Archaeology: Dating Methods in Archaeology and Paleoanthropology

Dating Archaeological and Paleoanthropological Remains

Anthropologists who study the human and prehuman past—paleoanthropologists and archaeologists—are vitally concerned with accurately determining when the organisms whose fossils they find actually lived and at what point in time the artifacts they find were made and used. Without firm dates, paleoanthropologists cannot accurately reconstruct such things as the path of extinction and evolution that led to modern humans, and archaeologists cannot accurately trace such things as cultural development. Numerous scientific methods have been developed to date hominin fossils and artifacts, and some of these will be described below.

Exact dates are often difficult to establish, since many factors can affect how successfully artifacts and fossils are preserved over time. The type of dating method used depends on the type of material to be dated, as well as the environmental and geological setting of the deposits. Two major dating methods are in use today: **relative dating methods** and **chronometric (or "absolute") dating methods**. *Relative dating methods* are used to determine whether an object is older or younger than another object. By formulating a chronological sequence of artifacts or fossils, researchers can begin to compare and contrast these items and establish the relationships between them. In essence, relative dating allows anthropologists to identify the approximate age of an item but not its exact age. In order to establish more exact dates, archaeologists and paleoanthropologists use *chronometric dating methods*, which rely on scientific techniques performed in laboratory settings.

relative dating methods Dating methods that arrange material evidence in a linear sequence, each object in the sequence being identified as older or younger than other objects.

chronometric (or "absolute") dating methods Dating methods based on laboratory techniques that assign age in years to material evidence.

strata Layers; in geological terms, a stratum is a layer of rock and soil.

stratigraphic superposition A relative dating method that relies on the depth of strata and associated artifacts and fossils.

It is important to note that although chronometric dating is more accurate than relative dating, it should not be taken as providing an "absolute date," as there is always a margin of error that must be considered. As with any other scientific procedure, it is essential to document the uncontrolled variables that may affect the outcome of the procedure. In addition, the quality of the object must be considered, as this can affect the reliability of the date that either relative or chronometric dating methods indicate. In order to generate a reliable argument for a date, archaeologists and paleoanthropologists tend to combine multiple dating methods and techniques whenever possible. This sort of multi-pronged approach typically results in a number of dates that will, when taken together, provide a more reliable date.

Relative Dating Methods

Relative dating methods are useful to begin to create a timeline for different objects. While these methods are not as exact as chronometric dating methods are, they allow archaeologists and paleoanthropologists to understand whether certain fossils or artifacts are older or younger than others.

Stratigraphic Methods

Over time, fossils and artifacts become integrated into the natural environment, forming part of geological deposits. Thus, archaeological and paleoanthropological investigations often involve meticulous excavation of rock or soil layers, known as **strata**, and their associated artifacts and fossils in order to calculate relative dates. **Stratigraphic superposition** is a form of relative dating that is based on the idea that older strata will generally be deeper underground, with more recent

FIGURE F2.1 | Stratigraphic superposition is dramatically on display in the Grand Canyon, where layers of rock and soil, laid down sequentially over millions of years, have been exposed by erosion.

strata found above (Figure F2.1). Researchers document the relative depth of these layers to create a timeline according to the **law of superposition**.

However, it is important to realize that many natural and human influences can alter these geological and archaeological deposits. For example, strata can be dug up, eroded, and washed or blown away. Molten lava can also disturb strata as it forces its way through fractures in the rock on its way to the surface. As you might expect, such disturbances can make dating through stratigraphic superposition more challenging. Even when researchers are aware that these sorts of disturbances have occurred, they cannot always place fossils and artifacts back into their original strata within the stratigraphic record. Sometimes, however, researchers can look at nearby sites that have not been disturbed to create a local relative dating sequence. This sequence can then be used to date fossils and artifacts from disturbed sites through comparison.

By associating the relative age of certain fossils with the distribution of groups of these fossils, archaeologists are able to identify patterns of fossil distribution in different rock layers. This approach is known as **biostratigraphic dating**. Two kinds of fossil species are most useful for this type of dating: those that spread out quickly over a large area following the widespread extinction of their parent species, and those that evolved so rapidly that a fossil representing any evolutionary stage is a good indicator of the relative age of other fossils found in association with it.

