Indira Gandhi
National Open University
School of Social Sciences

# MAN-002
# Archaeological Anthropology

Block

# 4

## DATING METHODS

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# BLOCK 4 DATING METHODS

## Introduction

Archaeology is a multidisciplinary social science that routinely adopts analytical techniques from disparate fields of inquiry to answer questions about human behaviour and material in the prehistoric, protohistoric and historic periods till recent past. It is unique in respect to 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. With the many advances that have been made in the related fields of archaeology, one of these is the dating techniques as most successful endeavour made by scientists. Therefore, the success of archaeology in reconstruction depends mostly on our ability to make chronological orderings, to measure relative amounts of elapsed time and to relate these events to our modern calendar. Here, chronology which draws its methods from geology, botany, zoology and physics played a vital role. The main objective of various geological methods is to trace the development of time scale in years which extend back into distance past beyond the historical calendar. The field application of geochronology is in prehistoric archaeology and human palaeontology. The evolution of human being, both from the anthropological and cultural points of view cannot be properly understood, unless the time element is introduced. Someone had rightly said 'History without chronology is like a picture without frame', or 'History without date is a grandmother's tale'. Therefore this text has been written with special regard to archaeology. The most important contribution of various geochronological dating methods is that it is now possible to build a unified chronological framework for the archaeology of the whole world. It has brought many changes in the traditional chronologies. Here we are going to discuss how chronologies and time-frames of culture, climate or geographical events are determined through different dating methods. A broad range of methods are now available for dating events in Earth history. Some of these are more precise than others. Four categories are recognised e.g. numerical-age methods, calibrated-age methods, relative-age methods and correlated-age methods.

However in archaeological literature, two categories of dating are customarily recorded- relative and absolute. Relative dating techniques which identify the order in which sites or artefacts were used in a sequence from earliest to latest while absolute or chronometric dating techniques try to establish an exact or approximate calendar date for a site or artefact. It will be interesting to look back at the revolution radiocarbon dating has brought all over the world, about 50 years ago. It came as a god-sent to archaeology. For the first time the prehistorian could hope to date his finds, both accurately and reliably by a method that made no archaeological assumptions what so ever. As we are covering quite a few dating techniques, it is not possible to go into their great details, but have been discussed in a simple manner so that the reader can appreciate more the potential and limitations of different dating methods.

# UNIT 1 RELEVANCE OF DATING

**Contents**



**Learning Objectives**

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

- discuss about the different kinds of methods to date the archaeological / pre-historic sites; and
- describe the importance of dating methods in pre-historic Archaeology.

## 1.1 INTRODUCTION

In the study of archaeology, time is no more and no less important than environment. Dating is used to generate temporal units such as period and horisons, which in turn are useful in the study of the growth and development of society. Time is employed in evolutionary studies in order to measure the direction of cultural growth and development as well as rates of change. In practical sense, time is defined by the archeologist / palaeoanthropologist as a succession of events whose order can be defined. In archaeological literature, two types of dating are customarily recognised- relative and absolute. The following are some of the dating methods used in archaeological studies:

| Relative dating | Absolute dating |
|---|---|
| Stratigraphy | Radiocarbon dating |
| Geological calendar | Potassium-argon dating |
| Glacial calendar | Thermoluminescence dating |
| Fossil fauna calendar | Archaeomagnetic dating |
| River terraces | Dendrochronology |
| Fluorine test dating | Varve analysis |
| Nitrogen dating | Oxygen 16/18 Ratio Method |
| Palynology (pollen dating) | Obsidian hydration dating |
| Patination | |

Stratigraphy, Geological calendar, Glacial calendar, Fossil fauna calendar, River terraces, Fluorine test dating, Nitrogen dating, Palynology (pollen dating) and Patination are some of the important dating methods in Relative Dating where as Radiocarbon dating, Potassium-argon dating, Thermoluminescence dating, Archaeomagnetic dating, Dendrochronology, Varve analysis, Oxygen 16/18 Ratio Method and Obsidian hydration dating are some of the important Dating methods in Absolute dating.

## 1.2 RELATIVE DATING

Relative dating is basic to chronology. It is ordering of events in the absence of any written record or evidence. Relative chronology is important in reconstructing prehistoric archaeology / palaeoanthropology. In relative dating the duration of the event is unknown, so also the elapsed time between events is very difficult to determine. Furthermore, the temporal distance between any past event and the present cannot be determined. All of these deficiencies can be overcome when relative time is transformed into an absolute scale.

### 1.2.1 Stratigraphy

Stratigraphy is the study of layered deposits. Stratigraphic study is based on the law of superposition, which declares that deposits, whether of natural or cultural origin, form with the oldest on the bottom of the sequence and each overlying stratum younger, or more recent, than the layer below. Once the strata have been observed from early to late, it is possible to date the artifacts and eco-facts of each layer according to Worsaae's law of association. This position states that objects, both natural and cultural, found together in the same layered deposit are of the same age. Thus the relative dating of the super positioned deposits also dates their fossil specimens. The law of association is useful not only in the ordering of site historiographies, but also in the construction of local regional sequences.

### 1.2.2 Geological Calendar (Refer the Chapter on Pleistocene Period)

The history of the earth is subdivided by the geological calendar. Originally this history was organised by the relative age of the various rock formations that comprise the stratigraphic record of the science of historical geology. Later this relative chronology was converted to an absolute chronology by the use of the various radiometric-dating techniques. The oldest rocks, of Pre-Cambrian age, have been dated to 4.6 billion years ago by uranium-lead radiometric assays. Younger sub-divisions of the geological calendar are dated in a relative sense by the fossil content of the rock units and in an absolute manner through the broad range of isotopic decay techniques.

The subdivisions of the geological calendar with taxonomic breakdown into eras, periods and epochs are presented in the table. The Cenozoic, the latest era, is the subdivision during which modern forms of life evolved. The Cenozoic era is subdivided into two periods, the Tertiary and Quaternary, respectively the third and fourth subdivisions of the geological calendar. The Tertiary period saw the rise of mammals, including primates during the last 65 million years. The Quaternary is of prime importance to the study of cultural evolution because it is the period of humankind. During the Quaternary, the fossil record shows the biological evolution of humans and their primate relatives over the last two million years.

**The Standard Geological Calendar**

| Major Geological Intervals | Era | Period | Epoch | Duration in million years (Approx.) | Millions of years Ago (approx) | Appearance of new forms of life |
|---|---|---|---|---|---|---|
| CENOZOIC | CENOZOIC | Quaternary | Holocene | Approx. last 10,000 years | | Plant and animal domestication |
| | | | Pleistocene | | 1.9 | Stone tools |
| | | Tertiary | Pliocene | 3.6 | 5.5 | Humans appear |
| | | | Miocene | 20.5 | 5.5 | Savannas expand Early apes |
| | | | Oligocene | 12 | 38 | New and old world monkeys appear |
| | | | Eocene | 16 | 54 | Early primate radiate |
| | | | Paleocene | 11 | 65 | Early primates appear Archaic mammals dominate |
| MESOZOIC | MESOZOIC | Cretaceous | | 71 | 136 | Dinosaurs, birds, placentals and marsupials |
| | | Jurassic | | 54 | 190 | Therian mammals, dinosaurs dominate |
| | | Triassic | | 35 | 225 | Early dinosaurs, mammal like reptiles |
| PALAEOZOIC | PALAEOZOIC | Permian | | 55 | 280 | Many reptiles |
| | | Carboniferous | | 65 | 345 | First reptiles, true fish, insects |
| | | Devonian | | 50 | 395 | Land animals, amphibians |
| | | Silurian | | 35 | 430 | Land plants, jawed fishes |
| | | Ordovician | | 70 | 500 | Jawless fishes, earliest vertebrates |
| | | Cambrian | | 70 | 570 | Many marine invertebrates |
| PRE-CAMBRIAN | PRECAMBRIAN | | | 4,030 | | Single cell organisms |

Formation of earth's crust about 4,600 million years ago

## 1.2.3 Glacial Calendar

The Quaternary period of the geological time scale in turn is subdivided into two epochs, the Pleistocene and the Holocene. The Pleistocene is characterised as the "Ice Ages" when pre-modern humans evolved. Fully modern humans, called Homo sapiens in biological terminology, appear at the end of Pleistocene and flourished during the last 10,000 years, epoch called Holocene. The Holocene epoch is the geological interval following the ice ages and hence is often called post-glacial. It has witnessed essentially modern climates and is marked by the appearance of the first agricultural village and ultimately of urban civilisation.

The Pleistocene is characterised as an epoch of widely fluctuating climates with world temperature averages ranging between 4º and 5º C below today's values. During cold climatic episodes the polar icecaps thickened and continental glaciers advanced as snow accumulated at high latitudes, while mountain glaciers formed and advanced in middle latitudes. While water was stored in ice sheets, the world sea level dropped because of the retention of water at high latitudes. Alternately during warm, interglacial episodes of the Pleistocene, the icecaps melted, glaciers retreated, and sea levels rose.

The glacial calendar is subdivided according to oscillation of climates from cold to warm. The cold episodes are called glacial stages. In Europe at least four glaciations have been recognised and named as Gunz, Mindel, Riss and Wurm in Alps mountain region and Elster, Wieschel, Saale and Wardha in Scandinavian region. Three warm climate phases have been identified and named Gunz-Mindel, Mindel-Riss and Riss-Wurm interglacial in southern Europe, and Cromerian, Holsteinian and Eemian in northern Europe. The capitalised glacial stage names are pulses of cold climate with internal variations. These minor oscillations of intense cold are called stadials while the intervening relatively warmer sub-episodes are called inter-stadials.

