sutures disappear entirely. The region where the pubic bones come together—the **pubic symphysis**—can also be used to estimate the age at death of an individual. At their point of articulation, the faces of the left and right pubic bones go through a fairly regular, age-dependent sequence of changes.

Deciduous Dentition: Baby teeth. The teeth that are shed like the leaves of deciduous trees.

Diaphysis: The shaft of a long bone. On either end of the diaphysis there is an epiphysis.

Epiphyses: The endcaps of the long bones. The epiphyses join at the ends of the diaphysis of each long bone.

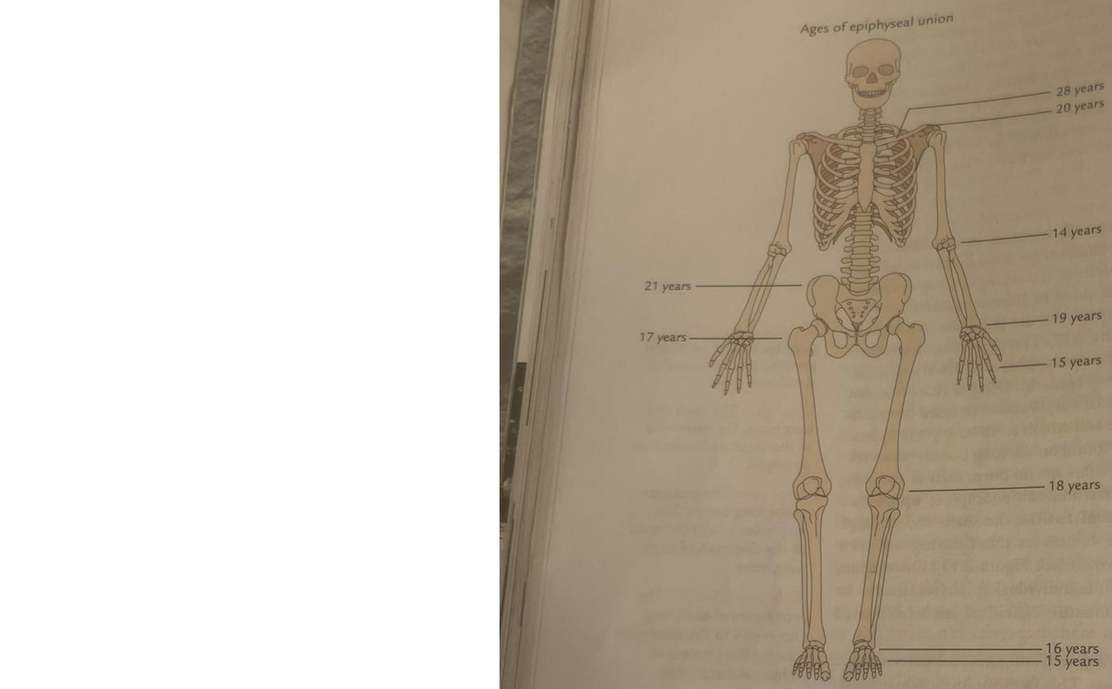
Epiphyseal Fusion: The epiphyses of each long bone join to the diaphyses during the process of physical maturation.

Cranial Sutures: Lines of connection between cranial bones. Sutures progressively disappear with age and can be used to provide a general estimate for age at death.

Pubic Symphysis: Point of articulation between the two pubic bones of the pelvis.

GEOGRAPHIC ORIGIN

We all recognize that people's physical features differ based on the geography of their origins; humans from different parts of the world possess a constellation of



Age at which the epiphyses in the indicated area fuse to the shafts.

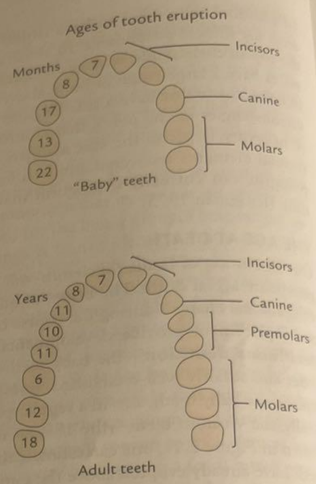


FIGURE 2.17
These diagrams show the order of tooth eruption and epiphyseal fusion for human beings. Careful analysis of skeletal remains can reveal species, sex, age at death, nutritional status, cause of death, and geographic origin of the individual.

physical traits—skin color, nose shape, hair texture, body proportions—that tend to distinguish them from people from other parts of the world. Skeletal traits also vary geographically; so in some instances, the skeletal remains of individuals can be traced to the part of the world from which they came. For example, one reason we know that Native Americans originated in Asia is that the oldest skeletal remains in North America share a group of skeletal characteristics with Asian people (see Chapter 7).

In an episode of one of the programs in the *Law and Order* franchise, the bones of a small child were found. There was no obvious match between the child represented by the remnant skeletal elements and any child reported missing in the

Greater New York City region. It became the job of the medical examiner (ME) to try to coax out the child's biography as revealed by his bones. The ME performed what, even by the standards of television cop dramas, seemed to be magic; she told the investigating officers that the child had been born in Africa, as well as where he had been raised (which was different from his birthplace) and even how long he had been in the area of New York City.

