UNIT 3 ABSOLUTE CHRONOLOGY

Contents

Learning Objectives

Once you have studied this unit, you should be able to:

- define the different types of dating techniques – Relative and Absolute Chronology;
- understand underlying principles of different absolute dating techniques;
- understand reasons why particular techniques are appropriate for specific situation; and
- understand the limitations of different dating techniques.

3.1 INTRODUCTION

Archaeological anthropology is unique with respect to the other branches of the social sciences and humanities in its ability to discover, and to arrange in chronological sequence, certain episodes in human history that have long since passed without the legacy of written records. But the contributions of archeology to this sort of reconstruction depend largely on our ability to make chronological orderings, to measure relative amounts of elapsed time, and to relate these units to our modern calendar.

Many important problems in archeology like origins, influences, diffusions of ideas or artifacts, the direction of migrations of peoples, rates of change, and sizes of populations in settlements can be solved with the help of different methods of dating. In general, any question that requires a definite statement like the type, A is earlier than B, depends on dating. Then, if it can be shown that, A is earlier than B, and not contemporary with or later than B; the two alternative hypotheses can be ruled false.

Archaeologists have used many different techniques to work out the age of artifacts and sites for which they have no historical dates and in order in which they were used. These dating techniques can be broadly subdivided into two groups:

- Relative dating techniques which identify the order in which sites or artifacts were used in a sequence from earliest to latest.
- Absolute (or chronometric) dating techniques that try to establish an exact or approximate calendar date for a site or artifact.

The techniques selected depend on the specific task and evidence as well as practical consideration such as cost. Many of the scientific techniques are expensive and require high level of technical skill to use and to interpret. The span of human history studied by the archaeologists is so vast and environments so varied that technique suitable for one place and period may be unsuitable for another.

3.2 ABSOLUTE METHOD OF DATING

All of us are familiar with calendars and clocks that are based on the observed periodicity of certain natural events. Calendars give elapsed time measured relative to the movements of heavenly bodies; clocks are ultimately related to the same cycle, and time consists essentially of subdivisions of it. The important point about these measurements is that they depend on the repetition of events at uniform intervals. In this sense, a day is a day without regard to the year in which it occurs.

With calendric and horologic time, it is easy to date the succession or synchrony of events anywhere in the world. It permits placing of chronologically successive but geographically separate events, and ultimately establishes the basis for studies of rates of change, differential development in separate areas, and the identification of the geographic sources of widespread cultural influences.

Different techniques of determining absolute time of an archaeological sites or artifacts which deserve mentioning are namely: $Carbon^{14}$ dating, Potassium-Argon Dating, Thermoluminiscence, Palaeomagnetism, Varve Analysis, Dendrochronology, Amino Acid Recimization, Oxygen Isotope, Fluorine-Uranium-Nitrogen dating.

$Carbon^{14}$ dating, Potassium-Argon Dating, Thermoluminiscence, Palaeomagnetism, Varve Analysis, Dendrochronology, Amino Acid Recimization, Oxygen Isotope, Fluorine-Uranium-Nitrogen dating are some of the important techniques for determining absolute time.

3.3 RADIOCARBON DATING OR C^{14} DATING

Radiocarbon dating has made a revolutionary impact in the fields of archaeology and quaternary sciences. It is the best known and most widely used of all chronometric dating methods. J. R. Arnold and W. F. Libby (1949) published a paper in *Science* describing the dating of organic samples from object of known age by their radiocarbon content. Since the radiocarbon dating method became a regular part of the archaeologist's tool kit we began to have a world chronology for prehistory, based almost entirely on dates obtained by Libby's technique.

Principles

The radiocarbon dating method is based on the fact that cosmic radiation produces neutrons that enter the earth's atmosphere and react with nitrogen. They produce Carbon ^{14}, a carbon isotope with eight rather than the usual six neutrons in the nucleus. With these additional neutrons, the nucleus is unstable and is subjected to gradual radioactive decay and has a half-life of about 5730 years. Libby's equation describing the reaction as

$$N^{14} = C^{14} + H^{1}$$

Chemically C^{14} seems to behave exactly as ordinary nonradioactive carbon C^{12} does. Thus the C^{14} atoms readily mix with the oxygen in the earth's atmosphere, together with C^{12}, and eventually enter into all living things as part of the normal oxygen-exchange process that involves all living plants and animals. As long as matter is living and hence in exchange with the atmosphere, it continues to receive C^{14} and C^{12} atoms in a constant proportion. After death the organism is no longer in exchange with the atmosphere and no longer absorbs atoms of contemporary carbon.