Chronological Chart of Pleistocene Period and Palaeolithic Cultures in the Old World

| **Glacial calendar** | **Europe** | **Africa** | **Africa** | **Southeast Asia** | **Southwest Asia** | **Fossil finds** |
|---|---|---|---|---|---|---|
| 10,000<br>Wurm III | Magdalenian<br>Solutrean<br>Gravettian<br>Perigordian/<br>Aurignation<br>Chatelperronian | Capsian<br>Ibero-Maurusian<br>Aterian<br>Egyptian Up.Pal.<br>Dabban, etc<br>Lupembian | Upper<br>Palaeolithic | ? | Upper<br>Palaeolithic | Cro-Magnon<br>Man |
| Wurm<br>I and II/<br>Weichsel<br>80,000 | Mousterian<br>Final Acheulean | Mousterian<br>Upper Acheulean<br>Sangoan | Late Soan<br>Middle<br>Palaeolithic | Final Anyathian | Mousterian<br>Final<br>Acheulean | Homo<br>Neanderthals |
| Riss / Wurm<br>200,000 | Pre-Mousterian<br>Upper Acheulean | Upper Acheulean | Middle<br>Palaeolithic<br>Up. Soan | Anyathian | Acheulean | |
| Riss / Saale | Clactonian<br>Upper Acheulean<br>Middle Acheulean | Acheulean | Acheulean<br>Soan | Choukoutien | Acheulean | Homo<br>erectus |
| Mindel/Riss | Clactonian<br>Middle Acheulean<br>Early Acheulean | Acheulean | Soan | | Old<br>Acheulean | |

| Glacial calendar | Europe | Africa | Africa | Southeast Asia | Southwest Asia | Fossil finds |
|---|---|---|---|---|---|---|
| Mindel/Elster 500,000 | Clactonian<br>Early Acheulean<br>Abbevillian | Old Acheulean | Lower Palaeolithic<br>Old Soan | Choukoutien-1<br>Choukoutien-13 | Ubeidyia | |
| Gunz/Mindel | Flakes? | Oldowan | - | - | - | Australo-pithecines |
| Gunz | ? | Oldowan | - | - | - | - |
| Danube 1.9 million | Upper Villafranchian<br>Vallonet pebble tools | Oldowan | | | | |

Customarily, the Pleistocene epoch is periodised in a three-fold scheme as upper (late), middle and lower (basal). The Lower Pleistocene is marked by: 1) the first cold phase, 2) the Biber glaciation, 3) the two Donau glaciations, and 4) the Gunz glaciation. The time interval of the Lower Pleistocene period extends from 700,000 to 2.0 million years ago. The Middle Pleistocene contains the Cromerian and Holesteinian interglacial plus the Mindel and Riss glacial stages, according to the terminology of the Alpine-Swiss sequence of Europe. The corresponding glacial stages, Elster and Saale, are advances of the Scandinavian sheet that pushed down from the Baltic Sea onto the north German plains. And finally, the late (upper) Pleistocene epoch is a comparatively short period of time approximately of 100,000 years including the Eemian interglacial and Wurm / Weichsel glaciation and ending about 10,000 years ago with the final retreat of the worlds continental and mountain glaciers. The Pleistocene period in Africa has witnessed the downpour of rains called pluvials. These are named as Kageran, Kamasian, Kanjeeran and Gamblean pluvials corresponding to the glacial episodes of Europe. These pluvials are alternately represented by inter-pluvials such as Kageran-Kamasian, Kamasian-Kanjeeran, and Kanjeeran-Gamblian. These pluvials and inter-pluvials represent wet and dry climates respectively.

### 1.2.4 Fossil Fauna Calendar

Pleistocene events were reconstructed based on animal and plant fossils collected or unearthed from different geomorphic features of the Pleistocene period. The faunal remains discovered by Boucher de Perths along the Somme River in northern France were systematically classified by the palaeontologists and geologists, which were considered as index of relative chronology of that time. *Elephasmeridionalis*, an archaic *Elephasantiquus*, the Etruscan rhinoceros, Merck's rhinoceros, hippopotamus, the archaic *Elephasstenonis*, the sabre-toothed tiger, *cervussolhilacus*, the Somme deer, the giant beaver- *trogontherium*etc were the Pleistocene fauna of that part of the Pleistocene Period. Whenever deposits of unknown age containing such or similar faunal assemblages were discovered they were being dated to the same relative age based on the principal of association. It soon became evident that the Pleistocene was a time of giant animal forms and rapid species evolution, a process called speciation. Since tooth enamel is durable and teeth are highly distinctive to each animal species, the Pleistocene was easily subdivided on the basis of its palaeontology, particularly the teeth of various elephant species. One particular faunal assemblage, name the Villafranchian after a type-site located in France, was elected as the horison marker separating the end of the Tertiary period (Pliocene epoch) from the beginning of the Quaternary period (Pleistocene epoch). The Plio-Pleistocene boundary marker is typified by a list of now-extinct giant animals including an elephant like animal, rhinoceros, horse, and a huge beaver.

### 1.2.5 River Terraces

In the study of relative chronology the rivers extend wonderful evidences. Rivers are sensitive to physical forces and provide habitat for several biological species, including humans. It is evident that several of the present day rivers had formed or shown dynamism during the Pleistocene Period. Rivers have the capacity of erosion and deposition. When there is an abundant supply of water, rivers generate erosion capacity while deceleration in supply deposit whatever they carry, resulting in river geomorphology. A permanently flowing river would be in a state of erosion, if there were no oscillations of sea level, or fluctuations of climate, or tectonic movements of the ground. Such a river would cut down its bed all the time to discharge its waters and maintains a thalweg (a gently sloping curve), which is roughly a parabolic in shape. The rivers at the origin are active and they are considered as young, while at the mouth they are old as they are stable, but at the middle reaches they are called matured with lot of floodplains. Rivers have the generic character of changing their courses, which depends on the change in climate and depends on the terrain, thereby they are the indicators of several episodes of events (time and climate).

According to their modes of origin, three kinds of river terraces are distinguished: i) Tectonic terraces, ii) Thalassostatic terraces, and iii) Climatic terraces. All these terraces are due to interruptions or sudden intensifications, which are paramount for palaeo-climatic study.

i) **Tectonic terraces:** One possible source of such disturbances is tectonic subsidence or uplift of part of the river's course. In nature, these movements may be extremely complicated and since tectonic terraces have little significance for the general chronology of the Pleistocene period.

ii) **Thalassostatic terraces:** Thalassostatic terraces are located at the river mouths resulted due to the fluctuations of the level of the sea. A drop of the sea level creates a step at the former mouth of the river, which is gradually moved upstream by erosion. The result is a nick point and a terrace, which diverges from the later thalweg in the down stream direction and ends abruptly at the coast. A rise in sea level usually leads to the formation of a funnel shaped estuary. If this is shallow enough and the river carries a sufficient amount of detritus and will be deposited gradually at the estuary. In some cases the aggradation above the new high water mark pushes out an estuarine sediment towards sea resulting in deltas. Thalassostatic terraces are of great stratigraphic value where they depend on eustatic fluctuations of the sea level.

iii) **Climatic terraces:** Climatic terraces are most important from the stratigraphic point of view as they provide direct evidence of climatic fluctuations suitable for relative chronology.

*Uplift upper course of river:* Let us assume that the course of the river is crossed by a fault and that the entire upper portion of the river has been raised. A waterfall, or rapids, will then be formed where the river passes from the raised block down to the stable portion, and increased erosion will gradually gnaw back the upper edge. After sometime no more will remain than a portion of the river's course, with a gradient steeper than above and below, it will join smoothly with the lower portion of the thalweg curve, but its upper end will be represented by a distinct break in the curve, which will become weaker and weaker the more it works itself upstream. Such break is called a nick point. The remnants of the ancient level of the river from the nick point as far as the fault will form a 'terrace', which at the fault, runs out into the air. The gravel sheet of such terrace will be thin (about equal to the depth of the river), since no aggradation took place.

*Subsidence of upper course of river:* In the case of subsidence of the upper course of the river the fault will create a bar crossing the thalweg. It is very obvious that this bar prevents much of pebbles, sand and mud from traveling further down the river, and the break at the fault will, after sometime, be filled in with deposits. This aggradation will rise slightly upstream, but its gradient will be smaller than that of the portion of the upper course above it. In this portion erosion will continue, until the break at the upper end of the aggradation is smoothed out. The break at the fault is of the shape of the nick point and the normal erosion of the un-disturbed lower course of the river will smooth it out, gnawing a channel across the fault into the aggradation. The result is that a terrace remains at the side of the valley, which is not parallel to the modern thalweg and which, in its middle portion above the fault, consists of aggraded river gravels.

### 1.2.6 Fluorine Test Dating

Fluorine test dating is another method of relative dating. It is based on the fact that amount of fluorine deposited in bones is proportional to their age. The oldest bones contain the greatest amount fluorine, and vice-versa. The fluorine test is useful in dating bones that cannot be ascribed with certainty to any particular stratum and cannot be dated according to the stratigraphic method. A shortcoming of this method is the fact that the rate of fluorine formation is not constant, but varies from region to region. The quantity of fluorine can be determined either through chemical analysis or with the X- ray crystallographic method.

### 1.2.7 Nitrogen Dating

Nitrogen provides another measurement of relative age. By contrast to fluorine, nitrogen in bone decreases with the length of time it has been buried. The nitrogen test together with fluorine will provide information as to the relative age of bone specimens. Such techniques are especially important when we wish to establish whether all the bone specimens in a level or of the same age or whether they are of different ages and their association in the level are due to secondary deposition.

### 1.2.8 Palynology

Relative dating can also be done on the evidence of floral remains. A common method, known is Palynology (the study of pollen grains). The kind of pollen found in any geological stratum depends on the kind of vegetation that existed at the time such stratum was deposited. A site or locality can therefore be dated by determining what kind of pollen was found associated with it.

### 1.2.9 Patination

Stones either buried in the ground or laying on the surface for a length of time undergo chemical alteration. Such alteration, termed patina, is manifest in a milky coloured coating on the surface of the stones. The differences in degree of patination are assumed to represent differences in relative age.

## 1.3 ABSOLUTE DATING

Dates termed absolute are really of two separate categories. Those, which are stated in terms of years in our calendar, are true absolute dates. The true absolute dates may be derived from tree rings, ancient calendrical systems, coins, and varves where traced directly back in time from present. The other category consists of techniques, which yield dates expressed in years with an associated probability factor. These methods depend on knowing the rate of change and the amount of change, the number of years that have elapsed since the process of change began. The methods based on this principle are Carbon-14, Potassium-Argon (K-Ar), Uranium-Thorium (Ur/Th), Thermoluminescence (TL), Archaeomagnetic etc. The term chronometric dating refers to quantitative measurement of time with respect to a given scale. It is synonymous with the more traditional term absolute dating, but is gaining favour among dating specialists who regard it as more appropriate term. The dating methods rely upon the half-life period or the radioactive isotope decay constants are often referred as isotopic dating methods.