It wasn't magic at all, but the application of a set of techniques useful to medical examiners and forensic anthropologists, as well as archaeologists and paleoanthropologists. Just as raw materials like turquoise or obsidian have diagnostic trace element signatures, so do a region's soils. Those signatures become enshrined in plants that grow in a region and then those same signatures become fixed in the bones of the animals and people who eat the plants that grow in that region.

The element strontium (chemical symbol Sr) is particularly useful in this kind of analysis. The ratio of the two isotopes of strontium varies between regions, and (here's the coolest part) the strontium becomes a part of your teeth as you are developing, and your tooth enamel reflects the ratio of those isotopes when they first developed (B. Fowler 2007). For example, the strontium isotope ratio in your adult tooth enamel right now reflects the ratio when the enamel developed when you were a little kid (the buds of your adult teeth were already in your upper and lower jaws when you were an infant). It doesn't change through time. So, if a forensic anthropologist were to examine the strontium in your teeth today, he or she could probably match it up with the geographic region in which you lived when you were young, showing where you were born and where you spent the beginning of your life. In an application of this form of analysis, for example, researchers were able to determine that some of those buried in high-status graves at the Bolivian sites of Tiwanaku and Chan Chan (see Chapter 13) were born locally, and some were outsiders (Knudson et al. 2004).

The strontium in your bones, on the other hand, does change through time, but very slowly, measured over the course of a decade. So, the strontium isotope ratio in your bones isn't necessarily a reflection of where you were born but, instead, where you've lived for the last decade or so. Strontium analysis of a bone from a man buried in a cave located at another Tiwanaku site in southern Bolivia, for example, revealed that he had lived in the general area for more than a decade. In other words, he was a local person and not someone from outside of the region (Knudson et al. 2005). The geographic origins of some of those buried at Stonehenge have been traced using their strontium signatures (Chapter 9).

Strontium isotope analysis, therefore, provides a useful way of measuring migration patterns and social patterns of movement across a landscape.

PATHOLOGY, DISEASE, AND DIET

The 206 bones in a human body are like a book on which some of that human's life experiences are written. Healed bone breaks, episodes of malnutrition during growth, specific dietary deficiencies, the ingestion of certain poisons, arthritis, tuberculosis, syphilis, cancers, and many other conditions leave recognizable traces on bones. These marks can be read by the specialist in **paleopathology**. The paleopathological evidence on the bones of European Neandertals is discussed in

Paleopathology: The study of ancient disease, trauma, or dietary deficiency. Hominin skeletons often bear evidence of these.

Chapter 5; the high level of malnutrition evident on their bones may explain why the Neandertals became extinct.

As mentioned previously in this chapter, two photosynthesis pathways, C3 and C4, differ in the degree to which they utilize one of the stable varieties of the element carbon (specifically, ^{13}C); C3 plants (mostly trees) tend to filter out ^{13}C, while C4 plants (mostly grasses and sedges) do not. As a result, as mentioned earlier, C3 plants tend to have a measurably lower ^{13}C "signal" or concentration than do C4 plants. The bones of animals, including those of people, who eat plant products reflect the ^{13}C levels of their foods. So, the bones of a people who subsisted on tree foods (fruits and nuts) will exhibit a lower ^{13}C signal than those bones of a people who relied to a greater extent on the seeds, leaves, or roots of grasses. When the bones of these two different peoples are studied, their ^{13}C signals can be determined, and the source of the bulk of their foods—C3 or C4 plants—can be deduced.

DETERMINING THE AGE OF A SITE OR SPECIMEN

It may be the first question people ask about an archaeological site or artifact: "How old is it?" In fact, it is one of the key questions that archaeologists and paleoanthropologists hope to answer about the sites they excavate and the artifacts they uncover. In attempting to illuminate the chronology of human evolution, paleoanthropologists need to know the ages of the various fossils discussed in this book. In their efforts to produce a narrative of the lengthy history of the human race before there was writing and to expose the cultural processes at work that produced that narrative, archaeologists need to know when major developments—the earliest production and use of tools, the origins of hunting, the development of agriculture, the growth of class societies—took place.

Chronology has always been important in paleoanthropology and archaeology, but until fairly recently in the history of these disciplines, dating fossils and sites depended on sequences based on **stratigraphic** layering of the earth's surface—and a lot of guesswork. The fundamental technique had changed little since William Smith recognized its applicability in the late eighteenth and early nineteenth centuries (see Chapter 1). Dating was not absolute, but relative; scientists could determine whether a fossil or site was older or younger than another fossil or site depending on whether it was in a higher or lower stratigraphic layer. Fossil specimens and archaeological sites were assigned to particular stratigraphic layers. Though no certainty could be achieved, scientists derived dates based on assumed rates of formation of the layers above and below, on the guessed ages of fossils of extinct species found in association with human remains, and on a bit of intuition.

Stratigraphic (Stratigraphy): Related to the geological or cultural layer in which something has been found.

Dating Techniques Based on Radioactive Decay

Stratigraphic sequences, fossil associations, and even a bit of intuition are still used by paleoanthropologists and archaeologists in dating specimens, but these are no longer the only or primary methods of dating. Researchers can now rely on **radiometric** dating techniques based on the known rates of decay of several radioactive (unstable) isotopes (varieties) of common elements such as carbon (^{14}C dating), uranium

Radiometric: Any dating technique based on the measurement of radioactive decay.