Typological Sequences (Archaeology)

After artifacts have been recovered from a site, they are typically classified into groups (or types) based on similarities and differences. When classifying artifacts, researchers must choose the attributes on which they will base their comparisons very carefully, as different qualities will lead to different typological categories. For example, grouping artifacts based on the materials of which they were made would result in all ceramics being grouped into the same category, regardless of their function. This sort of approach represents a *characteristic* typology. Conversely, grouping ceramics based how or why they were used would result in bowls being grouped separately from cups or plates. This sort of approach represents a *functional* typology. Once groups of similar objects have been formed, they can be organized into a sequence based on how their appearance changed over time.

As you can see, artifacts can be grouped and organized in various ways and based on different characteristics. The specific typology a researcher chooses to create generally depends on the questions that he or she wants to answer. Recognizing the benefits and limitations of each possible approach helps the researcher choose the typology most appropriate to her or his study.

law of superposition A principle of geological interpretation stating that layers lower down in a sequence of strata must be older than the layers above them and, therefore, that objects embedded in lower layers must be older than objects embedded in upper layers.

biostratigraphic dating A relative dating method that relies on patterns of fossil distribution in different rock layers.

Grouping Artifacts

Most Canadians have an assortment of jackets and coats that have specific uses—thick coats that keep them warm in winter, waterproof coats that keep them dry in the rain, dressy jackets that make them look sharp on formal occasions, and so on. Think about the collection of jackets and coats that you own, and identify the various ways you could organize them into types (e.g., by colour, material, or function). Once you have identified a few approaches, choose the one that you think would be most useful for categorizing your jackets and coats, and create a typological sequence. Why did you choose the categories that you did? Why was this approach effective? What would be an ineffective approach? Why? What assumptions did you make when organizing your groups, and how could these assumptions misrepresent your collection?

When sequencing artifacts, archaeologists often assume that artifacts that look alike were made at the same time. Based on such assumptions, archaeologists can arrange groups of similar artifacts into a linear sequence; this technique is referred to as **seriation**. Specific changes in artifact types can be seen as a trajectory of style changes that is most commonly apparent in artifacts like pottery and stone tools. Organization based on changes in styles is referred to as *contextual seriation*. Organizing types based on style changes can be challenging, as the changes that are detectable may be very subtle. Moreover, it is difficult to get the order of artifacts exact using this method. However, this type of seriation can be very useful when one or more objects can be dated, as estimates for the dates of the rest of the artifacts in the series can then be established with greater accuracy.

A slightly different approach to seriation, known as *frequency seriation*, takes into account the frequency with which certain artifacts appear at certain points in the archaeological record. This method assumes that the proportion of artifact styles in an assemblage represents the popularity of those styles at the time the assemblage was formed. When the frequencies of different artifacts from a series of assemblages are plotted on a graph and sites containing similar frequencies are kept together, the result is a relative chronology of assemblages based on the rising and falling frequencies of the different styles. As with contextual seriation, frequency seriation is most useful when a date for one or more artifacts within the series can be determined, as this creates a fixed point around which all other artifacts in the series can be arranged.

seriation A relative dating method based on the assumption that artifacts that look alike must have been made at the same time.

isotopic dating Chronometric dating methods based on scientific knowledge about the rate at which various radioactive isotopes of naturally occurring elements transform themselves into other elements by losing subatomic particles.

non-isotopic dating Chronometric dating methods that assign age in years to material evidence but not by using rates of nuclear decay.

Thinking like an Archaeologist

Consider how the popularity of different types of family cars has changed over the past fifty years.

Period	Most Popular Family Vehicle
1960s–early 1970s	Station wagon
mid 1970s–early 1990s	Minivan
mid 1990s–present	SUV

With this progression in mind, imagine that you are an archaeologist working in the twenty-third century and you are digging up an auto-wrecking yard that has been buried since 2050. Using the information listed above, assign approximate dates to the following strata.

1. Strata "O," which contains many minivans, few station wagons, and no SUVs
2. Strata "L," which contains station wagons but no minivans or SUVs
3. Strata "T," which contains many SUVs, a few minivans, and hardly any station wagons

Now put these strata in relative order, from oldest to most recent. (You should find that your ordering spells "LOT.") If you were not already aware of the decades in which these vehicles were popular, how might you have decided which strata was oldest and which was most recent?

Chronometric (or Absolute) Dating Methods

Compared to relative dating methods, chronometric dating methods provide more precise dates. They do this by using two different approaches: **isotopic dating** and **non-isotopic dating**. Isotopic dating methods are typically used to determine dates for objects that are billions of years old. Non-isotopic dating methods, on the other hand, are most useful for determining dates for objects that were created or deposited more recently.

