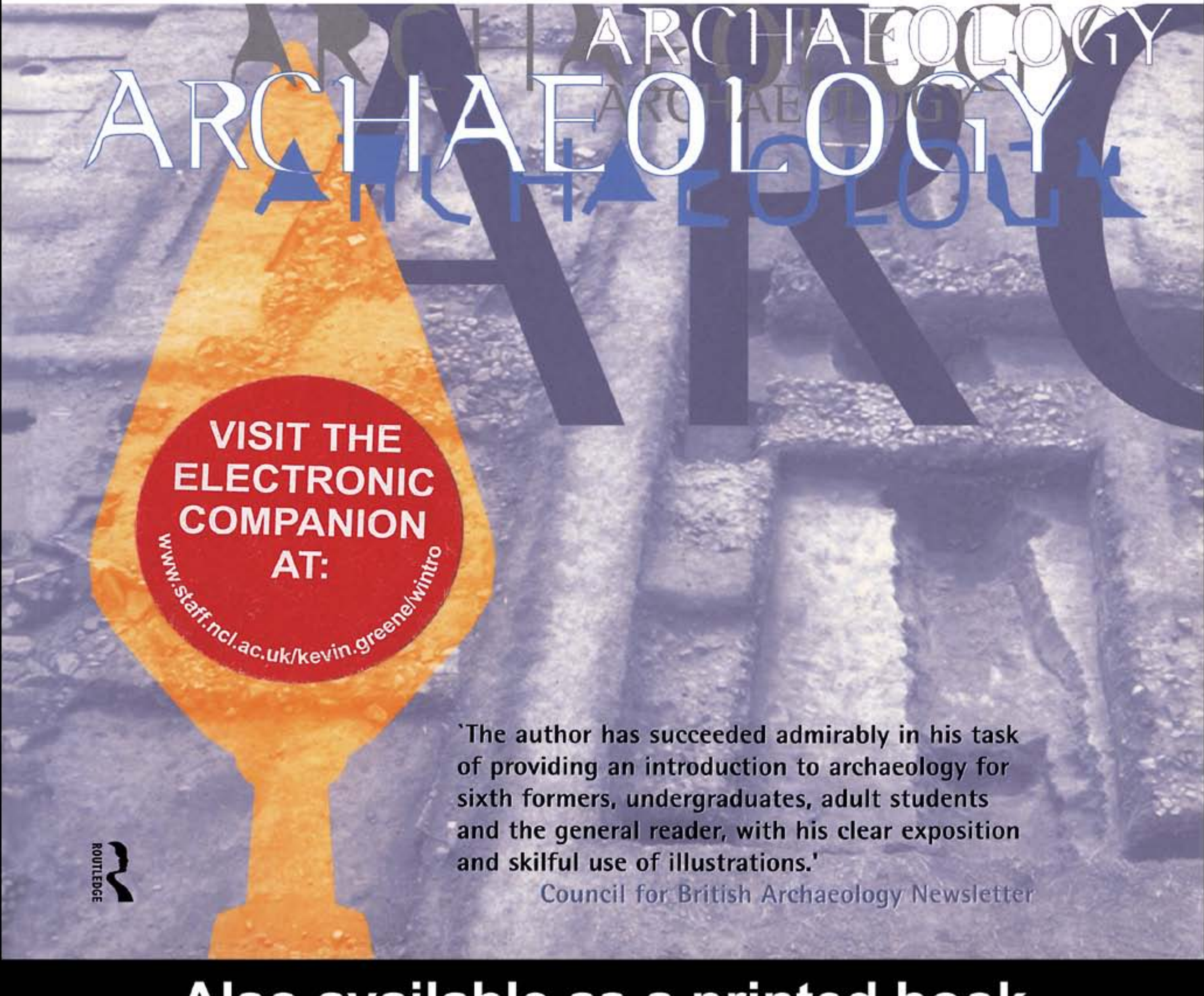
Third Edition Fully Revised

ARCHAEOLOGY
An Introduction

Kevin Greene



ARCHAEOLOGY

An Introduction

The History, Principles and Methods of
Modern Archaeology

Third Edition Fully Revised

Kevin Greene

ROUTLEDGE
Taylor & Francis Group

4 Dating the past

Dating is the key to organizing all archaeological evidence. Furthermore, the development of dating methods, whether 'traditional' or scientific, illustrates the ingenuity and lateral thinking that make archaeological problem-solving such a fascinating exercise. This chapter will examine the use of historical evidence and some methods of relative dating based upon artefacts before looking at scientific techniques. As in earlier chapters, the historical development of the subject will be stressed at various points. It is interesting to see how tree-rings, varves and pollen analysis were used to construct relative and absolute dating for prehistory in the first half of the twentieth century. The intellectual appeal of this pioneering work is just as attractive as that of more recent methods.

1 Background

Chapter 1 described how the biblical accounts of the Creation, the Flood and the peopling of the world were gradually eroded, and how, by the 1860s, scientists had undermined Bishop Usher's date of 4004 BC for the Creation. An awareness of geological time scales, combined with Darwin's concept of evolution, emphasized the slow and gradual nature of developments in human societies and artefacts. Prehistoric time could be subdivided with growing confidence and artefacts could be subjected to more detailed classification. While observations of geological and archaeological stratification and contexts provided evidence for sequences of fossils and artefacts, they only placed them into a correct relative order. Absolute dating remained firmly in the hands of archaeologists working on the literate civilizations such as Greece or Rome. The scope of historical dating was extended to Egypt and the Near East when their scripts were deciphered in the early nineteenth century. By then, Thomsen had already used archaeological finds in Scandinavia to validate the concept of three successive ages of stone, bronze and iron, but these remained essentially undatable before Roman imports appeared in Iron Age phases.

At the beginning of the twentieth century it must still have been inconceivable that reliable dates could ever be established for European prehistory, other than those that depended on tenuous connections between Egypt and the Aegean in the second millennium BC. Dating began later in most other parts of the world; apart from South America, India, China and other parts of the Far East where literate civilizations existed, dating began with the first contacts between native peoples and European explorers and colonizers. Not until 1950 did absolute dates become a reality for prehistoric archaeology in areas outside Scandinavia and the south-west of the United States, where varves and tree-rings had begun to provided a locally applicable dating method some decades earlier.

The dating of sites by stratigraphy was examined in Chapter 3 and the concepts of the *terminus post quem* and *terminus ante quem* were explored (p. 67). Many of the dating techniques surveyed in chapter 4 are independent of stratification, but it is important to stress that they are most valuable when objects or samples to be dated come from properly recorded, stratified contexts on excavations.

2 Historical dating
(South 1977)

Scientific dating techniques have received considerable attention since 1950, but their most spectacular successes have tended to affect prehistory. It is impossible for archaeologists working in historical periods to cause such dramatic changes as the destruction of the accepted framework for dating Neolithic and Bronze Age Europe, or the addition of several million years to the estimated age of toolmaking hominids from the Olduvai Gorge in East

Africa. Prehistorians had already constructed a framework from archaeological sources by the end of the nineteenth century, long before scientific dates became available; the introduction of independent dates caused adjustments to the framework, rather than complete rebuilding. Archaeologists working in a historical setting are in a very different position, for documentary sources have already been used to establish a framework of dates and cultures into which they are expected to incorporate archaeological evidence.

However, prehistorians sometimes overestimate the accuracy and detail of frameworks based on historical evidence; in practice, early written sources may provide little more information than a scatter of radiocarbon dates. The extent of documentation varied considerably in 'historical' cultures and the information that survives today is determined by a variety of factors. People wrote about a restricted range of subjects in the past; their successors only preserved what was still of interest to them, and they frequently rewrote it from their own point of view, introducing errors and misunderstandings. Historical writing has only recently attempted to aim at objectivity. It was normally written with a clear purpose, either to represent an individual or regime in a good or bad light (depending on the writer's point of view), or to convey a particular philosophical or religious point. A number of considerations have to be weighed up before a piece of information contained in a historical or biographical account is accepted: the date and quality of the surviving manuscripts; the distance (in time and place) of the author from the events described; the author's record of accuracy on items that may be checked independently; the quality of the writer's sources; and any personal biases or motives for distorting the truth.

Some documents were written with a clear historical purpose, but the value of others is a result of attention from modern historians and archaeologists. The first category includes narrative historical works or biographies such as those written by Tacitus or Bede, as well as the chronicles maintained in many monasteries in medieval times. Documents without a historical purpose include laws, land-charters, wills, accounts, miscellaneous letters and anything else written for use rather than posterity. This kind of material is often preserved today in archive offices, and it becomes more abundant as it decreases in age. Post-medieval and industrial archaeologists may find precise dates for sites and structures in company accounts, building designs and detailed maps.

Historical documents may be discovered in archaeological excavations; thousands of clay tablets with cuneiform inscriptions were found in Mesopotamia before Rawlinson deciphered their script, while everything from the lost works of Greek poets to gossipy letters, written on fragments of papyrus, have been recovered from the desiccated rubbish tips of Graeco-Roman cities in Egypt. Inscriptions carved on stone were particularly important in Egypt and the Greek and Roman world, and their content ranges from terse building dedications giving the date and builder's name, to lengthy historical, religious or legal material (fig. 4.1). Coins are historical documents of a kind, and besides dates they sometimes bear short inscriptions about rulers and events that may not appear in surviving documents. A datable coin provides an excellent *terminus post quem* when it is found in a significant stratigraphic position on an excavation (see figs 3.9; 3.12). The unique importance of these kinds of historical evidence is that they are *primary* documents that have not been copied out many times over the centuries by scribes who might introduce fresh errors at every stage.

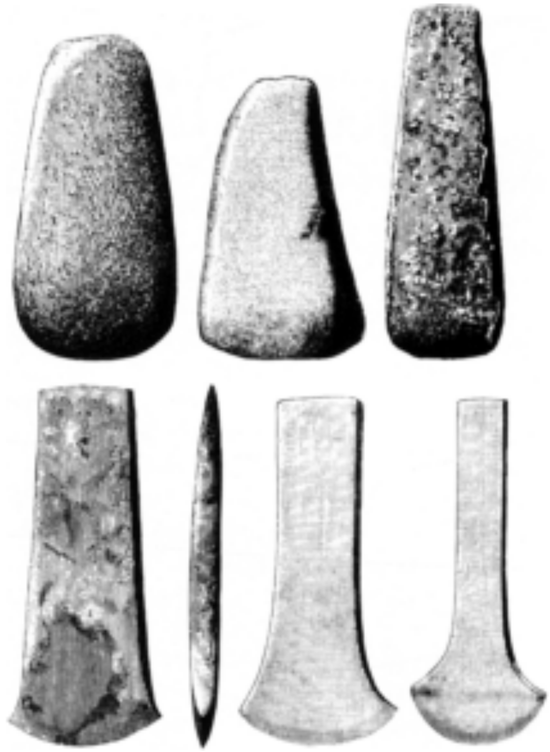
Dates derived from historical information should be related to sites with care. Sometimes a direct association is established, perhaps by a coin in a stratified sequence, or an inscription from a specific building. Otherwise, there tends to be at least one remove between the evidence and the archaeology, whether it is the use of cross-dating by dated finds, or the identification of places named in texts with remains of sites found by fieldwork. Cross-dating is used extensively in the study of artefacts in historical periods. Roman Germany provides a good sequence of military sites established between the late first century BC and the later second century AD, resulting from advances, retreats and modifications along the Rhine-Danube frontier. Sites of the first century AD are particularly useful, for many new forts were founded and they may be dated very closely, thanks to the *Histories* and *Annals* written by Tacitus towards the end of the century. By the early twentieth century German archaeologists had worked out detailed typologies for pottery and other artefacts by comparing finds from sites of different dates, and these dates could then be applied to undated sites in other areas where the same artefacts were discovered. In India, Mortimer Wheeler's cross-dating of sites near Pondicherry in 1945 involved Italian tableware (Arretine ware) that had been classified and dated thanks to its occurrence on early military sites in Germany (Wheeler, 1954, 119–25).

A danger of historical archaeology is that dates may have a rather mesmerizing effect. If a layer containing burnt debris and broken artefacts is excavated, there is an inevitable tendency to search the local historical framework for a reference to an invasion or warfare in the region, and to date the excavated context accordingly. Unfortunately, historical information is patchy even in the Roman period, and there may have been many unrecorded episodes that could equally well account for the remains found. In any case, buildings and even whole forts or towns could burn down accidentally; it happened to London in 1666. If an excavated context and the artefacts that it contains are dated incorrectly in this way, there is a real danger that cross-dating will apply inaccurate dates to similar artefacts found on other sites.

One of the most precise examples of historical dating is provided by Pliny the Younger's eye-witness account of the burial of Pompeii and Herculaneum by the eruption of Vesuvius in AD 79. The volcanic deposits that sealed these cities are a rare example of a *terminus ante quem,* for everything found beneath them must be earlier than AD 79. Objects found in circumstances that show that they were in use at the time of the eruption (such as pottery vessels left on a table) are particularly well dated, but finds from uncertain contexts could be several hundred years old. Thera, a Bronze Age city on the Greek island of Santorini in the Aegean, has been compared to Pompeii because it was buried by an even more cataclysmic volcanic eruption. The excavator dated the destruction to around 1500 BC, ultimately on the basis of cross-dating to historical records in Egypt, and the same eruption was thought to have destroyed Minoan palaces on Crete, providing a valuable dating horizon for the Aegean Bronze Age.