(uranium series dating), and potassium (potassium/argon, or K/Ar, dating). These techniques provide **absolute dates** rather than **relative dates**. This does not necessarily mean they are always accurate or precise, though we strive for both accuracy and precision. The term *absolute* means only that we can associate a year or range of years with an object or site rather than place the sites or objects only in chronological order, as is the case in relative dating. Absolute dating is also referred to as *chronometric*, meaning, literally, that in its application we are attempting to measure time.

Absolute Date: Any date where a year or range of years can be applied to a site or artifact.

Relative Date: A date that places a fossil or archaeological site or artifact in a sequence with other specimens.

K/AR DATING

One technique that has been particularly useful when applied to early human ancestors is **K/Ar dating** (Dalrymple and Lanphere 1969). A newer version of the technique, **argon/argon dating**, is more accurate and is now relied on more often than the older procedure, but it is still based on measuring the amount of argon-40 buildup in volcanic rock (Deino, Renne, and Swisher 1998). Argon/argon dates can be extremely accurate; a recent refinement of the technique produces dates that are within 0.25% of the date of an object of known age (Kuiper et al. 2008).

K/Ar Dating: Potassium/argon dating.

Argon/Argon Dating: Absolute dating method based on the decay of radioactive potassium to stable argon gas. Because of the long half-life of radioactive potassium, there is no upper chronological limit to the application of the technique.

Potassium is a common element found in volcanic deposits. A radioactive variety of potassium decays into argon gas. When a volcanic layer is deposited, all of the argon already present from previous potassium decay bubbles off into the atmosphere. In a sense, the atomic clock in the ash or lava is set to zero and there is no argon left in the deposit. When the volcanic rock solidifies, the unstable potassium continues its slow decay to argon, which is trapped in the rock. Because we know the rate at which the radioactive variety of potassium decays to argon—its **half-life** is 1.25 billion years—by measuring how much argon has accumulated in the rock, we can determine how long the argon has been building up since the rock was last liquefied (that is, since the volcanic eruption deposited the lava) and, therefore, when that rock was deposited.

Half-Life: Measurement of the amount of time it takes for half of the radioactive isotope in a given sample to decay into a stable form.

Potassium/argon and argon/argon dating provide an age for the rock itself. You can't use the technique directly to date an artifact made from the rock. For example, there is a volcanic deposit in Connecticut that has been dated to about 180 million years ago. People living in the valley bordering the mountain where exposures of that volcanic rock can be found quarried some of it and made tools about 5,000 years ago. The tools are 5,000 years old, even though potassium/argon or argon/argon dating would still provide a date of 180 million years; that date indicates when the molten lava solidified and not when people made artifacts from that rock.

In most applications of potassium/argon and argon/argon dating, human fossils are found above or below a datable layer (Figure 2.18). When a fossil is found above a dated layer, the fossil must be younger than that layer; that is, the creature was alive at some point after the volcanic layer was deposited. The date on the layer below a fossil represents a maximum age for the fossils; they cannot be any older than the age of the volcanic flow that underlies them. When a fossil is found beneath a dated layer, we can be sure it is older than that deposit; that is, the creature was living in the area before the dated layer was deposited. The date on a layer above a fossil represents a minimum age; the fossils may date to any time before the volcanic layer that overlies them, but they cannot be any younger.