### 1.3.1 Radiocarbon (C 14) Dating

Radiocarbon dating had its origin in a study of the possible effects that cosmic rays might have on the earth and on the earth's atmosphere. Willard Frank Libby, a Noble Laureate in chemistry for his pioneering work in developing this technique, has provided us with a thorough account of the early research. He credits Serge Korff with having discovered that neutrons are produced when cosmic rays enter the earth's atmosphere. These particles, being uncharged, are very effective in causing transmutations in the nucleus of any atom with which they colloid. Neutrons are found to have an intensity that corresponded to the generation of about two neutrons per second for each square centimeter of the earth's surface. Libby theorised that, upon entering the earth's atmosphere, they would react with Nitrogen-14. The reaction produces a heavy isotope of carbon, carbon-14, which is radioactive.

$$14\ N + n \longrightarrow 14\ C + H$$

The two carbon-14 atoms per second per square centimeter go into a mixing reservoir that consists not only of living matter, but also of the dissolved carbonaceous material in the oceans, which can exchange carbon with the atmospheric carbon dioxide. For each square centimeter of the earth's surface, there are about 7.25 grams of carbon dissolved in the ocean in the form of carbonates, bicarbonate and carbonic acid, and the biosphere itself contain about 0.33 gm per square centimeter of surface. Adding all elements of the reservoir, Libby observed that one arrived at a total of 8.5 gm of diluting carbon per square centimeter, and that the two carbon-14 atoms disintegrating every second should be contained in 8.5 gm of carbon.

Libby argued that one could assert that organic matter, while it is alive, is in equilibrium with the cosmic radiation, and all radiocarbon atoms that disintegrate in living things are replaced by the carbon-14 entering the food chain by photosynthesis. At the time of death, however, the assimilation process stops abruptly. There is no longer any process by which carbon-14 from the atmosphere can enter the body. In the disintegration process, the carbon-14 returns to nitrogen-14, emitting a beta particle in the process. The half-life is measured by counting the number of data radiations emitted per minute per gram of material. Modern carbon-14 emits about 15 counts per minute per gram, whereas carbon-14, which is 5700 years old, should emit about 7.5 counts per minute per gram.

$C^{14} \qquad \beta N^{14}$

### Half-life of Carbon-14

The present official half-life of carbon-14 is 5568 ± 30years, and was derived from the weights average of three determinations: 5580 ± 45 years, 5589 ±75 years, 5513 ± 165 years. However, the 5$^{th}$ and 6$^{th}$ International Radiocarbon Dating conferences agreed that 5730 ± 40 years was the best value available.

### The preparation and dating of sample

The datable sample is converted into a gas form – carbon dioxide, methane, acetylene, or benzene by burning or by other means. The gas, however, contains radioactive and electronegative impurities derived from the original material. These are removed in an elaborate vacuum system, through which the sample passes. The purified sample is then piped into a proportional counter, which operates on the principle that the size of electrical pulses originating in it is proportional to the energy of the beta particle initiating each pulse. The sample is counted for 1000- min intervals and each sample is counted at least twice, preferably with at least a week intervening between the two counts. The net activity of the sample then is compared with the activity of modern standard.

### Calculation of a radiocarbon date

$$I = Ioe^{t} \qquad \text{——— (1)}$$

Where

I = the activity of the sample when measured.

Io = the original activity of the sample (as reflected by a modern standard)

= The decay constant = 0.693/$T_{1/2}$ the $T_{½}$ the half-life.

t = time elapsed.

$T_{½}$ = 5568 years, then we can write the equation for a routine calculation as

$$T = \log\ Io \times 18.5 \times 10^{3} \text{ years} \qquad \text{——— (2)}$$

### Datable materials

Nearly any material containing carbon is potentially suitable for radiocarbon dating. Organic material with high carbon content such as charcoal, wood, bone, shell, and iron are most reliable. In addition to these, peat, paper, parchment, cloth, animal tissue, leaves, pollen, nuts, carbonaceous soils, the organic temper in pottery sherds, wattle and daub construction material, and prehistoric soot from the ceiling of caves are also used for dating.

### Limitation

The level of the counter background sets a practical limit of about 50,000 years to the age that can be determined. The limit can be extended by artificial enrichment of carbon-14 relative to the carbon-12 with the aid of a thermal diffusion column. Thus, at present time, the technique of radiocarbon dating has an operational limit of 70,000 years.

## 1.3.2 Potassium-Argon (K-Ar) Dating

The Potassium-Argon (K-Ar) dating method covers nearly the whole range of the time scale, with published dates extending from 4.5 billion years ago to 2,500 years ago. This impressive range is due in part to the extremely long half-life 1.3 billion years ± 40 million years of the radioactive isotope of potassium, potassium-40, with its decay produces argon-40.

The potassium-argon dating method can only be used in situations where new rock has been formed. The lavas, tuffs and pumice found as overlying strata at localities that contained culture-bearing deposits in such diverse areas as Italy, East Africa and Java are useful for this dating.

### Underlying principle of the method

Potassium (K) is one of the elements that occur in great abundance in the earth's crust. It is present in nearly every mineral, either as a principal constituent or as a trace element. In its natural form, potassium contains 93.2% $K^{39}$, 6.8% $K^{41}$ and 0.00118% radioactive $K^{40.}$ For each 100 $K^{40}$ atoms that decay, 89% become calcium-40 and 11% become argon-40, one of the rare gases.

Argon-40 an inert or inactive gas, which by means of diffusion can easily escape from its parent material under certain conditions. During rock formation virtually all $Ar^{40}$ that had accumulated in the parent material will escape. As the rock or mineral crystallises, the concentration $Ar^{40}$ drops off to practically zero. The process of radioactive decay of $K^{40}$ continues, but the concentration of $Ar^{40}$ that develops over time will now, when dated, denote the moment of rock formation.

### Sample preparation

Sample preparation involves first, crushing of the rock samples, second concentrating it to high purity, third washing it on sample screens to remove fines, and fourth, treating it with hydrofluoric acid. The main problem of the technique is the elimination of atmospheric argon from the sample. By removing the outer layer of the sample, most of the atmospheric argon will be removed. However, treatment of samples with hydrofluoric acid has proved to be very effective in reducing the atmospheric argon in the sample. Immediately after sample preparation and drying it should be put into the extraction line and place under vacuum.

### Potassium-Argon analysis

Potassium-argon dates are calculated from measurements of the sample content of argon-40. The amount of potassium in a sample fraction can be determined by a flame photometer, although for small concentrations, isotopic dilution analysis and even neutron activation analysis can be used. The determination of the concentration of argon is determined by mass spectrometric analysis.

**Calculation of Potassium-Argon dates**

The $Ar^{40}$ and $K^{40}$ contents are used to calculate the Potassium-Argon date of sample. The primary assumption, required to assure a correct age, is that the initial concentration of $Ar^{40}$ was zero, and that no diffusion losses took place.

t = 1/ in 1+ (1+R)/R x (40 Ar rad)/(40 K) ——————— (1)

Where

(40 Ar rad) and (40 K) are given in number of atoms,

= The total decay constant of 40 K

R= the banding ratio of the double decay of 40 K.

By substituting the values = 5.32 x$10^{-10}$ $y^{-1}$ and R=0.123 (the most reliable decay constants) replacing $K^{40}$ by K total (using the isotopic abundance of $K^{40}$) converting the ration (40 Ar rad)/(K) into the units and using the common logarithms instead of the natural logarithms, equation (1) can be reduced to the form

$$T= 4320 \log 10 \quad \frac{\{1+ 134.7 \text{ (40 Ar rad)}\}}{K} \qquad \text{——————— (2)}$$

Where t is given in million of years.

t = 2.53 x $10^5$ x (40 Ar rad)/K ——————— (3)

**Datable materials**

Potassium-argon dates have been determined for such igneous minerals as muscovite, biotite, phlogopite, orthoclase, sanidine, microline, and leucite, for volcanic glasses (obsidian), and for the sedimentary minerals gluconite, illite, carnallite and sylvite.

## 1.3.3 Thermoluminescence (TL) Dating

Farrington Daniels of the University of Wisconsin suggested the dating of ancient pottery by thermoluminescence measurements as early as 1953. Since then this dating technique has undergone serious investigations and development, and at present has become fully operational as an absolute dating technique with an accuracy of plus or minus10%.

**The Principle of Thermoluminescence**

Thermoluminescence is released in the form of light of stored energy from a substance when it is heated. The phenomenon occurs in a number of different crystalline solids, including pottery. All ceramic materials contain certain amounts of radioactive impurities, for example uranium, thorium and potassium, in parts-per-million concentration range. These elements emit alpha, beta and gamma radiation at a specific rate that will depend only on the impurity content of the sample. This radiation will cause ionisation within the sample, and electrons and other charge carriers (called holes) will result. Also within the ceramic materials will be crystal imperfections (or traps) that were formed during and after crystallisation. The released charge carriers will tend to be trapped in this lattice of crystal imperfections at ordinary ambient temperatures. These charge carriers will exist in a metastable state, a few electron volts above the ground state. When the ceramic is heated the electrons and holes are released from their traps at definite temperatures. Upon their release, electron-hole recombination will occur, returning these charge carriers to their ground state, and affecting the release of their excessive voltage as light, measurable in photons. The longer the ceramic has been crystallised, the more ionising radiation will have resulted and the more trapped electrons and holes will be held in the crystal structure.

The thermoluminescence observed is a measure of the total dose of radiation to which the ceramic has been exposed since the last previous heating. In the case of pottery, the event dated is the firing of the pot during the pottery making process. The temperature of the firing environment, believed to have been in excess of $750^0$C was high enough to remove the thermoluminescence that had been acquired by the clays and tempering materials during geological times.

**Dating procedure**

After the samples have been prepared (by crushing grains ranging from 1 mm to 1 µm or less) the tiny disk of sherd grains are placed individually in special apparatus designed to generate up to $500^0$ C heat rapidly and to record the thermoluminescence emitted by means of a photo multiplier tube. The glow recorded by the photo multiplier tube is measured with an electrometer, which, in turn, is attached to a recorder that produces a graph of light output versus temperature (glow curve). The height of the plateau in the natural glow curve is taken as the natural thermoluminescence. An evaluation of the total dosage is made in rads (1 rad =100 ergs of absorbed energy) by measuring the sensitivity of thermoluminescent minerals found in the pottery sherd. In addition to knowing the natural TL of the sherd, and the sensitivity of the TL components of the sherd to alpha and beta irradiations, it is also necessary to know the natural radiation dose received by the sherd each year. The total uranium and thorium measured in terms of alpha activity using a device called a scintillation counter. The $K^{40}$ content of the sherd is usually determined by means of X-ray fluorescent analysis.

The actual age of pottery sherd is then given by the relationship:

$$\text{age} = \frac{\text{Natural TL}}{\text{(TL/rad)a x (rads/ year)a + (TL/rad), x (rads/year)}}$$

in which

(TL/rad) denotes thermoluminescent sensitivity and (rads/years) denotes annual dosage of radiation.