4.1 This stone slab, which is just over one metre long, is a primary source for dating the construction of Hadrian's Wall. It was found in the 1750s at the site of a milecastle that formed part of the original plan for the Wall, and probably once adorned its gateway. It was common for this kind of dedication slab to be carved to mark the completion of a Roman building. The inscription reads IMP CAES TRAIAN HADRIANI AUG LEG II AUG A PLATORIO NEPOTE LEG PR PR, which can be translated as 'This work of the Emperor Caesar Trajan Hadrian Augustus [was built by] the Second Legion Augusta under Aulus Platorius Nepos, propraetorian legate' (RIB 1638; Collingwood & Wright 1965, 520). It associates the Wall not just with Hadrian himself, but with Nepos, who was governor of Britain from AD 122–6, and shows that the first phase of the frontier structure had already been completed early in Hadrian's reign (AD 117–38). *Museum of Antiquities, University of Newcastle upon Tyne*

The analogy between Thera and Pompeii proved to be misleading, for scientific techniques have produced a series of conflicting dates that still cause argument. On the whole, scientific evidence now favours an earlier date for the eruption and fails to support any connection with events in Crete (Hardy & Renfrew 1990). Many archaeologists now relate the destruction of Thera to a major volcanic episode that had been noted in Greenland ice-cores and has subsequently been dated by tree-rings to 1628 BC (below, p. 114). Considering the warning (issued above) about the danger of using historical dates, it is interesting to note that scientific dating may have now the same effect: 'Any sloppily dated archaeological event, within a century or so, tends to be "sucked in" to the precisely dated tree-ring events. We all have to be on our guard against circular arguments' (Baillie 1989, 313). Ultimately archaeologists and historians share the same general objectives; the principal contrasts lie in the kinds of evidence that they explore, and the different aspects of the human past that they are able to address most successfully with the material or documentary information available to them.



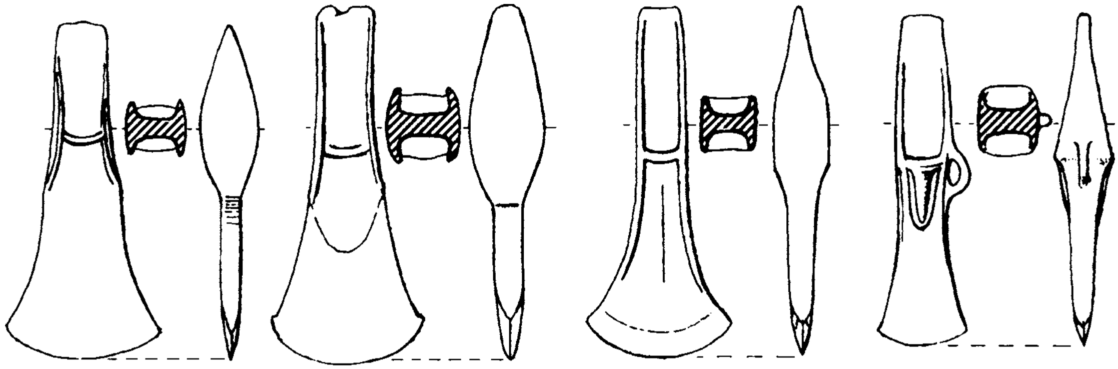
4.2 In an explanation of his methods for studying typology, Montelius illustrated the transition of the axe head from stone to metal. The first copper axes (top row) were very similar to their stone counterparts (extreme left), but it was soon realized that metal could be saved by making them thinner, while increasing their effectiveness by hammering out a wider cutting edge (bottom row). *Montelius 1903, 22*

3 Typology
(Graslund 1987)

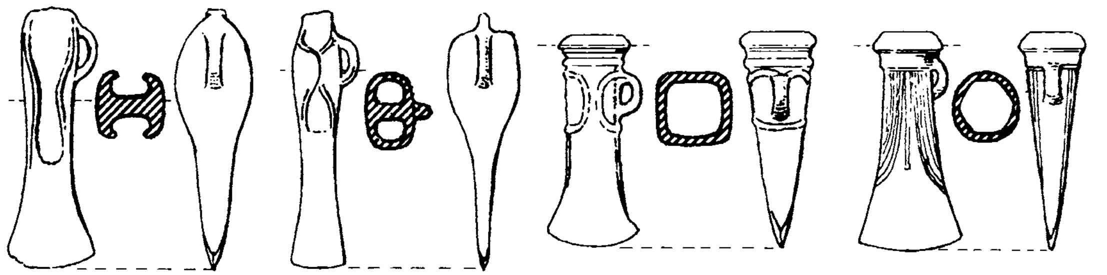
Although Pitt Rivers was an early exponent of typology, his ideas of its universal validity were too abstract to have any chronological promise (see fig. 1.12). In Sweden, Oscar Montelius advanced typology into the realms of firmer dating by producing comprehensive publications of European artefacts from the 1880s. He sought **associations** between artefacts of different forms buried together, such as grave-goods in individual burials, or collections of objects buried in ritual deposits. Each form of artefact was classified in a **type-series**, and the sequence of find contexts normally confirmed progress from simplicity towards greater elaboration or efficiency (figs 4.2–3). These procedures are perfectly acceptable today.

A third technique used by Montelius, **cross-dating** (or *synchronism*), was entirely logical in theory, but, in retrospect, has been very misleading. In its strongest form, cross-dating takes account of artefacts made in historically dated areas, such as Egypt or Mesopotamia, found in association with other artefacts made in undated areas. For example, in 1891 Flinders Petrie found pottery from Crete on Egyptian sites, in contexts dating to around 1900 BC (fig. 4.4). He subsequently identified Egyptian exports at Mycenae in mainland Greece that could be dated to *c.* 1500 BC (Drower 1985, 182–5). Thus, dates derived from Egyptian historical records were extended to sites and cultures in Crete and Greece that lacked internal dating evidence. An obvious limitation was that no historical dates extended beyond 3000 BC, so that the age of earlier artefacts could only be guessed. Whereas Petrie's links were based on direct associations with Egyptian material, Montelius extended cross-dating right across Europe into Britain and Scandinavia by noting associations between artefacts found far from their area of manufacture and local types. These fixed points allowed type-series of different areas to be interlocked, but unfortunately every step away from Egypt increased the possibility of a weak link in the chain (see fig. 6.1).

Two further criticisms are apparent: objects imported from distant sources may have been treasured for long periods before being lost or buried in



Growth of the stop-ridge

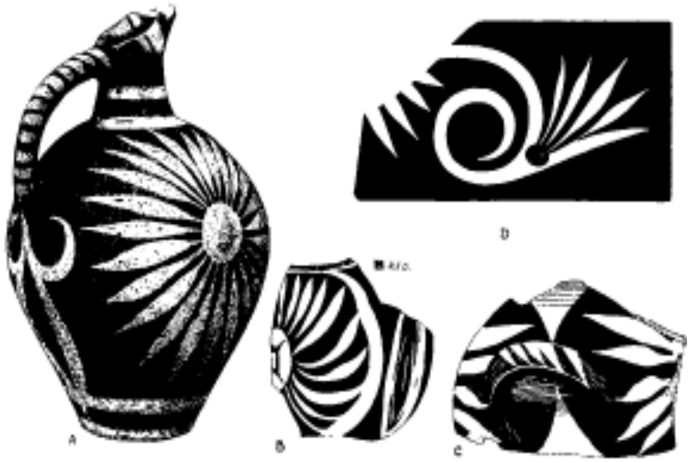


Growth of the wings

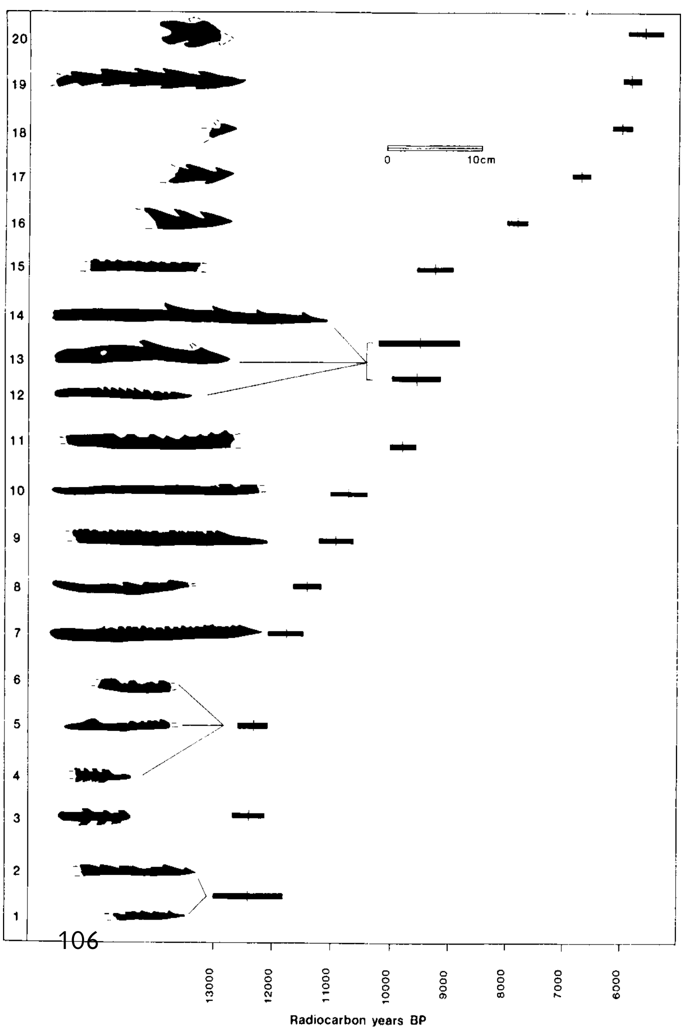
4.3 Some technical reasons for further modifications of Bronze Age 'celts' (axes) were explained by Pitt Rivers in 1875: '...the celt of the neolithic period, chipped only at first and subsequently polished...gave rise to the copper celt of the same form having convex sides, which grew into the bronze celt with flat sides. Then the bronze celt was furnished with a stop to prevent its being pressed too far into the handle by the blow. Others were furnished with projecting flanges to prevent them from swerving by the blow when hafted on a bent stick. Others had both stops and flanges. By degrees the flanges were bent over the stops and over the handle, and then the central portion above the stops, being no longer required, became thinner, and ultimately disappeared, the flanges closed on each other, and by this means the weapon grew into the socket celt. On this socket celt you will see that there is sometimes a semicircular ornamentation on each side. This...is a vestige of the overlapping flange of the earlier forms out of which it grew, which, like the rings on our brass cannon, are survivals of parts formerly serving for special uses.' (Lane-Fox 1875, 507) The development of copper alloy axes ended at this point, for the introduction of iron from c. 1000 BC provided a superior metal for edge tools, with radically different manufacturing techniques. *Audio Visual Centre, University of Newcastle, after Smith 1920*

association with local items; and superficially similar artefacts found in different areas may be unconnected and not contemporary at all. However, confidence in Montelius' cross-dating was increased by the assumption that all cultural advances in Europe were inspired by the civilizations of the Aegean and Near East. The effects of this 'diffusionist' view survived into the 1960s, when radiocarbon dates suddenly snapped the chain of connections into many unrelated links.

Typology has not been superseded, but radiocarbon dates have reduced the burden of prehistoric chronology that it was once made to carry



4.4 Cross-dating by pottery: Arthur Evans used imported Egyptian artefacts to date his excavation of the Palace of Knossos in Crete (fig. 1.15). Local Cretan pottery found on this site could also be dated because similar sherds had been found in Egypt. A, B and D are from Crete and bear decoration of Evans' Latest Middle Minoan II Phase, while C was found at Kahun in Egypt. *Evans 1921, fig. 198*



4.5 Unlike Bronze Age axes, the shapes of harpoon points used by hunters in Britain after the end of the last Ice Age show no clear typological development. However, small samples of the bone from which they were made can now be dated by the AMS radiocarbon technique, and these dates may be used to place them into chronological order. *Smith 1992, fig. 1.2*

(fig. 4.5). Type-series remain an extremely useful means of describing and classifying artefacts of any period, and for understanding their technology and function. Radiocarbon dating (below, p. 115) now allows the typology of prehistoric bronze objects to be checked independently, for remarkably precise results can be derived using the AMS technique from small fragments of wooden handles or shafts that occasionally survive in the sockets of spears or axes (Needham 1986). Association and cross-dating are still important in the historical period; Roman metalwork, pottery, glass and coins were traded to Scandinavia, Central Europe and even India, where they provide valuable dates when found with local artefacts. In the early medieval Migration period (fourth to sixth centuries AD), typological analyses of brooches and buckles linked to Germanic peoples (such as the Goths, Huns or Franks) are still important in the study of 'barbarian' settlements within the former Roman

Empire (Greene 1987). It is important to realize that cross-datings and associations obey the same principle as a *terminus post quem* in an excavation (p. 67); dated finds only establish fixed points *after* which the contexts that they were discovered in must be dated.

4 Sequence dating and seriation

These dating techniques rely on careful excavation and recording, for they both place **assemblages** of artefacts into relative order. Petrie used sequence dating to work back from the earliest historical phases of Egypt into PreDynastic Neolithic times, using grave-groups that could be assumed to consist of contemporary artefacts deposited together at a single time (Petrie 1899; Drower 1985, 251–4). Decisions were made about 'early' and 'late' artefacts in graves by typological judgements about their form. Grave groups were then arranged in a sequence according to their combinations of artefacts of early or late character, in a kind of 'simultaneous typology' that weighed up the development of every item found in each grave. Petrie drew graphs of pottery types that occurred in his sequence of fifty pre-dynastic phases, and showed that types did not appear and disappear abruptly, but became popular gradually before declining equally gradually (1920, pl. L). This phenomenon is confirmed by the ways that modern clothing and jewellery go in and out of fashion at different rates.