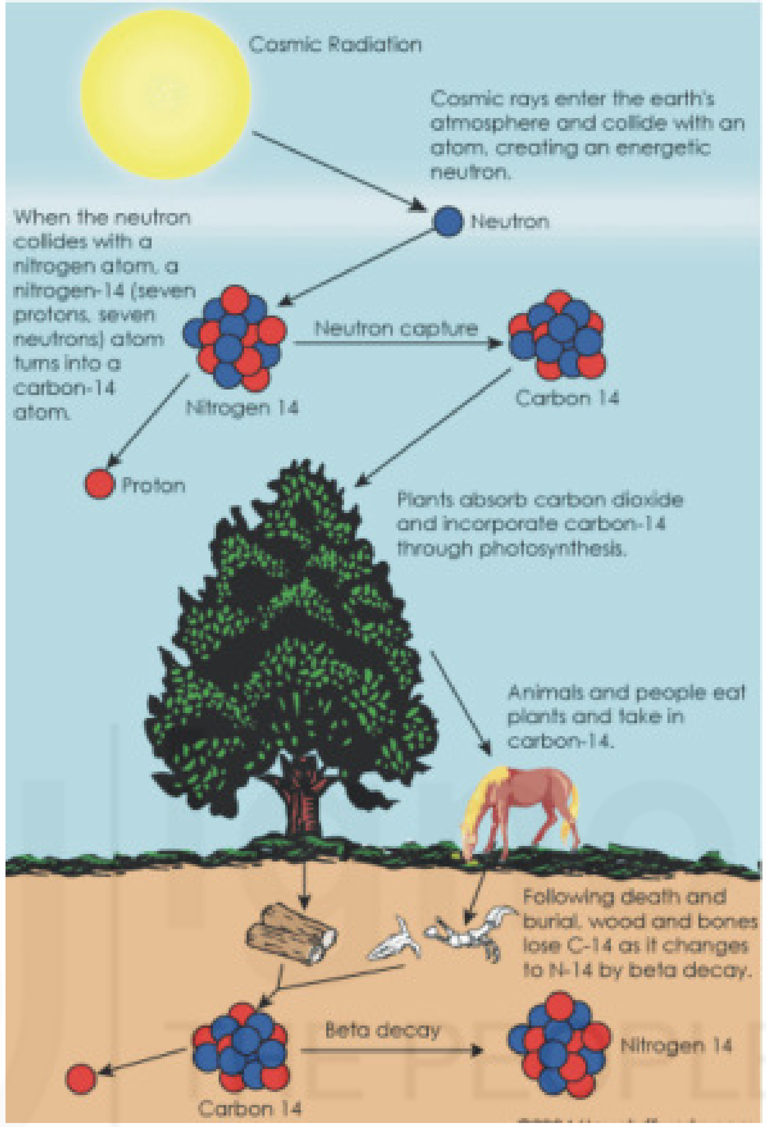
After the death of an organism the C^{14} contained in its physical structure begins to disintegrate at the rate of one half every 5730 years; thus, by measuring the amount of radiocarbon remaining, one can establish the time when the plant or animal died. Half-life (t 1/*2)* is measured by counting the number of beta radiations emitted per minute (cpm or counts per minutes) per gram of material. Modern C^{14} emits about 15 cpm/g, whereas C^{14} 5700 years old should emit about 7.5 cpm/g. In the disintegration the $C^{‘14}$ returns to N^{14}, emitting a beta in the process. Thus:

$$C^{14} = B - + N^{14} +$$

Suitable Materials for Radio Carbon Dating

Radiocarbon dates can be taken from samples of many organic materials. The kinds of material selected for C^{14} dating are normally dictated by what is available. The ideal material for radiocarbon dating is wood and charcoal burned at the time the archeological site was occupied. Charcoal and wood are generally considered optimal since they can be readily treated by sodium hydroxide. Bone burned at the time when the site was inhabited can also be dated. Unaltered wood from dry sites, soot, grasses, dung (animal and human), well preserved antler or tusk, paper, calcareous tufa formed by algae, lake mud, parchment, peat and chemically unaltered mollusc shells all contained enough C^{14} to allow them to be dated. Unburned bone contains a substance called collagen, which is rich in carbon, and this can be extracted and dated.

Other vegetable or animal products such as leaves, nuts, paper, parchment, cloth, skin, hide, or hair can be dated but are seldom or never present in prehistoric associations.



Procedure of Radiocarbon Dating

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

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

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

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

The radiocarbon age has the reading ± 180 attached to it. This is the *standard deviation,* an estimate of the amount of probable error. The figure 180 years is an estimate of the 360 year range within which the date falls.

The conventional radiocarbon method relies on measurements of a beta-ray decay rate to date the sample. A number of laboratories are now experimenting with an ultra sensitive mass spectrometer to count the individual $Carbon^{14}$ atoms in a sample instead. The practical limits of radiocarbon dating with beta decay approaches are between 40,000 to 60,000 years.

Accelerator mass spectrometry allows radiocarbon dating to be carried out by direct counting of $Carbon^{14}$ atoms, rather than by counting radioactive disintegrations. This has the advantage that samples up to *1/1,000* the size can be dated, especially for the time span between 10,000 and 30,000 years ago. Accelerator dating distinguishes between $Carbon^{14}$ and $Carbon^{12}$ and other ions through its mass and energy characteristics, requiring far smaller samples to do so.

Sources of Error in Radio Carbon Dating

Errors of three kinds reduce the absolute dating value of the technique:

(a) statistical-mechanical errors, (b) errors pertaining to the C^{14} level of the sample itself, and (c) errors related to laboratory storage, preparation, and measurement. These facts may be outlined briefly.

a) A statistical-mechanical error is present as a result of the random, rather than uniform, disintegration of radioactive carbon. This is expressed in the date by a plus-or-minus value in years (e.g., 6,240±320 yrs.). This statistical error can be reduced by increasing the time of measurement.

b) Sources of error in the C^{14} content of a sample may be a result of (1) past fluctuations of the C^{14} concentration in the C^{14} exchange reservoir; (2) unequal C^{14} concentration in different materials; and (3) Subsequent contamination of samples *in situ.*

Archaeological Applications

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

Limitations

Radiocarbon dates can be obtained only from organic materials, which mean that relatively few artifacts can be dated. But associated hearths with abundant charcoal, broken animal bones and burnt wooden structures can be dated. Artifacts contemporary with such phenomena are obviously of the same age as the dated samples. Chronological limits of Carbon 14 dating are accurate from around 40, 000 years B.P. to A.D. 1500.

3.4 POTASSIUM – ARGON METHOD

Next to radiocarbon, the most spectacular results in isotopic dating have been obtained with the potassium-argon method. It is the only viable means of chronometrical dating of the earliest archaeological sites. Geologists use this radioactive counting technique to date rocks as much as 2 billion years old and as little as 10,000 years old.

Potassium (K) is one of the most abundant elements in the earth's crust and is present in nearly every mineral. In its natural form, potassium contains a small proportion of radioactive potassium^{40} atoms. For every hundred potassium 40 atoms that decay, eleven become argon^{40}, an inactive gas that can easily escape from its material by diffusion when lava and other igneous rocks are formed. As volcanic rock forms by crystallisation, the concentration of argon^{40} drops to almost nothing. But regular and reasonable decay of potassium^{40} will continue, with a half-life of 1.3 billion years. It is possible, then, to measure with a spectrometer the concentration of argon^{40} that has accumulated since the rock formed. Because many archaeological sites were occupied during a period when extensive volcanic activity occurred, especially in East Africa, it is possible to date them by associations of lava with human settlements.

