Methods of dating

The fossil record of primates begins in the latest Cretaceous period, so primate palaeontologists are interested in techniques of dating applicable over the past 70 million years. Fossil bones themselves are rarely datable with any precision, and these are mainly of late Pleistocene or Holocene age. In general, it is the geological materials with which they are found that are dated. For this reason, dating usually begins with an attempt to order past events, and to relate fossils to rock layers that can themselves be dated. Once this is done, the ages of fossils can be estimated by determining the ages of rocks that lie lower and higher in a stratigraphic section.

During the past 50 years, many techniques for measuring the age of rocks and minerals have been established. These fall into three categories:

- Methods that depend on radioactive decay of one element or another – *isotopic methods*; for example, radiocarbon, potassium-argon, fission-track, uranium disequilibrium and thermoluminescence dating
- Methods that depend on slow chemical processes; for example, amino acid racemisation dating
- Methods that require calibration by radioactive or chemical means; for example, palaeomagnetic polarity stratigraphy, tephrochronology and biochronology

Each technique has its own age range, its own restrictions on materials that are suitable and a need for an event to 'set the clock' – and also an inherent uncertainty in the result.

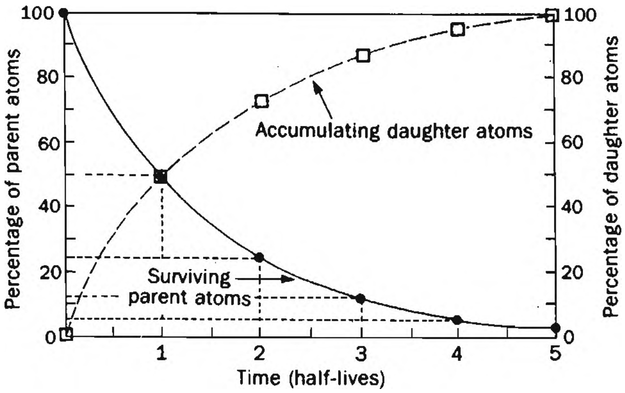
Radiocarbon dating

Radiocarbon or carbon-14 (^{14}C) dating is based on the decay of ^{14}C atoms to nitrogen-14 (^{14}N) by beta-emission. Because the half-life of ^{14}C is only 5730 years, it must be constantly produced or it would no longer be present on earth. This production takes place in the upper atmosphere where ^{14}C is formed from neutron reactions with ^{14}N and other nuclides. Once produced, the ^{14}C is oxidised to carbon dioxide ($^{14}CO_2$), and enters biological systems through various biochemical reactions, and the surface waters of lakes and oceans by diffusion. As a result, living organisms are radioactive, as are the carbonates precipitated from most natural waters. When an organism dies, or when carbonate minerals form, they are removed from this active carbon cycle and the ^{14}C within them begins to decay. By comparing the activity of their ^{14}C with its assumed initial activity, an age can be computed from the ratio of the two numbers.

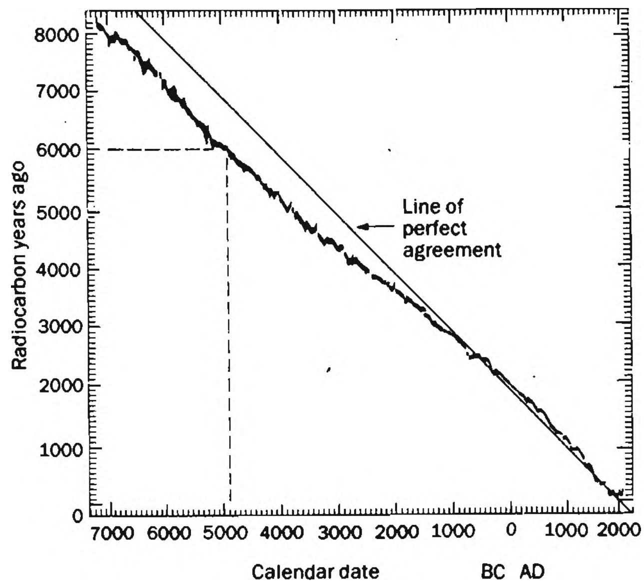
There are various uncertainties in this estimate, which arise from statistical errors at several stages of the dating process – during the determination of radioactivity, by the contamination of samples by older or younger carbon, and the preferential incorporation by the sample of one isotope over another when carbon is withdrawn from the general environment and enters living material. These sources of error can be dealt with by increasing the period of examination of each sample, dating multiple samples, and measur-

Years ago	10^8	10^7	10^6	10^5	10^4	10^3	Datable materials
Fission track							Volcanic minerals, glass, pottery
Potassium-argon ($^{40}K/^{40}Ar$ and $^{39}Ar/^{40}Ar$)							Volcanic minerals and rocks
Rubidium-strontium ($^{87}Rb/^{87}Sr$)							Volcanic minerals and rocks
Uranium disequilibrium ($^{234}U/^{238}U$)							Carbonates (e.g. coral)
Optically stimulated luminescence							Quartz, zircon
Electron spin resonance							Carbonates, silicates, apatite (e.g. tooth enamel)
Uranium disequilibrium ($^{230}Th/^{234}U$)							Inorganic and organic carbonates, volcanic rocks, ?bone, ?tooth dentine
Thermoluminescence							Ceramics, quartz, feldspar, carbonates
Uranium disequilibrium ($^{231}Pa/^{235}U$)							Inorganic and organic carbonates
Radiocarbon (^{14}C)							Organic materials (e.g. bone, shell, charcoal); carbonates

Age ranges over which selected dating methods are applicable, and materials on which they can be used.



