BLOCK 2

DATING METHODS AND RECONSTRUCTION OF THE PAST

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UNIT 5 DATING METHODS*

Contents

Learning Objectives

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

- Know about different dating methods that assist archaeological study;
- Know how these methods provide an understanding of the chronological order of events; and
- Know about the human morphological and cultural evolution.

5.0 INTRODUCTION

Studies in Palaeoanthropology or archaeological anthropology have little meaning unless the chronological sequence of events is reconstructed effectively. Whenever a new fossil or a new archaeological artifact is discovered it is very important to find out how old it is. In modern day palaeoanthropology or archaeology, the scientific interest rests not so much in the fossil or the artifact itself but the information it can provide to the questions that the scientist may be asking. One of the principal questions an archaeologist will certainly ask is "how old the artifact and the site are"? In fact, without a chronological framework, a fossil or an archaeological artifact loses its true scientific significance. It is important to understand where a fossil or an artifact fits into the scheme of human morphological or cultural evolution. For a specialist, finding out the age of rocks is critical to reconstruct the history of the earth. To find out the age of fossils, artifacts or rocks, the scientists depend upon several dating methods. These methods can be divided into two broad categories: (a) relative dating methods and (b) absolute dating methods.

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Check Your Progress

1) What are the two types of dating methods?

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5.1 RELATIVE DATING METHODS

Relative dating is a technique of determining the relative sequence of past events or past objects without actually knowing their absolute age. It is the stratigraphical or archaeological age of a specimen or formation (Oakley, 1964). In an assemblage of fossils or artifacts, these methods can be used to find out their relative age without knowing their actual age in absolute terms. Employing these methods a palaeontologist may be able to ascertain, which fossil is older than the other in an assemblage without knowing their actual age in years. In other words, relative dating determines the age of a fossil, an artifact or a site, as older or younger or of the same age as others, but does not provide specific dates (in years). Before the discovery of radiometric dating techniques, in the second half of the twentieth century, archaeologists, palaeontologists and geologists had to mainly rely upon relative dating techniques. As a result, it was difficult to chronologically compare fossils from different parts of the world. Though relative dating technique can only provide information about the sequential order of occurrence of events and not the actual time of occurrence of the events, it still remains useful for materials that lack properties for absolute dating. Even now these can be useful for relating palaeontological or archaeological finds from the same or nearby sites with similar geological histories. Stratigraphy and fluorine dating are among the common relative dating methods.

5.1.1 Stratigraphy

It is one of the oldest and the simplest relative dating methods. Stratigraphy is a branch of geology that is concerned with stratified soils and rocks, i.e. soils and rocks that are deposited as layers. Stratigraphy is basically the study of the sequence, composition and relationship of stratified soils and rocks. If we go to the countryside where there are some hills, we can see different layers of rocks which may be horizontal or inclined. Each layer can be differentiated from the other layer on account of the difference in colour, chemical composition or texture. Each layer represents a time period when the process of deposition of sediments continued uninterrupted in one manner. The next layer represents a change in the process of deposition. There are two fundamental principles of stratigraphy: *uniformitarianism* and *superposition*.

Uniformitarianism is a fundamental unifying doctrine of geology, which was originally conceived by British geologist James Hutton in 1785 and subsequently developed and explained by Sir Charles Lyell in 1830 in his '*Principles of Geology*'. According to this principle, the geologic processes now operating to modify the Earth's crust have acted in the same manner and with essentially the same intensity throughout geologic time, and that past geologic events can be explained by phenomena and forces observable today. In a nutshell the expression, "present is key to the past", explains uniformitarianism.