Isotopic Methods

Isotopic dating methods rely on changes through time that occur in the chemistry of artifacts, ecofacts, and fossils. Various radioactive isotopes exist naturally in rocks and living organisms, and these isotopes transform into other elements by losing subatomic particles. When this *decay* occurs in a radioactive isotope, it is measured in terms of its *half-life*—the time it takes for half of the original radioactive sample to decay into the non-radioactive end product. Rates of decay make useful atomic clocks because they are typically unaffected by other physical or chemical processes.

Geologists using isotopic dating methods to determine the ages of rocks generally agree that the earth is about 4.6 billion years old. Paleoanthropologists are most interested in only a tiny fraction of all that geological time, perhaps the last 65 million years, the period during which non-human primates and then human beings evolved. Archaeologists focus on an even narrower slice: the last 3.3 million years.

Described below are several reliable isotopic dating methods. A more complete list of numerical dating methods, with the periods for which dates are the most accurate, appears in Figure F2.2.

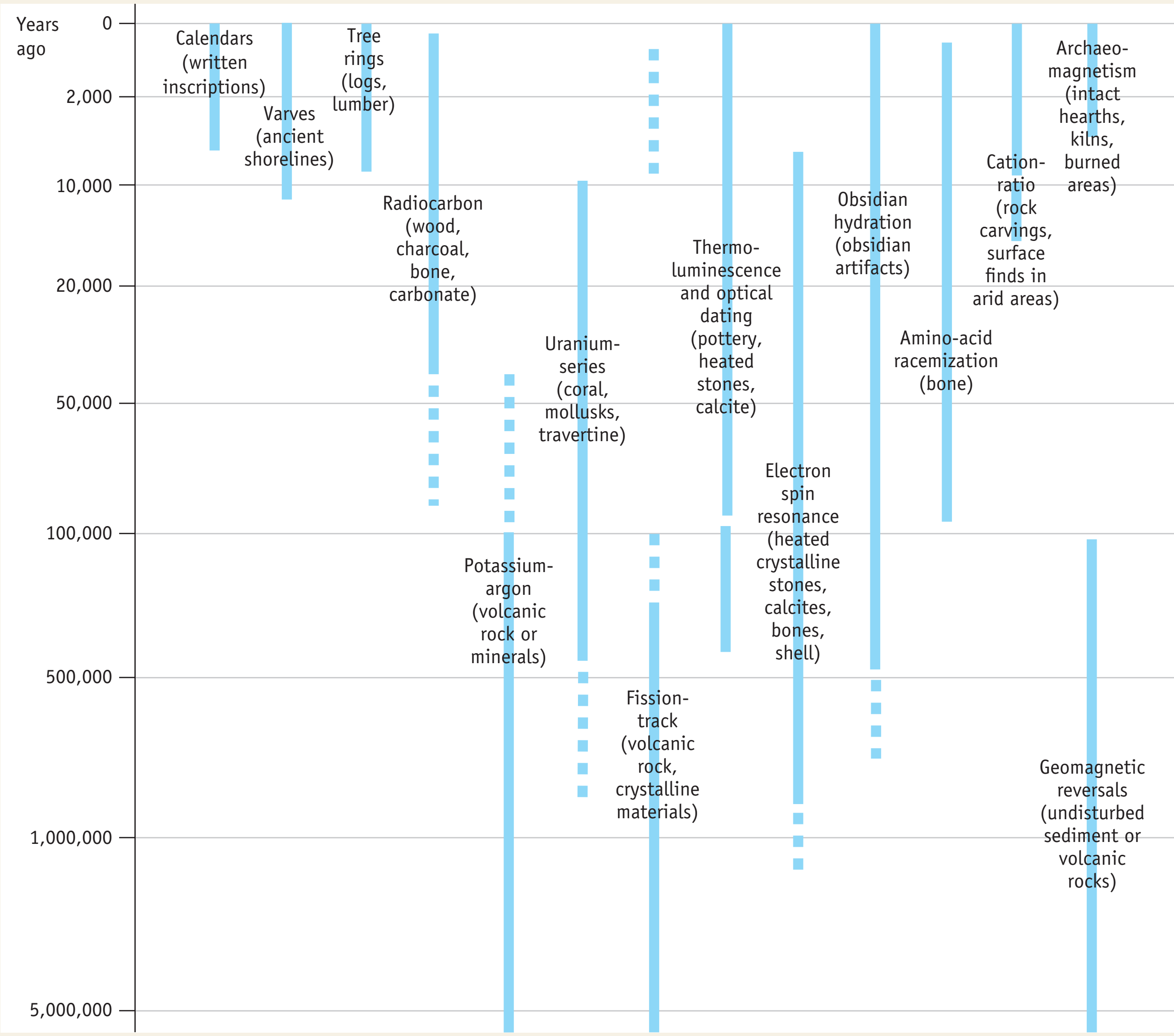

FIGURE F2.2 | Chronometric dating methods can be used to anchor a series of fossils or artifacts dated by relative methods to a fixed point in time. This chart summarizes some of the most important chronometric methods, showing the spans of time and materials for which each is applicable. (Adapted from Renfrew and Bahn 2008, 133.)

Potassium–Argon Dating

Potassium is one of the most commonly occurring elements in the earth's crust. One isotope of potassium that occurs in relatively small quantities is radioactive potassium 40, which decays at a known rate into argon 40. During volcanic activity, very nearly all of the argon 40 in molten lava escapes, resetting the atomic clock to zero. Potassium, however, does not escape. As lava cools and crystallizes, any argon 40 that collects in the rock can only have been produced by the decay of potassium 40. The date of the formation of the volcanic rock can then be calculated, based on the half-life of potassium 40, which is 1.3 billion years.

The potassium–argon method is accurate for dates from 4.6 billion to about 100,000 years ago. This method is valuable to paleoanthropologists because it can date volcanic rock formed early in the evolutionary history of non-human primates and human beings and thus any fossils found in or under volcanic rock layers themselves. Fortunately, volcanic activity was common during these periods in areas like eastern Africa, where many important fossils of early human ancestors have been found.