Curves showing the decay of a radioactive parent (P) to a single stable daughter (D). The sum P + D is 100 per cent, whereas the ratio D/P increases from 0 to 1 after one half-life, 3 after two half-lives, and so on.



Radiocarbon ages are corrected to calendar ages using a curve established by radiocarbon dating samples of wood that have been given a calendar age by counting tree rings. A radiocarbon age of 6000 years corresponds to a calendar age of 4900 BC.

ing the content of the stable carbon isotope ^{13}C to determine the amount of preferential incorporation. Most radiocarbon dates are accompanied by an estimate of the probable error: the plus/minus term (standard deviation) quoted with the date.

Variations in the rate of production of ^{14}C in the past also affect the age estimate, but any uncertainties can be eliminated by calibrating samples against tree rings of known age. Ages are usually expressed in years before present (with the present taken as AD 1950). With careful work, an accuracy of about 2 per cent can be achieved.

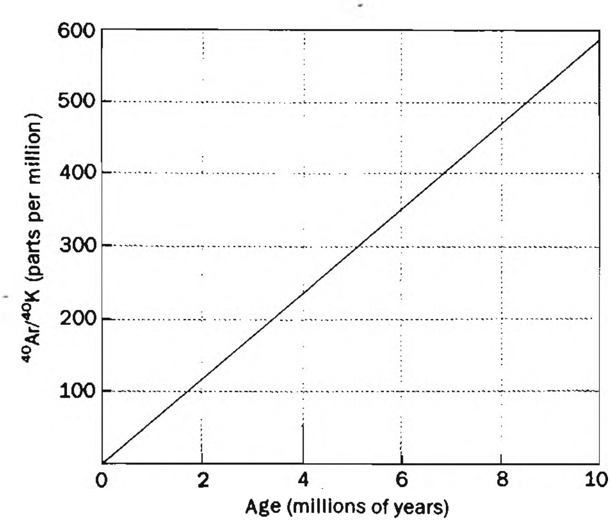
The use of particle accelerators as sensitive mass spectrometers has made it possible to measure the number of ^{14}C atoms in a sample directly, rather than waiting for their decay. This method has now been applied in radiocarbon dating. Only very small samples (1 mg or less) are needed so the technique can be used to age valuable palaeontological and archaeological material that previously could not be dated by the traditional radiocarbon method. A recent example of this was the dating of the Turin Shroud to the fourteenth century AD. Because such small samples are sufficient for the accelerator mass spectroscopy (AMS) method, a tiny piece of charcoal or a single wheat grain can now be radiocarbon dated.

The AMS technique is proving useful in many other ways. For example, it has done much to refute claims for the presence of humans in the New World 50000 or 100000 years ago. Skeletons thought to be very old turn out to date to only a few thousand years ago using this new method.

An application of the radiocarbon method to primate palaeontology has been to date extinct lemurs in Madagascar. Some fossils of extinct species found at Amparihingidro in the north-west of the island are only about 3000 years old, and those at Lake Itampola in the south are only about 1000 years old. These forms have therefore disappeared in recent times – since the colonisation of Mada-

Potassium-argon dating

The potassium-argon method is used to date volcanic rocks and minerals and is important in primate palaeontology. It depends on the fact that about one part in 10000 of naturally occurring potassium (^{40}K) is radioactive and decays slowly but steadily to the stable isotopes argon (^{40}Ar) and calcium-40 (^{40}Ca). In natural samples, the fraction of ^{40}K is constant, but the ^{40}Ar content increases with age. By comparing the amounts of ^{40}K and ^{40}Ar, an age can be computed (the half-life of ^{40}K is 1250 million years). The ^{40}Ar in a sample comes mainly from two sources – the radioactive decay of ^{40}K and the atmosphere. As argon makes up about 0.9 per cent of the earth's atmosphere by volume, a correction must be



After volcanic material cools, ^{40}Ar accumulates through decay of ^{40}K, changing the $^{40}Ar/^{40}K$ ratio. Over short times, the change in ratio is

1. CORRELATING THE EAST AFRICAN HOMINID SITES

Once a hardened volcanic ash layer or *tuff* in one stratigraphic section has been dated by the potassium-argon method, its identification in other sections can date those as well. The technique is known as *tephrochronology*.