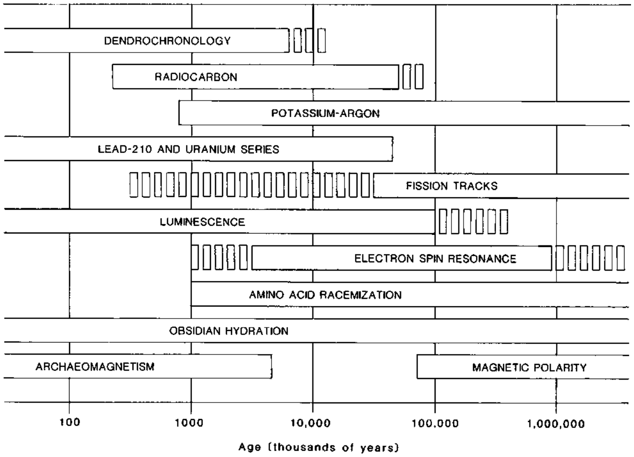
Seriation is based on the same principle, and it has been applied to finds from grave groups, strata or other kinds of assemblages, whether found on individual sites or over a wider area. It works best on assemblages that contain a range of definable characteristics, such as types of pottery or flints, especially those that are subject to change rather than continuity. The numbers of selected artefact types found in each assemblage are converted into percentages to make them comparable. The figures are then arranged into the best possible sequence on the assumption that the percentages of artefacts will have increased and declined in an orderly manner. This process may be carried out by eye if the percentages are marked on individual strips of graph paper to represent each assemblage and shuffled to find the best fit. Random statistical variations and possible differences in the character of the assemblages that are being compared make it very unlikely that the results will form perfect 'battleship curves'. Seriation is only a relative dating method, but it remains useful in the study of finds that do not occur on stratified sites where the sequence is revealed by excavation; like artefact typologies, it is now used within an absolutely dated framework. Petrie's desperate, but inconclusive, attempts to establish an absolute date for the *beginning* of his prehistoric Egyptian sequence underline the enviable position of modern archaeologists (Petrie 1899, 4–6).

5 The advent of scientific dating techniques (Zeuner 1946)

> For Prehistory, no calendars are available. Up to not many years ago, the time-scales suggested for the evolution of early man and his cultures were pure guesses, not to say imagination. From a scientific point of view they were worthless. (Zeuner 1946, 1)

This quotation underlines the complete transformation of archaeological dating that began around 1950 and continues to this day (figs 4.6–7). However, archaeologists tend to forget that geology had already undergone a revolution in scientific dating during the first half of the twentieth century. Seen in the context of the development of dating methods over the previous century, radiocarbon does not seem quite as dramatic as it is sometimes portrayed.

Frederick Zeuner's book *Dating the Past: An introduction to geochronology* (first published in 1946) integrated geological dating with archaeology in an exemplary manner. The text was updated and expanded several times up to 1958, by when Zeuner was able to document the introduction of new techniques such as radiocarbon and potassium-argon dating. Because it gives such a vivid impression of

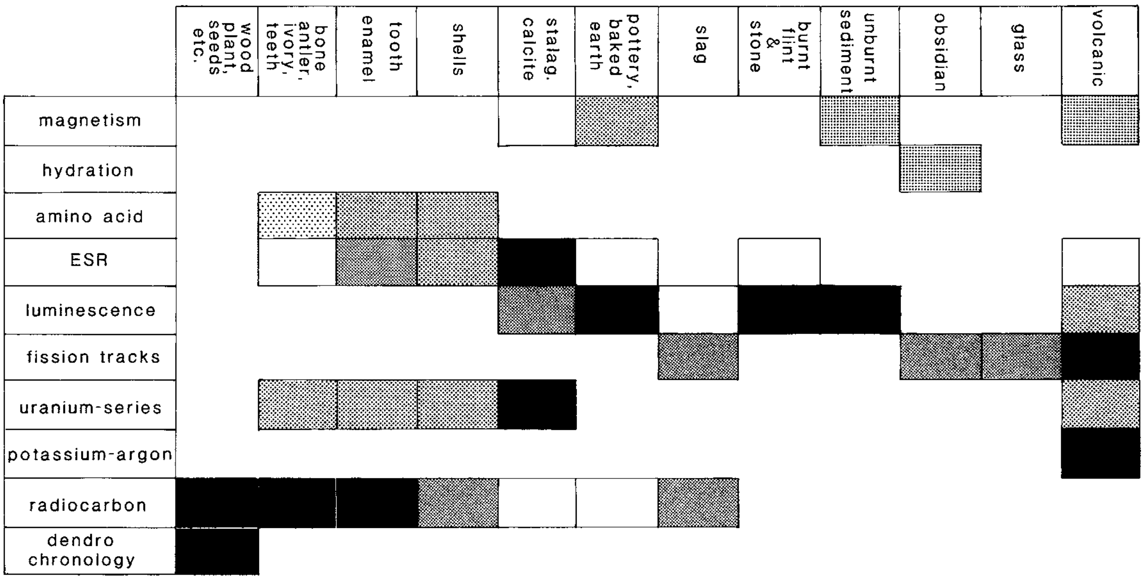


4.6 The leading scientific dating methods are applicable to widely differing periods of the past. Each horizontal bar indicates the range of an individual method; interrupted bars show periods where the potential is less good. Techniques with the greatest time-span are not necessarily the most useful: see fig. 4.7. *Sandra Hooper, after Aitken 1990, fig. 1.2*

the difficulties and triumphs of archaeological dating as it emerged from the nineteenth century, Zeuner's book provides an excellent companion—and contrast—to Aitken's 'state of the art' survey, *Science-based Dating in Archaeology* (1990). While Aitken organized his book according to the scientific basis of each dating technique, Zeuner had adopted a very different approach that began with techniques applicable to the recent past and worked back towards measurement of the age of the Earth. My account will group methods together according to their scientific basis, but it will begin with some of the earliest methods to emerge into general use in the hope of retaining some of the atmosphere of discovery that characterizes Zeuner's writing.

5.1 Geological time scales

Nineteenth-century geologists were preoccupied with the age of the Earth, and Darwin's demand for gradual evolution underlined the length of the time scales involved. Glimpses of 'deep time' could be gained by estimating the rate of erosion of geological formations; Darwin suggested 300 million years to produce the



4.7 Summary chart of materials that can be examined by different scientific dating techniques; the best results will be obtained from the techniques and samples with the darkest shading. Thus, wood and other plants respond well to dendrochronology and radiocarbon, but no other techniques are applicable; conversely, volcanic materials are unsuitable for either of these methods, but offer many other possibilities. Archaeologists need an understanding of figs 4.7–8 to take the right kinds of samples for dating methods, appropriate to the period with which they are concerned. *Sandra Hooper, after Aitken 1990, fig. 1.1* modern form of the South Downs. Lyell used the rate of evolution of certain shells to calculate the age of the Earth and arrived at around 240 million years for the time that had elapsed since the appearance of life (Zeuner 1946, 307–8). However, Lord Kelvin's estimate of as little as 20 million years, based on the rate of cooling of the planet, was widely accepted (ibid. 315–16). The problem was solved by a growing understanding of radioactive decay and measurement of the rate that uranium decayed to produce lead. From around AD 1900 Arthur Holmes and other scientists used the radioactivity method to extend the date of preCambrian rocks back to an age of nearly 2000 million years (Zeuner 1946, 333).

Thus, estimates of geological time underwent a transition from informed guesswork to scientific precision in the fifty years that followed the publication of Darwin's *Origin of Species* in 1859. Accurate knowledge of the age of the Earth was of little direct help to archaeologists, but it emphasized the potential of scientific dating techniques. The first half of the twentieth century witnessed a similar transition that began with the dating of recent geological periods when early humans first lived, and ended with the introduction of radiocarbon dating. As a result, by 1950 absolute dates were available for important stages of recent prehistory, such as the inception of farming and the first use of metals.

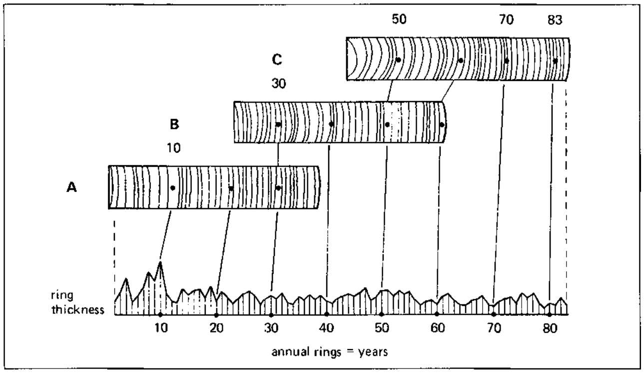
While some geologists concentrated on the age of the Earth, others studied distinctive surface traces left behind by changes in the extent of the polar ice cap. They established the existence of a succession of Ice Ages and worked out a sequence of climatic phases based on evidence for alternations between glaciations and more temperate conditions. If these could be dated, much could be learned about the emergence of modern humans and their interaction with different environments. Some calculations were attempted by measuring the depths of deposits and comparing them with the formation rate of similar deposits in modern times, but there was no way that these estimates could be checked (Zeuner 1946, 134–5). However, an attractive idea that had been developed with increasing precision since the 1780s was that glaciations coincided with changes in solar radiation and that these changes were caused by regular and measurable variations in the Earth's orbit. However, the correlation between periods of glaciation and periods of low solar radiation remained hypothetical until independent dating was achieved with the help of ocean-bed deposits and potassium-argon dating between the 1950s and 1970s (Aitken 1990, 17–19).

6 Environmental methods (Aitken 1990)

6.1 Tree-ring dating (dendrochronology) (Schweingruber 1988)

It had been recognized since at least the fifteenth century that trees produce annual growth rings, and their physiology was well understood by the eighteenth century (Schweingruber 1988, 256–7). Well-documented examples of their use for dating begin in North America in the late eighteenth century; for example, the Reverend Cutler counted 463 rings in a tree that had grown on a native American burial mound at Marietta in Ohio and deduced (correctly) that the mound must antedate Columbus (Daniel 1981, 40–2). Because annual growth rings are subject to seasonal factors that affect their thickness, distinctive patterns recognized in different samples of timber may be compared and used to establish their contemporaneity (figs 4.8–9). In 1901 A E Douglass had begun to study fluctuations in solar radiation and their effects on climate by looking at patterns of varying ring thickness in trees in Arizona and his work became inseparably linked to archaeological dating in the 1920s. Many timbers preserved in *pueblos* (prehistoric native American sites in arid areas of Arizona and New Mexico) could be dated by cross-referencing them to his series (fig. 4.10). An overlapping series of rings was gradually built up from many timbers found on sites in the southwest of the United States, and the sequence was extended back to the fourth century BC. In 1954, bristlecone pines still growing in California were found to be as much as 4000 years old, and a combination of specimens from living trees and old trunks preserved in the White Mountains

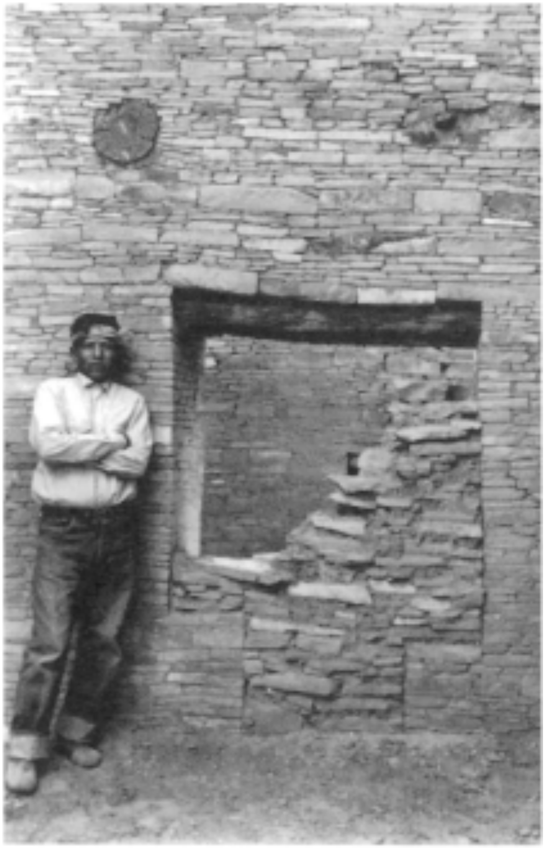
4.8 Apparatus for measuring tree-ring thicknesses. The screen in the centre of the photograph shows a series of rings from a sample mounted beneath a microscope and video camera on the left. Individual rings can be measured precisely and recorded by a microcomputer, while the more sophisticated computer on the right runs programs to match the series of measurements with sequences of known date. *Laboratoire de ChronoEcologie de Besançon; photograph by Olivier Girardclos*



4.9 Dating by dendrochronology: A, B and C are sections from three different trees showing annual growth rings that cover a period of 83 years, from the innermost ring at the left of timber A to the outermost of C. The overlapping (contemporary) portions of the timbers can be matched by observing similarities in the pattern of their rings, especially when unusually wide or narrow rings reflect particularly good or bad growing seasons for the trees. The graph records the average annual ring thickness for each year, allowing for the fact that the outer rings are always narrower than the inner because their volume of wood is spread thinly around a large trunk. Long overlapping sequences from dated timbers provide a reference graph against which individual undated samples can be compared. Thus, if this graph began in AD 1000, timber B was felled in AD 1060, and this is a *terminus post quem* for any structure into which it was incorporated. *Audio Visual Centre, University of Newcastle*

now provides a continuous record back to 6700 BC that is of vital importance for checking radiocarbon dates (below, p. 116). An even more impressive achievement is the establishment of a tree-ring sequence that extends beyond 5000 BC, based on a large number of trees from northwestern Europe. Many of the early samples have been taken from ancient tree-trunks preserved in peat bogs. Some earlier 'floating' sequences that could not yet be linked to absolutely dated timbers were dated approximately by 'wiggle matching' with the radiocarbon curve (p. 117) and extended the range of dendrochronology back to around 9000 BC. By 1993, the sequence in Germany had reached 9494 BC by following pine trees back beyond a period that was too cold for oaks to grow (Becker 1993).