Potassium–argon dating has two main limitations. First, it can be used only on volcanic rock. Second, its margin of error is about ±10 per cent. A volcanic rock dated by the potassium–argon technique to 200,000 years ago ±10 per cent could have been formed anywhere from 220,000 to 180,000 years ago. Nevertheless, no other technique yet provides more accurate dates for the periods in which early hominin evolution occurred. Since the late 1980s, a variant called the $^{40}Ar/^{39}Ar$ method has been developed, which produces more precise dates using samples as small as a single grain of volcanic rock.

Uranium-Series Dating

This dating method is based on two processes. First, when uranium 238, uranium 235, and thorium 232 decay, they produce intermediate radioactive isotopes until eventually they transform into stable isotopes of lead. Second, uranium is easily dissolved in water; as it decays, the intermediate isotopes it produces tend to solidify, separate out of the water, and mix with salts that collect on the bottom of a lake or a sea. Using their knowledge of the half-lives of uranium isotopes and their intermediate products, scientists can date soil deposits that formed in ancient lake or sea beds.

Uranium-series evidence can be used to date broad climatic events, such as glaciations, that may have affected the course of human evolution. But it also allows paleoanthropologists to date inorganic carbonates, such as limestone, that accumulate in cave, spring, and lake deposits where hominin fossils are sometimes found. Uranium-series dating is significant because it is useful for dating many important archaeological sites that contain inorganic carbonates and because it provides dates for periods of time not covered well by other dating methods, particularly the period between 150,000 and 350,000 years ago, when *Homo sapiens* first appeared (Klein 2009, 38–41). At present, uranium-series dating is particularly useful for the period 50,000 to 500,000 years ago.

Radiocarbon Dating

Radiocarbon dating may be the method of absolute dating best known to non-anthropologists, and it is the most common dating technique used by archaeologists. It measures the ratio of stable carbon (carbon-12) to radioactive carbon (carbon-14) in once-living organisms. The method is based on four assumptions: (1) that the amount of radioactive carbon-14 in the atmosphere has remained constant over time, (2) that radioactive and non-radioactive carbon mix rapidly so that the ratio of one to the other in the atmosphere is likely to be the same everywhere, (3) that radioactive carbon is just as likely as non-radioactive carbon to enter into chemical compounds, and (4) that living organisms are equally likely to take radioactive carbon and non-radioactive carbon into their bodies.