Nearly all volcanic ashes (*tephras*) from different eruptions can be distinguished from one another by chemical analysis of their contents (glass and various crystals). This is because each ash is the product of a unique mix of processes before and during an eruption, such as partial melting of the source rocks, storage in a magma chamber and crystallisation.

Some volcanic ash layers extend over several thousand kilometres, allowing strata in different depositional basins to be linked. In East Africa, several tephras first known from the Turkana Basin (Omo, Koobi Fora and West Turkana) have been identified from many other areas, including the Awash Valley, some 1100 kilometres to the north-east, and also the deep sea in the Gulf of Aden and the Somali Basin.

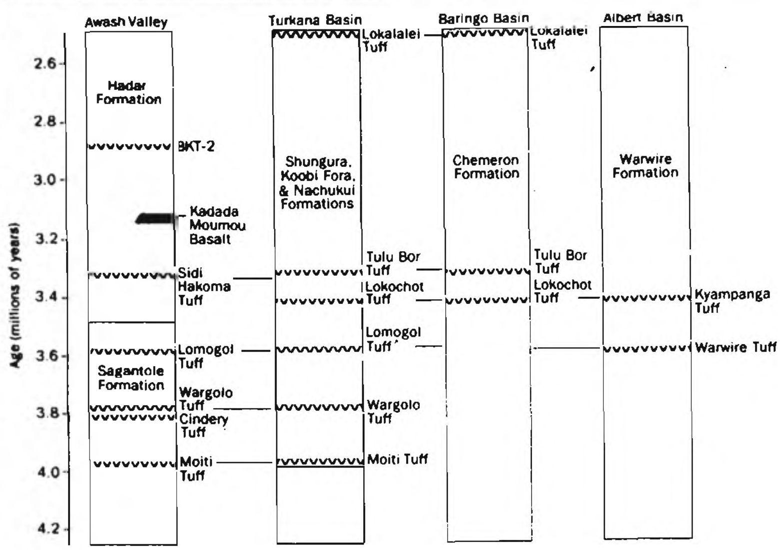
The figure shows some of these correlations, which allow us not only to match these widely separated fossil localities stratigraphically but also to apply palaeoclimatic information from the deep-sea cores to the hominid sites on land.

The Koobi Fora Formation contains 58 distinct tuffs. The dispute over the age of the so-called KBS Tuff was eventually resolved by K-Ar and $^{40}Ar/^{39}Ar$ dating. It was just below the KBS Tuff that the *Homo habilis* skull KNM-ER 1470 was found. For several years, the tuff was thought to be around 2.6 million years old, on the basis of preliminary K-Ar dates and results from fission-track dating. Later, the date was revised, with all the methods confirming an age of 1.88 + 0.02 million years.

Important evidence for the younger age came from correlation of the KBS Tuff with Tuff H-2 of the Shungura Formation in the Omo Valley, which had been dated at about 1.85 million years old. Correlations of pig fossils in Ethiopia and Kenya (see Box 2) also suggested that the deposits just under the KBS Tuff were close to 2 million years old.

Another, even more important result of recent tephrochronological studies in East Africa has been the discovery that several ash layers of – it now turns out – quite different age had all been mapped (erroneously) as the KBS Tuff.

F.H. Brown



Some volcanic ash layers (tephras) extend over immense areas and connect fossil hominid sites stratigraphically at the localities shown. Many of the hominids known from the Hadar site were found in deposits between the BKT-2 and Sidi Hakoma Tuffs. Their dates were uncertain until these correlations were made. The gracile australopithecine known as 'Lucy' was found above the Kadada Moumou Basalt and below the BKT-2 Tuff.

made for this in order to determine the amount of radiogenic argon in the sample.

Potassium-argon dating is usually applied to minerals separated from hardened volcanic flows (tuffs) because they are often interspersed with fossil-bearing sediments, and are formed quickly at temperatures high enough to remove any argon of radioactive origin that was initially present.

The main uncertainties in potassium-argon ages arise from errors of measurement of potassium and radiogenic argon, by contamination of the sample with older materials, from argon contained within the dated material that is not produced by radioactive decay of potassium (excess argon), and from leakage of argon from the samples. The last problem is serious for lava flows that have been altered by weathering or other geochemical processes.