## 1.3.4 Archaeomagnetic Dating

Archaeomagnetic dating is based on the known fact that the direction and intensity of the earth's magnetic field vary over the years. Clay and clay soils contain magnetic minerals and when the clay is heated to a certain temperature, these minerals will assume the direction and a proportional intensity of the magnetic field, which surrounds them. They will retain this direction and intensity after they are cooled. By measuring these qualities, the age of the sample can be determined if the changes in the earth's magnetic field at that location are known.

**The magnetic moment**

The magnetic field of the earth at any given point is defined by three measurements, the angle of declination, the angle of dip, and the magnetic intensity. When a needle is suspended at its center of gravity so that it can swing freely in all directions, and is then magnetized, it will assume an inclination to the horisontal direction. The angle of magnetic dip is strongly latitude dependent, varying from $0^0$ at the magnetic equator to $90^0$ at the magnetic poles. In addition to inclination, the needle will exhibit definite directions in a figurative horisontal plane. The directions defined by the needle are called magnetic north and magnetic south. The angle between magnetic north and geographic north is called the angle of declination.

**Measurement procedure**

Robert Dubois, a specialist in archaeomagnetic dating, uses what is referred to parastatic magnetometer in his specially constructed dating laboratory at the university of Oklahoma. This magnetometer embodies the principle of the compass needle. It consists of three bar magnets, spaced on a slender rod suspended from a very fine wire of phosphor bronze or quartz. The entire assembly is enclosed within a plastic tube that protects it from air currents. A thin beam of light shines on a mirror glued to the rod, then reflects, like a pointer, to a numbered scale. The horisontal component of the earth's magnetic field is annulled by passing an electric current through large coils of wire that surround the magnetometer by means of wooden scaffolding. Locally produced magnetic fields with a vertical gradient are annulled by the use of the three bar magnets. The upper and lower magnets are equal in strength and antiparallel to the middle magnet, which has double strength. With this arrangement there is zero torque from any vertical magnetic field.

The three magnets act like a double set of diametrically opposing magnets of equal strength. Since the pull on the two parts of each magnet system is equal and opposite, the effect of the earth's field is cancelled and the beam of light points to zero. When a sample is placed on a platform directly beneath the suspended magnets, the entire assembly above it rotates slightly. This rotation is caused by the lower magnet, which is affected more strongly than the other magnets, and swings toward the direction of the sample, rotating the entire assembly as it moves. The reflected beam of light moves across the scale, exactly like a compass needle, indicating just how far the clay sample has caused the magnets to turn.

By setting the sample on its top and bottom, its angle of declination is measured directly; the angle of dip is calculated from readings taken when the sample is set on each of its four sides. These values then are used to calculate where the geomagnetic pole was located when the clay was fired. Measurements on a number of samples enable the investigator to compute a mean vector. This is the common and recommended procedure for archaeomagnetic dating.

## 1.3.5 Dendrochronology (Tree Ring Analysis)

Dendrochronology is a method that uses tree-ring analysis to establish chronology. A major application of dendrochronology in archaeology is, as a tool for establishing tree-ring dates. Another application of this analysis is the influence of past environmental conditions. The modern science of dendrochronology was pioneered by A.E. Douglass, an astronomer who had set out to investigate sunspot cycles by tracing climatic factors reflected in the growth of trees. From his earliest studies, which were purely climatic in a systematic manner, an absolute chronology for the southwestern United States.

### The underlying process

Tree-ring analysis is based on the phenomenon of formation of annual growth rings in many trees, such as conifers. Usually trees produce one ring every year from the cambium, the layer of soft cellular tissue that lies between the bark and the old wood. The growth rings of trees vary throughout. This variation is caused by two major factors: first the thickness varies with the age of the tree, the rings becoming narrower as the tree gets older. The second factor that affects the thickness of growth rings is the change in climate from one year to another. In years with unfavorable weather, such as drought, the growth rings will be unusually narrow. On the other hand, during years with exceptionally large amounts of rain, the tree will form much wider growth rings. Most of the trees in a given area will show the same variability in the width of their growth ring because of the climatic fluctuations they all endured. Such trees are said to be *sensitive*, those that do not exhibit variability are said to be *complacent*. The pattern of narrow and wide rings that sensitive trees in an area display is the basis for cross dating among specimens. This pattern is unique, since the year-to-year variations in climate are never exactly the same, and the resulting wide and narrow ring sequences will not be exactly the same through along period of time.

### The technique of analysis

In the analysis of tree-ring specimens, the first objective is the establishment of cross-dating between samples, and then cross-dated specimens are matched against a master chronology, which itself is a product of previously cross-dated pieces. Essentially, what is involved is the recording of individual ring series and their comparison with other series. Consequently, the initial requirement is the positive identification of each of the visible growth increments within the sample.

Several different instruments designed to accurately record widths along a radius have been developed. These include the Craig-head-Douglass measuring instrument, the De Rouen Dendrochronograph, and the Addo-X. After the measured values are translated into plotted graphs, both visual and statistical comparisons can be made.

It is necessary to build a known tree-ring chronology that goes back far enough to overlap and cross-date with the unknown segment. Starting with modern samples of known date, successively older and older specimens are cross-dated and incorporated into the matrix until a long-range tree-ring chronology is established. The validity of tree-ring dating ultimately depends upon the precision with which cross dating can be accomplished.

## 1.3.6 Varve Analysis

Varves are laminated layers of sediments, which are deposited in lakes near a glacial margin. Each varve is made up of two layers, a coarse, thick usually lighter coloured layer on the bottom and a thin, fine grained, darker coloured layer on top. The two layers together represent the deposition from one year's glacial melt. The coarser layer may be correlated with summer melt and the thin layer with the winter's runoff.

Varves are variable in thickness, but this is not a problem in their use for dating. A major restriction is that varves occur only in glaciated regions and therefore are absent in most of the world. Their most outstanding occurrence is in Scandinavia where they have been traced continuously back in time from the present to 17,000 years ago. Gerhard De Geer first described the varve sequences on the basis of the Scandinavian evidence. Subsequently varve analysis has been applied in certain areas of North America, South America, and Africa.

### 1.3.7 The Oxygen 16/18 Ratio Method

The oxygen 16/18 techniques provide climatic data, primarily a record of fluctuations in past temperature. Nonetheless, this method may be used by extrapolation for the dating of Pleistocene events. The primary application of the method has been in the analysis of deep-sea cores, although ice cores have also been studied. Deep-sea cores are made up of the layered ooze on the sea floor, which accumulates at a very slow rate, one to several centimeters per 1000 years. The components of Globigerina ooze are clay and from 30 to 90 per cent of calcium carbonate derived from the shells of Foraminifera. The ocean temperature at the time these Foraminifer were living can be assessed by the ratio of the two stable isotopes, Oxygen-16 and Oxygen-18, in the calcium carbonate of their shells. The temperature graph so determined is of little value for short-term fluctuations because of the reworking of bottom sediments by burrowing sea floor fauna. For long-term fluctuations it is reliable and presents us with a temperature curve adjusted to that of the oceanic surface. The oceanic curve may then be correlated with continental phenomena, primarily glacial advances and retreats. The resultant curve is therefore a record of Pleistocene climatic fluctuations, the later portion of which has been precisely dated by carbon-14 and Pa 231/Th 230 methods. By exploration the deep-sea core curve may be used to estimate the duration of Pleistocene events beyond the range of precise dating techniques.

### 1.3.8 Obsidian Hydration Method

A freshly broken surface of obsidian exposed to the atmosphere absorbs water to form a visible surface layer, termed a hydration layer. It increases in thickness at a fixed rate. We thus have available another natural clock for the precise measurement of elapsed time. In as much as a great many stone implements were made from obsidian, the potential of such a method is indeed great. The application of method is simple. First a small thin section is removed from the specimen with a diamond lapidary saw. The sample is mounted on a microscope slide and then examined with a polarising petrographic microscope. The polarised light makes the hydration layer visible, and its thickness in microns may be directly measured.

However, it is not possible to compare this measurement with a universal thickness standard because hydration does not occur at the same rate in every region. There seems to be a correlation with temperature and other environmental factors, which suggests that regional rates of hydration are possible. Lists of dates have been prepared for various selected areas, and they show promise of an acceptable reliability. Problems limiting the method are variable chemical composition of different obsidians, or surface exposure, or frequent variations in temperature and precipitation. A final problem is reuse of obsidian implements. In spite of these limitations, the method has merit where the specimens dated are of a similar variety of obsidian and all the specimens have been buried in similar environment since use.

## 1.4 SUMMARY

The spatial and temporal scales are important in understanding the bio-cultural evolution of humankind. This unit provides the nature of temporal scale and its components in extending the time dimension. Time is such an important factor that it embraces every object, either of biological or culture in the process of evolution. Therefore, the dating of an object is integral in anthropological studies. There are two kinds of ways in determining the age of an object, would it be a fossil, an object or an event of culture. They are relative and absolute dating methods, the former is useful in putting the objects on relative timeframe in a bracket of millennia or million, while the later pinpointing the age in numerical years (very close to decades or centuries).

Several kinds of dating methods are presented in this unit. They can be broadly categorised into three groups such as earth science related (geological and glacial calendars derived on geomorphological studies such as stratigraphy, river terraces, varves etc.), radio active isotopic analysis dependent (Carbon-14, Potassium-Argon, Thermoluminescence, archaeomagnetic etc.), chemical analysis based (fluorine – uranium – nitrogen (F-U-N), and fossil studies (faunal and floral fossils including dendrochronolgy and palynology). Any one or combination of these methods is of great help in extending the time dimension to the objects of study. In chronological studies the precession of the dating adds value to the object or event in the spatio-temporal scale.

### Suggested Reading

Brothwell, D and E. Higgins. 1970. *Science in Archaeology*. New York: Praeger.

Butzer, K.W. 1971. *Environment and Archaeology*. Chicago: Aldine-Atherton.

Cornwall, I.W. 1958. *Soils for the Archaeologist*. London: Phoenix House.

Michels, J.W. 1973. *Dating Methods in Archaeology*. New York: Seminar Press.

Zeuner, F.E. 1958. *Dating the past*. London: Methuen.

### Sample Questions

1) Discuss the relevance of dating in archaeological studies.

2) What are isotopic dating methods? Describe one of the isotopic dating techniques used in prehistoric studies.

3) What is a fossil? Bring out the palaeontology dependent dating techniques and their use in understanding bio-cultural evolution.

4) Write an essay on Pleistocene Period by integrating different calendars used in chronological studies.

