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 Wurm III	Magdalenian Solutrean Gravettian Perigordian/ Aurignation Chatelperronian	Capsian Ibero-Maurusian Aterian Egyptian Up.Pal. Dabban, etc Lupembian	Upper Palaeolithic	?	Upper Palaeolithic	Cro-Magnon Man
Wurm I and II/ Weichsel 80,000	Mousterian Final Acheulean	Mousterian Upper Acheulean Sangoan	Late Soan Middle Palaeolithic	Final Anyathian	Mousterian Final Acheulean	Homo Neanderthals
Riss / Wurm 200,000	Pre-Mousterian Upper Acheulean	Upper Acheulean	Middle Palaeolithic Up. Soan	Anyathian	Acheulean	
Riss / Saale	Clactonian Upper Acheulean Middle Acheulean	Acheulean	Acheulean Soan	Choukoutien	Acheulean	Homo erectus
Mindel/Riss	Clactonian Middle Acheulean Early Acheulean	Acheulean	Soan		Old Acheulean	

Glacial calendar	Europe		Africa	Africa	Southeast Asia	Southwest Asia	Fossil finds
Mindel/Elster 500,000	Clactonian Early Acheulean Abbevillian		Old Acheulean	Lower Palaeolithic Old Soan	Choukoutien-1 Choukoutien-13	Ubeidyia	
Gunz/Mindel	Flakes?		Oldowan	-	-	-	Australo-pithecines
Gunz	?		Oldowan	-	-	-	-
Danube 1.9 million	Upper Villafranchian	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} βN^{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 5th and 6th 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

$$I = Ioe^{t} \quad \text{———— (1)}$$

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

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

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.

$$t = 1/ \text{ in } 1+ \ (1+R)/R \times (40 \text{ Ar rad})/(40 \text{ K}) \qquad \text{———— (1)}$$

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 $\times 10^{-10}$ 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

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

Where t is given in million of years.

$$t = 2.53 \times 10^5 \times (40 \text{ Ar rad})/K \qquad \text{———— (3)}$$

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 750^0C 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.