A useful cross-check for the internal consistency of K/ Ar dates is provided by paleomagnetic stratigraphy. Unaltered lavas that remain in place undisturbed preserve a record of the earth's magnetic field at the time of their cooling. Apart from the minor movements of the magnetic poles with time, magnetohydrodynamic processes in the earth's fluid core have repeatedly reversed the positions of the north and south magnetic poles. Consequently, paleomagnetic data shows a bimodal distribution in "reversed" and "normal" fields. K/Ar dating has demonstrated the existence of normal polarity "epochs" from 690,000 years to the present, and again from 3.3 to 2.4 million years ago, of reversed polarity epochs prior to 3.3 million years and again between 2.4 and 0.69 million years ago. Unfortunately, each of these epochs was interrupted by a number of brief "events," characterised by rapid switches of the earth's magnetic field. Although the paleomagnetic record is correspondingly complicated, it nonetheless provides opportunity to check the consistency of K/ Ar dates.

A cross-check on the "absolute" calibration of K/Ar dating has been provided by fission-track dating of volcanic glass from Bed I, Olduvai Gorge. This method uses different assumptions and is prone to other sources of error. The number of "tracks" caused by spontaneous fission of U238 during the "life" of the sample is counted. Age is determined by obtaining the ratio of the density of such tracks to the number of uranium atoms, which is obtained from the increase in track density produced by fission of U^{235}. The Olduvai cross-check provided a fission track age of 2.0 million years that compares reasonably well with K/ Ar dates averaging about 1.8 million years.

Datable Materials and Procedures

Potassium argon dates have been obtained from many igneous minerals, of which the most resistant to later argon diffusion are biotite, muscovite, and sanidine. Microscopic examination of the rock is essential to eliminate the possibility of contamination by recrystallisation and other processes. The samples are processed by crushing the rock, concentrating it, and treating it with hydrofluoric acid to remove any atmospheric argon from the sample. The various gases are then removed from the sample and the argon gas is isolated and subjected to mass spectrographic analysis. The age of the sample is then calculated using the argon 40 and potassium 40 content and a standard formula. The resulting date is quoted with a large standard deviation-J or early Pleistocene site, on the order of a quarter of a million years. (http://www.jrank.org/history/pages/6430/Potassium-argon-Dating).

Archaeological Applications

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

The first archaeological date, and one of the most dramatic, obtained from this method came from Olduvai Gorge, Tanzania, where Louis and Mary Leakey found a long sequence of human culture extending over much of the Lower and Middle Pleistocene, associated with human fossils. Samples from the location where the first cranium of *Australopithecus boisei* was discovered were dated to about 1.75million years. Even earlier dates have come from the Omo *Valley in* southern Ethiopia, where American, French, and Kenyan expeditions have investigated *extensive Lower Pleistocene* deposits long known for their rich fossil beds. Fragmentary australopithecines were found at several localities, but no trace of tools; potassium argon dates gave readings between two and four million years for deposits yielding hominid fossils. Tools were found in levels dated to about two million years. Stone flakes and chopping tools of undoubted human manufacture have come from Koobi Fora in northern Kenya, dated to about 1.85 million years, one of the earliest dates for human artifacts.