# UNIT 2 RELATIVE CHRONOLOGY

**Contents**



**Learning Objectives**

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

- understand the importance of stratigraphy, which was the outcome of different geomorphic agencies;
- 'change is the law of nature' – change in climate particularly during Pleistocene Epoch is significant in anthropological studies; and
- fossils, both animal and plant are of great help in reconstructing Pleistocene environment during which man had evolved.

## 2.1 INTRODUCTION

Archeological sites, depending on the cultural time range involved, may represent former houses, villages, or towns; they may pertain to temporary or seasonal camps, or to killing or butchering sites. Other sites may have little or no ecological meaning, but consist only of scattered artifactual material, possibly redeposited within a river trace. Sites dating from historical or late prehistoric times are commonly found on the surface, possibly buried under cultural debris or a little blown dust, and altered by a weak modern soil profile. Many sites belonging to different periods are found exposed at the surface. A great number of prehistoric sites, however, are found in direct geologic context, within or underneath sediments deposited by some geomorphic agency.

## 2.2 STRATIGRAPHY

Stratigraphy is the study of layered deposits. Stratigraphic study is based on the law of superposition, which declares that deposits, whether of natural or cultural origin, form with the oldest on the bottom of the sequence and each overlying stratum younger, or more recent, than the layer below. Once the strata have been observed from early to late, it is possible to date the artifacts and eco-facts of each layer according to Worsaae's law of association. This position states that objects, both natural and cultural, found together in the same layered deposit are of the same age. Thus the relative dating of the superpositioned deposits also dates their fossil specimens. The law of association is useful not only in the ordering of site historiographies, but also in the construction of local regional sequences.

For the archeologist a "stratified" site is one with distinct archeological horisons, with or without a geologic context. The term "surface" site might be used to describe a variety of things, such as an archeologically un-stratified surface-find or even an ancient open-air encampment now buried by a meter or two of loess or marl. From the archeologist's point of view, sites may be classified according to their cultural-ecological meaning or according to digging criteria. The earth scientist, interested in providing a stratigraphic date or a geographical-ecological meaning for a site, would naturally use different criteria of classification.

"Stratified" and "surface" sites: The most interesting kind of archeological site for the earth scientist is one found in a direct geologic context, i.e. geologically stratified or geologically in situ. This should not imply that the cultural materials have not been derived, but only that their present location is geologically circumscribed. For the sake of Convenience "Stratified" will here be used in this geologic sense only. "Surface" site will be restricted to materials found at the surface, without geologic context.

According to the basic geomorphological situation or the type of deposits involved, archeological sites can be geologically classified as follows:

a) Alluvial sites: artifacts, fossils, occupational floors and the like found within former stream deposits.

b) Lacustrine sites: archeological materials found in former lake beds, in ancient bogs, swamps, or spring deposits.

c) Aeolian sites: archeological materials found in or under wind-borne sand or loess, or found in relation to features resulting from deflation or wind scour.

d) Cave sites: archeological materials found in direct relation to erosional or depositional phenomena associated with former coastlines.

e) Costal sites: archeological materials found in caves with some form of geologic or archeological stratigraphy.

f) Surface sites:the great mass of scattered archeological materials and sites found at the surface, with little possibility of direct association with any geomorphic event.

Identification of the depositional medium contemporary with or subsequent to an archeological site is vital to the earth scientist. The specific relation of a cultural horison to a geomorphic event can provide direct paleo-environmental information. This local environmental setting may in turn be stratigraphically linked to regional or worldwide changes of climate.

## 2.3 ALLUVIAL (RIVER) DEPOSITS

The intensity and extent of alleviation in a stream valley varies in different environments. In the arctic barrens and tundra, streams are overloaded and deposit sediments along the length of their courses. In arid and semi-arid zones water loss through evaporation leads to alleviation along the river course. In the boreal forests floodplains are common while in the temperate and tropical woodlands, the rate and extent of downstream alleviation is comparatively limited. The savanna lands are somewhat exceptional through significant colluviation.

Streams accelerate their activity in terms of erosion when there is increase in water supply due to heavy rains, the sediment loads increase and depending upon the river gradient readjustment sets in. streams reestablish a form of equilibrium related to its gradient (thalweg curve) and transport ability, and cut down its bed to a lower and smaller floodplain. The old floodplain becomes obsolete, and is separated from the new, functional floodplain by vertical escarpments forming terraces. Such alluvial terraces consists of benches, built of river deposits, remaining at the level of defunct, higher floodplains.

**Terrace formation**

At the start, the floodplain has a certain elevation and rate of deposition. Increased flood discharge with greater transport ability and load will lead to (a) more extensive flooding and consequently enlarging the floodplain, with undercutting of nearby hill slopes and, (b) a higher floodplain level due to accelerated deposition. The new floodplain, across which the river migrates horisontally, is broader and higher and characterised by deposition of more and larger-sized materials. When the volume and rate of deposition decreases to their original level, the stream will attempt to maintain its velocity- despite a decreasing volume by shortening its course and thereby increasing the gradient. A straighter course is adopted, usually associated with a predominance of down cutting. The new floodplain will be smaller, and will be cut out as a limited section of the greater floodplain. In this way alluvial deposits are built up at various elevations and with a distinctive morphology.

Alluvial sites rank second only to cave sites in the early history of archeological excavations. Excavations or borings in river valleys have frequently struck alluvial sands or gravels of various ages containing animal remains or human artifacts. Natural exposures in terrace faces have also revealed archeological materials. Many such sites have little more to offer than sporadic, water-rolled stone implements and possibly a little bone of dubious association. Other sites, however, may represent occupation floors with rich associations of undisturbed tools and fossils. Interpretation of such sites can, with due effort, be carried to a satisfactory stage of environmental and stratigraphic understanding (Butzer, 1971).

The periglacial stream terraces of the Old World were probably first studied by Paleolithic archeologists, and the well-known Somme River succession of northern France was established as a sequence of integrated solifluction beds, loesses, and periglacial stream deposits. Once assumed to be the framework of Paleolithic cultural stratigraphy, many of the sites in question are of limited importance since they were mainly collection of derived artifacts rather than occupation floors. The pluvial terraces of the arid zone have played a significant role archeologically in both the Old and New World, even in rather late prehistoric times. The twin sites of Torralba and Ambrona, in the Spanish province of Soria, were situated on the marshy floodplain margins of a stream valley during a moist, cold phase of the Lower Pleistocene. Swanscombe is an example of a significant site associated with downstream valley alleviation during a high, Middle Pleistocene sea level. The site was occupied on a Thames floodplain almost 30 m. above that of the present. Although not wholly undisturbed by stream redeposition, the contemporaneousness of the human and animal fossils was established by fluorine tests.

## 2.4 GLACIAL DEPOSITS (MORAINES)

Glaciers provide important stratigraphic data to permit identification of glacial or interglacial epochs, either locally or on much larger scale through melt water deposits and through the world-wide oscillations of sea levels. Glaciers develop in cool areas with heavy snowfall. Once formed, the glaciers create a microclimate of their own. They reflect radiation (increase *albedo*), lower the summer temperature by contact and radiative cooling, thereby lead to significant temperature inversions in the lower atmosphere, i.e. a cold skin of air underlying warmer air above. The larger is the glacier, the greater is the environmental modifications, and hence they are the markers of palaeo climate and time episodes.

Ice fields that form where snowfall exceeds annual ablation are the result of compaction and structural alteration from snow to ice. The density of fresh snow is in the order of o.15 – 0.16. after settling, removal of part of the pore space, and recrystallisation, the stage of granular snow or firn (with density of 0.5 – 0.8) is attained. Repeated melting and refreezing, aided by further compaction under pressure of overlying firn and snow leads to complete impermeability to air and densities exceeding 0.82 is defined as ice, which is capable of plastic flow. The resulting ice mass may form either mountain, valley, or piedmont glaciers in rough highland terrain, or ice caps in areas of smoother topography.

**Moraines:** Although permanent ice covers only 10 per cent of the world land surface today, it extended over 32 per cent at the time of maximum Pleistocene glaciation. Apart from the areal significance of glacial phenomenon, moving ice is also the most powerful agent of erosion and deposition. When snow fields persist over several years they evolve to larger ice masses, erosional niches will be created in the valley-head areas. If there is much accumulation of snow the ice basin will over deepened and broadened leading to quarrying of lateral rock faces. Such loosened rock is embedded and carried within, on top of, or below the ice. The flow passes through stream valleys by cutting deep, broad floors flanked by over-steepened cliff faces to further flow of ice. These U-shaped or trough valleys are commonly several hundred meters deep in the case of matured glaciers, and are conspicuous hallmarks of valley glaciation. Towards the terminus of the ice, debris accumulation may take the form of frontal ridges or end moraines, as sub-glacial ground-moraines, or as side or lateral moraines which extend back through much of the glacial valley. Coalescing ice tongues may also leave intermediate ridges of rock and dirt known as medial moraines. The melt water deposits of sand and gravel stream-laid a head of the ice terminus are known as outwash.

## 2.5 AEOLIAN DEPOSITS

Wind is one of the natural agencies had the capacity of erosion and deposition thereby modifying the topography of the earth. But, erosion by wind is limited to dry, loose, and fine-grained sediments, not protected by a plant cover. Under natural conditions wind erosion will be more or less limited to the arid zone and high arctic barrens, except for locally favourable areas: broad sand beaches, and exposed stream or lake beds during low-water. Particles in the silt or fine and medium sand size (< 0.2 mm) are carried in suspension by strong winds. Coarse sands are moved by saltation. Transport of the suspended load, consisting of silts and finer sand grades, is effected over long distances. During strong dust storms, great masses of Aeolian materials may be carried over hundreds of kilometers, only to be deposited very slowly in response to decreasing wind velocities, or more rapidly by being washed down by rain. Extensive Aeolian sedimentation of silt and fine sand may then occur well outside of those environments suitable for wind erosion. The coarser sands of the bed load can only move along the ground, migrating as sand ripples, ridges, or dunes. These materials will ordinarily be confined to the general source region, with exception of smaller dunes migrating from the coast or along other local sources of sand.

Corresponding to mode of transport of the different particle sizes, wind-borne sediments may consist of striking coarse-grained sand mounds or dunes, of smooth, extensive sheets or mantles of fine-grained materials. The morphologically conspicuous, coarse-grained types are largely confined to the world deserts and the arctic barrens, whereas the sand or dust (loess) sheets may be deposited almost anywhere, although they only retain structure and other characteristics when laid down in open country.