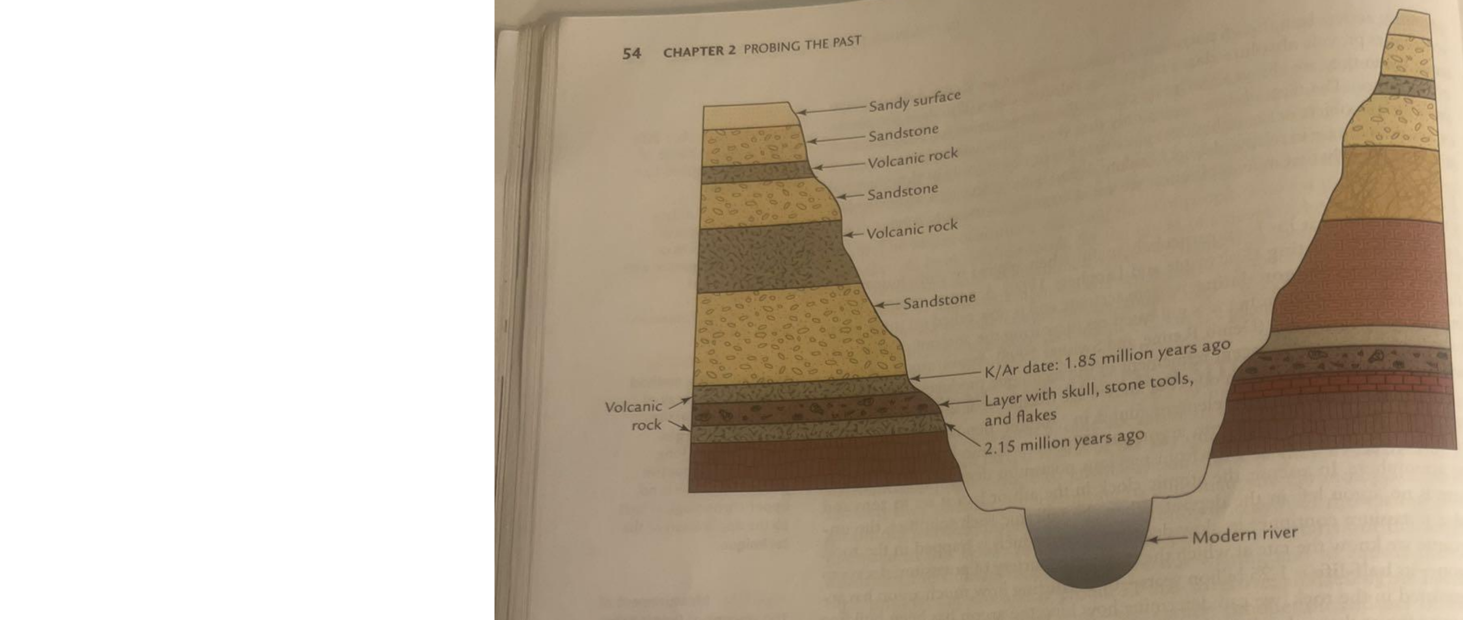


FIGURE 2.18
Combining stratigraphic analysis with potassium/argon dating has enabled scientists to bracket the ages of ancient hominin skeletons and artifacts. In this hypothetical example the remains of a human ancestor have been found in a layer overlying a lava flow dated through potassium/argon to 2.15 million years ago and underlying a subsequent flow dating to 1.85 million years. The hominin remains must date, therefore, to some time between 1.85 and 2.15 million years ago.

Under the best of circumstances, the fossils can be associated with layers both above and below them, enabling us to bracket their age.

There is one notable exception to the indirect application of these dating procedures. The humanlike footprints found in hardened volcanic ash at Laetoli in Tanzania, to be discussed in more detail in Chapter 3, must be the same age as the rock itself; the ash fell and was moistened by a soft rain, and then two individuals walked across it, leaving their trails. The wet ash quickly hardened, was covered by additional ash, and, in this way, was preserved. Dating the rock therefore allows for a precise, direct determination of the age of the footprints.

^{14}C DATING

Carbon is an extremely abundant element and one of the building blocks of life on earth; every living thing contains carbon. The most common and stable variety of carbon is ^{12}C. The numeral 12 refers to the number of particles in the carbon atom's nucleus: 6 positively charged particles, or protons, and 6 neutral particles, or neutrons. A radioactive isotope of carbon is produced when swiftly moving solar particles smash into free neutrons, which then collide with nitrogen atoms in the earth's atmosphere. The resulting variety of the element is carbon 14 (^{14}C) for the 14 particles in its nucleus (6 protons and 8 neutrons).

Because ^{14}C and ^{12}C are nearly identical chemically, they combine equally with oxygen to produce carbon dioxide, which plants take in through respiration. Plants exhale oxygen and keep the carbon atoms—both ^{14}C and ^{12}C—which they then use in the production of leaves, branches, roots, nuts, seeds, or fruits. Again, because ^{12}C and ^{14}C are so similar chemically, the proportion of ^{12}C to ^{14}C in grasses, trees, and bushes is the same as it is in the atmosphere (one trillion ^{12}C atoms for every one ^{14}C atom). When animals eat the products of these plants and again when other animals eat these animals, the ratio of ^{12}C to ^{14}C across the food web remains the same. In fact, all living things on earth are part of the carbon cycle and maintain the same proportion of stable ^{12}C to unstable ^{14}C during their lifetimes—a proportion that is, in turn, the same proportion as is seen in the atmosphere.

As an unstable isotope, ^{14}C ultimately decays, reverting back to the nitrogen atom from which it was produced. Like radioactive potassium, ^{14}C decays at a regular, naturally fixed half-life—in its case, 5,730 years. Once an organism dies, no new carbon is respired or ingested, and so the constantly decaying ^{14}C is no longer replenished. When an organism has been out of this carbon cycle for a substantial amount of time—measured in the hundreds, thousands, or tens of thousands of years—it contains significantly less ^{14}C than it did when it was alive. How much less can be measured and the amount of time it must have taken based on its known, fixed rate of decay for that much loss to have occurred can be determined based on the known rate of decay.

So the decay of ^{14}C provides a natural clock, a kind of hourglass where the rate at which the sand pours into the bottom of the glass is known (Figure 2.19). One need only determine how much sand (^{14}C) was present initially in the hourglass (organism) and how much now remains to establish approximately when the glass was overturned (when the organism died). For the **radiocarbon dating** (**carbon dating**, ^{14}C dating) to produce accurate results, the item being dated needs to be at least a few hundred and ordinarily less than about 50,000 years old. **Accelerator mass spectrometry (AMS)**, another method of

Radiocarbon Dating: Radiometric dating technique based on the decay of a radioactive isotope of carbon: ^{14}C or radiocarbon.

Carbon Dating: Radiometric dating technique based on the decay of a radioactive isotope of carbon: ^{14}C or radiocarbon.

Accelerator Mass Spectrometry (AMS): A variety of radiocarbon dating. In AMS dating, the amount of carbon-14 left in a sample is measured directly by an actual count of atoms.