Tree-rings may also be used for relative dating on waterlogged sites where successive timber structures have been excavated. At Charavines (Isère, France), a large scatter of wooden stakes was found preserved on a neolithic village site submerged in a lake, but no coherent plan was apparent. However, when posts made from trees felled in the same year were plotted, they revealed the plans of two rectangular structures built in successive years (Bocquet 1981). This technique became even more valuable when the tree-rings were dated absolutely. Many studies have been conducted in medieval buildings—such as the cathedrals at Trier in Germany or Chartres in France—to identify or date periods of construction that were not fully documented in surviving historical records. Roman forts and bridges in Germany and the Netherlands have also been investigated in the same way; the precision of tree-ring dating is impossible to achieve by any other means. Once dated, the sites can be integrated into historical accounts of the area.



4.10 Pueblo Bonito, in Chaco Canyon, New Mexico, is an extensive native American site built mainly from stone but with timber beams, lintels, roofs, etc. Since the arid desert environment had ensured the preservation of wood for hundreds of years, it was the first site to be studied systematically with the help of tree-ring dating. A combination of dendrochronology and architectural analysis revealed a detailed picture of the development of Pueblo Bonito from c. AD 900–1100 (Judd 1964). The end of a large beam and a horizontal lintel visible in this photograph provide useful sources for dating this part of the structure. Although the latest (outer) tree-ring will provide a *terminus post quem* (the date after which the structure must have been built), there is always a possibility that old timbers were re-used from an earlier phase of the building. The obvious blocking of the doorway suggests that the function of these rooms changed during the life of the building. *Neil Judd, 1926; copyright: National Geographic Society*

Unfortunately there are many problems in the direct application of dendrochronological dating. Not all tree species are sufficiently sensitive to display distinctive variations in their ring characteristics, particularly when growing in temperate climates. Wood only survives under exceptionally wet or dry conditions, and large timbers must be recovered to provide sufficient rings for valid comparisons, because they rely on patterns that accumulated over several decades. Timbers used in buildings were normally trimmed into regular shapes, removing the evidence for the exact date of their felling, and they may have been stored for many years before use. Worse still, timbers were frequently reused several times in repairs or reconstructions of wooden buildings, whose foundations rot long before their roof. Re-use is a particular problem on arid sites, where timbers do not decay easily. Despite these problems, tree-rings are perhaps the only source of truly absolute dates, in terms of a single year. Unfortunately, they will never be universally applicable, partly because of regional and environmental variations in the growth of trees, but principally through the rarity of suitably wet or arid conditions that ensure their preservation.

The provision of samples of known age for testing the accuracy of radiocarbon dates is not the only indirect use of tree-rings. Variations in ring widths reflect climatic conditions, and there are several instances of extreme disturbances to normal growth. A series of exceptionally narrow rings indicates an episode of cold, wet weather from 1159 BC that was almost certainly the result of a volcanic eruption marked in ice-cores at 1100 ± 50 BC. Ash in the upper atmosphere reduced solar radiation to such an extent that human settlement patterns and farming practices were disrupted for sufficiently long to cause an abandonment of upland areas of northern Britain. Thus, tree-rings provide not only dates for sites, but also for environmental catastrophes that influenced changes in human behaviour (Baillie 1989).

At a more intimate level, the precision of tree-ring dates adds an exciting dimension to other finds associated with dated timbers. In the late 1980s timbers from the Somerset Levels trackways were tied in to the dated European series; suddenly, their construction ceased to be 'somewhere in the early fourth millennium', and became an event that took place in 3807/6 BC. This precise date extended to other finds, such as tools and pottery, found in the same context (Hillam 1990). The impact is similar in historical periods; it is now known that a wooden grave chamber erected within the famous Viking ship burial at Oseberg in Norway was constructed from trees felled in AD 834 (Bonde and Christiansen 1993).

6.2 Varves

Every summer, the melting of glaciers causes erosion by streams and rivers, and the resulting sediments are eventually deposited on lake beds (fig. 4.11). The sediments become sparser and finer as the year progresses, for the flow of water is reduced when temperatures begin to fall; winter freezing then stops erosion until the next summer. Sections cut through lake beds in glacial regions reveal a regular annual pattern of coarse and fine layers, known as varves. Variations in climate produced observable differences in the thickness of sediments, and, like the patterns of variation in tree-rings, this allows comparisons to be made between deposits in separate lake beds. Varves had been recognized and understood as early as the 1870s in Sweden. From 1905 onwards, Baron de Geer carried out extensive fieldwork with the aim of establishing a continuous sequence from overlapping deposits preserved in beds of the hundreds of lakes that formed during the retreat of glaciers after the last Ice Age. Whereas tree-rings can be counted back from a tree felled today, de Geer lacked a secure fixed point at the end of his sequence. However, a lake known to have been drained in AD 1796 gave an approximate pointer, and he published a sequence covering around 12,000 years in 1910.

Varves allowed the end of the last Ice Age to be dated with confidence to around 6800 BC and provided the first extension of 'calendar' dates into European prehistory. They also made it possible to date individual sites if their positions could be related to former lakes or seashores. Work on varves continues, particularly in North America, and it may one day be possible to tie the sequence of Scandinavian varves to some areas of the New World. Varves also contribute information to archaeomagnetic dating, for they contain a record of the Earth's magnetic field in their iron-rich clay particles (below, p. 121). Even more important, until radiocarbon dating was introduced after 1950, varves provided the only method that could be used to date the climatic sequence revealed by changes in vegetation known from pollen analysis.

6.3 Pollen analysis
(Dimbleby 1985)

Microscopic wind-blown pollen grains survive well in many soil conditions, and the ease of distinguishing different plant species is of considerable value in the study of past environments (p. 143). Pollen that has accumulated in deep deposits such as peat-bogs supplies a sequential record of changes in vegetation since the last Ice Age, for variations in temperature and rainfall resulted in periods of markedly different plant and tree populations in the past. Work on pollen began in Scandinavia in the 1920s and it confirmed the general pattern of climatic change that had been proposed from visible plant remains. Fortunately, since these changes were also reflected by varves, each distinctive climatic phase could be dated.

The value of this technique for archaeology lay in the fact that climatic phases were likely to have been fairly uniform throughout northern Europe. Thus, plant species found in a sample of pollen from an archaeological site could be fitted into the climatic sequence. Correlations could be established between sites belonging to similar climatic phases in different countries, and this form of cross-dating did not have to rely on dubious links between artefacts. However, even individual artefacts could be dated if they were found in peat-bogs, or if they had sufficient soil attached to them for the identification of pollen. For example, a mesolithic bone harpoon dredged from the bottom of the North Sea was placed into the period when pine was declining in favour of trees that preferred warmer conditions around 7000 BC (Zeuner 1946, 91–2).

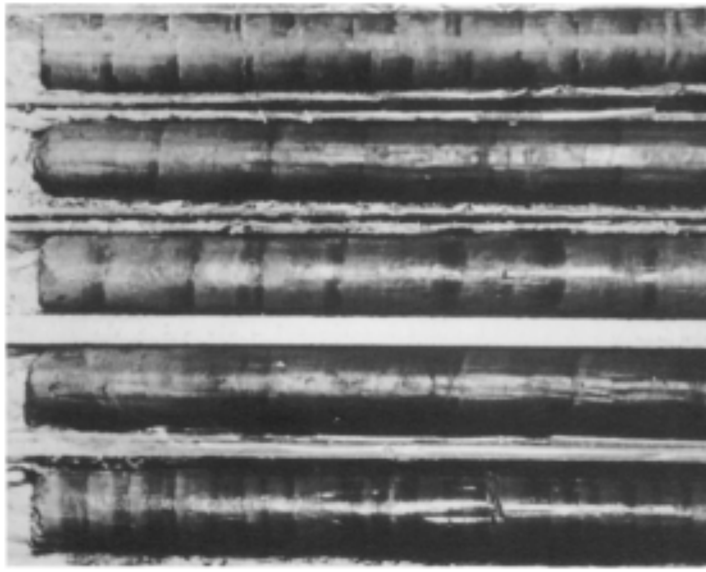
A further benefit of dating sites and artefacts to climatic phases was that new insights could be gained into their environmental context. The significance of the location of settlements was increased by understanding the state of contemporary vegetation and the landscape, and the functions of tools also took on more significance. Since climatic zones established from pollen have been dated absolutely by radiocarbon, they are no longer required as chronological indicators; nevertheless, pollen analysis continues to supply important evidence for the interpretation of the ancient environment (below, p. 143).

6.4 Sea-bed deposits

An approach to geological dating analogous to varves was developed during the 1950s. Deep sediments exist on the sea-bed, representing a slow accumulation of shells and skeletal material from dead marine creatures. Cores (typically 10 metres in depth) extracted from these deposits reveal variations in oxygen isotopes in the shelly material, caused by fluctuations in the volume of the ocean that reflect global temperatures and ice ages. A pattern of climatic variation is derived from temperature-sensitive species of marine fauna and from measurements of oxygen isotopes. It correlates with geological evidence for cold and warm periods that are dated according to deviations in the Earth's orbit around the sun (above, p. 109). Sea-bed sediments also contain material derived from the erosion of land containing iron particles; their magnetic alignment has been measured to produce a dated sequence of changes in the Earth's magnetic field, which undergoes complete North-South reversals from time to time. As a result of studies of deep-sea cores, geologists and archaeologists interested in the earliest stages of human development now possess an integrated dated record of global temperature and magnetism. Thus, if bones or tools associated with early hominids, such as the famous series from East Africa, are found in geological deposits related to periods of extreme temperature or magnetic reversals, they are now datable (below, p. 128).

6.5 Ice-sheet cores

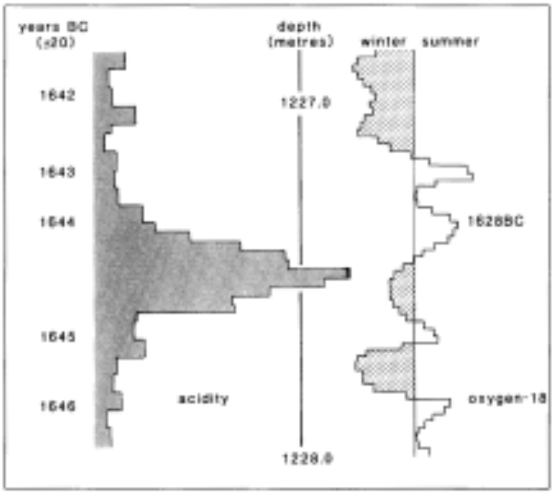
Yet another form of dating based on a cumulative natural phenomenon has been developed by climatologists who have extracted cores from the ice sheets of Greenland. Each winter's snowfall creates a distinct layer, and the annual layers have been counted back almost 6000 years in a core more than 2 kilometres in depth, with an excelent level of reliability within around 50 years (standard deviation



4.11 These cores bored from sedimentary lake deposits in Sweden show distinctive varves; each band of light to dark silt marks a single year's deposition of water-borne sediment. Varves vary in thickness from a few millimetres to several metres; these average approx. 2.5 cm. *Prof. D Tarling, University of Plymouth*

±10). The thickness of each layer varies, as do the proportions of different oxygen isotopes whose formation is known to reflect temperature; thus, long-term patterns of variation reflect changes in climatic conditions. A further factor of value for dating is the recognition that even when the individual layers are no longer distinguishable by eye, they contain annual fluctuations in dust and acidity that have extended the annual record back almost 10,000 years, at which point the layers become too thin for counting (Aitken 1990, 23).

Some layers of ice contain high levels of dust and acidity caused by volcanic eruptions (fig. 4.12). Volcanoes known from historical records, such as Krakatoa (1883) or Vesuvius (AD 79), can be correlated with ice-cores; further undocumented eruptions in prehistoric times may also be detected. Ideally, prehistoric eruptions dated by ice-cores would provide precise dates for sites, especially when calibrated with tree-rings, which may show abnormal growth patterns caused by volcanic disturbance of the climate. The massive eruption that destroyed much of the island of



4.12 Major volcanic eruptions affect the atmosphere by emitting large quantities of acidic ash; it may be revealed by abnormal acidity in layers within cores taken from deep ice-sheets in Greenland. Even when the annual layers are not clearly visible, the pattern of yearly temperature variations is indicated by changes in oxygen isotope levels. Here, an eruption that left its mark around 1644±20 BC was almost certainly the same event that caused damage to trees in rings dated to 1628 BC; it is usually assumed to have been the explosion of Thera in the Aegean. *Sandra Hooper, after Aitken 1990, fig. 2.10*

Santorini in the Aegean should probably be linked to signs visible in ice-core and tree-ring data from 1628 BC, but many interesting conflicts between archaeological and scientific dating remain unresolved (Hardy & Renfrew 1990). Akrotiri, a Bronze Age town on the island, was buried under deep volcanic ash, and the same ash also fell on Crete and Turkey, offering the potential for dating sites over a wide area. Volcanic eruptions may also give indirect dates for wider changes in settlement patterns, for ash in the upper atmosphere may cause severe disturbances to the weather, and if these circumstances were prolonged for many years they could lead to the abandonment of adversely affected sites (below, p. 183).

Finally, ice-cores and varves provide an additional way of checking the reliability of radiocarbon dating in periods beyond the range of samples from precisely dated tree-rings. Abrupt signs of climatic change dated by ice-cores and varves to around 8750 BC, are underestimated by approximately 700 years by uncalibrated radiocarbon dating.

7 Absolute techniques (Aitken 1990)

> The proper meaning of absolute dating is that it is independent of any other chronology or dating technique, that it is based only on currently measurable quantities. (Aitken 1990, 2)

We have seen that, by 1950, a number of dating techniques had emerged that could offer chronological frameworks for the study of prehistory at least as reliable as those used by historical archaeologists. Unfortunately, all required special circumstances, such as the survival of timber for tree-rings, the proximity of glacial lakes for varves, or the existence of soil conditions that favoured the preservation of pollen. However, the successful development of dating methods for geological periods, whether they relied upon radioactive decay or variations in the Earth's orbit, offered the possibility that a similar, generally applicable, technique might one day be found that would give absolute dates for prehistoric archaeology.