Limitations

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

Chronological Limits

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

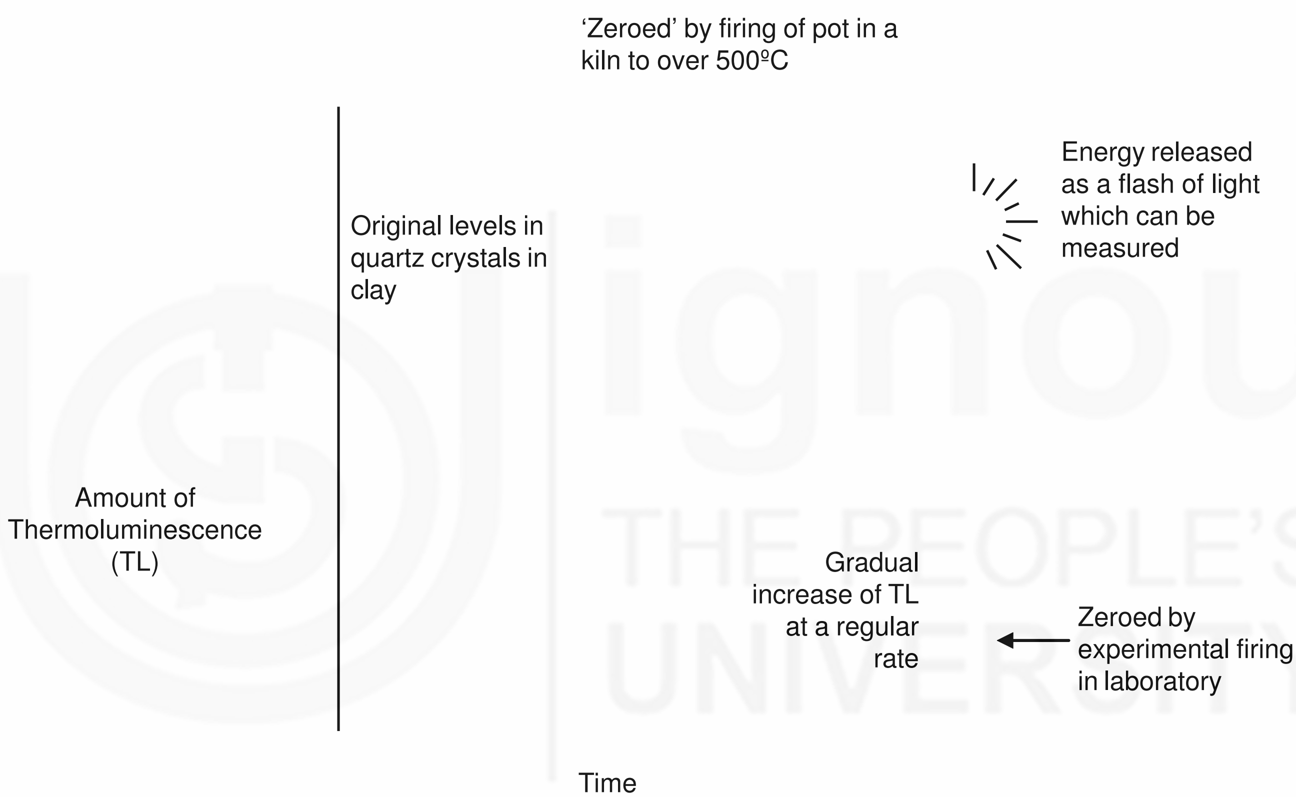
3.5 THERMOLUMINESCENCE OR TL DATING

Introduction

Thermoluminescence dating popularly now known as TL is the determination by means of measuring the accumulated radiation dose of the time elapsed since material containing crystalline minerals was either heated (lava, ceramics) or exposed to sunlight (sediments) (http://wn.com/Thermoluminescence_dating).

The Principle

The materials from which pottery is made have the property of storing energy by trapping electrons as atomic defects or impurity sites. This stored energy can be released by heating the pottery, at which time visible light rays, known as thermoluminescence, (a weak light signal) are emitted. All pottery and ceramics contain some radioactive impurities at a concentration of several parts per million. These materials emit alpha particles at a known rate, depending on how densely concentrated they are in the sample. When an alpha particle absorbed by the pottery minerals around the radioactive impurities, it causes mineral atoms to ionise. Electrons are then released from their binding to the nuclei and later settle at a metastable (relatively unstable) stage of higher energy. This energy is stored, unless the parent material is heated — as when the pot is being fired — when the trapped electrons are released and thermoluminescence occurs. After the pot is fired, alpha particles are again absorbed by the material and the thermoluminescence potential increases until the pot is heated again. Thus a clay vessel is dated by measuring the thermoluminescence of the sample as well as its alpha-radioactivity and its potential susceptibility to producing thermoluminescence. In the laboratory, the trapped electrons are produced from a pottery fragment by sudden and violent heating under controlled conditions.



The amount of energy released is relative to the amount of time since last heated to over 500ºC the 'clock setting event'.

(How Thermoluminescence Work)

Archaeological Applications and Limitations

Thermoluminescence dating is used for material where radiocarbon dating is not available, like sediments. Its use is now common in the authentication of old ceramic wares, for which it gives the approximate date of the last firing.Thermoluminescence has been used with reasonable success to date heat altered stone tools, burned hearths, and pottery. Exciting possibilities are emerging from experiments with dating Ice Age sediments such as loess, some in contexts where there are associations with Stone Age artifacts.

3.6 PALAEOMAGNETIC OR ARCHAEOMAGNETIC DATING

Introduction

After World War II, geologists developed the paleomagnetic dating technique to measure the movements of the magnetic north pole over geologic time. In the early to mid 1960s, Dr. Robert Dubois introduced this new absolute dating technique to archaeology as archaeomagnetic dating (http://archserve.id.ucsb.edu/courses/anth/fagan/anth3/Courseware/Chronology/11_Paleomag_Archaeomag).

The Earth's magnetic core is generally inclined at an 11 degree angle from the Earth's axis of rotation. Therefore, the magnetic north pole is at approximately an 11 degree angle from the geographic North Pole. On the earth's surface, therefore, when the needle of a compass points to north, it is actually pointing to magnetic north, not geographic (true) north (http://archserve.id.ucsb.edu/courses/anth/fagan/anth3/Courseware/Chronology/11_Paleomag_Archaeomag).

The Earth's magnetic north pole has changed in orientation (from north to south and south to north), many times over the millions of years. The term that refers to changes in the Earth's magnetic field in the past is *paleomagnetism*. In addition to changing in orientation, the magnetic north pole also wanders around the geographic North Pole. Archaeomagnetic dating measures the magnetic polar wander.

Principles

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

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

Datable Materials and Procedures

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

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

Archaeological Applications and Limitations

From the archaeological point of view, archaeomagnetism has but limited application because systematic records of the secular variation in the earth's magnetic field have been kept for only a few areas. Declination and dip have been recorded in London for four hundred years, and a very accurate record of variations covers the period from A.D. 1600. France, Germany, Japan, and the southwestern United States have received some attention. At the moment the method is limited, but as local variation curves are recorded from more areas, archaeomagnetism is likely to far more useful for the more recent periods of prehistory, when kilns and other burned-clay features were in use.

Chronological Range

By archaeomagnetic dating one can date two thousand year old human evidence.

3.7 VARVE ANALYSIS

Varves are annual, graded, bands of sediment laid down in glacier-fed lakes contiguous with the margins of continental glaciers. Detailed work by G. de Geer (1912, and later authors) on such annual sediment layers shows that a new load of sediment enters the lake in the wake of each spring's thaw. The coarser materials (mainly silts) settle down first while the finer ones (clays) gradually settle during the course of the summer. In larger lakes, wave motion may impede fine sedimentation until autumn when the lake surface freezes over. In numerous cases, fine sedimentation continues under the ice throughout the winter. When coarse silts or fine sands are deposited again during the succeeding spring, a sharp contact zone is formed, so enabling clear identification of the annual increment.

Further seasonal distinctions are provided through biological evidence. The coarse springtime accretion is generally dark and rich in organic matter, while the fine summer sediment is light-colored due to calcium carbonate precipitation. The late summer and autumn sediments are dark again. Pollen examinations of the upper dark layers have shown pollen sequences according to the time of blooming, while microorganisms such as diatoms are concentrated in the light, summer segment.