Superposition is one of the principles of stratigraphy, which is commonly utilized in a relative dating method. The principle was first given by a Danish scientist Nicholas Steno in 1669, who is also considered to be the father of stratigraphy. According to this principle, the oldest layer lies at the bottom and the youngest layer lies at the top, in undisturbed strata. He also pointed out that beds of sediment deposited in water initially form as horizontal (or nearly horizontal) layers. As layers accumulate through time, older layers get buried underneath younger layers. This principle can be clearly seen in Figure 1. The layer-A that was deposited earlier lies at a lower level and is, therefore, older than the overlying layers-B to F which were deposited subsequently. Though we may not know how old each layer is but, among the layers-A to F, we can tell which one is older than the other. In this way the relative time relationship of rock layers and the fossils or artifacts buried in them can be understood. But this principle should not be applied blindly. The principle is applicable where the normal order of superposition of the rock layers has not been disrupted by natural or human agencies. It is well known that natural diastrophic movements can disrupt the normal order of superposition through folding and faulting of the rock strata. As a consequence older rocks may come to lie over younger rocks. Human or animal agencies can also disturb normal order of rock layers through digging for burials where relatively younger artifacts may come to lie at relatively older levels. Figure-2 shows the disturbance of original strata. In this case the bone-A and bone-B may not be of the same age even though they both are buried in the same layer, i.e., layer-2. Therefore, before applying the principle of superposition for relative dating one must ensure that the original sequence of rocks layers has not been disrupted.

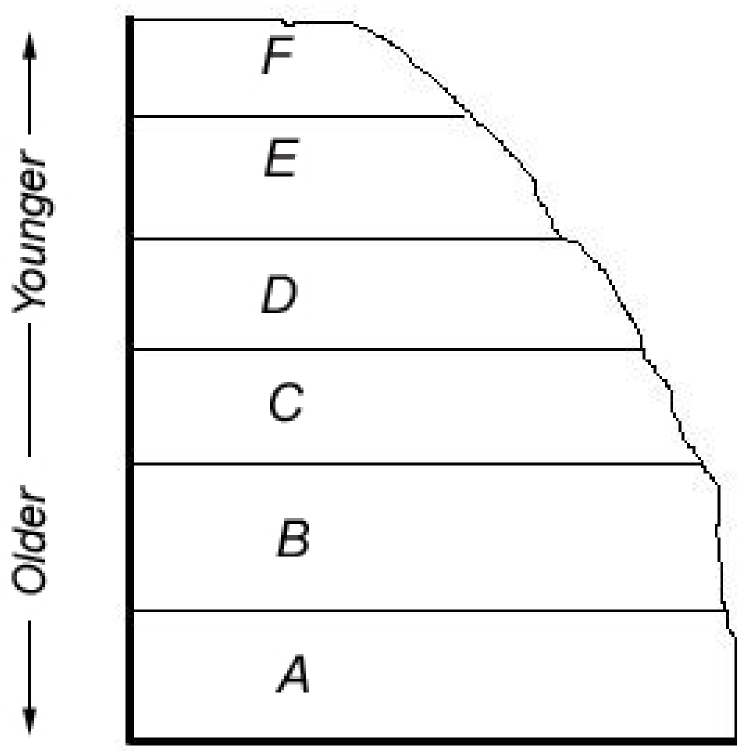

Fig. 1: Diagrammatic Representation of a Sequence of Rock Layers Showing Superposition where Lower Layer A is Older than Upper Layer F

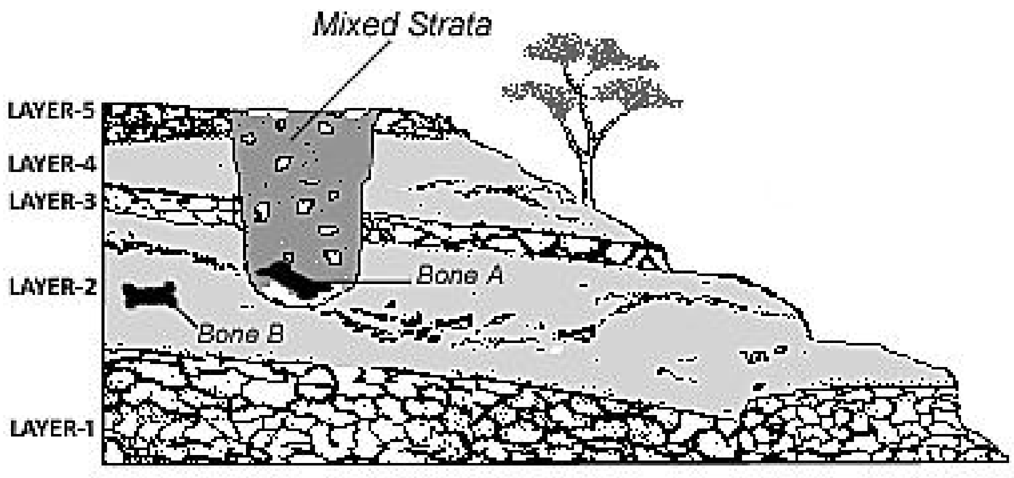

Fig. 2: Disturbance of Original Disposition of Rock Strata. Bone-A and Bone-B, Though Lie in the Same Layer-2 but may not of the Same Age due to Mixing of Strata. Under Such Situations Principle of Stratigraphy is not Applicable

Check Your Progress

2) What do you understand by stratigraphy?