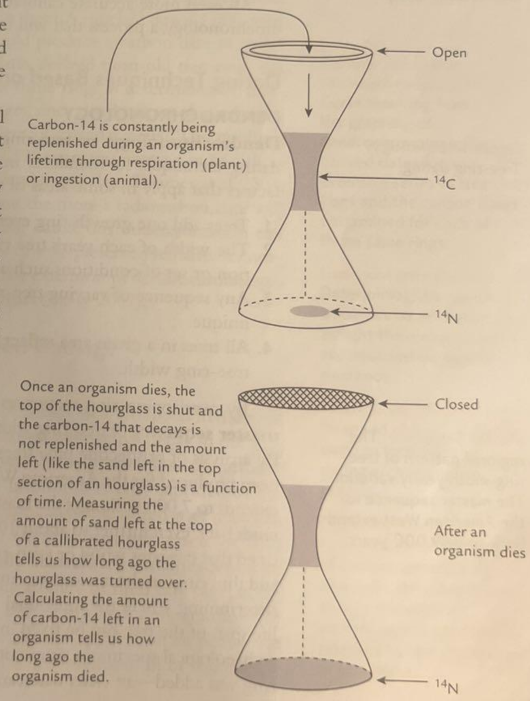


FIGURE 2.19

The process of radioactive decay of ^{14}C can be likened to the sands pouring out of the top of an hourglass. In an hourglass, sand escapes the top chamber and accumulates on the bottom at a fixed rate; the amount of sand left on top can be used to calculate how long ago the hourglass was flipped over. In an analogous manner, ^{14}C decays to nitrogen at a fixed rate; the amount of radiocarbon left in the remains of an organism can be used to determine how long ago it died.

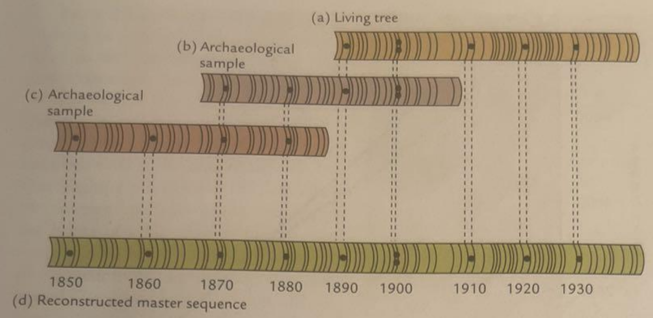


FIGURE 2.20
Cross section of tree rings from a living tree (a) overlaps the ring sequence from an archaeological sample (b), which, in turn, overlaps part of the sequence of another archaeological sample (c). The overlapping of many samples allows for the construction of a "master sequence" of tree-ring width patterns (d). *(From Robert J. Sharer and Wendy Ashmore, Archaeology: Discovering Our Past, © McGraw-Hill Education)*

Dendrochronological master sequences have been used to assess the accuracy of radiocarbon dating. Here's how that worked. First, individual tree rings were carbon-dated. Old rings are no longer growing and are, therefore, removed from the carbon cycle; ^{14}C is not being replenished in them. A ring laid down 1,000 years ago in a *living* redwood tree, for example, should produce a carbon date of about 1,000 years. A very large sample of carbon dates derived from old tree rings has been carefully compared to the age of each of those rings as determined by dendrochronology (those are called the calendar ages; since dendrochronological dates are actual, counted years, they are the equivalent of calendar years). The resulting **calibration curve**, now extending back to 12,593 years ago, allows a radiocarbon date within this period to be converted to a calendar year date (Reimer at al. 2004; Figure 2.21). In general, the further back in time, the more a radiocarbon date will *underestimate* the actual age of whatever is being dated; this underestimation can amount to several thousand years. The discovery of well-preserved remains of enormous Kauri trees in New Zealand may enable the extension of dendrochronological calibration back to 50,000 or even 60,000 years (Barry 2007).

Calibration Curve (dendochronology): Curve resulting from the graphing of dendrochronologically derived dates for an extensive series of tree rings and the carbon dates determined for each of those same rings.

Luminescence Dating: Determining the age of an object by releasing as light the energy it has accumulated during its existence.

Thermoluminescence: A "trapped charge," radiation damage technique for dating archaeological objects.

Optically Stimulated Luminescence: Method of luminescence dating in which the time-dependent energy stored in an archaeological specimen is released by the application of laser light.

Dating Techniques Based on Radiation Damage

LUMINESCENCE DATING

Luminescence dating measures the amount of energy that is trapped in material recovered at archaeological sites as a result of natural radioactive decay in the surrounding soil. Again, such energy is released at a set rate in a given soil, so the amount captured in site materials reflects their age. The amount of energy captured by the archaeological material over time and, hence, its age can be measured after releasing the energy by heat (in the application called **thermoluminescence**, or **TL**) or by laser light (in the application called **optically stimulated luminescence**, or **OSL**). Luminescence dating has been applied successfully to fired clay objects, especially pottery, as well as to stone that has been heated to a high temperature—for example, the rocks lining a fireplace. In both cases the application of heat—the firing of the pot or the heating of the stone in a fire—releases all of the energy