The thickness of the annual deposit or varve varies from year to year depending on the course of the annual weather and its influence on the ablation of the nearby glacier. A warm year produces large varves, a cold year narrow ones. A requisite to the regular laminar sedimentation is the temperature contrast of warmer, inflowing waters and cold lake waters, whereby the sediment is distributed evenly over the lake bed. Such conditions are best met in ice-margin lakes.

De Geer first recognised that varve sequences were very similar between nearby lakes – within a kilometer of each other – on account of the similarity of local climate. On this basis sequences were correlated and extended in time from area to area. By following the various stands of the retreating ice front. De Geer established an almost complete sequence covering 15,000 years from the late Upper Pleistocene well into historical times. This provided a true chronology whereby glacial features related to the retreat and dissipation of the European glacier could be more or less precisely dated. For example, the close of the Pleistocene was fixed by the event of the draining of the Baltic ice lake, which, according to the varves, occurred in 7912 B. C. Radiocarbon cross-dating suggests that this date may be at most a few centuries off.

Difficulties in the Varve Chronology

Within Fennoscandia the varve-chronology, as established by De Geer (1912, 1940) and Sauramo (1929), has in part remained a respectable body of evidence. It has been shown, however, that storms create multiple varves annually in shallow lakes through addition of extra influx and the stirring of sediments. As most of the lakes south of the Fennoscandian moraines, dating about 9000 B. C., are shallow, the earlier chronology is now considered doubtful.

The establishment of varve-chronologies outside Scandinavia, as attempted by Antevs (1925) in North America, has not been very successful. A major reason for this failure has been extrapolation of sequence segments over hundreds of miles. World-wide correlations of a frivolous type were attempted later whereby reversed seasons in the northern and southern hemispheres, of nonglacial characteristics of varves, have been simply ignored. These attempts have discredited the varve method and generally speaking, other techniques have now replaced the varve chronologies everywhere except in Fennoscandia.

3.8 DENDROCHRONOLOGY OR TREE-RING DATING

Dendrochronology, or tree-ring dating, was originated in Arisona by A. E. Douglass in about 1913. Tree-ring analysis is a botanical technique with strong analogies to varve study.

Principles

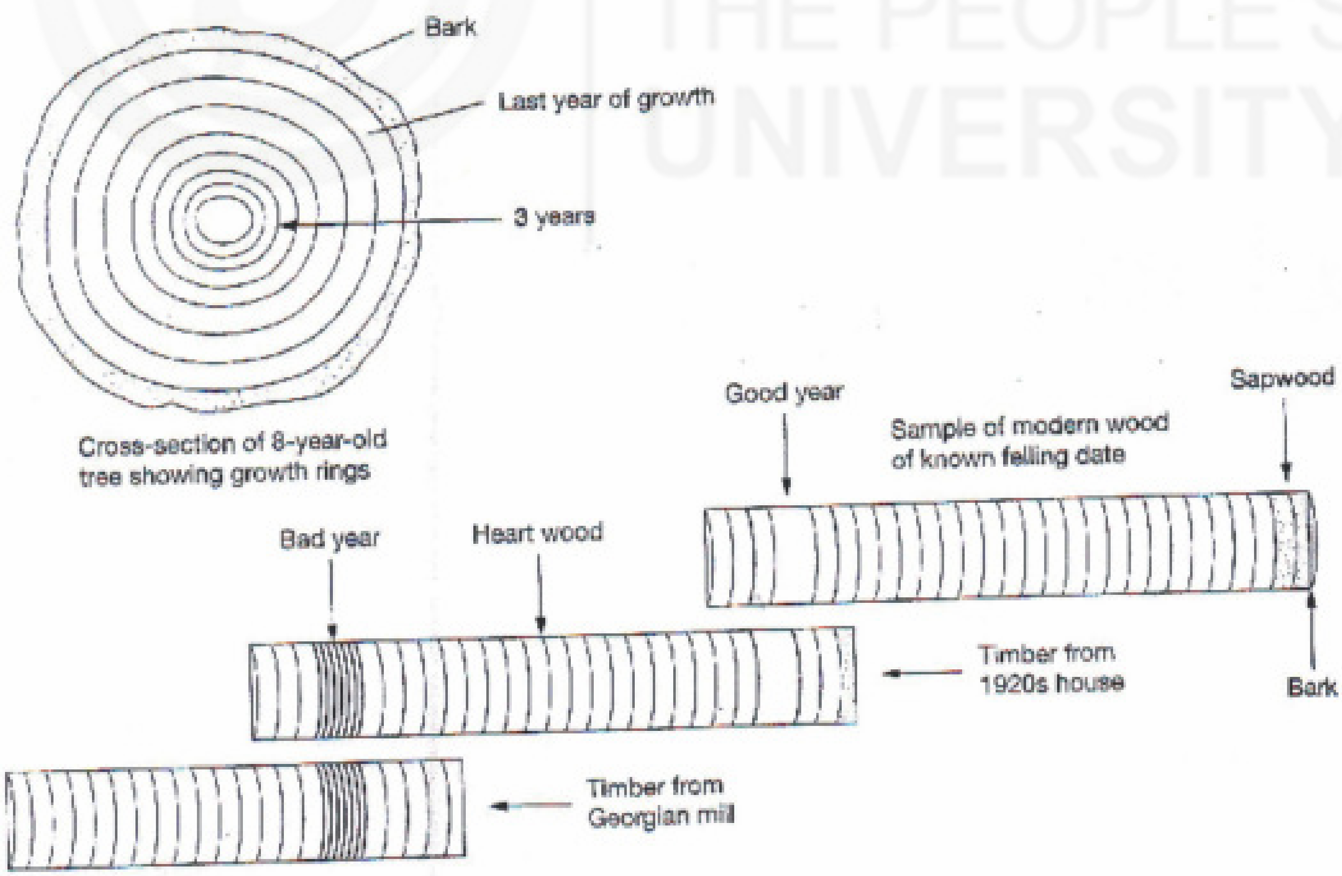
The underlying principle is that nontropical trees add an annual growth increment to their stems. Each tree ring, the concentric circle, representing annual growth, visible on the cross-section of a felled trunk. These rings are formed on all trees but especially where seasonal changes in weather are marked, with either a wet and dry season or a definite alternation of summer and winter temperatures.