Sand Dunes: Dunal forms include migratory 'free' dunes, whose existence is independent of topography, and 'tied' dunes, related to some permanent wind obstruction. The free dunes include several types:

a) Longitudinal dunes occur in groups of long, parallel ridges, with many peaks and sags. They may be 100 km. long and over 100 m. high, lying parallele to the direction of strong winds. Their formation may be aided by local turbulence, leading to accumulation now on one side or on the other.

b) Crescentic dunes or *barchans,* as the name implies, are crescentic in plan, the horns and steep concave slopes facing downwind. These dunes may attain 30 m. in height and 400 m. in width and length. They develop with unidirectional effective winds.

c) Transverse dunes form irregular, wave like ridges at right angles to the effective wind direction, sometimes merging or occurring simultaneously with barchans fields.

d) Parabolic or U-shaped dunes are superficially similar to a barchan, but are more elongated and slightly asymmetrical, with the gentle, concave slope facing windward, the steeper, convex face down wind.

Specific archeological associations with Aeolian features are mainly of three kinds.

a) Occupation floors or scattered artifacts found under or on top of sand dunes;

b) Archeological materials found under, within, between or on the surface of the loess,

c) Archeological materials exposed by wind deflation or scour.

One of the best examples of an archeological site related to a complex sequence of stream and wind erosion and deposition is the Holocene San Jon site of eastern New Mexico. Most of the terminal Pleistocene Siberian cultures of the Kom, Ombo plain and Egypt, were deflated and are now partly found on yardangs scoured out of old Nile deposits. In late Pleistocene, innumerable loess sites from central and Eastern Europe are examples of occupation during or after loess sedimentation. Geomorphological investigation of aeolian sites is primarily concerned with whether aeolian activity was contemporary with occupation, and whether it preceded or followed occupation. Evidence of soil development in the stratigraphic profile are important, and other indications of sedimentary breaks may be obtained from vertical curves of particle sizes, carbonate, or humus content. With due caution, pollen studies may also be possible in the humic horisons of an aeolian profile. In general, the exact stratigraphic correlation of sediments and archeological levels can be determined, and careful examination may possibly reveal the contemporary environmental setting of the site as well as the changing environmental patterns of the period.

## 2.6 LACUSTRINE DEPOSITS

Lake and swamps beds have been laid down in standing waters and are more generally known as lacustrine deposits. They include:

a) evaporates, usually gypsum or salts;

b) calcarious beds, including chalk;

c) marls;

d) silts and clays;

e) sands; organic deposits.

*Evaporites* consist mainly of gypsum (calcium sulfate) and other salts such as sodium, magnesium and potassium chlorides or sulfates. Such beds frequently indicate dessication or lake shrinkage- periodic shrinkage during the dry season or long-term reduction of a larger lake to a lagoon or salt pan (e.g. Dead Sea). Evaporates, with the exception of open coastal lagoons are indicative of some degree of aridity or at least of a high ratio of evaporation to precipitation (Butzer, 1971).

*Lacustrine chalks* usually indicate perennial lakes which are not subject to very great seasonal fluctuations of oxygen content. Lacustrine chalks are common in many climatic zones. In temperate Europe they may be deposited organically by pond weeds; in dry areas such as the Sahara, inorganic precipitation is more important. Plant and animal remains are more common in such beds (Butzer, 1971).

*Marls* are calcareous silts deposited both in lakes and swamps. The lime content may be derived through plant or inorganic agencies; the clays and silts represent soil products carried in by streams and rain-wash. Common in humid and even semiarid lands, freshwater marl sedimentation is commonly confined to comparatively small water bodies.

*Silts and clays* are generally carried into standing waters in suspension by local streams. They may occur wherever finer weathering products are available. Lacustrine silts and clays are however, most common in moist climates.

*Sands* of lacustrine deposition are most widely found in areas with limited vegetation. In lower latitudes the widespread lacustrine sands of the Sahara were largely derived from sandy wadi deposits in the course of Pleistocene. The prehistoric Chad and Fayum lakes of northern Africa are striking examples of lacustrine sands derived from direct stream influx as well as lake wave-action on local sandstone bedrock.

Organic deposits, of many different kinds and complex origins, are most common in cooler latitudes although they are not quite unknown in the tropics and subtropics. Prehistoric settlements were common around the banks of lakes. For example, the early Holocene site of Star Carr, Yorkshire, was situated next to a now extinct lake, and subsequently buried by bog depostis. In the Fayum depression of northern Egypt, high Nile floods were responsible for the creation and maintenance of several late Pleistocene and Holocene lakes. Various Paleolithic and Neolithic populations occupied the fringe vegetation of those lakes, leaving cultural and animal remains along the former shorelines or within the sand of the beaches. At the Lower Pleistocene site of Ternifine, western Algeria, a rich fauna with skeletal remains of the hominine *Atlanthroupus (Homo) mauritanicus* is exposed in clays and spring deposits of a former lacustrine basin. *Zinjanthropus* and "pre-Zinj" sites found in mixed lacustrine and volcanic ash beds of Bed I, at Olduvai Gorge, Tanganyika dating from the Basal Pleistocene. These examples are all related to pluvial climate of Pleistocene period.

In higher-latitude Europe, lacustrine beds were mainly found in poorly-drained ground moraine areas abandoned by the continental glacier. So for example, the Lower Paleolithic occupation level at Hoxne, near Ipswich, is located in clayey silts of Holstein interglacial age. The beds record a former lake within a depression in Elster till. The interesting Middle Paleolithic spear of Lehirngen, near Hannover, was found with an intact elephant skeleton in lacustrine marls of Eem interglacial age, overlying the Saale ground moraine.

Swamp and bog deposits, some of them postdating sites, have long enjoyed considerable archeological interest in northern Europe. They have produced potsherds, plowshares, house or village foundations, and even fully intact corpses.

## 2.7 CAVE DEPOSITS

Caves were first 'discovered' for science by archaeologists, and despite the enthusiasm of ameture cave explorers, caves and archaeology remain almost synonymous in the public mind. The earth sciences have also shown some considerable interest in caves and subterranean caverns. Various processes of groundwater solution and cave formation are a part of karst geomorphology. Practically, all true caves have developed as a result of solution in limestone, and the term "karst" refers to landscape noticeably modified through the dissolving agency of underground waters.

Man and animals have sought shelter in caves since the beginnings of prehistory, and some of the most interesting cultural sequences have been derived from cave sites. The cave strata had been intensively studied and in fact these studies are basic in understanding biological evolution and geomorphic environments tied up with relative time scale. Today certain sequences of cave sediments, faunal assemblages, and pollen are as vital for Pleistocene stratigraphy as the cultural horisons are for Stone Age archaeology.

Two major kinds of caves are distinguished: exterior caves, and interior passages and caverns. The exterior type may vary from simple overhangs and shelters (rock-shelters) to shallow caves. Most of these have been dissolved or eroded near the water-mark by streams or wave-action at the coast. Sometimes they are produced by hallowing out of softer rock strata. Cave environments are highly variable. Direct sunlight is reduced or eliminated entirely. Relative humidities are high, particularly in deep, shaded caves. Except at the very entrance, temperatures are usually too low for soil development, and chemical weathering is practically limited to carbonate solution.

The stratigraphic layers found in caves are of either external origin and partly internal. The extraneous materials may be washed in by rainwash, drawn in by gravity, blown in by wind, moved in through solifluction or washed through rock joints by percolating soil and groundwater. In addition, man and beast had carried in a variety of inorganic objects and materials, deliberately or inadvertently. Due to these natural and artificial reasons the cave sediments would consists of:

1) Fossil layers: animal bones, carcasses, feces, etc;

2) Archaeological layers: the occurrence of individual proofs of human presence with or without fossil remains; and

3) Cultural layers: sediments strongly influenced by human activities such as fire and tool-making along with many imported objects such as stones, bones, shells, plant matter etc.

The only point of further interest requiring comment is the use of caves by early man. In all but the rarest cases, occupation was limited to the foreparts or entrance area of a cave. Deep interior caverns were widely use for ritualistic or artistic purposes in some areas, but such damp, lightless vaults would ethnological analogies have bearing on Paleolithic cave-dwellers, it may be mentioned that the Australian aborigines of the northern Lake Eyre area, the Shoshones of the Great Basin and the Kalahari Bushmen are all known to have occupied caves or overhangs (rock-shelters) on occasion.

Cave sites have assumed importance at many times and in many areas, ranging from the australopithencien caves of South Africa to the crevice breccias of Peking, from the Upper Paleolithic caves of southern Frnace and adjacent Spain to the terminal Pleistocene cave cultures of the southwestern U.S.A. In India too we have a very good number of rock-shelter and cave sites denoting prehistoric cultures together with relative time-scales. The Bhimbetka in Madhya Pradesh, Bethamcherla in Andhra Pradesh, Gudium in Tamil Nadu can be quoted as examples in this direction.

## 2.8 FOSSILISATION

Mineralised end product of an organic matter is a fossil. The organic materials are largely decomposed and carried away in solution. In this fossilised condition, the bone is characteristically light in weight, porous and brittle. Soil waters may percolate freely through fossilised bone, carrying oxides and carbonates in solution. When the soil dries out, a film of mineral precipitates is left in the pore network of the bone. Eventually these spaces are refilled, and mineral replacement of bone material by calcium carbonate, sequioxides, or silicates may take place. Dehydrated animal bone consists of about two-thirds mineral matter and one third of organic matter. The mineral component is mainly calcium phosphate with some calcium carbonate and other salts. The organic components include fat, citric acid, organic carbon, nitrogen, and amino acids which are combined in proteins and fats. Depending on the conditions of sedimentation or the chemical environment, rapid burial of bone or shell may preserve either the mineral or organic matter. Fossil bone and shell may be obtained from a number of natural and cultural sedimentary environments:

a) Stream, lake, swamp and spring beds;

b) Beach and estuarine beds;

c) Loess and volcanic ash;

d) ”fossil”, “archaeological” and “cultural” cave strata; and

e) Artificial situations such as kitchen middens, burial pits, etc.

The study of such materials by palaeontologists or palaeozoologists may yield data of considerable environment and stratigraphic importance, which is the prime concerned of an anthropologist or a culture historian. The study involves several steps and they are:

a) Taxonomic identification, for which purpose skull, dentition, antlers, horn cores, and long bones are particularly useful;

b) Quantitative analysis, i.e. determination of the minimum number of individuals for a species present, for which the quantity of the most frequent diagnostic skeletal part is used;

c) Age, sex, and size composition;

d) Ecological interpretation, based on comparison of the morphology, behaviour, and ecological relations for a living species, or comparative anatomical collections for an extinct species.