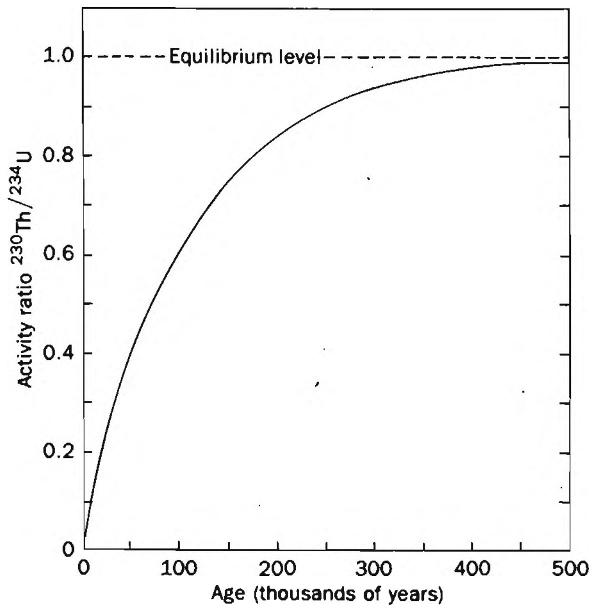
Potassium-argon dates are normally expressed in millions of years, together with a statement of the probable error. With good material the errors are generally about 1 to 3 per cent of the age. Potassium-argon ages can be used only to date stratigraphic levels between which a fossil lies. They hence provide boundary dates only, and a palaeontologist must assess the timing of events between the dated layers. For example, it may be judged that sedimentation was more or less continuous, or that there is a gap in the section, and so on.

This method has been more important in understanding the primate fossil record than any other dating technique. Its use to establish dates for boundaries between geological periods, and between epochs of the Tertiary period, makes it possible to state the approximate age of many primate fossils by studying the fossil remains with which they are associated. In East Africa and elsewhere, where volcanism and sedimentation happened at the same time, it is possible to establish the age of primate fossils precisely by dating tuffs in the fossil-bearing strata. This has been particularly successful for Pliocene and Pleistocene hominid fossils at sites such as Koobi Fora and West Turkana in Kenya and Omo and Hadar in Ethiopia (see Box 1).

An important variant of the K-Ar method is $^{40}Ar/^{39}Ar$ dating, in which the sample is irradiated to produce ^{39}Ar from ^{39}K. The argon is then extracted in a series of steps at higher and higher temperatures. This method has the advantages that potassium (computed from the ^{39}Ar content) is measured on the same sample as the ^{40}Ar and that an age can be calculated for each fraction of the gas. It is also possible to detect if excess argon is present.

The most elegant variation of the $^{40}Ar/^{39}Ar$ dating technique is the single-crystal fusion method, which uses a laser to melt previously irradiated crystal fragments to release the argon. Because the heating is so localised, background argon (of atmospheric origin) is reduced so that precise ages can be measured on individual small crystals. The technique greatly reduces the amount of sample needed for an age determination.

Potassium-argon dates could be cross-checked by rubidium-strontium (Rb-Sr) dating of volcanic rock materials, but this is seldom done.

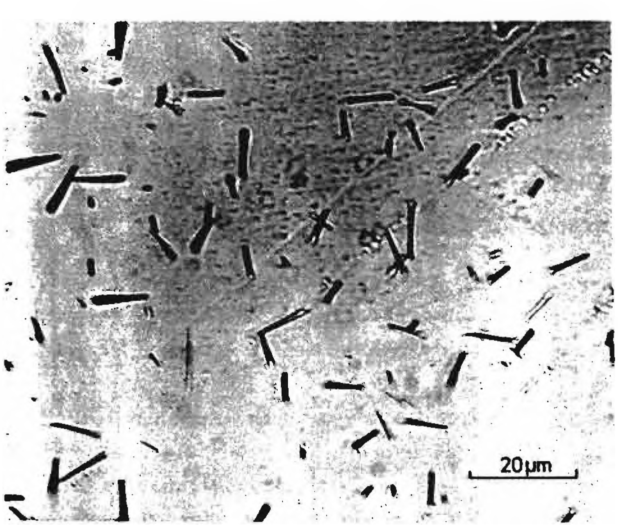


When calcite crystallises it contains uranium but no thorium. As time passes ^{234}U decays to form ^{230}Th, which is itself radioactive. Initially, the activity of ^{230}Th is zero but it increases as ^{230}Th atoms form, until it decays as rapidly as it forms and the activity ratio is 1.00. Although the $^{234}U/^{238}U$ activity ratio has been set equal to 1.00 to draw this curve, it is usually greater (1.15 in sea water), which alters the shape of the curve. In practice, the shape is corrected by measuring the $^{234}U/^{238}U$ ratio in the sample.

Fission-track dating

Fission-track dating is based on the spontaneous fission of uranium-238 (^{238}U), during which a trail of damage is created near the site of the uranium atom. Its main use in primate palaeontology lies in its application to volcanic rocks and minerals. When these are formed, they contain no fission tracks. The number of tracks increases with time at a rate that depends on the uranium content. By measuring the uranium content and the density of tracks, an age can be computed.

Zircon is the material most commonly used for fission-track dating. It normally contains more uranium than other volcanic minerals, any tracks formed within it are exceptionally stable, and it is very resistant to weathering. In addition, individual zircon grains can sometimes be dated, and volcanic zircons can be identified by their sharp crystal outlines. Other materials that have been dated in this way include apatite, biotite, sphene, and volcanic glasses such as obsidian.