Particularly in “stress” zones, along the polar and grassland tree limits, annual radial growth fluctuates widely, depending on the fluctuations of the growing season climate. In warm semiarid regions, available moisture largely controls the rate of radial growth of trees: the tree ring of a moist year is wide, while that of a dry year is narrow or, on occasion, missing entirely. In sub polar regions, rainfall is less significant since the late spring snows keep the water content of the soil sufficiently high. Instead summer, and particularly July, temperatures show the most significant correlation with radial growth.

Dendrochronologists have invented sophisticated methods of correlating rings from different trees so that they build up long sequences of rings from a number of trunks that may extend over many centuries. By using modern trees, whose date of felling is known, they are able to reconstruct accurate dating as far back as 8,200 years. Actual applications to archaeological wood are much harder, but archaeological chronology for the American Southwest now goes back to 322 B.C.

Datable Materials and Procedures

The most common dated tree is the Douglas fir. It has consistent rings that are easy to read and was much used in prehistoric buildings. Pinon and sagebrush are usable, too. Because the latter was commonly used as firewood, its charred remains are of special archaeological interest. The location of the sample tree is important. Trees growing on well-drained, gently sloping soils are best, for their rings display sufficient annual variation to make them more easily datable. The rings of trees in places with permanently abundant water supplies are too regular to be usable. Samples are normally collected by cutting a full cross-section from an old beam no longer in a structure, by using a special core borer to obtain samples from beams still in a building, or by V-cutting exceptionally large logs. Once in the laboratory, the surface of the sample is leveled to a precise plane. Analysing tree rings consists of recording individual ring series and then comparing them against other series. Comparisons can be made by eye or by plotting the rings on a uniform scale so that one series can be compared with another. The series so plotted can then be matched with the master tree-ring chronology for the region. Measuring the tree rings accurately can also add precision to the plottings.



Archaeological Applications

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

One of the most remarkable applications of tree-ring dating was carried out by Jeffrey Dean (1970), who collected numerous samples from wooden beams at Betatakin, a cliff dwelling in northeastern Arisona dating to A.D. 1270. Dean ended up with no fewer than 292 samples, which he used to reconstruct a history of the cliff dwelling, room by room. Dendrochronology has been used widely in Alaska, the Mississippi Valley, northern Mexico, Canada, Scandinavia, Ireland, the British Isles, Greece, and Germany (Bannister and Robinson, 1975; Baillie, 1982). Recent European research has been especially successful. What the bristlecone pine is to the Southwest, oaks are to Europe.

Arisona tree-ring laboratories are trying to analyse data on annual variability in rainfall from the many trees encompassed by their chronologies. A network of archaeological and modern chronologies provides a basis for reconstructing changing climatic conditions over the past two thousand years. These conditions will be compared with the complex events in southwestern prehistory over the same period.

Limitations

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

Chronological Range

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

3.9 AMINO ACID RACEMIZATION (AAR) DATING

All living things use proteins as building blocks in the production of their physical forms. In turn, proteins are composed of folded strands of 20 diverse smaller subunits called "amino acids". All amino acids, except for one (glycine), come in two different forms known as the laevorotatory (L - left) and dextrorotatory (D - right) form, which are mirror images of each other, but cannot be superimposed one over the other.

What is especially attractive about these two L- and D-forms, at least for the purpose of this topic, is that the vast majority of living things only use the L-form. However, as soon as the creature dies, the L-amino acids start to spontaneously convert into the D-form through a process called "racemization". If the rate of conversion can be determined, this process of racemization might be useful as a sort of "clock" to determine the time of death.

Basic Assumptions

In order to use the rate of racemization as a clock to exactly estimate when a living thing died, one must know how diverse environmental factors may have affected the rate of change from the L- to the D-form. As it turns out, this rate, which is different for each type of amino acid, is also exquisitely sensitive to certain environmental factors. These include: Temperature; Amino acid composition of the protein; Water concentration in the environment; pH (acidity/alkalinity) in the environment; Bound state versus free state; Size of the macromolecule, if in a bound state; Specific location in the macromolecule, if in a bound state; Contact with clay surfaces (catalytic effect); Presence of aldehydes, particularly when associated with metal ions; Concentration of buffer compounds; Ionic strength of the environment.

Of these, temperature is generally thought to play the most significant role in determining the rate of racemization since a 1^{o} increase in temperature results in a 20-25% increase in the racemization rate (Coote, 1992; Stuart, 1976). Clearly, this factor alone carries with it a huge potential for error. Even slight ranges of error in determining the "temperature history" of a specimen will result in huge "age" calculation errors.

"Amino acid dating cannot obtain the age of the material purely from the data itself. The rate of racemization cannot be standardised by itself because it is too changeable. Thus, because of the rate problem, this dating technique must rely on other dating techniques to standardise its findings. As a matter of fact, the ages obtained from racemization dating must rely on other techniques such as Carbon 14, and if the dating of Carbon 14 is not accurate, racemization dating can never be certain. So, how is it thought to be at all helpful? Well, it is thought to be helpful as a "relative" dating technique.

Interestingly enough, the racemization constant or "k" values for the amino acid dating of various specimens decreases dramatically with the assumed age of the specimens. This means that the rate of racemization was thousands of times (up to 2,000 times) different in the past than it is today. Note that these rate differences include shell specimens, which are supposed to be more reliable than other more "open system" specimens, such as wood and bone.

Add to this the fact that radiocarbon dating is also dependent upon the state of preservation of the specimen. In short, it seems like the claims of some scientists that amino acid racemization dating has been well established as reliable appears to be wishful thinking at best.