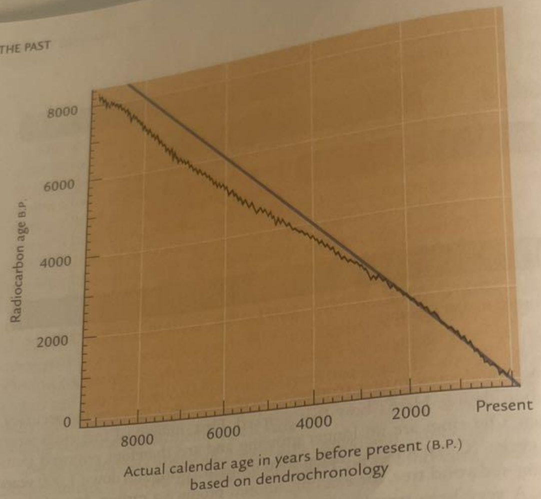


FIGURE 2.21 Calibration curve for radiocarbon dates. The vertical axis represents the radiocarbon dates derived for a large number of tree-ring samples, and the horizontal axis represents the actual dendrochronologically derived dates for those same tree rings. As you can see, for tree rings that are more than about 3,000 years old, radiocarbon dates generally understate the true age of a sample.

previously trapped in the material. This effectively sets the trapped-charge clock to zero. Then once the pot or stone is returned to the earth, it again begins to accumulate energy at the set rate produced by the natural radioactivity of the surrounding soil. Knowing that rate allows calculation of how much time has elapsed since the object was heated and, therefore, when people were present at the site making pots or banking their hearths with stones.

Dating by Measuring Paleomagnetism

PALEOMAGNETIC DATING

Paleomagnetic Dating: Dating method based on the movement of the earth's magnetic poles.

Paleomagnetic dating is based on the fact that the position of magnetic north is not a fixed point and continuously moves. In fact, the north magnetic pole of the earth is currently moving about 50 km (31 miles) each year in a northwesterly direction (Perkins 2007).

When heated sufficiently, ordinarily in excess of 500 or 600 degrees Celsius (930 to 1100 Fahrenheit), naturally magnetic particles on the earth's surface will align themselves with the current location of magnetic north. Once their temperature cools, for example, in a lava flow, that alignment is frozen in place and can be measured. If the material in which the magnetic particles are aligned can then be dated (for example, with the Ar/Ar method), we now know the direction and timing of the location of magnetic north. Dates can then be determined for other places when the alignment of magnetic particles found there matches the alignment of previously dated features. Using this procedure, scientists have produced a master map of North Pole locations for the last 7,000 years (Perkins 2007).

^{14}C dating, may ultimately extend the viable dating range back beyond this. For now, AMS dating allows for much smaller samples to be radiocarbon-dated.

Fluctuations in solar radiation cause changes in the production of ^{14}C in the atmosphere over broad stretches of time, and this variation has an effect on the dates derived through radiocarbon dating. During periods when ^{14}C was being produced at a slightly higher rate, dated items will produce dates that are a little younger than their actual, or "calendar," age. On the other hand, during periods when ^{14}C was being produced at a lower rate, dated items produce dates that are a little older than their actual age. There are a number of ways to address this issue involving the production of **calibration curves**. For example, datable, organic samples have been recovered from a series of 651 layers spread out among more than 40,000 annually deposited layers in the Japanese lake Suigetsu (Ramsey et al. 2012). Carbon dates were derived from those materials which could then be converted to actual calendar years by counting layers in the lake sediments. This allowed researchers to develop a general graph of calendar years from the layer counts and radiocarbon dates for those layers that extends from 11,200 to 52,800 years ago. Using that graph, a radiocarbon date falling within that period can be roughly converted to a calendar year date.

Calibration Curve: To correct for changes in the amount of ^{14}C through time, a large number of ^{14}C dates have been compared and linked to precise, year-by-year dates derived through other methods, especially tree-ring dating and varve analysis (layers of sediment deposited in lakes).

An even more accurate calibration and conversion can be derived from dendrochronology, a process that will be discussed in the following section.

Dating Techniques Based on Biology

DENDROCHRONOLOGY

Dendrochronology: Tree-ring dating.

Dendrochronology, or tree-ring dating, is an extremely accurate biological dating technique. Its usefulness in dating archaeological sites results from four factors that apply in some areas of the world.

1. Trees add one growth ring every year.
2. The width of each year's tree ring is controlled by an environmental condition or set of conditions such as spring rainfall amount or temperature.
3. Any sequence of varying tree-ring widths over a long period of time is unique.
4. All trees in a given area reflect the same pattern of changes through time in tree-ring width.

Master Sequence: The regional pattern of tree-ring width yearly variations. The master sequence for the American West extends back some 9,000 years.

By overlapping ring sequences of living trees with those of old dead trees, a **master sequence** of tree-ring width variation over many years has been developed. By analysis of bristlecone pine trees, a master sequence greater than 9,000 years has been produced for the American West. The master sequence constructed in England extends to 7,000 years ago; the master sequence developed in western Germany extends back even further to about 10,000 years ago. When an archaeological site is located that contains wood or even entire cross sections of logs, the succession of thick and thin rings in the ancient specimens can be compared to the master sequence. By determining where the individual sequence overlaps with the master sequence, the life span of the tree can be fixed in time (Figure 2.20). By seeing in what year these archaeological specimens were cut down—the actual year in which the tree's final ring was added—an exact date can be associated with the site.

foreign archaeologists to excavate in their countries, nor were they asked permission to remove the material evidences of their histories for display elsewhere. In some cases there were no local laws regulating archaeology and no real national institutions to oversee the archaeological activities of locals, much less foreigners. At best, archaeologists struck deals with local leaders or politicians and, like their natural resources, the archaeological heritage of many nations was plundered.