7.1 Radioactive decay

Several scientific dating techniques exploit the phenomenon of **radioactive decay,** including those first used to date the age of the Earth in the early years of the twentieth century (above, p. 109). Many elements occur in different forms, and some are unstable; these **isotopes** have extra neutrons besides their standard number of protons and they are designated by a number representing their atomic weight (carbon-14 or ^{14}c). Unstable isotopes are radioactive and emit rays of particles at a known rate. Some isotopes become stable after emitting these particles, while others (such as uranium) go through a protracted series of 'daughter' elements before reaching a stable form (e.g. uranium to lead: p. 123 below). The speed of decay is expressed as the **half-life,** the time taken for half of the total radioactivity to decay; this may vary from seconds to millions of years.

7.2 Radiocarbon dating
(Bowman 1990)

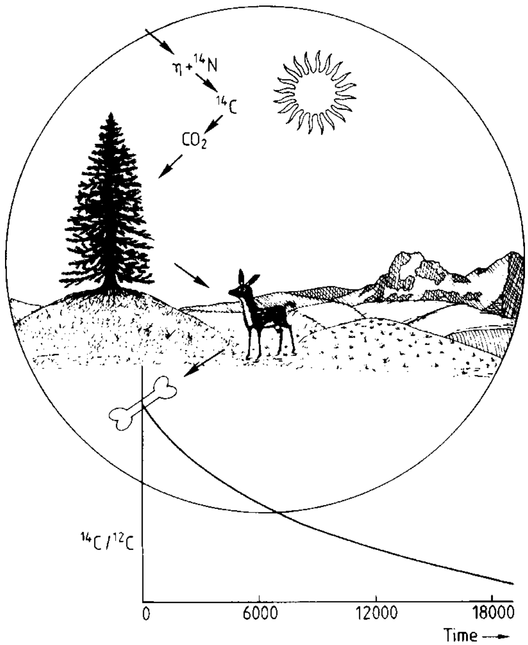
Amongst the numerous peaceful by-products of accelerated wartime research into atomic physics and radioactivity in the 1940s was **radiocarbon dating**. The rate of decay of carbon-14, which has a half-life of 5730 years, is long enough to allow samples of carbon as old as 70,000 years to contain detectable levels of radioactive emissions, but short enough for samples from periods since the late Stone Age to be measured with reasonable precision. However, the feature of carbon-14 that makes it exceptionally important is that it is absorbed naturally by all living organisms, but ceases to enter them when they die (fig. 4.13). In theory, all that needs to be done is to measure the radioactivity of a sample from a dead animal or plant and to calculate from the level that remains the time that has elapsed since its death. The practicalities of age estimation are rather more complicated, and the discussion that follows will attempt to highlight the principal advantages and disadvantages of carbon-14 rather than to provide a comprehensive account.

This simplified description does not do justice to the inspired formation and testing of hypotheses carried out by Willard F.Libby in Chicago in the 1940s for which he received a Nobel Prize in 1961. However, the publication of his preliminary results in 1949 was only a beginning. By a happy chance, the period of the past where it promised to be most effective from the outset was one of particular significance to prehistoric archaeologists, for it encompassed the transition from hunting and gathering to farming, and the emergence of the first civilizations. There are now more than 80 radiocarbon laboratories all over the world and upwards of 30,000 archaeological dates have been calculated. Accuracy and precision are improving, and the introduction of **Accelerator Mass Spectrometry** laboratories in the 1980s allowed very small samples, one hundredth of the size required in the 1950s, to be dated. AMS allows direct dating of actual artefacts and bones, rather than just the contexts where they have been found. It therefore offers particularly exciting prospects in early prehistory, for example in dating fragments of fossil bones associated with the disappearance of Neanderthals and the appearance of modern humans in Europe and Asia between 50,000 and 30,000 years ago (Stringer 1986).

Radiocarbon dating has grown exponentially, and many problems and inaccuracies have been isolated and examined, some leading to major adjustments of the results. Despite many problems, radiocarbon dates now provide a framework for the prehistory of the world; for the first time, its study has become more like that of historical periods, and emphasis has shifted away from pure chronology towards more fundamental social and economic factors.

Positive factors

- **radiocarbon dating is universal,** because the radioactive isotope carbon-14 is formed continuously throughout the Earth's atmosphere by the effects of cosmic radiation.



4.13 This drawing by Robert Hedges illustrates the basis of radiocarbon dating with unusual clarity. The arrows follow the formation of the carbon-14 isotope in the atmosphere by cosmic radiation, and its incorporation into a tree through photosynthesis of carbon dioxide. It then passes to a deer that has eaten the foliage, but this animal ceases to take in fresh carbon-14 when it dies. Thus, a bone is placed at the top of a graph that shows the steady decline of the radioactive isotope over time. *Research Laboratory for Archaeology, Oxford University*

- carbon-14 has a known h**alf-life, an**d decays at a constant rate.
- the rates of **formation and decay are in balance;** cosmic radiation in the past should have maintained carbon-14 and the other isotopes of carbon in the atmosphere at constant levels.
- **all life-forms contain carbon,** and living organisms absorb carbon from the atmosphere, mainly in the form of carbon dioxide photosynthesis by plants is one common mechanism. Animals and plants therefore maintain the same proportion of newly formed carbon-14 as the atmosphere until their death, when it begins to decay.
- **dendrochronology** provides an independent 'benchmark' of dated samples of wood from annual tree-rings stretching back nearly 10,000 years. The initial source was bristlecone pine trees found in the south-west of the USA; some are still growing after more than 4000 years. Older samples come from dead trunks that had resisted decay in this semiarid habitat, and from trunks of oak trees preserved in bogs or river sediments in Europe.

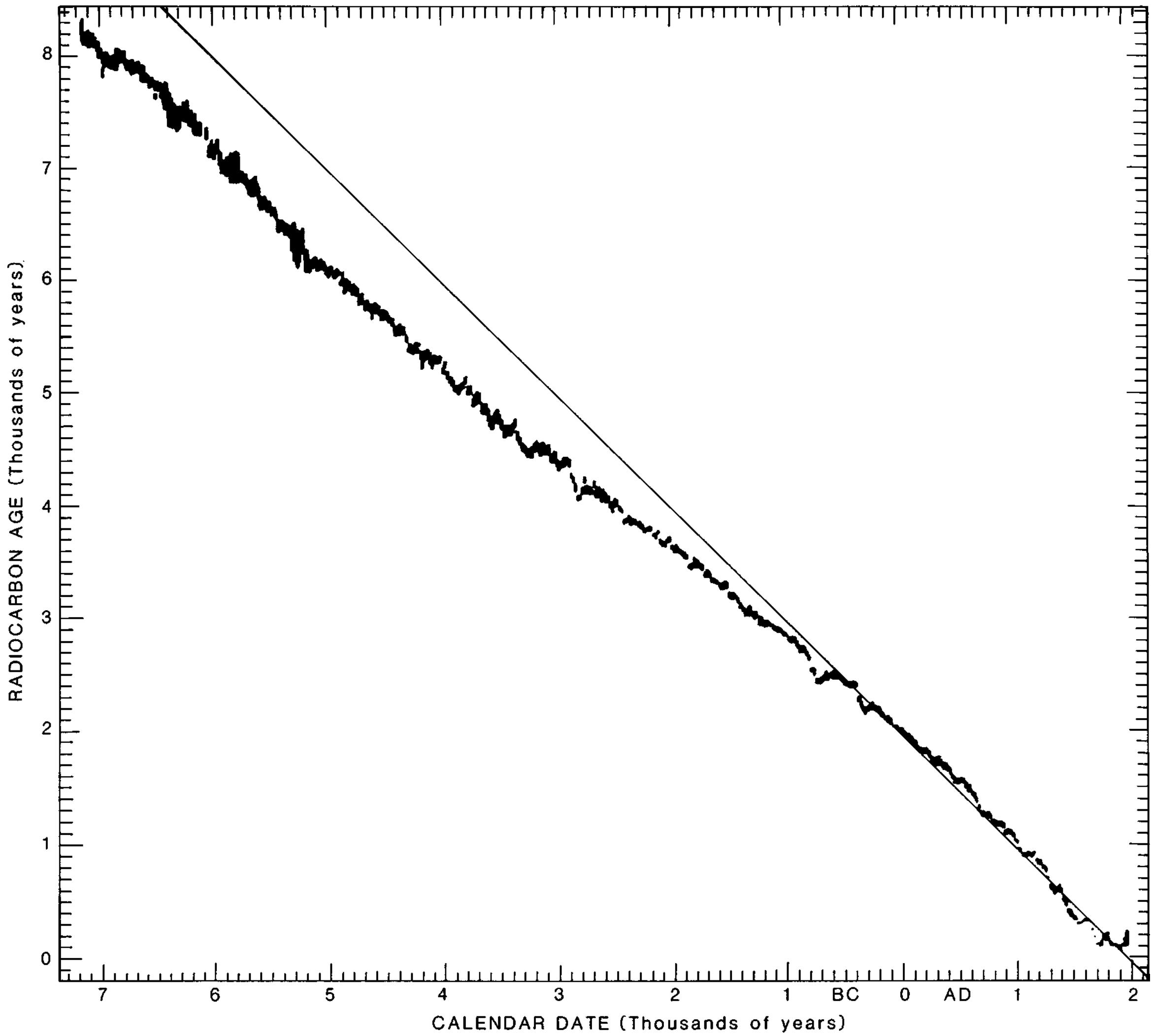
Thus, if a sample of ancient wood, charcoal or other organic matter is processed in a laboratory so that carbon is isolated, the amount of radioactivity that remains can be measured; the older it is, the fewer radioactive emissions of beta-particles will occur in a period of observation. Ten grams of modern carbon-14 produce 150 disintegrations per minute; the age of an ancient sample of the same weight that produced only 75 counts should therefore be equal to the half-life of the isotope, around 5730 years.

The measurement of radiocarbon requires highly accurate laboratory equipment to keep the margins of error within reasonable limits. By the 1950s the technique had moved rapidly from using solid carbon to gases such as carbon dioxide, and in the 1960s **liquid scintillation counting** joined **gas counting**. All of these radiometric methods require some means of detecting natural cosmic radiation that may penetrate the apparatus, to ensure that only radioactive emissions derived from the sample itself are recorded. A new technique, **accelerator mass spectrometry,** was developed in the late 1970s; AMS is fundamentally different because it measures the concentration of carbon-14 in a sample (relative to carbon-12) rather than its radioactivity.

Negative factors

Several aspects of radiocarbon dating require careful examination to achieve a correct understanding of the interpretation of its results. Some of Libby's original assumptions were incorrect, and the method of calculating dates has been revised several times since the technique began to be employed.

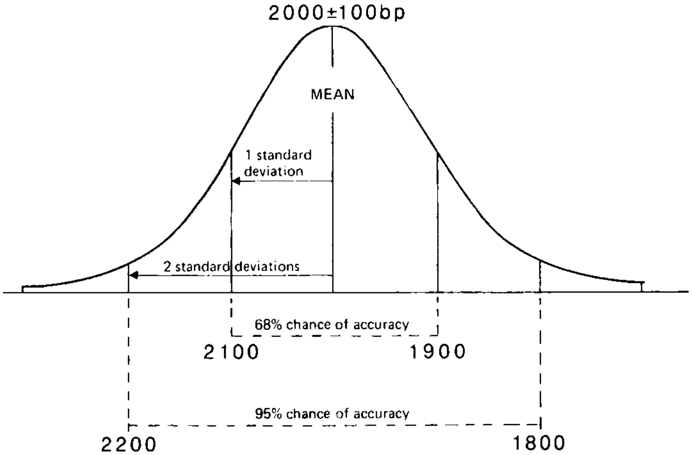
- **the half-life** has been shown by more accurate measurement to be too low by around 3%; it is now judged to be around 5730 years, rather than 5568.
- different isotopes of carbon are taken into organisms at different rates (**fractionation**)**;** the proportions of carbon-13 and carbon 14 must be checked and an adjustment made to the estimated date.
- he level of **cosmic radiation** has fluctuated over time, perhaps in relation to sunspot activity and the Earth's magnetic intensity. This means that the formation of carbon 14 in the atmosphere has varied; thus, samples from organisms that absorbed abnormally larger or smaller amounts of carbon 14 will give misleadingly younger or older dates.
- **a calibration curve** must be used to convert 'radiocarbon years' into calendar years (fig. 4.14). Tree-rings have not only revealed short-term fluctuations in carbon-14 levels, but also a divergence between carbon 14 dates and 'real' calendar years that becomes increasingly serious before *c.* 1000 BC. Samples with a radiocarbon age of 5000–7000 years require upward adjustment of as much as 500–1000 years, and this trend increases as dates extend further back in time; at a point when Uranium-Thorium dating measures coral as being around 30,000 years old, its age in radiocarbon years is only around 26,000.
- calibration reveals that dates from the **southern hemisphere** are around 30 years too old compared with those from the North; this is probably because the greater



4.14 Pearson's tree-ring calibration curve for radiocarbon dates. The straight line shows what the relationship would have been had the amount of carbon-14 in the atmosphere had remained constant over the last 10,000 years: i.e. 4000 radiocarbon years would be equivalent to c. 2000 BC. However, beyond 500 BC there is an increasing divergence, so that a radiocarbon age of 8000 years has to be increased by almost 1000 years, from c. 6000 to c. 7000 BC. The process of calibration looks deceptively simple at this scale, but the 'wiggles', combined with other statistical uncertainties, make calculations much more complicated. *After Pearson 1987*

area of oceans has affected the distribution of carbon 14 in the atmosphere.

- a statistical estimation of error, expressed as a **standard deviation,** is attached to laboratory counts of radioactivity. Since isotope decays occur at random, a reasonably long counting period is needed to reduce this inherent error. Several counting sessions of the same fixed length are normally carried out and the range of differences between the separate results is conveyed by a figure that follows the date, preceded by '±'. Fig. 4.15 shows how the reliability of a date should be envisaged.