Animal remains, including bone and a wide range of organic refuse pertaining to dietary habits, are invariably richest in occupation sites of man or ‘sedimentary’ predators. The latter include the cave-dwelling bears, hyenas, lions and owls of European Pleistocene.

### Pleistocene Fauna

The environmental significance of the European Upper Pleistocene fauna is better understood than that of any other Pleistocene fauna. Only three of the genera are extinct and two of those, the woolly mammoth and rhino, have been found more or less intact at certain localities, so that their diet and cold adaptations are well known. A half dozen further species became extinct at the close of the Pleistocene, but allied species of the same genera are still present. In all, these Upper Pleistocene faunas can be carefully evaluated in terms of their modern (or historical) environmental distributions. They are therefore an interesting case in point.

The characteristic mammalian species of the interglacial (Eem) fauna are the extinct, straight-tusked woodland elephant (*Elephas [Palaeoloxodon] antiquus),* the extinct woodland rhino (*Dicerorhinus mercki),* the African hippopotamus (*H. amphi bious major), the boar (Sus scrofa),* fallow deer (*Dama dama*), and roe deer (Capreolus *capreolus*). In mid-latitude Europe these animals are rarely found in glacial age deposits. They do however occur in the Mediterranean lands during part or all of the Wurm. In addition to these species there are a few dozen mammals of the temperate and boreal woodlands are also found in mid-latitude Europe during glacial periods. These include elk (*Alces alces*), red deer (*Cervus elaphus*), aurochs (*Bos primigenius*), the woodland horse ancestral to Equus*caballus silvestris*, lynx, wild cat (*Felis silvestris*), fox (*Vulpes vulpes*), wolf, wolverine, sable (*Martes zibellina*), and brown bear (*Ursus arctos* ssp.).

The glacial (Wurm) fauna includes temperate and boreal woodland forms consists of "typical" tundra fauna: reindeer (*Rangifer tarandus*), musk-ox (*Ovibos moschatus*), the snow shoe and arctic hares (*Lepus timidus*, L. *arcticus*), the mountain lemming (*Lemmus* [*Myodes*] *Lemmus*), and the arctic fox (*Vulpes* [*Alopex*] l*agopus*). Alpine forms such as the steppe ibex (*Capra ibex prisca*), the chamois (*Rupicapra rupicapra*), the alpine marmot (*Marmota marmota*), and alpine vole (*Microtus nivalis*) were found well outside of their high mountain haunts.

In addition to these, a cool, mid-latitude steppe fauna was also present, ranging through Hungary into southern France. They are saiga antelope (*Saiga tatarica*), the wild steppe horse of tarpana and Prezewalski type, the steppe fox (*Vulpes corsac*), the steppe polecat (*Putorius putorus eversmanni*), the steppe marmot (*Marmota bobak*), the hamster (*Citellus citellus*), and a gerbil (*Allactaga saleins*). Some of the best known "cold" elements include the wooly mammoth, wooly rhino, the steppe bison and the giant elk. The characteristic cave faunas of the European Pleistocene include the cave bear, the spotted cave hyena, and cave lion. Each of these species was cold tolerant but rather intermediate in its requirements. They are not 'cold' indicators by any means.

### Pleistocene Plant Fossils- Pollen

Pollen analysis or palynology is one of the important indicators of palaeoclimate and dating in palaeo ecological studies. The basic principle of pollen analysis is that most wind-pollinated trees, shrubs, and grasses emanate pollen in great quantities. The particle size of pollen is on the order of 0.01 – 0.1 mm.' and the absolute weight less than $10^{-9}$ grams. Consequently, pollen grains are readily removed by wind and widely dispersed in the lower atmosphere where the grains are carried in suspension. Distances of 100-250 km. are readily crossed by traveling pollen, and grains may be found up to several kilometers in the lower atmosphere. Pollen density is greatest at elevation of 200 to 500 meters above the ground, and it remains appreciable to elevation of 2 km. Pollen accumulation in any one locality will therefore provide a regional rather than a local cross-section of the pollen-emanating plants present.

The annual pollen 'rain' in a vegetated area amounts to several thousand grains per square centimeter. A part of this pollen may be preserved indefinitely if oxidation is limited or absent, particularly in dense, poorly aerated sediments or in acidic environments such as provided by bogs or many lake beds. Year after year stratified laminae of sediments, including a small cross-section of the year's pollen that is preserved, may be laid down under various conditions at a number of localities. Each of these sediments, then, preserves its own chronological and environmental record (Butzer, 1971).

**Application of pollen analysis**

Pollen analysis may be applied to a broad range of palaeo-environmental problems.

a) *Reconstruction of local vegetation*: Careful interpretation of contemporary pollen spectra from neighbouring sites may provide a good picture of local vegetation and ecology. Certain floral elements are characteristics of certain environments, although most genera are distributed rather than more broadly. If species identification is possible and supported by some macro-botanical evidence reconstruction of forest type is possible.

b) *Regional pollen maps*: Plotting of data of approximately contemporary pollen spectra over wider areas can be made.

c) *Climate change*: Although with considerable qualification, it may be said that specific changes in pollen spectra with time may indicate climate or ecological change at a locality.

d) *Stratigraphic dating*: Characteristic pollen diagrams have been described for certain interglacial periods or for the Holocene period in temperate Europe. Such standard profiles are frequently used as dating tools, either within the span of a certain diagram, or as fossil assemblages referring to a particular interglacial interval. Artifactual materials in bog can occasionally be dated according to their position within pollen profiles.

e) *Prehistoric settlement*: Forest clearance, burnings, and agricultural colonisation are dramatically recorded in pollen profiles by sudden abundance of NAP, appearance of weed or cereal pollen, and the like. In fact the earliest agricultural settlements in temperate Europe frequently have been first recognised by pollen diagrams, as in the case of Denmark.

## 2.9 SUMMARY

The 'stratigraphy'– the descriptive account of sequence of layers formed due to the geomorphic agencies is the main source of data system used in relative dating ever since the chronological understanding of events. Natural agencies like wind, water, ice etc. had the high energy capacities to erode materials during dynamic conditions, while in low energy conditions remain as depositing agents. Due to these dynamic conditions the rivers, lakes, seas, oceans, glaciers etc, the surface of the earth has been subjected to topographical changes, which can be learned through the geomorphology. A wind range of deposits (alluvial, aeolian, morainic, lacustrineare, karst etc.) are systematically brought out in understanding chronological ordering of events.

Since the Pleistocene Period embraces the human emergence and initial development, the dynamic nature of depositing agencies were presented in this unit. The fauna and flora are sensitive to climatic change, thereby the faunal and floral variation in given time frame were of great significance in relative chronology besides the palaeoclimatic inferences. The geomorphological studies together with biological remains in the form of fossils (both macro and micro) go a long way in understanding the environmental changes that had taken place during the Pleistocene Period.

## Suggested Reading

Brothwell, D and E. Higgins. 1970. *Science in Archaeology*. New York: Praeger.

Butzer, K.W. 1971. *Environment and Archaeology*. Chicago: Aldine-Atherton.

Cornwall, I.W. 1958. *Soils for the Archaeologist*. London: Phoenix House.

Michels, J.W. 1973. *Dating Methods in Archaeology*. New York: Seminar Press.

Zeuner, F.E. 1958. *Dating the Past*. London: Methuen.

## Sample Questions

1) Discuss various kinds of Glacio-Pluviation climatic events that had taken place during Pleistocene Period.
2) Describe the process of formation of river terraces and bring out how the terrace formations are useful in relative chronology.
3) What is palaeontology? Discuss the importance of paleontology in understanding palaeo-climate.
4) Write short notes on the following
   - i) Moraines
   - ii) Cave deposits
   - iii) aeolian sands iv.lacustrine deposits
5) Write an essay on integrating the Pleistocene climatic sequence against the geomorphological events and the fossil fauna- floral evidences.

# 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.

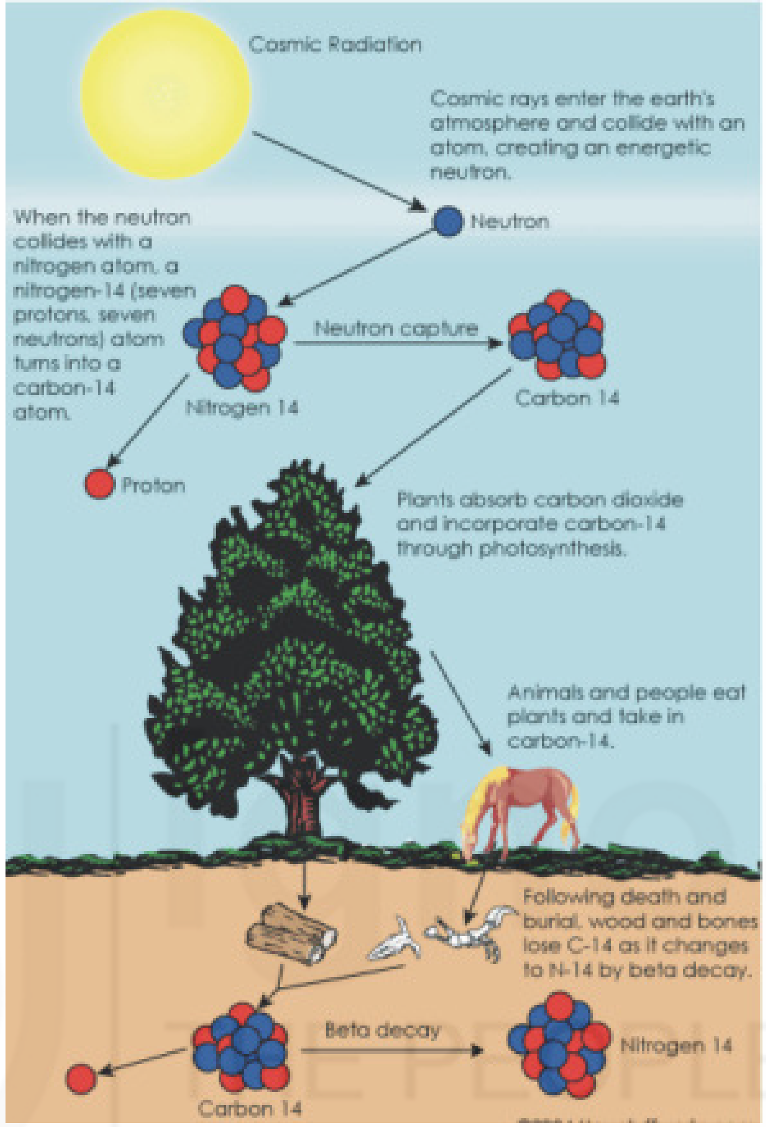
After the death of an organism the $C^{14}$ contained in its physical structure begins to disintegrate at the rate of one half every 5730 years; thus, by measuring the amount of radiocarbon remaining, one can establish the time when the plant or animal died. Half-life (t 1*/2)* is measured by counting 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.