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5.1.2 Fluorine Dating

It is a relative (chemical) dating method that compares the accumulation of fluorine content in bones. Fluorine dating method probably developed due to the collaborative efforts of Emile Rivière and Adolphe Carnot in the 1890s (Goodrum and Olson, 2009). But it was not until the 1940s and early 1950s that this method was improved and widely implemented by Kenneth P. Oakley to resolve several problems in palaeoanthropology (Goodrum and Olson, 2009).

Water soluble fluorides are found in trace quantities (parts per million-range) in ground water around the world. The skeletal elements buried in the ground absorb fluorine from the percolating ground water. In case of bones or teeth, fluoride ions replace the hydroxyl-group of hydroxy-apatite, the main component of bones and teeth, and are locked in place in the mineral matrix of these tissues principally composed of calcium hydroxyapatite. Hydroxyl ions slowly are displaced with a form of soluble fluorides. These ions form fluorapatite which is markedly less soluble and more stable. Once they enter the bone substance they are not released, unless the whole bone becomes dissolved. The process goes on continuously, and the fluorine-content of the bone or tooth increases in course of time. The older a bone is, the more fluorine content it will accumulate.

$Ca_5(PO_4)_3OH$ + Fluorine ion $\qquad$ $Ca_5(PO_4)_3F$

One can argue that since the fluorine content of bones increase with time why this method cannot be used for absolute dating. This is simply because of the reason that the fluorine concentration of ground water varies from place to place. Younger bones in a fluorine rich area may accumulate more fluorine than even older bones in a different area where ground water fluorine concentration is comparatively very little. It is therefore not possible to date bones in terms of years.

However this method is very useful means of distinguishing fossilized bones of different ages occurring at a particular place. If, however, one is interested in separating bones of different ages at one locality, estimation of fluorine-content is helpful as it can provide ages of bones at a site relative to each other based on their fluorine content. Older assemblage would be distinguishable from the younger assemblage on the basis of their fluorine content. Bones that have been buried at a place for some length of time will have broadly comparable fluorine content. Moreover, contamination of the assemblage by younger or older bones will be revealed by anomalously higher (older bones) or lower fluorine (younger bones) contents.

Fluorine dating has been very successful in bringing to light the hoax of 'Piltdown Man', one of the biggest hoaxes in paleoanthropology. Piltdown skull and jawbone were subjected to fluorine testing (Oakley, 1950). The levels of fluorine in the skull and jawbone were significantly lower than in other bone specimens collected from the same area. Subsequently, with the help of fluorine test Weiner et al. (1953) proved the bones to be a modern human braincase and an Orangutan jawbone that were chemically stained to appear ancient.

5.2 ABSOLUTE DATING METHODS

Absolute dating methods provide the precise age of a fossil, artifact or a rock in years. These are obviously more useful methods than the relative dating methods. Unlike relative dating methods which provide only an order of events, absolute dating methods provide a numerical age with reference to a calendrical system. There is a diversity of methods that provide actual calendrical dates for fossils or artifacts. Most actually assign dates to the strata the bones are in, or associated materials, and not the fossils themselves. Absolute dating methods are frequently based on the physical or chemical properties of the fossils or materials of artifacts or rocks themselves. These may be radiometric or non-radiometric. Radiometric dating is based on the decay of radioactive isotopes into their radiogenic daughter isotopes at a known and constant decay rate. Examples of radiometric dating methods are Radiocarbon dating, Potassium/Argon dating, Fission-track dating, etc. Non-radiometric methods are based on some chemical or physical properties of the materials. Dendrochronology is one of the common non-radiometric dating methods.

Check Your Progress

3) What do absolute dating methods provide?

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5.2.1 Non-Radiometric Dating Methods

Below we provide a description of a non-radiometric dating method which helps us in identifying the archaeological age of beings.