4.15 Every radiocarbon measurement has a statistical margin of error, which is quoted in terms of the mean and one standard deviation (e.g. 2000±100 bp). A normal distribution curve shows how it should be interpreted: one standard deviation either side of the mean will give a 68% probability of the true date lying within a 200-year bracket (and consequently a 32% chance of it not doing so), whilst two standard deviations increase the probability of accuracy to around 95%. *Audio Visual Centre, University of Newcastle*

Summary table

POSITIVE	NEGATIVE
Radiocarbon dating is universal because carbon-14 is distributed throughout the atmosphere	There is a 30-year difference between dates from the N and S hemispheres
Carbon-14 has a fixed half-life and decay rate	The half-life is now known to be 5730 years, rather than 5568
The formation and decay of atmospheric carbon-14 are in balance	Variations in cosmic radiation have caused carbon-14 levels to fluctuate
All life-forms contain carbon	Isotopes of carbon are taken into organisms at different rates (fractionation)
Plants and animals take in newly formed carbon-14 until their death	Marine creatures absorb old carbon from deep-sea water
Dendrochronology provides an independent measure of accuracy	Radiocarbon underestimates the true age of tree-rings to an increasingly serious extent beyond 2000 BP
Pearson's calibration curve converts radiocarbon estimations into calendar dates	The curve contains many sections where calibration is imprecise or ambiguous
Conventional and AMS dating now provide very accurate dates	The results are still subject to a statistical margin of error, indicated by the standard deviation
Excellent results may now be obtained from small samples	Good results depend on the careful selection of appropriate samples, and the quality of the archaeological context remains crucial

7.3 Presenting and interpreting a radiocarbon date
(Stuiver 1993)

> **Health warning!** Proper calibration is not easy for the non-mathematician, but doing it incorrectly, wrongly interpreting the result, or even not understanding the potential of calibration may seriously damage your archaeology. Take advice from the experts know what calendrical band-width is necessary for correct interpretation and discuss this with the dating laboratory, preferably before taking and certainly before submitting samples. Think first, not after you get the radiocarbon date. (Pearson 1987, 103)

Because interpretation is so complex, all radiocarbon dates included in an archaeological publication must be presented in a standard manner. For example, a series of charcoal samples obtained from a late neolithic site at Galgenberg (Bavaria) is shown in Table A below (Aitchison 1991, 113).

The first column contains the code for the Gironingen radiocarbon laboratory (GrN) together with a unique serial number for this particular sample, so that it could be checked with laboratory records if any problem arose. The archaeological number refers to an excavated context at the Galgenberg site, and its nature is explained in the final column. The determined age of this sample is expressed in 'raw' uncalibrated form in years BP (before the 'present', standardized to AD 1950), complete with an unavoidable counting error estimated by the laboratory (±35). The 'raw date' has already been adjusted to compensate for fractionation, but it is calculated according to Libby's half-life of 5568 years rather than the more recently determined estimate of 5730 years; this practice is maintained to avoid confusion in comparisons with older results. The standard counting error of 35 years means that the (uncalibrated) date has a 68% chance of lying between 4350 and 4420 BP, and a 95% chance that it lies between 4315 and 4455 BP. This emphasizes the importance of regarding radiocarbon ages as ranges of possibilities, rather than 'dates'.

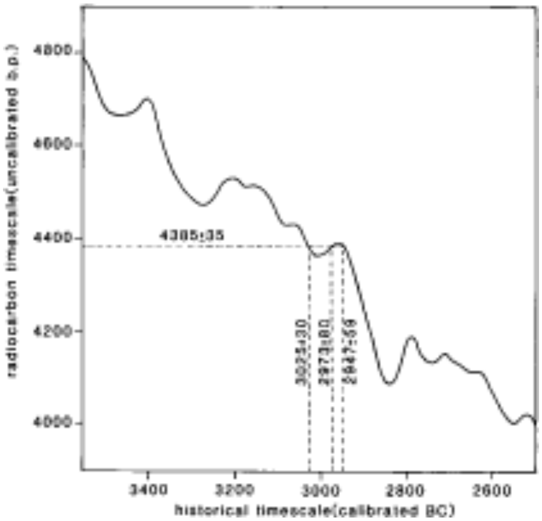
This 'date' has not yet been calibrated. Reference is normally made to the calibration curve, derived from dated tree-ring samples, published by Pearson in volume 28 of the periodical *Radiocarbon* in 1986 (supplemented in 1993 by volume 35.1). A rapid inspection of the curve suggests that the radiocarbon estimation will be transformed into a calendar date with a range falling roughly between 2900 and 3100 BC. However, closer inspection of this particular age determination reveals a common problem: a 'wiggle' in the calibration curve at around 4400 BP means that it could represent three different 'historical' dates (fig. 4.16; Aitchison 1991, 113); see Table B below. The tree-ring calibration curve is itself subject to statistical variations; for this reason the standard deviation should be considered as only a *minimum* estimate of unreliability. Furthermore, precision varies according to which part of the curve

(A)

lab no.	arch. no.	uncalibrated determination B.P.	archaeological context
GrN-12702	T14 1P	4385±35	collapsed palisade fence in W ditch

(B)

uncalibrated determination B.P.	corresponding historical dates BC	estimated standard errors
4385±35	2947	59
	2973	80
	3025	30



4.16 This diagram shows how a single radiocarbon age estimation (from the Galgenberg, Germany) may produce three different calendar dates of varying reliability if it happens to coincide with a difficult 'wiggle' in the calibration curve. For the purposes of dating a neolithic sample, it would normally be sufficient to know that the calibrated date lay somewhere between 2800 and 3100 BC, but a margin of error of this size would be too great for historical periods. *Sandra Hooper, after Aitchison* et al., *1991. fig, 4*

is being consulted; if the line is steep, the prospects are good, but if it is flatter, the date range will be very wide. Thus the 'date' of 3025 has the lowest of the three estimated levels of error. When all thirteen samples from Galgenberg were examined together, the main period of the whole site's occupation was estimated to lie between 2810 and 3100 BC.

Thus, Galgenberg illustrates some of the problems that lie between the receipt of an age estimation from a laboratory and its interpretation in meaningful chronological terms for a site or an artefact. This is why Pearson advised archaeologists to consider the 'calendrical band-width necessary for correct interpretation' before submitting samples. In the context of later prehistoric Britain, a sample from the British late Bronze Age and early Iron Age that was expected to give calibrated results between 1100 and 800 BC would be very worthwhile, for it would coincide with a steep slope on the calibration curve. In contrast, samples from the period between 800 and 400 BC are almost useless, for this part of the curve is much flatter, and does not permit refinement within a range of around four centuries; traditional forms of dating would be more accurate; see fig. 4.14; Bowman 1990, 55–7.

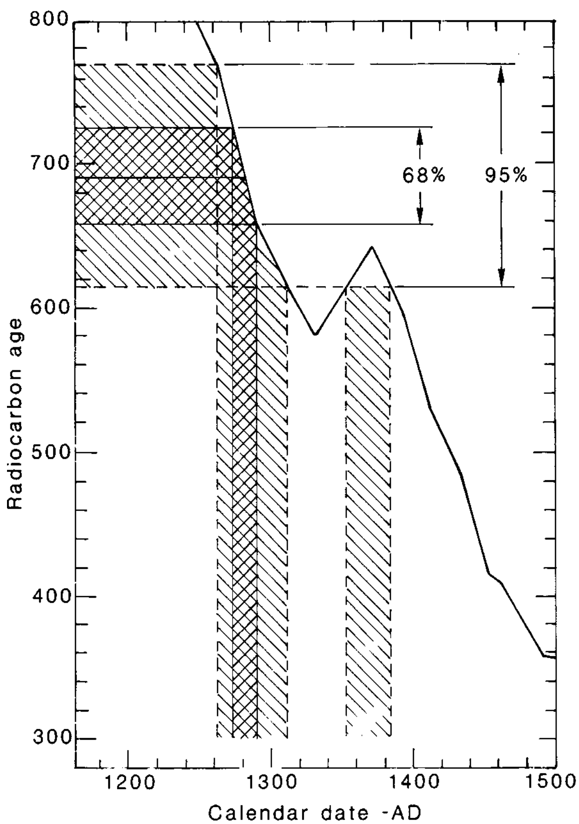
It should be noted that in many British publications, uncalibrated dates are indicated with a lower-case 'ad' or 'bc', while calibrated dates are cited as '1000 BC' or '1000 AD'. This practice has not been followed elsewhere; an International Radiocarbon Convention in 1985 recommended that uncalibrated age determinations should always be quoted in the form '1000 BP' (Before Present; for this purpose, the 'present' is standardized as AD 1950). If dates are calibrated according to 'an agreed curve', they should be cited in the form '1000 cal BP'. In areas of the world where the AD/BC division is useful, calibrated dates can be converted to '1000 cal BC' or '1000 cal AD' (Gillespie and Gowlett 1986, 160). 'Perhaps with the benefit of hindsight it might have been preferable if radiocarbon measurements had never been expressed as "ages" or "dates"; then there could be no misunderstanding' (Bowman 1990, 49).

Radiocarbon samples

Most materials containing carbon are suitable for dating; the lower the carbon content, the larger the sample needs to be. Charcoal derived from the burning of wood is a common find on archaeological sites and samples of around 10–20 grams dry weight are adequate for conventional counting, compared with around 50–100 grams of peat, or 100–500 grams of bone (Aitken 1990, 91). 'Mini-counting' methods cope with samples less than a tenth of this size (e.g. 0.1–0.5 grams of charcoal), while AMS requires only around one hundredth (e.g. 0.01–0.1 grams). Many other materials may be tested, including cloth, flesh, pollen, shell, soil and even iron, which usually contains some carbon impurities. The collection of samples needs to be scrupulous and their storage and handling must avoid contamination, even though they are subjected to a chemical 'laundry' process before being tested.

Archaeologists must know exactly *what* is being dated and, in the case of samples from excavations, their precise stratigraphic relationship to the site. The nature of charcoal and wood samples is very important—twigs or nuts are ideal, because they only contain carbon-14 taken in during a short growing season, whereas the central portion of a large tree will obviously give a date decades (or even centuries) earlier than its use for fuel or construction. Thought must also be given to the extent that samples are related to the objects or contexts that they are intended to date. Thus, the same significance must not be attached to fragments of charcoal from a general occupation level and to a sample taken from part of a wooden artefact or a human body. One of the most widely publicized examples of direct dating was the examination of the Turin shroud; since only very small samples of linen could be provided from this unique artefact, AMS was an ideal method. By good luck the result (691 ±31 BP) matched a favourable part of the calibration curve and gave a date of 1275–90 cal AD at the 68% confidence level (fig. 4.17); whatever the nature and date of the strange image painted (?) on the shroud, the linen from which it was woven grew no earlier than the thirteenth century AD, making it impossible that it was ever associated with Jesus.

Even in prehistory radiocarbon raises questions of a 'historical' nature. For example, evidence of very early human settlement linked with a hunter-gatherer economy was recently found on the island of Cyprus, whereas it had previously been thought that farming communities had settled there in the Neolithic period. However, since the relevant radiocarbon dates were too early for the conventional calibration curve, it was difficult to provide a calendar date for the earliest occupation. Evidence from varves, floating tree-rings, Uranium-Thorium dates from coral, and various other forms of dating suggest a date around 10,000–11,500 BC in 'calendar' years—but this may be changed or refined in future (Manning 1991). Technical limitations upon radiocarbon dates are just as significant in the case of relatively recent (in European terms, historical) periods. The question of the date of colonization of New Zealand is a good example: estimates ranged up to 2000 years ago, with a majority favouring around 1000 years ago. A large number of radiocarbon estimations now demonstrates that it took place as recently as the fourteenth century AD, but many samples derived from shell, bone and old wood had given misleading earlier dates (Anderson 1991).



4.17 The precision of AMS radiocarbon dating gave an unambiguous answer to questions about the age of the Turin shroud, a mysterious piece of cloth that bears such a striking image of Christ that it was believed possible that it really had been preserved from the Crucifixion in the first century AD. Accelerator dating was able to test very small samples of the cloth, and the age estimation matched a particularly favourable part of the calibration curve. Results from three different laboratories combined to give a remarkably precise indication that there was a 68% chance that the cloth dated from AD 1275–90; the safer 95% significance level increased this to 1275–90 and 1355–85. Thus, whatever explanation for the image on the shroud is proposed, it must start from the knowledge that the cloth is of medieval date. *Sandra Hooper, after Aitken 1990, fig. 4.10*

First-order radiocarbon dating

Emphasis on accuracy and precision in radiocarbon dating is not always appropriate. Occasionally, results from a much quicker and simpler method may be quite sufficient for some needs—at only one four-hundredth of the cost. First-order radiocarbon dating is applicable to carbon dioxide gas derived from shells using the liquid scintillation counting technique. It has proved very effective on shell middens up to at least 20,000 years old, and it can be checked against samples of charcoal from the same deposits. It revealed exploitation of marine resources in Victoria (Australia) three to five thousand years earlier than had been thought, because it could be employed on older, less well preserved shell middens that had not been considered good enough to be tested by more expensive conventional methods (Frankel 1991). The advantage was summarized well in a recent article: 'We believe that in many archaeological situations it is better to have 10 dates with standard deviations around the mean of 200 years, than one date with a 40-year standard error' (Glover 1990, 566).

The impact of radiocarbon dating

(Taylor 1987; 1992)

Without doubt, radiocarbon dating has made the greatest single contribution to the development of archaeology since geologists and prehistorians liberated themselves, a century earlier, from the constraints of historical chronology by rejecting the biblical Creation. The major stages of human development from hunting through to urbanization are now well dated over most of the world. However, so few radioactive carbon-14 isotopes remain in a sample more than 40,000 years old that it is difficult to measure the small number of particle emissions. The technique is therefore unsuitable for studying most of the Palaeolithic period; fortunately, a related method based on an isotope of potassium allows the examination of early hominid developments beyond the range of radiocarbon.