Because of these problems AAR dating of bone and teeth (teeth in different locations in the same mouth have been shown to have very different AAR ages) is considered to be an extremely unreliable practice even by mainstream scientists. That is because the porosity of bones makes them more "open" to surrounding environmental influences and leaching. Specimens that are more "closed" to such problems are thought to include mollusk shells and especially ratite (bird) eggshells from the emu and ostrich. Of course, even if these rather thin specimens were actually "closed" systems (more so than even teeth enamel) they would still be quite subject to local temperature variations as well as the other above-mentioned potential problems. For example, even today "very little is known about the protein structure in ratite eggshell and differences in primary sequence can alter the rate of Asu formation by two orders of magnitude [100-fold] (Collins, Waite, and van Duin 1999). Goodfriend and Hare (1995) show that Asx racemization in ostrich eggshell, heated at 80 ^{o}C has complex kinetics is similar to that seen in land snails (Goodfriend 1992). The extrapolation of high temperature rates to low temperatures is known to be problematic.

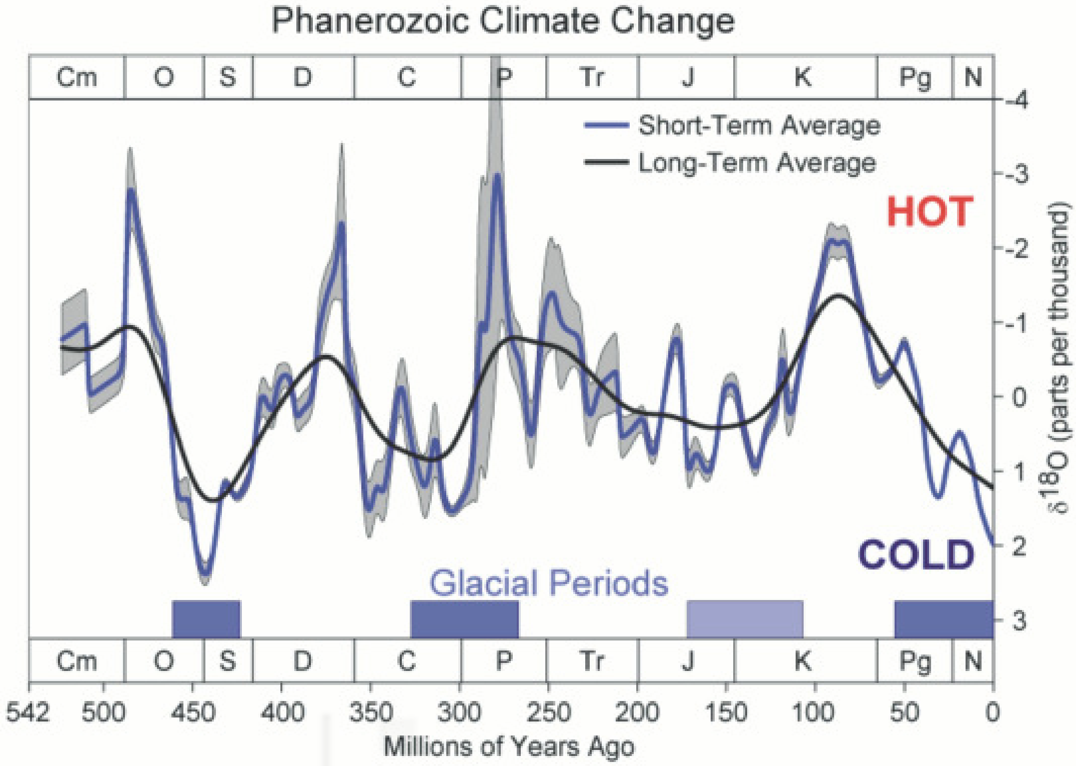
3.10 OXYGEN ISOTOPE AND CLIMATIC RECONSTRUCTION

Isotopes of a particular environment will have the same chemical properties, but their different masses cause them to be separated or fractioned by certain natural processes.

The oxygen isotopes have been useful in the reconstruction of past environmental condition. It has three isotopes each with a different atomic mass (same number of protons but varying numbers of Neutrons). The oxygen with eight neutrons has an atomic mass of sixteen and is designated ^{16}O, the isotope with nine neutrons is designated ^{17}O, and the isotope with ten neutron is designated ^{18}O. When water evaporates the lighter oxygen isotope (^{16}O) is preferentially incorporated into water vapor, while the heavier isotope (^{18}O) becomes proportionately higher in the remaining water. The fact that ^{18}O is preferentially left in ocean water during evaporation has been used to infer global climatic fluctuations. This has led to a revolution in our understanding of environmental and climatic change during the time of human biological and behavioral development. When this climate change is dated, they can sometimes be used to ascertain the age of archaeological sites. Isotopic signals content in marine sediment, calcite veins and ice core sequence appear to provide a continuous record of global climatic change for the interval associated with the archaeological record. These isotopic signals have been related to relative sea level change and alternative periods of colder global climates (Glacial) and warmer global climates (Inter glacial).

During ice-age the ^{16}O isotope of oxygen does not immediately recycle back into the ocean but instead becomes part of the large ice sheets. The heavy oxygen isotope (^{18}O) becomes more common in oceans during these colder intervals. This colder isotope ratio is recorded in the shells of Ocean's living organisms. When warmer global climatic intervals prevail, the lighter isotope, which had been trapped in the ice, returns to the ocean. Thus, during interglacial, there is proportionately less ^{18}O in the oceans. The change in the oxygen isotope ratios have been used to connect artefact bearing deposits with climate chronologies. The variation in oxygen isotopes from the deposits-ridden shell was correlated with the deep sea isotope record.

The advantage of the marine oxygen isotope record is that it provides a continuous record of the climatic change that have occurred during the past 2 million years.