A sample of zircon polished to reveal an internal surface and etched so that the fission tracks can be seen. The number of tracks per unit area increases with the age of the sample at a rate determined by the uranium content.

Because fission tracks are only about 10 micrometres long, they must be enlarged so that they can be seen under an optical microscope. An internal surface of the grain to be dated is exposed by grinding and polishing, and the surface is chemically etched. Then the tracks in a fixed area are counted. The concentration of ^{238}U is measured by irradiating the sample with a known number of neutrons, which induce ^{235}U (but not ^{238}U) to undergo fission; the sample is then repolished and re-etched, and the uranium concentration computed from the density of new tracks.

An important application of the fission-track method has been to check potassium-argon dates at East African hominid sites.

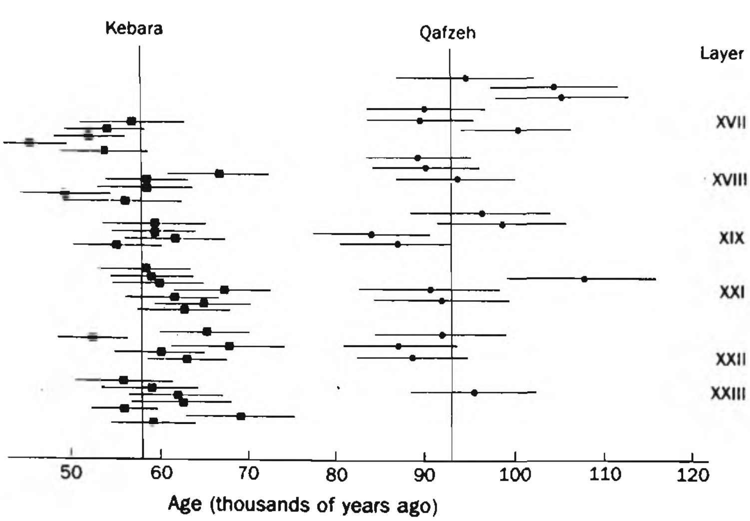
Uranium disequilibrium dating

Several different elements are formed as naturally occurring radioactive isotopes of uranium – uranium 235 (^{235}U) and uranium-238 (^{238}U) decay by emission of alpha- and beta-particles to stable isotopes of lead. For example, uranium-234 (^{234}U) is the third daughter isotope and thorium-230 the fourth of the parent isotope ^{238}U, and proctanium-231 (Pa) is the second daughter product of ^{235}U. An uranium-containing mineral will in time contain each one of the elements in the decay series, in a concentration related to each element's half-life. This condition is termed *radioactive equilibrium*.

Measurements being taken in Pontnewydd Cave, North Wales, where a hominid molar of early Neanderthal type and associated Acheulean stone tools were found in 1981. The lowermost archaeological layers were shown by uranium disequilibrium dating of a stalagmite to be at least 220 000 years old. This date was confirmed by thermoluminescence measurements on the same stalagmite and on a burnt flint.

Under radioactive equilibrium, the radioactivities of each of the decay products in the series are equal. However, these decay products may be separated from each other by processes such as weathering, differential adsorption, crystallisation of minerals that incorporate one element but exclude another and various biological events to form a system that is out of equilibrium. How much out of equilibrium is a measure of the time when the series was disrupted.

Uranium-disequilibrium dating systems, especially those that depend on the ratio between ^{234}U and ^{238}U, have been applied to non-marine carbonates, such as calcite in caves. The half-life for this process is 248 000 years so that the method has a range of about 1 million years.



Thermoluminescence ages of burnt flints from Kebara and Qafzeh caves, Israel, for which the external dose was measured by burying dosimeters at the site. Neanderthal fossils were recovered at Kebara (the younger site), whereas early modern human fossils were found at Qafzeh.

The related thorium-230/uranium-234 ($^{230}Th/^{234}U$) method is also used to date inorganic carbonates. Like other uranium-series methods, it depends on the high solubility of uranium in water. Thus, ground and surface water seeping into limestone caves usually contains uranium but not its daughter isotopes, such as ^{230}Th, which are relatively insoluble. Once crystals of calcite precipitate as stalactites and stalagmites on the cave walls and floors, however, ^{230}Th starts accumulating as the result of the decay of ^{234}U and ^{238}U and this continues until equilibrium is reached. The ratio of ^{230}Th to ^{234}U provides a measure of the time that has elapsed since crystal formation.

The $^{230}Th/^{234}U$ method is useful for mineral samples younger than 300 000 years and has been applied to cave sites in Europe that were once occupied by early *Homo sapiens*, where there are no volcanic rocks suitable for dating by the potassium-argon method. These include Bilzingsleben (Germany), Vértesszöllös (Hungary) and Pontnewydd (Wales), which have ages of 500 000 to 200 000 years.