7.4 Potassium-argon dating

Potassium is abundant throughout the Earth's crust. Among its isotopes is a small percentage of K-40 that decays into calcium-40 and a gas, argon-40. This gas escapes while new volcanic rocks are being formed, but as minerals crystallize they begin to trap Ar-40, which can be released from samples in the laboratory and measured. At 1250 million years, the half-life of K-40 is staggeringly long in comparison with that of carbon-14. Its potential for geological dating had been realized by 1940, but archaeological applications began in the 1950s. Dates are arrived at by measuring the amount of Ar-40 trapped in potassium-rich minerals in comparison to K-40; the less there is, the more recent was the formation of the material involved. The inaccuracies inherent in measuring minute quantities of Ar-40 make it difficult to use in periods less than 100,000 years old. However, improvements in the measurement of comparatively recent samples will allow checks to be made on thermoluminescence dating in the period beyond the effective range of radiocarbon dating (at best 50,000 years).

Potassium-argon is ideal for dating early hominid fossils in East Africa, for they occur in an area that was volcanically active when the fossils were deposited between one and four million years ago. Layers containing bones and artefacts may be found 'sandwiched' between volcanic deposits of ash or lava that provide excellent samples of newly formed minerals for measurement. Very occasionally the association between human remains and volcanic deposits may be much more intimate, as in the case of human footprints around 3.6 million years old found on a layer of freshly deposited ash at Laetoli, Kenya (Leakey and Lewin 1992, 103).

Independent radioactive techniques, including uranium series and fission-track dating, give similar results that support dates derived from potassium-argon. Margins of error measured in thousands of years are unimportant in periods of such long duration, but they are useless in later prehistory, when, for example, the entire European Bronze Age lasted for only around 1000 years. A more serious problem involves the nature of the material required for sampling; few areas in the world provide archaeological remains that are stratigraphically related to sequences of freshly formed but undisturbed volcanic material, containing crystallized minerals of the kinds best suited to measurement. Potassium-argon has also been very important to geologists for checking the dates of some major reversals of the Earth's magnetic field (below, p. 128) and climatic patterns revealed by sea-bed cores (above, p. 113); both sources of information are valuable for dating purpose in places where volcanic minerals suitable for the potassium-argon method are not available.

7.5 Uranium series dating

The dating of geological periods followed the discovery of radioactivity, and the age of rocks back to the Pre-Cambrian was assessed by mesuring the proportions of uranium and lead or uranium and helium. Uranium could be used in this way because it remains radioactive for very long periods; elements with shorter decay periods are of course more helpful for recent geological and archaeological dating. Thorium-230 is a useful isotope because it has a half-life of 75,400 years. Although coral is the ideal sample material, calcite crystals contained in stalagmite may also be sampled, and this makes it suitable for dating early human activity in caves, anywhere between 5000 and 350,000 years ago; calcium carbonate deposits from spring also provide suitable material. Large samples of around 50 grams are required unless mass spectrometry is available. In any case, the precise relationship between the sample and an archaeological event or activity must always be established. Uranium series dating is frequently used in conjunction with ESR (electron spin resonance—below, p. 124), for the latter may also be carried out on the kinds of samples typical of cave finds, such as teeth, shells and stalagmite calcite. Uranium-Thorium dating of coral has also allowed radiocarbon dates to be calibrated back to around 20,000 BC, because coral, a living organism, also contains carbon.

8 Radioactive effects on crystal structure
(Aitken 1990)

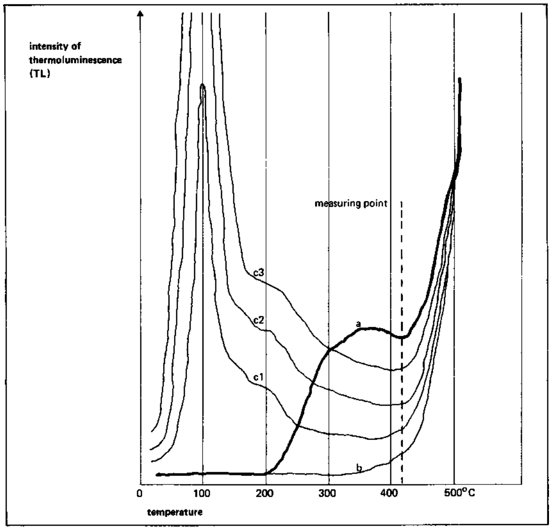
The following absolute techniques do not simply measure radioactive emissions or the products of radioactive decay; instead, they examine the effects of radioactive impurities on the crystal structure of minerals.

8.1 Thermoluminescence dating
(Aitken 1985)

TL dating is most effectively appiled to fired clay, which normally contains crystalline impurities, or burnt flint. In addition to being subjected to continuous cosmic radiation, these materials are also affected by radioactivity from uranium, thorium and potassium, contained in the artefacts themselves or in the soil where they have been buried until excavation. Crystals have defects in their structure that 'trap' electrons produced by this radiation; 'deep traps' do not begin to release these electrons unless they are heated above 300°C. When electrons *are* released, some recombine immediately with a **luminescence centre** (another type of defect) and emit light in proportion to their number. As soon as heating is over, electrons begin to accumulate again, until reheating to the same temperature occurs.

The first stage in calculating a date is to measure the amount of light released by a suitably prepared sample from an appropriate material and to plot its 'glow-curve' on a graph as the sample is heated up to 500°—the 'natural' glow-curve. This is then compared with another, 'artificial', glow-curve derived from an identical sample subjected to a known amount of radiation in the laboratory (fig. 4.18). The relationship between the two curves gives information about the reliability of the sample, as well as revealing the amount of energy that had accumulated since it was last heated (the **palaeodose).** The palaeodose does not reveal the age straightaway. It is necessary to measure the **annual dose** derived not only from radioactive impurities in the sample itself, but also from the radioactivity of the soil where it had been buried. When this has been done, and a number of additional factors have been allowed for, the age is equivalent to the palaeodose divided by the annual dose. Thus, a palaeodose of 8.5 Gy divided by an annual dose of 5.18 Gy (Grays, a standard measurement of absorbed radiation) would give an age of 1640 years—around AD 350 (Aitken 1990, 151).

The most important material for TL is fired clay; hearths, kilns and especially pottery form an important part of the archaeological record in most parts of the world. Since pots are fired at a temperature well above that required to release all the electrons that have been trapped in their crystal lattices, the energy released in the laboratory today will have built up from the date of their firing. The older the pots, the more energy that should have accumulated. Unfortunately, there are



4.18 Thermoluminescence apparatus provides a graph of light released by a sample prepared from an ancient artefact as it is heated (a). A second measurement of the same sample provides a different graph for the same material without its ancient energy (b); the bulge in curve (a) between 300° and 400°C resulted from the electrons trapped in the sample. Curves c1–3 are further measurements taken to study the luminescence produced after the sample has been exposed to known levels of modern radioactivity in order study its sensitivity. When further factors about the context in which the artefact was found have been taken into account, a date may be calculated. *Audio Visual* Centre, *University of Newcastle*

many problems connected with measurement. Clays contain a variety of mixed minerals of differing particle size that vary in their ability to trap electrons. Samples require elaborate preparation to separate particles of the optimum size, and extremely sensitive equipment must be used to record the very slight amounts of thermoluminescence emitted. Furthermore, measurement of the radiation absorbed from the soil that surrounded a buried clay artefact is difficult, but crucial for an accurate calculation of the age; this is even more critical in the case of flint. Obviously, it is not possible to measure this form of radiation in objects from museum collections whose precise find spot is unknown; TL will still detect modern forgeries that lack trapped electrons, however.

The TL dating technique is particularly valuable for dating in situations where no suitable materials for radiocarbon dating have been found, or if the age exceeds 40,000 years, when radiocarbon is of rapidly diminishing usefulness. Fortunately, site finds from early periods of prehistory usually include stones and flint implements burnt in fires in caves or camp sites at a sufficiently high temperature to release their trapped electrons. Flints found in deposits with relatively low radioactivity may have a potential datable range of up to 500,000 or even a million years. In areas where volcanic materials suitable for potassium-argon dating are absent, this is of great significance. Stalagmite may also be dated, and so too can volcanic materials or the soil over which molten lava has flowed (Aitken 1990, 172). It is even possible to date deposits of soil or sediment that were subjected to intense sunlight and subsequently buried. It has been established that this kind of exposure to heat and light is sufficient to remove trapped electrons ('bleaching'), but they begin to accumulate again as soon as it is covered (ibid. 173–5).

8.2 Electron spin resonance (ESR)

The basis of ESR has much in common with thermoluminescence, for both measure electrons that have become trapped in the crystal lattice of minerals. It differs from TL in the nature of suitable samples, which include teeth, shells and stalagmite calcite. The method of measurement is also unlike TL, for ESR does not release the electrons, but subjects them to electromagnetic radiation in a magnetic field. At certain points of interaction between the magnetic frequencies and the magnetic field, the electrons resonate and absorb electromagnetic power. The strength of resonance reflects the number of trapped electrons, and their quantity is related to the time that has elapsed since the crystals were formed. The radioactive content of samples, combined with the external radiation that they have received, must always be measured so that their age can be calculated by dividing the palaeodose by the annual dose—in exactly the same manner as TL (see above).

ESR sample materials favour the study of the Palaeolithic period, for stalagmites may be related to cave occupation, and fossil teeth from large mammals such as mammoths may provide effective dating. Tooth enamel is required, for the dentine of the core—like bone—is porous, and new minerals continue to form long after the death of the animal, giving an underestimate of the true age. Aitken cites some convincing examples of ESR dates derived from samples of mammoth and rhinoceros teeth from Canada and Germany; the resulting dates of around 100,000 and 350,000 years old correlated well with the climatic stages to which the finds could be assigned, and with uranium-series dating (Aitken 1990, 198–9).

8.3 Fission-track dating

This method involves counting microscopic damage trails in minerals such as zircon, and glass, whether volcanic (e.g. obsidian) or of human manufacture. The trails are caused by fission fragments when the nucleus of uranium-238 splits during radioactive decay. In practice the most useful samples come from zircon, and from obsidian, a material used extensively for making tools. However, the sample must have been subjected to heating at the time of the archaeological context or event that is to be dated. Obsidian tools or waste flakes from tool production that have been dropped into a hearth would be ideal, for heat removes the fission-tracks that have accumulated since the obsidian first solidified after its volcanic formation. Glass, or a vitreous glaze on pottery, should *not* have been re-heated in this way if the date of its manufacture (rather than its last heating) is to be discovered. Fission-track dating, along with potassium-argon, has also assisted in checking the age of volcanic deposits associated with early hominid remains in East Africa (Aitken 1990, 135).

9 Derivative techniques (Aitken 1990)

Aitken draws a clear distinction between absolute and derivative dating methods (1990, 2); the latter may only be used for dating by comparing their results with a time scale or reference curve that has been established by other dating methods. Thus, the level of thorium-230 found in a sample of stalagmite is a product of its uraniurn content, and the sample's age is calculated from the known radioactive half-life of thorium-230, which is not affected in any way by its environment; this method can therefore be described as **absolute.** In contrast, measurement of one form of amino acid changing to another (outlined below) is a **derivative** method, for the rate of alteration is entirely dependent on the temperature of the context where the sample has been buried.

Fluorine, uranium and nitrogen testing was one of the first scientific dating methods used in the examination of bone. It did not attempt to provide an estimate of age, but addressed a more fundamental problem that affects bones or artefacts of any kind: are the finds excavated from a single level—for example, a layer containing artefacts and bones in a cave—really contemporary? Does the stratum contain older items that have eroded out of earlier contexts, or items dug up accidentally during a later phase of occupation? Amino acid racemization and obsidian hydration dating may also be used to detect stray items, for bones and artefacts buried in uniform conditions over the same length of time would produce identical results; if they do not, some disturbance must have taken place and the excavated material is of limited value for *any* dating method.

9.1 Fluorine, uranium and nitrogen tests (Price 1989)

Buried bone absorbs water containing elements that react chemically with the bone, adding fluorine and uranium, while nitrogen decreases through the decay of bone protein (collagen). Bones found in a single context should have been subjected to the conditions that cause these changes in a uniform manner, and their levels of these three elements should therefore be very similar. Older survivals and recent intrusions should therefore be distinguishable because of unusually high or low levels. The technique remains useful for checking bone samples that are to be submitted for radiocarbon dating, but other methods (such as ESR) are now more informative for dating purposes. Fluorine/ uranium/nitrogen testing holds a special place in archaeological history because of its role in proving that the skull and jaw of 'Piltdown

Man', excavated in Sussex in 1912 and claimed as evidence of an early hominid, was a forgery (Spencer 1990). Analysis showed that the find had been assembled from bones of several different ages and origins.