In most parts of the world today, governments have enacted laws that serve to protect their archaeological heritage by regulating the excavation of archaeological sites and controlling the disposition of artifacts recovered during those excavations. Most of these laws and regulations at least partially ensure that archaeological material remains the property of the government (or local university or museum) and is curated in the country of origin, though it may be loaned out for temporary analysis, exhibitions, or tours. In fact, in the last few years, I have been able to see artifacts and human body impressions from Pompeii (this chapter), the fossil Lucy (Chapter 3; and I have the *I Love Lucy* T-shirt to prove it), and the treasures of Egyptian pharaoh Tut Ankh Amen (Chapter 10), all during their national tours when they were on exhibit at the Discovery Center in Times Square, New York City.

In contrast, outside of Indian reservations, Native Americans in the United States are not able to control or regulate the vast majority of the archaeology conducted at the sites left behind by their ancestors, and most of that archaeology is conducted by people like me: non-Indians. It's easy to empathize with the discomfort some Native Americans feel about archaeology (Travis 2010); imagine a group of Native American scholars excavating the archaeological remains left behind by the U.S. cavalry during the Battle of the Little Bighorn (Custer's Last Stand) or the site left by the Pilgrims at Plimoth Plantation. It sounds fine to me, but I bet it might make a lot of people uncomfortable.

Indians do possess some control over one category of their cultural heritage: the burials of their ancestors. As a result of a U.S. law titled the Native American Graves Protection and Repatriation Act (NAGPRA), modern Indians are the legal stewards of burials that can be shown to contain the remains of their ancestors (http://www.nps.gov/nagpra/PUBLIC/INDEX.HTM).

NAGPRA is important, but far from perfect. A significant problem arises with ancient burials when it simply isn't possible to prove a direct historical connection between a living group and the ancient remains. It is simply impossible, for example, to prove that the 9,000-year-old bones found in San Diego, California, in 1976 are the remains of direct ancestors of the local Kumeyaay tribes who have claimed them in court (Gibbons 2011a). Scientists want to study the bones; the Kumeyaay want to rebury them. Problems arise as well when the very procedures that might help verify a direct connection between a specific group and an excavated skeleton (for example, a DNA study of the bones) are objectionable to the Native Americans who are claiming ownership. It can get particularly dicey when multiple claimants assert ownership, as is the case with Kennewick Man, where not just different Native American tribes claim a connection, but so does a group of Pacific Islanders, as well as a group of people of Norse descent (Thomas 2000; Chapter 7). Needless to say, that case is a mess.

If you've been paying attention, you've noticed that I have cleverly avoided addressing the ethical conundrum I posed at the beginning of this section concerning my own fieldwork. Unfortunately, I don't have any easy answers or even any not-so-easy answers to the question raised by archaeologist and professor Bettina Arnold in the title of one of her courses: "Who owns the past?" Is it all of the people of the country in which the remains are found? Is it just the tribe or even just the family of the descendants? Do such questions even apply to the fossils of ancient hominins discussed in Chapters 3 through 5 of this book?

As vexing as this issue can be, the good news is that in some places native people are embracing archaeology as a tool for illuminating their own histories. For example, the Navajo tribe has its own archaeology department (Two-Bears 2006); their motto is "Learning from the past to build our future" (http://www.greenguide.nau.edu/NNAD.html). In Connecticut, the resurgent Pequot tribe has its own team of archaeologists (most of whom are not Indians) who conduct research both on the reservation and off the reservation at sites important in Pequot history. For example, Kevin McBride, the director of archaeology for the Pequot (hired by, but not a member of, the tribe and not a Native American), is currently conducting archaeological and historical research at sites related to the Pequot War of 1637 (Urbanus 2015). Though there may never be an answer to the question "Who owns the past?" that satisfies everyone, archaeologists today realize that we have a special ethical obligation to the people whose histories we study.

COPING WITH CRAP: PSEUDOSCIENCE IN ARCHAEOLOGY

MESSAGES FROM THE PAST

This brief discussion of the application of the scientific method in archaeology and paleoanthropology isn't all that different from one that you might find in any other introductory science textbook. Things do get a bit weirder here, however, for the following reason. To a far greater degree than is true for sciences like chemistry, physics, or biology, we find that archaeology and paleoanthropology generate a host of speculations accompanied by an attendant plethora of cable television series and "documentaries" focused on those speculations. The producers of those shows claim that they reveal a "hidden history" of the human species, one intentionally hidden by the science establishment. In fact, those producers don't "reveal" any such history. They just make it up.

Here's the bottom line: If you were hoping that in this book you might find support for claims that human history can be best explained by the intervention of ancient extraterrestrial aliens in antiquity, you are going to be sorely disappointed. If you thought that, just maybe, you would find here the revelation of proof for the existence of biblical giants or "Nephilim," well, that's not going to happen. If you figured that you'd encounter data here that might explain the evolutionary significance of Sasquatch, oh well.