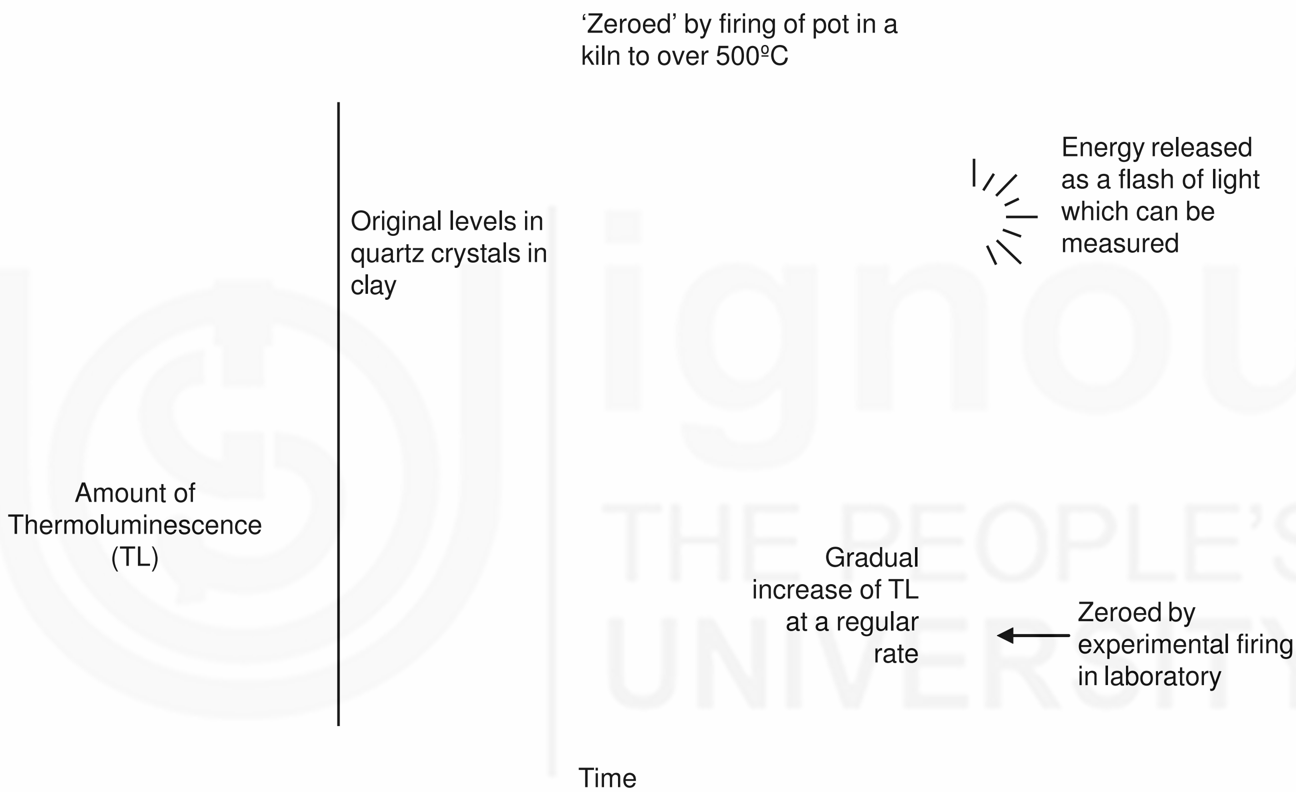
## 3.5 THERMOLUMINESCENCE OR TL DATING

**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

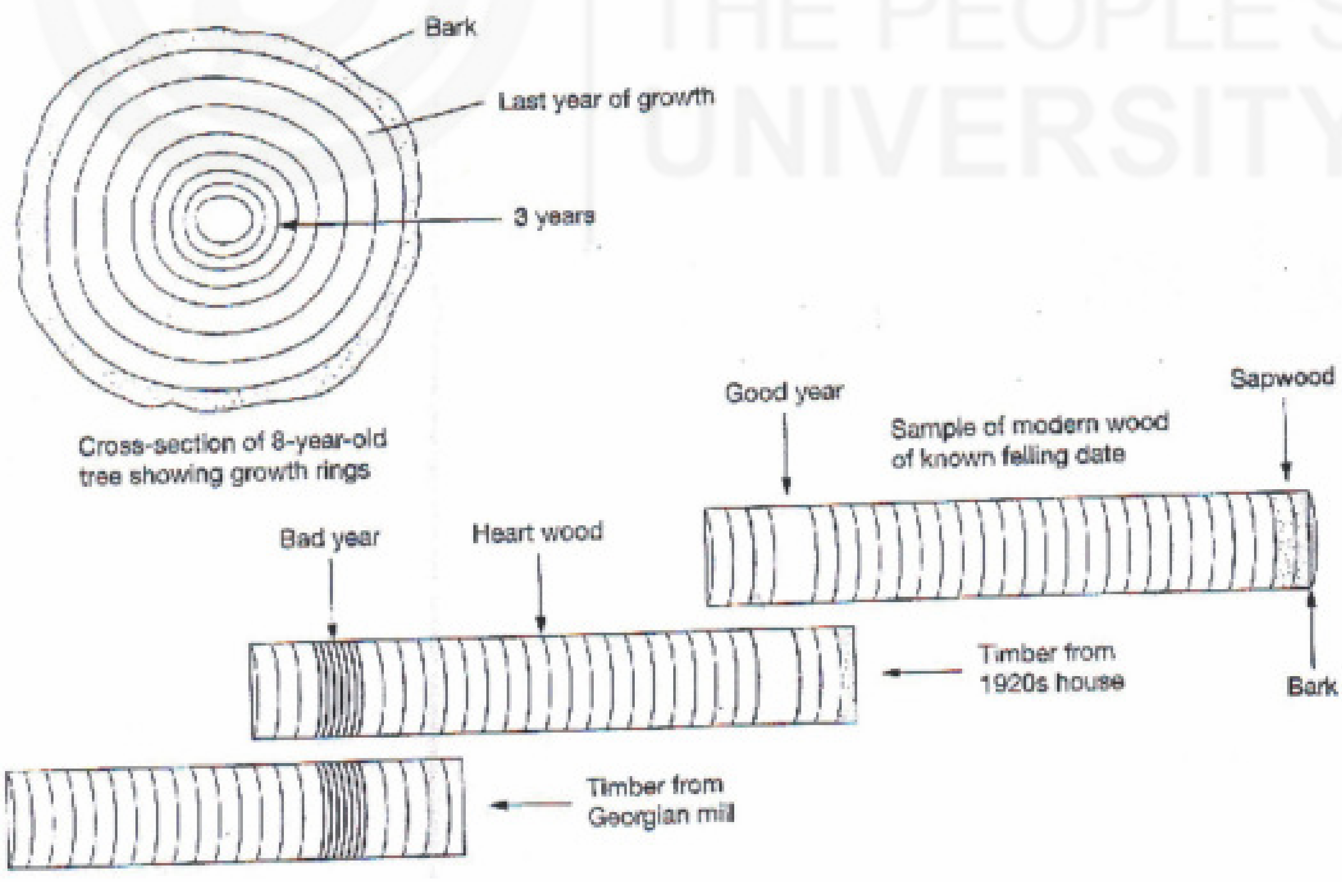
The underlying principle is that nontropical trees add an annual growth increment to their stems. Each tree ring, the concentric circle, representing annual growth, visible on the cross-section of a felled trunk. These rings are formed on all trees but especially where seasonal changes in weather are 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.

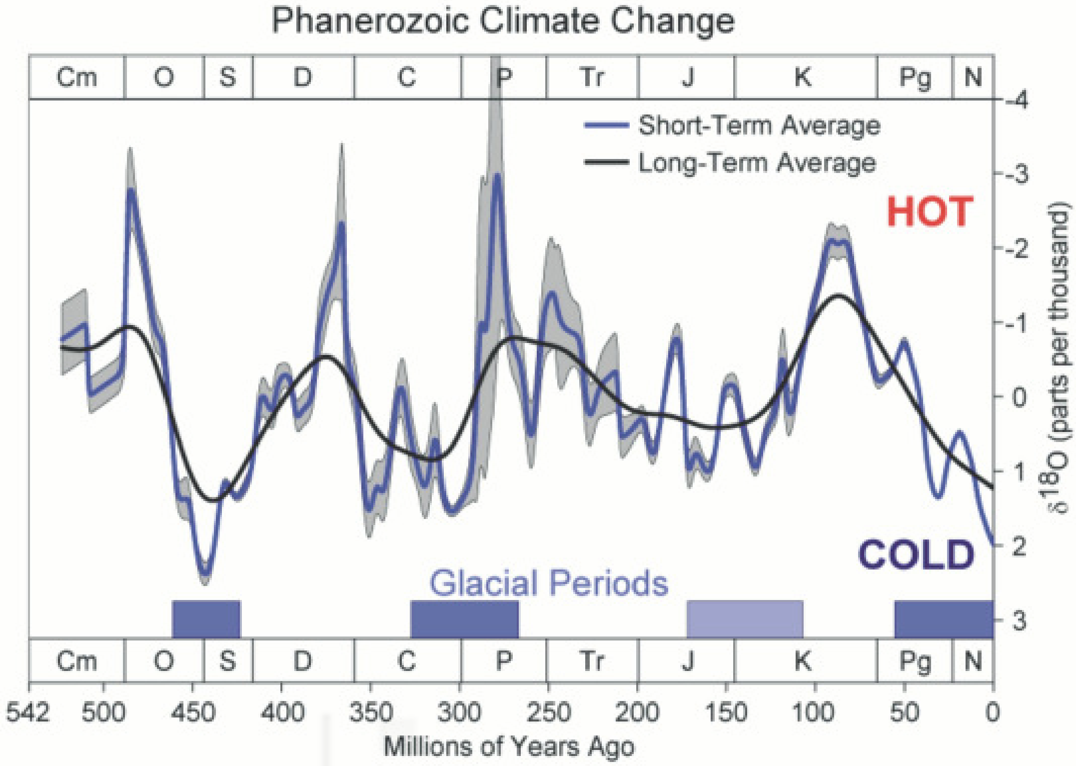
## 3.10 OXYGEN ISOTOPE AND CLIMATIC RECONSTRUCTION

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.