5.2.1.1 Dendrochronology

Dendrochronology is the scientific method of dating based on the analysis of patterns of tree ring variations. It is also known as tree ring dating. The method was devised in 1929 by A. E. Douglas, an astronomer at the University of Arizona, who intended to use it for studying climatic variations. But its application in archaeology became immediately apparent. It is common knowledge that a tree adds one ring of new wood each year between the existing wood and the bark. In temperate and sub-polar climates, cells added at the beginning of the growing season are generally large and thin-walled and become smaller and thick-walled as the growing season comes to a close. When a tree trunk is observed in cross-section, a boundary line is usually visible between the small-celled wood added at the end of the previous year's growing season and the large-celled spring wood of the subsequent year's growing season (Figure 3). By counting the number of rings one can estimate the age of the tree when it was felled. The annual growth rings are not of the same width. During years of favorable climate (wet years) the rings are broad; during years of unfavorable climate (during drought) they are narrow, since the trees grow less. In cold regions warmth may be a factor to influence growth. This causes the development of patterns of tree rings of alternating wet and dry seasons represented by thick and thin rings, which are unique for a period and not likely be repeated in future. It is this variation and unique nature of patterning of seasonal rainfall, depicted in patterns of tree ring thickness variations, which makes dendrochronology possible. The rings are more visible in temperate zones, where the seasons differ more markedly. This method may not be applicable in areas showing little seasonal variations in rainfall, such as tropical areas.

Fig. 3: Cross Section of a Tree Trunk Showing Clear Annual Tree Rings

Source: https://www.ltrr.arizona.edu/introdendro/

Trees from the same region will tend to develop the same patterns of ring widths for a given period of time. These patterns can be compared and matched ring for ring with trees growing in the same geographical zone and under similar climatic conditions. Following these tree-ring patterns from living trees back through time, chronologies can be built up, for entire regions. Thus by matching the rings of successively older samples of wood master tree ring variation charts for an area or a region are prepared going back to several thousand years. Thus wood from ancient structures can be matched to known chronologies and the age of the wood determined precisely. With the help of dendrochronology, timber or wooden log samples of unknown age recovered from archaeological sites can be dated by cross-matching their tree-ring patterns with tree-ring patterns of the master tree ring pattern chronology of the regions. This is known as cross-dating that is considered the fundamental principle of dendrochronology. Without the precision given by cross-dating, the dating of tree rings would be nothing more than simple ring counting. Initially cross-dating was done by visual inspection, until computers were utilized to do the statistical matching.

Tree ring master chart of an area can be prepared by matching the patterns of a tree living today with successively older tree logs. For example, beginning with a 200 year old tree cut today pattern of tree ring variation of past two centuries can be plotted. A wooden log cut for use in a house, stable or a ranch built in 1900 will match the rings of the first tree for first hundred or so rings, but if this log was also 200 years old, the two combined would provide a continuous sequence of rings back to 1700. This way the tree ring chronology can be extended back in time as successively older wooden logs are found and their tree ring patterns matched with that of younger trees of an area. An example of matching of tree ring patterns of successively older trees, beginning with recent, for making a master tree ring chronology of an area is given in Figure 4.

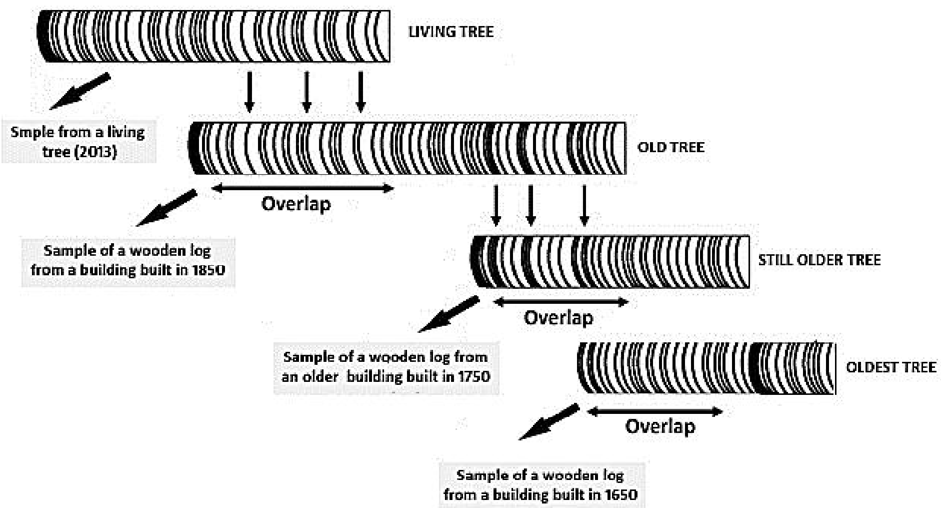

Fig. 4: Tree ring patterns of successively old trees can be matched to prepare a master tree ring pattern chart of an area that can be used to date wooden logs of unknown age