If these assumptions hold, then we can deduce that equal amounts of radioactive and non-radioactive carbon are present in all living tissues. Once an organism dies, however, it stops taking carbon into its system and the radioactive carbon-14 in its remains begins to decay at a known rate. The half-life of carbon-14 is 5730 years, making radiocarbon dating extremely useful for dating the remains of organisms that died as long ago as 30,000 to 40,000 years. Samples older than about 40,000 years usually contain too little carbon-14 for accurate measurement. However, a recent refinement in radiocarbon technology called *accelerator mass spectrometry* (or AMS) solves that problem in part for smaller samples. AMS counts the actual atoms of carbon-14 in a sample.

Charcoal, for example, can be reliably dated to 55,000 years ago using AMS (Klein 2009, 46).

Radiocarbon dating is not flawless. Evidence shows that the amount of carbon-14 in the earth's atmosphere fluctuates periodically as a result of such factors as solar activity, changes in the strength of the earth's magnetic field, and changes in the amount of carbon dioxide dissolved in the world's oceans. Scientists are also concerned that an organism's tissues can become contaminated by carbon from outside sources either before or after death; this problem is particularly acute in very old samples analyzed by AMS. If undetected, any of these factors could yield inaccurate radiocarbon dates.

Scientists have discovered that radiocarbon dates for samples less than about 7500 years old differ from their true ages anywhere from 1 to 10 per cent. Fortunately, radiocarbon dates can be corrected by dendrochronology (see below) over roughly the same 7000-year time span. Most archaeologists use radiocarbon dates corrected by dendrochronology to convert radiocarbon years into calendar years, assigning dates in "radiocarbon years" rather than in calendar solar years. Radiocarbon years are indicated when they are followed by the letters BP, meaning "before present"; for purposes of calibration, "present" was established as 1950. In addition, radiocarbon ages are always given with a plus-or-minus range, reflecting the statistical uncertainties of the method (e.g., 14,000 ± 120 years ago [Klein 2009, 45]).

Thermoluminescence

Rocks and clay are often exposed to radiation emitted by naturally occurring radioactive isotopes of uranium, thorium, and potassium that occur in the atmosphere. Electrons can then become trapped in the crystal structure of the irradiated substance. If the irradiated substance is subsequently heated, however, the trapped electrons will be released together with a quantity of light directly in proportion to their number. The light released in this process is called *thermoluminescence*.

If we know the amount of radiation our sample receives per year, heat it up, and measure the amount of thermoluminescence released, then we can calculate the number of years since the sample was last heated. This is a handy way of determining the date when ancient pottery fragments were last fired, when burnt-flint artifacts were last heated, or even when naturally occurring clays were heated accidentally by a fire burning above them. The accuracy of this method may be questioned if it can be determined either that trapped electrons sometimes escape without being heated or that radiation doses are not constant. Nevertheless, thermoluminescence is valuable because, like the uranium-series method, it uses an alternative set of materials to yield reliable dates for the troublesome gap between the upper limits of the radiocarbon method and the lower limits of the potassium–argon method—between 40,000 and 100,000 to 300,000 years ago (Fagan 1990, 64; Klein 2009, 35).

Non-isotopic Methods

Unlike isotopic techniques, non-isotopic dating methods do not use rates of elemental decay to provide numerical dates of materials recovered from excavations.

Dendrochronology

Dendrochronology yields numerical dates for trees and objects made of wood. A crosscut section of a mature tree exposes a series of concentric rings, which normally accumulate one per year over the tree's life. (Old trees do not need to be cut down to recover the tree-ring chronology they contain; instead, scientists bore long, thin holes into their trunks and remove samples that preserve the sequence.) Tree rings are thicker in wet years and thinner in dry years. The pattern of thick and thin rings is similar for all trees growing in the same habitat over many years. The older the tree, the more growth rings it has and the more complete is its record of the growth pattern for the locality. Clearly, only trees with seasonal growth patterns can be used successfully in dendrochronology—those that grow all year round, such as those in tropical rainforests, do not produce variable ring patterns.

Tree rings are similar to rock layers because scientists can use their distinctive sequences to correlate different sites with one another. Figure F2.3 shows how the tree-ring sequences from three old trees cut down at different times can be cross-correlated to yield an uninterrupted chronology that covers 100 years. Scientists use this master chronology to match wood recovered from archaeological sites against the appropriate sequence to determine when a tree lived and when it was cut down. Tree-ring chronologies based on the California bristlecone pine extend more than 8000 years into the past. In Europe, chronologies based on oak trees go back to about 6000 years ago (Renfrew and Bahn 2008, 139).