Uranium-series dating of archaeological remains in caves can be prone to error because of possible difficulties in working out the order of calcite deposition, especially where fragments of cave wall have broken off and layers have become mixed up. There is also the possibility that the dated calcite was contaminated by uranium from an external source, such as dust particles, or that some of the uranium leached from the carbonate after precipitation. For these reasons, several layers of deposit usually need to be dated and other techniques used to check the results.

Thermoluminescence, optically stimulated luminescence and electron spin resonance

The basis of these methods is the same: they measure the number of electrons caught up in defects in the lattice structure of crystals. The defects are caused by decay of small amounts of radioactive elements such as potassium, thorium and uranium within the crystal. The number of trapped electrons increases with time through exposure to this radiation so that the crystal acts as a dosimeter. Only when the electrons are released from the traps is the clock reset to zero.

In the thermoluminescence (TL) method, the accumulated dose of radiation in the crystal lattice is measured by heating the sample to a high temperature to excite the trapped electrons. As they escape from the lattice they emit light known as *thermoluminescence*. The intensity of thermoluminescence is proportional to the number of trapped electrons. The age of the material is obtained by dividing the accumulated dose by the annual dose. The latter is determined by measuring the amount of uranium, thorium and potassium within the sample and in the soil or rock surrounding it, or by irradiating the sample artificially and remeasuring its thermoluminescence. A companion

2. FOSSILS AS DATING INDICATORS

Before the days of radiometric dating, the best way of dating a fossil primate site was by comparing fossil mammals from the site with those from a dated sedimentary sequence elsewhere. For some sites without rocks suitable for radiometric dating, such relative dating still provides the main clues to the site's age. Even at those sites that can be radiometrically dated, it is essential to consider evidence from both fossils and rocks before an age is finally accepted.

When fossils are collected from sediments spanning a temporal range whose relative age can be determined because younger rocks lie above older rocks, there are usually changes through time in lineages of both single species and groups of species. For example, the size or complexity of a tooth in a species of pig may increase in successively younger rocks. In such cases, the 'stage of evolution' can be used as a dating tool.

Some sedimentary sequences are rich in fossils throughout and also contain datable volcanic rocks. One such is the Omo Group in Ethiopia and Kenya, which is exposed to the west, north and east of Lake Turkana and ranges from more than 4 million years to under 1 million years old. Many important hominid fossils have come from these rocks. The many animal fossils known from this sequence have been invaluable in clarifying the age of these hominids, particularly those from Koobi Fora, east of Lake Turkana.

When the hominid skull KNM-ER 1470 from the Koobi Fora Formation of the Omo Group was found in 1972, the geology of the sedimentary sequence was not fully worked out. A radiometric determination on a volcanic rock just above the hominid suggested an age of 2.6 million years. However, mammalian faunas associated with the cranium suggested that it was younger, close to 2.0 million years.

The pig genus *Mesochoerus* was particularly helpful here. Pig fossils are well known from a long and well-dated sequence in Omo Group rocks in Ethiopia, only 150 kilometres north of Koobi Fora. In two species, *Mesochoerus limnetes* and *M. olduvaiensis*, there was a steady increase in size of the third molar through time. The relevant *Mesochoerus* sample from Koobi Fora matched that from the 2-million-year levels in the Ethiopian part of the sequence.

Subsequent careful redating of the Kenyan rocks showed that their radiometric age was indeed close to 2.0 million years (1.88 + 0.2 million), not 2.6 million years as had previously been believed.

Caves in South Africa are an important source of fossil hominids, but contain no rocks suitable for radiometric dating. In the past 20 years, analysis of the fossil mammals in the cave sequences, especially the bovids (giraffe, pig and cattle family), has made it possible to compare each site with the calibrated East African sequence.

The Pliocene and early Pleistocene faunas of eastern and southern Africa are as dissimilar as are their counterparts today, so exact matches are difficult. Nevertheless, enough is now known to place the principal South African sites in relative order: they run (from oldest to youngest) Makapansgat, Sterkfontein, Kromdraai and Swartkrans.