Now the reason you won't be seeing any of that stuff here is assuredly not the result of my being part of a vast conspiracy of scientists sworn to secrecy on these and other out-there claims. We don't meet on alternate Thursdays in an underground government bunker as part of our evil strategy to keep you in the dark. Honest! Why in the world would we hide that stuff if it were true? It makes no sense. As a scientist and textbook author, I am confined and committed to evidence, not fantasy. You see, we actually know quite a bit about what happened in antiquity based on actual evidence, not hallucination. We know when the first hominins evolved and we know how the earliest tools were made by those ancestors (Chapters 3 and 4). We know many of the details concerning the evolution of the first modern humans and the development of the human intellect (Chapters 5 and 6). We have a pretty good idea about how our species spread across the face of the globe—and it didn't involve ancient spaceships (Chapter 7). We have a firm sequence for the development of agriculture (Chapter 8) and cities; and yes, we have some very good explanations for how the pyramids and other ancient monuments were built (Chapters 9–14). Human beings built them, and without the assistance of angels, aliens, or Atlanteans. We know these things because archaeologists and paleoanthropologists have conducted research, collected data, replicated ancient technologies, and written for publications where other colleagues challenge our assertions and conclusions before those articles ever get published.

Let me make this perfectly clear: In not a single instance has any evidence been found that supports claims of an extraterrestrial Peace Corps schooling our ancestors in agriculture, metallurgy, or pyramid construction. There is no archaeological or historical evidence for technologically advanced lost continents or twenty-foot-tall fallen angels walking around on Earth, having sex with human women, and constructing burial mounds in Ohio. For real (Feder 2014)! Does that mean that there are no mysteries, controversies, or uncertainties in science? Of course not. In each subsequent chapter in this book, you will find a section titled "Issues and Debates," which focuses explicitly on mysteries, controversies, and uncertainties about which archaeologists and paleoanthropologists, in fact, debate. Ultimately, I think, and I hope you will agree, the amazing story of human antiquity as revealed by science is far more interesting and certainly more meaningful than the speculations and outright falsehoods promulgated by the purveyors of pseudoscientific nonsense.

SUMMARY

Archaeologists and paleoanthropologists apply a broad array of techniques in their investigation of the human past. This chapter has briefly surveyed some of the more important procedures for recovering and analyzing the data on which the rest of the book is based. How sites are formed, how they are preserved, and how they are discovered are key questions for archaeologists and paleoanthropologists. Once found, data can be analyzed to determine the age of the sites, how tools were made and used, the subsistence base of the people, and aspects of their social and even religious lives. Past peoples can also be investigated directly through analysis of their physical remains, which determines the age, sex, health status, and geographic origin of ancient individuals. The evolutionary relationship between a prehistoric person and modern human beings can therefore be determined. Using the general procedures outlined in this chapter and many other very specific analytical techniques mentioned throughout this book, archaeologists and paleoanthropologists can reveal the chronicle of the human past. We begin that chronicle in Chapter 3.

Web links for this chapter can be found at www.oup.com/us/feder

Just as the orientation of magnetic particles in an ancient lava flow may become fixed, in **archaeomagnetic dating** magnetic orientation can become "fossilized" in cultural features. For example, the magnetic particles in sediments that have infilled a canal may become lined up with the earth's magnetic field at the time of their deposition (Eighmy and Howard 1991). Similarly, the magnetic particles in clay making up the bricks of a kiln, like so many natural compass needles, may point to the location of magnetic north at the time they were heated. Careful study of dated sites with features exhibiting evidence of past magnetic orientation has provided data necessary for the production of a "master map" showing the location of magnetic north as it changed through time (Eighmy and Sternberg 1990). Figure 2.22 shows the deduced location of magnetic north based on archaeomagnetism between A.D. 600 and 1975. When the orientation of the earth's magnetic field has been preserved in features found at an archaeological site dating to sometime in that period, a more precise estimate of the site's age can be deduced based on the dated location of magnetic north along this curve during the site's occupation.

FIGURE 2.22
Master map of the location of magnetic north from the period A.D. 600 to 1975 as determined at archaeological sites in the American Southwest (SWCV595). *(Courtesy of Jeffrey Eighmy)*

THE ETHICS OF ARCHAEOLOGICAL RESEARCH

Rather obviously I am a contemporary person, a product of the modern world, born in the middle of the twentieth century to an American family firmly ensconced in the middle class. I can add to this the fact that I am of European descent; my father's side of the family hails from Austria and my mother's from Poland, Germany, and Russia. Finally, I am university educated and trained as an archaeologist.

My personal identity and family bio are relevant here for the following reason: The vast majority of the archaeological fieldwork I have conducted during the course of my career has been at sites representing the villages, hunting camps, and quarries of Native Americans, people with whom I have no particular historical connection. This raises the following interesting ethical question: Since I am not ethnically Native American, what gives me the right to excavate the places where their ancestors lived?

This is not merely an issue of political correctness. For much of our discipline's history, archaeologists practiced what can best be described as archaeological colonialism. Europeans and Americans of European descent traveled the world looking for fabulous archaeological treasures, dug them up, and brought them home to sell or display in museums or, in some cases, just their own homes. The native peoples of places like Egypt, Peru, or China were rarely asked permission by

Archaeomagnetism: Orientation of the earth's magnetic field can become fixed in relatively recent cultural deposits like the sediments in a canal or the clay in bricks lining a kiln. The date of a site can be determined where that orientation points to a location of magnetic north already fixed in space and time along a master curve.