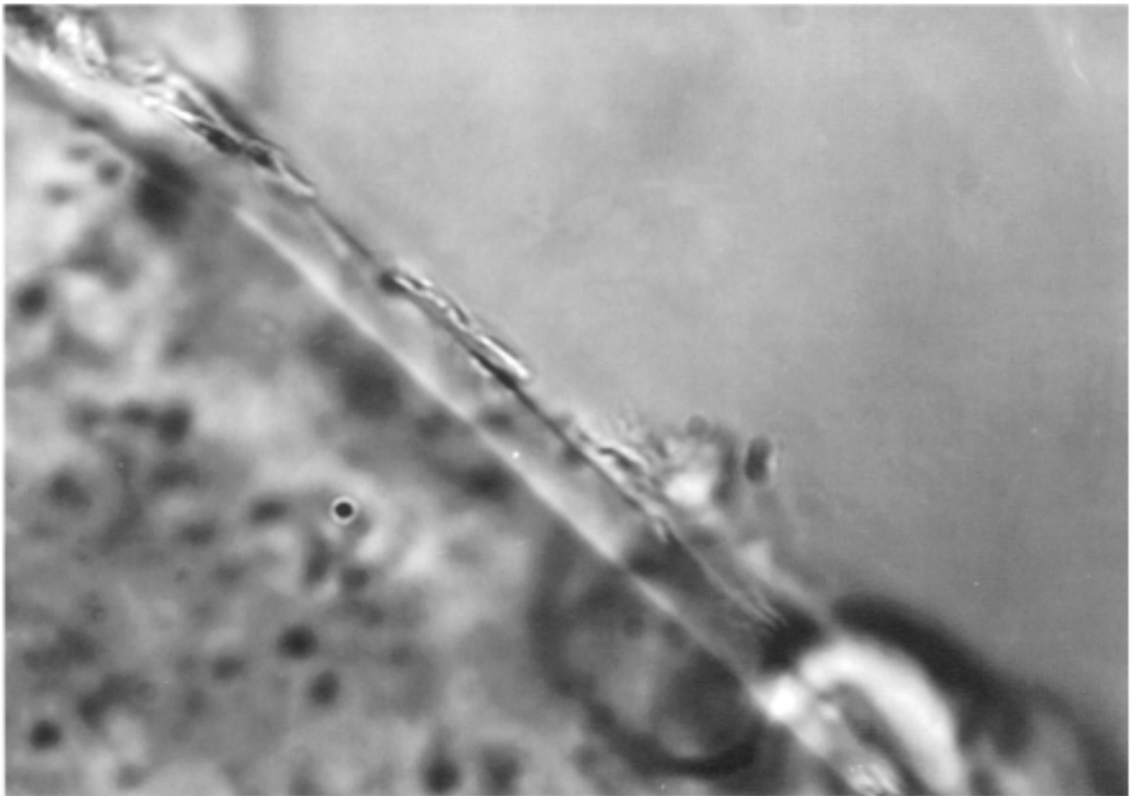
9.2 Amino acid racemization

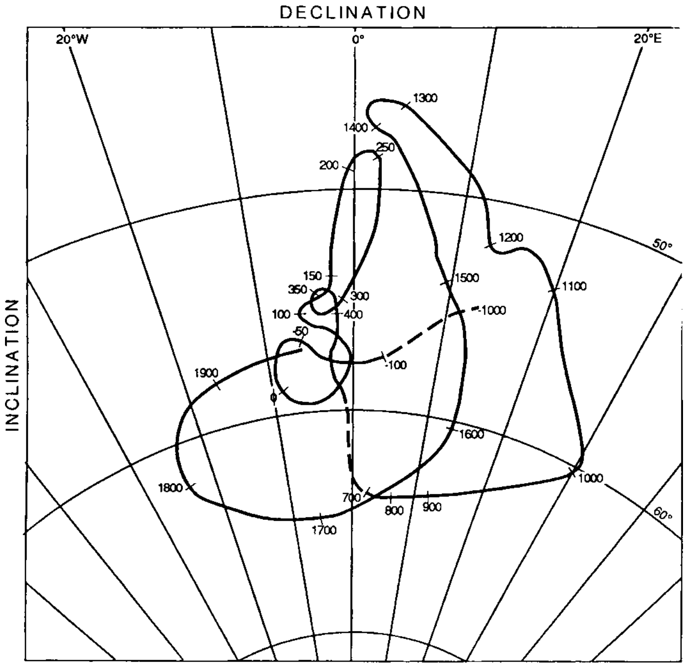
Samples taken from bone, teeth or shells contain detectable amino acids that undergo gradual change (racemization) from L-form to D-form over time; the ratio of the two is measured to indicate age. Since the rate of change is highly dependent on temperature it is necessary to use an independent method, such as radiocarbon, to date a sample from the same burial context. Once this has been done, the speed of racemization may be determined and other samples may be dated by this means alone. The upper limit for successful dating may range from 100,000 to several million years, according to the kind of sample material available and the amino acids selected for study.

9.3 Obsidian hydration dating

Like amino acid racemization, this dating technique relies on a transformation that takes place over time and, likewise, it is highly dependent on the temperature of the context where the sample of obsidian has been buried. Obsidian is a natural volcanic glass that was a popular alternative to flint for making flaked tools in many parts of the world (see fig. 5.2). As soon as a fresh surface of obsidian is exposed, for example during the process of making it into a tool, a microscopically thin 'hydration rim' begins to form as a result of the absorption of water (fig. 4.19). Furthermore, obsidian from different geological sources may weather at different rates. However, in regions where supporting dates are supplied by radiocarbon (notably Japan and South America), large numbers of measurements can be compiled to provide a calibration curve that may be used for checking the rim thicknesses of individual artefacts or assemblages found on similar sites.

4.19 This photomicrograph shows a section through the hydration rim of an obsidian artefact. The interior of the specimen is on the left; the diagonal band is a layer of weathering on the surface, and its depth is demarcated by a diffusion front that shows up as a paler line. This can be measured quite accurately, even though it is only three microns thick in this sample. *Prof. J Michels*





4.20 The movement of Magnetic North, measured from Britain. The graph shows *declination,* in degrees east or west of true North, and *inclination,* in degrees below the horizontal. These wandering lines are compiled from contemporary observations as far back as records allow, but samples from *dated* deposits or structures on archaeological sites must be found to project them further back into the past. Samples from *undated* sites can be measured in the laboratory, and dated according to where their magnetic alignments coincide with the curve established for the relevant geographical area. Difficulties do exist, however: identical readings occur wherever the curve crosses itself, for example between AD 1600, when the curve also matches late-Saxon measurements. *Prof. D Tarling, University of Plymouth*

This technique may also be used to check the contemporaneity of material from a single deposit and to detect modern forgeries. The thickness of the hydration rims of large numbers of artefacts from individual sites are plotted on a graph; if the site was occupied continuously they should display a reasonably smooth progression with age, while discontinuities may represent periods of abandonment. In warm climates where hydration is rapid, obsidian dating is useful for quite recent centuries, but, generally a margin of error of at least ±1% must be expected—in other words, a bracket 100 years either side of an age of 1000 years.

9.4 Archaeomagnetic dating
(Tarling 1983)

Fine grains of iron oxide are present in most clay and soil, and they take on a new magnetic alignment in two main ways. **Thermoremanent** magnetism is acquired when they realign according to the Earth's magnetic field after having been disoriented by heating above 650°C; some grains may retain the new field for hundreds of thousands of years. Magnetism is also acquired by means of the **deposition** of sediments, for instance in lake beds, where particles may settle into alignment with the prevailing magnetic field. Magnetic North wanders at random around the North Pole (and indeed reverses completely to the South Pole for long periods). From any reference point its position is measurable in terms of two components: movement up or down (**inclination** or 'dip') and from side to side (**declination**).

Magnetic dating measures the alignment in an ancient sample and attempts to relate it to a record of past changes in the magnetic field (fig. 4.20). However, although records of magnetic alignment have been made by scientists in Britain since before AD 1600, they began much more recently elsewhere in the world. Thus, information about the pattern of past variations has to be derived from suitable samples from archaeological sites that have been dated *independently* by some other means, such as historical evidence or radiocarbon dating. The reference curve of inclination and declination has been extended back to 1000 BC in Britain in this way. Unfortunately, the Earth's magnetic field varies from region to region, so that results from Britain are not even applicable in France. Thus, magnetic dating clearly illustrates Aitken's definition of a derivative method, for it is necessary to establish a separate independently dated series of measurements for every region where the technique is required. When multiple dates result from over-laps in the record of the magnetic field, one particular date may be selected on archaeological or historical grounds. Fortifications that were possibly erected by Charles the Bald at Pont-de1'Arche on the Seine in France produced dates around 360 BC, AD 580, AD 860 and AD 1580; obviously only AD 860±20 was appropriate for a historical reference to a Viking attack in AD 865 (Dearden and Clark 1990).

This technique may only be used on archaeological sites where solid clay structures that have not moved since becoming magnetized are found; kilns, hearths and burnt clay walls or floors are ideal. Small samples are selected, and their positions are carefully recorded in relation to the present magnetic field. This allows their alignment to be duplicated in a laboratory, so that differences between the ancient and present alignment can be measured. It is also possible to examine the 'dip' angle of portable fired objects such as bricks or pots, as long it is possible to assume that they were fired in a horizontal position.

One further dimension of archaeomagnetism is **magnetic intensity**, a measure of the strength rather than the direction of the magnetic field. Like magnetic alignment, it may be retained after heating or acquired through deposition, and it also varies from area to area. A dated reference series of measurements is therefore needed for any region before it may be used as an independent dating method. Insufficient variation has been discovered for it to become a useful chronological tool (Aitken 1990, 252–3).

The direction and intensity of the Earth's magnetic field are of an interest that extends beyond dating, for they probably have an influence upon global climate and cosmic radiation. The general pattern of major variations (such as North-South reversals) has been established by geologists, and it has considerable implications for archaeologists involved in the study of early human remains found in geological deposits in East Africa and elsewhere. Furthermore, absolute dates for the major reversals have been determined by the potassium-argon method. Thanks to the occurrence of iron oxide particles in sea-bed deposits, magnetic reversals have also been correlated with the climatic changes indicated by oxygen-isotope variations recorded in cores taken from ocean-floor sediments (above, p. 113). Thus, fossil bones or tools found in a stratum with magnetic characteristics that can be linked to a datable magnetic reversal may be dated *and* placed into their correct environmental context.

9.5 Cation-ratio dating (CR)

Prehistoric rock carvings ('petroglyphs') are not uncommon in arid areas where suitable surfaces have escaped erosion by the action of rain and frost. However, their age is notoriously difficult to determine unless they are found in contact with a datable stratified deposit. Petroglyphs are commonly covered by a so-called 'rock varnish', a chemically changed layer that builds up after around 100 years through weathering, enhanced by the action of micro-organisms. Using a method first put forward by Ronald Dorn in 1983, samples are taken by scraping the 'varnish' from petroglyph surfaces back to original rock surface. A separate cation (positively charged ion) leaching curve must then be established for different geographical areas, because local soil and moisture conditions affect the speed of its formation (Dorn 1988, 683). The date of the surface layer that has formed over the carvings may sometimes be checked by AMS radiocarbon dating, if sufficient carbon from micro-organisms was included in the initial 'glaze'.

Forty-six petroglyph samples from Piñon Canyon, an arid site in south-eastern Colorado, were dated to between 300 and 2000+ years before the present (Loendorf 1991). The results were consistent with a relative sequence established on typological grounds according to the style of the designs, and they also matched radiocarbon dates from associated sites. The first use of cation-ratio dating on carvings outside the USA was in the arid zone of south Australia, where it suggested exploitation of the area for over 30,000 years (Dorn 1988). However, Lanteigne has sounded a note of caution, because many underlying assumptions have not yet been fully tested (1991). As with radiocarbon and the derivative techniques (notably obsidian hydration), many modifications will no doubt be required before the potential and limitations are properly understood. It may also be possible to use this technique to date stone artefacts found on the surface of deserts; it would at least provide a minimum age for the time that has elapsed since they were exposed by erosion.

10 The authenticity of artefacts (Jones 1990)

It is inevitable that major museums that buy items for their collections become involved in expensive commercial dealings in the fine art market. The profits to be made not only stimulate illicit plundering of ancient sites, but encourage skilful forgeries. Scientific dating techniques bring obvious benefits, for precise dates are rarely required, simply an assurance that an artefact is not a modern fake. Thermoluminescence and archaeomagnetism provide adequate checks on pottery and a variety of highly priced elaborate ceramic 'terracotta' sculptures from Africa and South America. Where they survive, the remains of clay cores left inside bronze statues or objects after they were cast in moulds also provide suitable samples. It is very unlikely that a forger could create artificially the precise levels of radioactive energy or magnetic conditions that should be found in genuine items. Radiocarbon dating by the AMS technique now allows very small samples to be taken from small wooden, bone or other organic artefacts without affecting their appearance. Dendrochronology is helpful in the study of wooden panels used in furniture and early paintings, while paints and pigments may be examined by means of various forms of radioactive isotope dating.

11 Conclusions

> Thus scientific dating is not just a boring necessity that tidies things up by providing numbers, it is vital for valid interpretation.
> (Aitken 1990, 1)

Traditional forms of archaeological dating have been strengthened immeasurably by the growth of an extraordinarily diverse range of scientific techniques that helps to demonstrate the truly multi-disciplinary nature of modern archaeology. Traditional methods have *not* been replaced, however. The definition of sequences by means of stratigraphic excavation remains the basis for observations about sites and for typological studies of artefacts. Scientific dating techniques add precision and allow specific hypotheses about the relationships of sites, regional cultures or forms of artefacts to be tested. The transition from hunting and gathering to agriculture and the emergence of early civilizations may be interpreted in meaningful human terms now that we know—thanks to radiocarbon dating—when they occurred and how long the processes of transformation took. Similarly, potassium-argon dating (in association with several other methods) has provided a framework for the study of human evolution at the important point when there are the first clear signs that stone tools began to be used.

Scientific dating techniques play more of a supporting role in historical periods, and they are particularly valuable where there is doubt over historical dates, or where gaps exist in the historical framework. It must not be forgotten that even absolute methods such as radiocarbon had to be validated first by testing samples of known historical date. Libby used finds from Egyptian pyramids up to 5000 years old, dated by historical records of the reigns of pharaohs, to test the consistency of carbon-14 measurements beyond the range of tree-rings (Aitken 1990, 58, fig. 3.2). The refinement of radiocarbon dating, combined with dendrochronology, now feeds information back into this process; recent detailed scientific dating of the late Bronze Age around the Aegean confirms the sequences built up from artefact typologies and historical records over the last century (Manning & Weninger 1992). As with other scientific approaches to archaeology, the whole procedure is founded on cooperation, and the increasing complexity of methods used to refine the accuracy of scientific dating techniques demands ever closer collaboration between scientists, historians, prehistorians and excavators to produce results that benefit all in different ways. The best of the old should accompany the best of the new.

Note: a guide to **further reading** that includes topics covered in this chapter begins on p. 185.