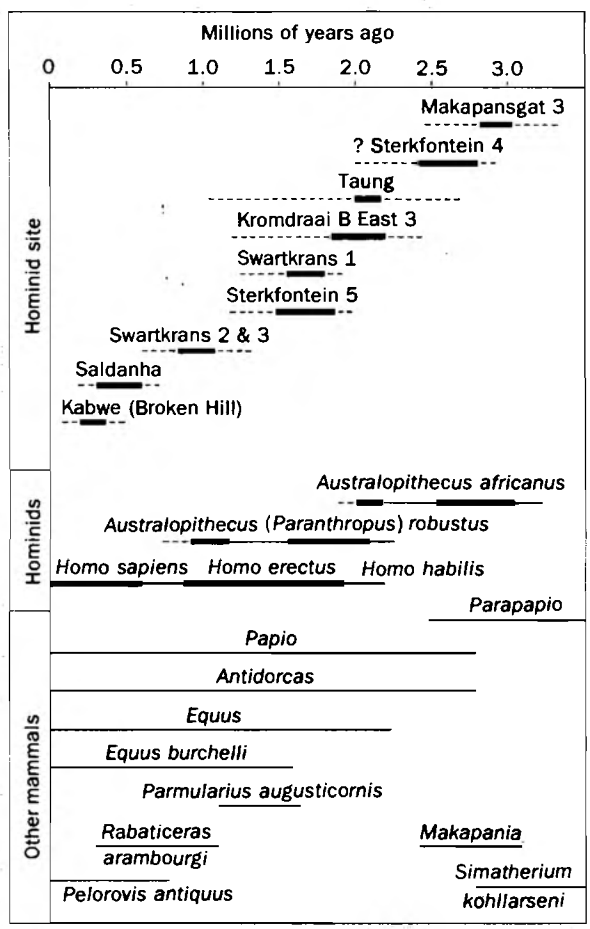
Progress is also being made towards giving these sites dates. For example, Makapansgat bovids are similar to those found at several sites in East Africa ranging from 3.7 to 2.5 million years ago. If all the evidence is taken into account, the date for the deposition of the Makapansgat cave sediments is probably around 3 million years ago.

These estimates are not as precise as the age determinations for the East African hominid sites, but they do help to clarify the evolutionary patterns of the southern populations of early hominids.

A third example of the use of fossil faunas in dating comes from the later hominid site of Jebel Qafzeh in Israel. From Qafzeh has come an important series of early modern *Homo sapiens*. On the basis of small mammals such as rodents its age was estimated as close to 90 000 years. But evidence from stone tools and the hominids themselves suggested an age of close to 40 000 years. Recent results from thermoluminescence dating suggest that the most probable age is indeed close to 90 000 years (see p. 183).

This is another demonstration of the importance of considering the faunal evidence as well as other kinds of dating evidence before accepting an age for a hominid site. *David Pilbeam*

See *also* 'Evolution of australopithecines' (p. 231) and 'Evolution of early humans' (p. 241)



Ages of some southern African hominid sites based on their fossil faunas. Also shown are estimated time ranges of the fossil hominid species known from the sites and of some of the mammalian taxa used to date them. The numbers after the site names are the stratigraphic units (members). *Parapapio* and *Papio* are baboons; *Equus* and *Equus burchelli* are zebras; the remaining species are bovids (buffaloes and antelopes).

technique called optically stimulated or photo-stimulated luminescence uses light instead of heat to evict the electrons from the traps.

In the electron spin resonance (ESR) method, the number of trapped electrons in the sample is determined not by driving them out by heating but by measuring their absorption of microwave radiation. Traps occupied by a single electron act as paramagnetic centres with a static magnetic field. When placed in a microwave-frequency electromagnetic field the electrons in the traps oscillate between orientation with and against the field. Energy is absorbed from the applied field according to the number of traps occupied by single electrons and correlates to the age of the sample. An advantage of ESR over TL is that a sample can be tested repeatedly by ESR whereas TL dating can be done only once.

TL and ESR measure the time elapsed since the last draining of electron traps – when the sample's clock was reset to zero. Fqr burnt flint artefacts this happens when the material is first heated – for example, in a hearth. Exposure to sunlight does this for sediments while they are being transpoprted and deposited. Burnt flints at Palaeolithic sites, deposits of loess, cave sediments, bone and teeth are among the materials that can be dated by these methods. They are less precise than radiocarbon but have a wider age range and can also be used to date inorganic materials. Careful adjustments have to be made for uptake of radioactive elements from the environment.

The TL method has had an important role in the controversy over the relationship between Neanderthals and anatomically modern people. Dates for burnt flints found at the cave sites of Kebara and Qafzeh in Israel support the idea that Neanderthals were not direct ancestors of modern humans, because they arrived in the Middle East several tens of thousands of years after the first anatomically modern people in the area.