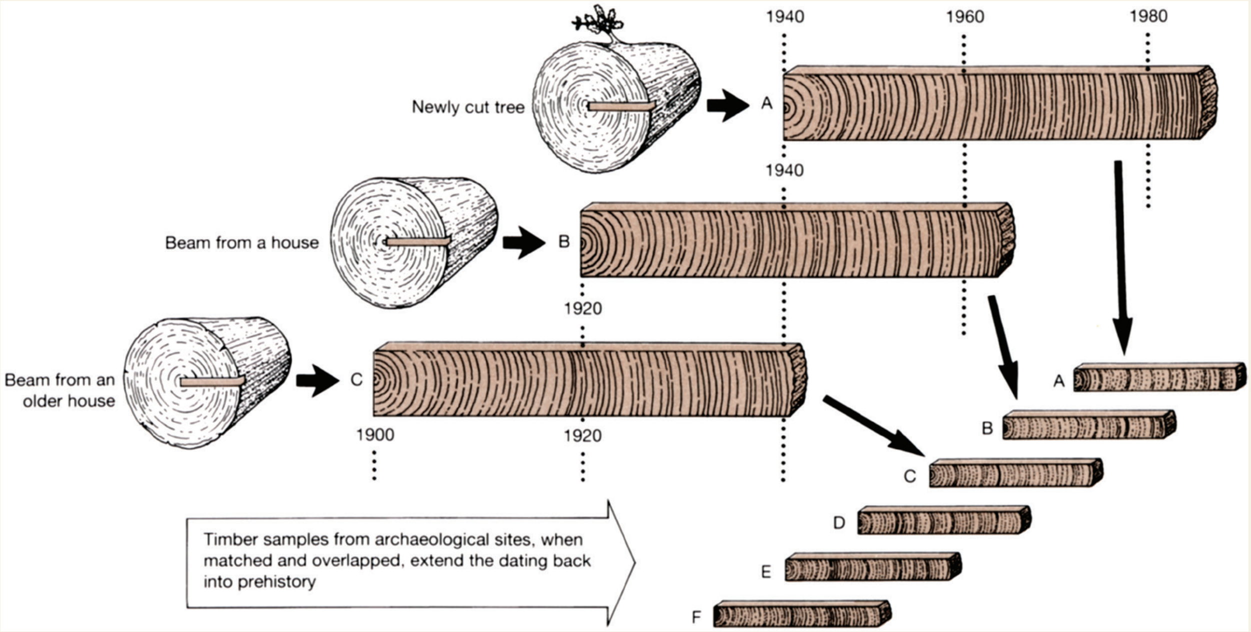

FIGURE F2.3 | Trees with annual growth rings are similar to rock layers in that their distinctive sequences can be correlated across sites to yield an uninterrupted chronology that may go back hundreds or thousands of years. Researchers use this master chronology to assign chronometric dates to wood recovered from archaeological sites. (Original drawn by Simon S.S. Driver, based on other sources [Renfrew and Bahn 2008, 139].)

Amino Acid Racemization (AAR)

The method known as amino acid racemization (AAR) is based on the fact that amino acids in proteins can exist in two mirror-image forms, left-handed (L-amino acids) and right-handed (D-amino acids). Usually, only L-amino acids are found in living organisms, but after the organism dies, they are converted into D-amino acids. The rate of conversion is different for each amino acid and depends on a variety of factors, including the surrounding temperature, moisture, and acidity level. If those levels can be determined since the time the specimen died, the ratio of D to L forms can be used to calculate how long ago death occurred. AAR has proved most accurate when dating fossilized shells (Klein 2009, 50).

Choosing the Right Dating Method

Of the dating methods described above, which one would you use to date each of the following objects? In each case, explain why you chose the dating method that you did.

1. Wood beams from a colonial site in Ontario
2. Shells found in a midden (i.e., garbage heap) deposit from a Mi'kmaq site in Nova Scotia
3. Pottery from an Inka site in Peru
4. Volcanic deposit associated with an *H. erectus* skeleton from southeastern Asia
5. Caribou bones from an Inuit site in Arctic Canada
6. *H. sapiens* burial remains found among limestone cave deposits in southern Africa

Key Terms

biostratigraphic dating
chronometric (or "absolute") dating methods
isotopic dating
law of superposition
non-isotopic dating
relative dating methods
seriation
strata
stratigraphic superposition

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