3.11 URANIUM SERIES DATING

Thorium-Uranium (Ionium-Deficiency) Method

Mollusks, marine coral, and freshwater carbonates contain uranium^{234} at or shortly after death, but no thorium^{230} , a daughter element of uranium that is virtually insoluble in natural waters. If the fossil carbonates subsequently remain closed to isotopes of the uranium series, the amount of Th^{230} present will reflect the original concentration of U^{234} and the period of isotopic decay. Since the half-life of U^{234} is 248,000 years, and that of Th^{230} is 75,000 years, Th grows to equilibrium with U in about 500,000 years. In the meanwhile, the ratio Th^{230} / U^{234} is a function of age. The effective dating range of this ionium-deficiency method is 200,000 to 300,000 years.

The major source of error is the introduction of foreign uranium and its daughter products after the death of the organism. To some extent this type of contamination can be screened out, but isolated age determinations cannot be accepted with any great confidence. The Th^{230}/U^{234} technique has been applied to the study of Pleistocene beaches and lake beds in different parts of the world and there has been sufficient internal consistency as well as consistency with accepted geological correlations to warrant a moderate degree of optimism. In effect, this method has proved crucial for correlating littoral deposits of the last two interglacial periods, both in relation to the radiocarbon-dated portions of the Wurm glacial, and to the apparent temperature fluctuations recorded in organic oozes of the deep-sea floor.

U^{234} *Method*

Uranium is present in carbonate solutions in very small concentrations. It is fixed after sedimentation and, barring possible contamination, is not susceptible to outside addition or loss. U^{234}, the daughter element of U^{238} ,is originally present in the carbonate solutions but increases through radioactive decay after sedimentation. If the initial proportions of U^{234} and U^{238} are known for a particular depositional medium, the U^{234} / U^{238} ratio of a fossil carbonate provides an approximate date with a potential dating range of 1 to 1.5 million years (Thurber, 1962). This ratio is fairly constant (1.15) in marine waters but rather variable in fresh waters. Dating of coral has yielded U^{234} ages consistent with independent age formation, although marine mollusks receive an unpredictable contribution of uranium from surrounding sediments, so that they are less reliable. Dating of freshwater carbonates, such as travertines, has been attempted after establishing the U^{234} / U^{238} ratio for modern waters. However, such ratios will vary considerably through time, and the resulting dates are not particularly consistent.

Uranium Series Dating

238_U

á ↓

234_{Th}

â

234_{Pa}

â

234_U

á

230_{Th}

Further decays

Protactinium-Thorium (Protactinium-Ionium) Method

The decay of uranium (U^{234} and U^{238} in ocean waters is attended by the formation of daughter elements, Pa^{231} and Th^{230} , which accumulate in deep-sea sediments. Being produced by the same element, the ratio of Pa^{231} (half-life, 32,500 years) and Th^{230} (half-life, 75,000 years) should be unaffected by the concentration of uranium in marine waters and should be a function of time only, independent of changes in geological conditions. These elements are generally but not always resistant to post-depositional diffusion within the sediment.

Although the laboratory preparation and ultimate analysis of samples is strictly a task for the qualified specialist, it is useful for the persons concerned to be aware of the different results possible, depending on the method of preparation used.

There is, at present, no standard method of preparation. Many authors specify their methods, others do not. Some authors have obtained pollen from certain samples by using one technique; others employing another method may fail to find any pollen. Some techniques are widely considered acceptable, while others are frequently considered of dubious validity, other less frequently mentioned but equally serious grievances are directed against over intensive preparation of samples with massive destruction or mutilation of pollen. Since pollen has now been widely and successfully studied from rather "unorthodox," nonacidic, sedimentary environments in the arid zone and humid tropics, new preparation methods have necessarily been introduced to preserve from wanton destruction.

Until recently the only evaluation of the problem, unfortunately not well suited for the nonspecialist, was a detailed compilation by C. A. Brown (1960). The revised text book of Faegri and Iversen (1964) consequently fills a long-felt need.

Only one, widely employed technique is briefly described here, in order to illustrate the stages of "cleaning." Three undesirable substances may be present and may be removed in the following manner:

a) Calcium carbonate is removed with cold, diluted (25 per cent) hydrochloric acid.

b) Silica is removed by letting the sample stand for 48 hours in 40 per cent concentrated hydrofluoric acid, after which the sample is washed and then heated with 10 per cent hydrochloric acid.

c) Unwanted organic matter is destroyed by first boiling in 10-15 per cent hydrogen peroxide and then, after washing, boiling the sample a second time in 10 per cent potassium hydroxide.

All three techniques may have to be applied to clays or marls, whereas only *(c)* may be required in the case of peat, lignite, or coal. When the various undesirables have been so removed, the final residue of pollen is mounted in glycerine jelly on a permanent slide or suspended in liquid glycerine for immediate investigation under the microscope with 300x to 1000x magnification.

3.12 SUMMARY

Archaeologists have used many different dating techniques to work out the age of artefacts and sites for which they have no historical dates and the order in which they were used. The different techniques selected depend on the specific task and evidence as well as practical consideration such as cost. Many of the scientific techniques are expensive and required high level of technical skill to use and to interpret. The span of human history studied by archaeologists is so vast and environments so varied that techniques suitable for one place and period may be unsuitable for another. The absolute methods that provide calendar dates have been used since the middle of the twentieth century. With the exception of dendrochronology, they all have margins of error and are expensive to use. There are some less commonly used methods, such as Fission Track, Electron Spin Resonance (ESR) which are still at an experimental stage. Several techniques measure the age of layers rather than the archaeological deposition and are limited to particular type of geology. Most of them are used in combination for cross dating.

Suggested Reading

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Sample Questions

1) Define Relative and Absolute methods of dating and discuss the relevance of dating in archaeological anthropology.
2) Write the principle and procedure of radiocarbon dating.
3) Discuss in brief about various aspects of potassium argon dating.
4) Discuss in brief about various aspects of varve analysis.
5) How is the amino acid racemization used to date bones and teeth?
6) Discuss how oxygen isotopes have been useful in the reconstruction of past environmental condition.
7) Discuss, in brief, about various aspects of dendrochronology.
8) Discuss, in brief, about uranium series dating.
9) Discuss, in brief, about palaeomagnetic dating.