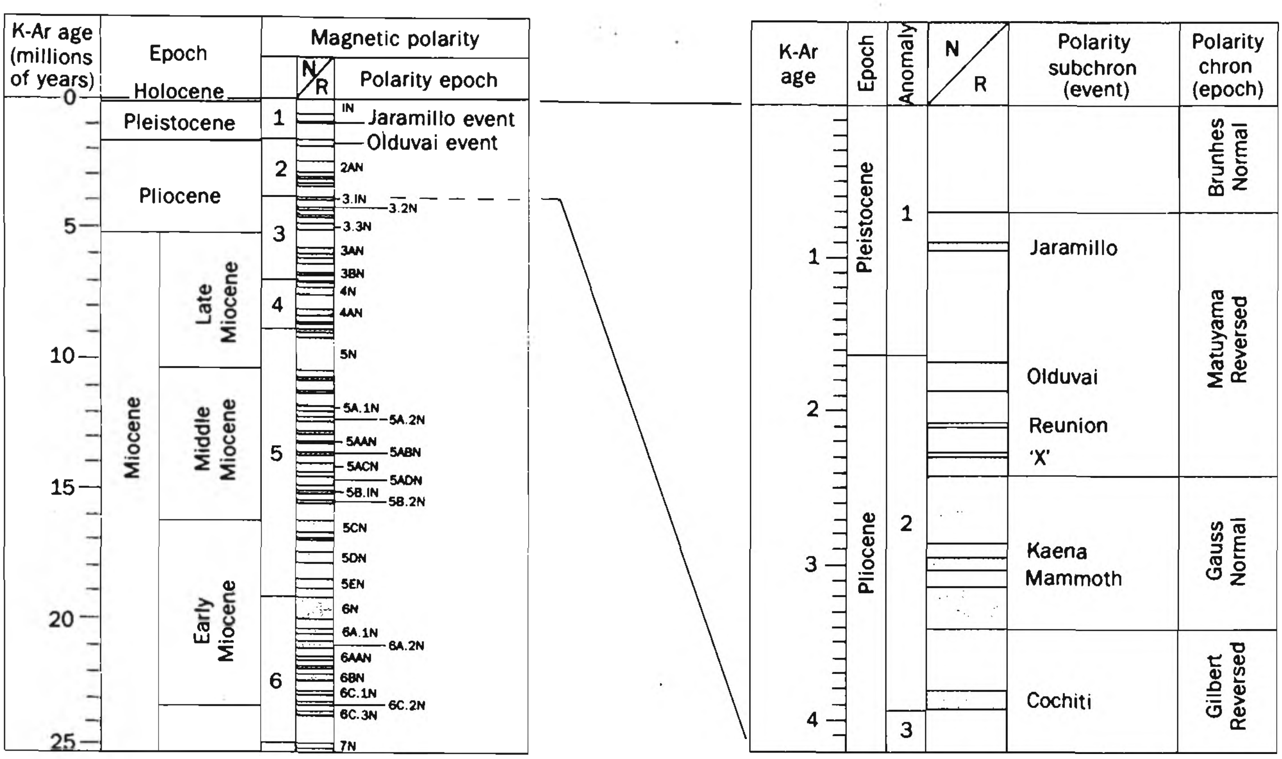
Amino acid racemisation

This dating method depends on the slow chemical conversion of left-handed amino acids present in living organisms to their right-handed counterparts. As this is a chemical (rather than nuclear) process, the rate of conversion is very sensitive to the environmental conditions in which it occurs. Not only temperature, but also the composition of the material in contact with the specimen changes the rate of conversion, and this limits the value of the technique.

The best material for this method at present seems to be eggshell of extinct and modern species of ostrich and owl, which is often found at archaeological sites. The technique may be especially useful in Africa at sites with remains of early modern humans that fall between the ranges of the radiocarbon and potassium-argon methods, between about 40000 and 200000 years old. In colder regions, the age range of the method may extend up to a million years.

Palaeomagnetic polarity stratigraphy

This dating method requires prior calibration. The magnetic field of the earth runs from pole to pole. At irregu-



Magnetic polarity intervals for the past 25 million years (left) with the interval from 0–4.2 million years expanded to show details more clearly (right). Normal intervals are shaded; reversed intervals, white.

lar intervals in geological time the polarity of this field has changed so that the modern pattern (positive in the Northern Hemisphere and negative in the Southern Hemisphere) has been reversed. Processes such as cooling of lava, settling of magnetic particles during sediment deposition and growth of iron-rich minerals within sedimentary rocks can preserve a record of the magnetic field when the rocks were formed. The field direction is measured using a magnetometer. Potassium-argon dating of lavas whose polarity has been measured in this way gives a timescale of the change of polarity for about the past 12 million years. This has been extended to the beginning of the Mesozoic era by study of magnetic anomalies on the ocean floor.

The pattern of ancient changes to the earth's polarity in samples through a stratigraphic section is compared with the known pattern of the palaeomagnetic polarity timescale. Most rock strata are not continuous, so that their approximate age must be established by fossils or by isotopic dating before their magnetic signature can be fitted to the correct time period.

This method gives important information on several primate fossil localities where the chronology is already reasonably well known – for example, at the hominid site of Olduvai Gorge in Tanzania. A most significant contribution has been to give age estimates of the Miocene sediments of the Siwalik region of northern Pakistan, where mammalian fossils, including hominoids, have been found. The faunas of the Nagri and Dhok Pathan Formations in this region are now known to be between 6 and 12 million years old. As 13 palaeomagnetic transitions exist in the sequence between 6.5 and 8.6 million years ago, it is possible to establish an accurate chronology for this portion of the sequence.

F.H. Brown

See also 'Climatic change in the past' (p. 174), 'Fossil deposits and their investigation' (p. 187), 'Evolution of australopithecines' (p. 231) and 'Evolution of early humans' (p. 241)