In some parts of the world, trees with exceptionally long life, such as Bristle Cone Pine tree (*Pinus aristata*) and Sequoia tree (*Sequoiadendron giganteum*) have proved to be very useful to develop tree ring chronologies. Some of the oldest living bristle cone pine trees are 4,900 years old. Based on bristle cone pine tree a fully anchored chronology extending back to 8500 years was developed by Ferguson and Graybill (1983) for Southwest US or White Mountains of California. Tree ring chronologies which extend back more than 11,000 years are available for river oak trees from South Germany and pine from Northern Ireland (McGovern et al., 1995; Freidrich et al., 2004).

Check Your Progress

4) Name a tree with a very long life which is useful to understand tree ring chronologies.

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Limitations: At present, tree ring dating method has limited applications. This is because one must be sure that the climate was practically the same over the entire region from which the master chart was prepared before the method can be used effectively. Dendrochronology is applicable in regions which show appreciable seasonal variation in climate. Trees from regions which have little seasonal variation in climate or rainfall are not suitable for dating with dendrochronology. The method has limited range because as yet, master tree ring pattern chronology has been developed going back to up to only 11,000 to 12,000 years before present.

5.2.2 Radiometric Dating Methods

A majority of absolute dates for rocks are obtained with the help of radiometric methods. Radiometric dating methods are based on the fact that every radioactive element decays. Radioactive decay is the process by which a "parent" isotope changes into a more stable" daughter" isotope by emitting radiation and particles. The atoms of some chemical elements have different forms, called isotopes. An isotope is an alternate form of an element with the same atomic number but different mass number. For example when 'parent' Uranium^{238} atom decays it produces subatomic particles, energy and 'daughter' element Lead^{206}. Each radioactive element decays at a known constant rate specific to it. The rate of decay is described by the half-life of the isotope, which is the time taken by an isotope to be reduced to half of its original amount. So if we can measure the proportion of parent and daughter isotopes in rocks now, we can calculate when the rocks were formed.

The nuclear decay of radioactive isotopes is a process that behaves in a clock-like fashion and is thus a useful tool for determining the absolute age of rocks. Radiometric dating has provided us a powerful tool for reconstructing the history of our planet. The idea that radioactivity could be used as a measure of the age of geologic formations was first suggested in 1905 by a British physicist, Lord Rutherford. However, it was the invention of the mass spectrometer after World War I that led to the discovery of isotopes and the calculation of their accurate radioactive decay rates. Several radiometric dating methods have been developed since the beginning of the second half of the 20th century such as radioactive carbon method, potassium/argon method, uranium/lead method, fission track method, etc. All these methods utilize the radioactive decay of the isotopes as a means of dating. These methods are better than other absolute dating methods because the rate of decay of radioactive isotopes is least affected by variations in temperature, pressure, alkalinity, humidity, etc.

5.2.2.1 Radioactive Carbon Method

Radioactive carbon or carbon-14 dating is probably one of the earliest and one of the best-known radiometric dating methods. In certain respects, radiocarbon dating has been one of the most noteworthy discoveries of the 20th century science. The method was developed by a team of scientists led by the late Professor Willard F. Libby of the University of Chicago in years immediately after World War II. Libby later received the Nobel Prize in Chemistry in 1960. Radiocarbon dating was the first chronometric technique widely available to archaeologists and palaeoanthropologists and was especially useful because it allowed researchers to directly date the organic remains often found in palaeoanthropological and archaeological sites, which besides fossils also include artifacts made from bone, shell, wood, and other carbon based materials. Its development revolutionized palaeoanthropology and archaeology by providing a means of dating fossils and artifacts, which allowed for the establishment of world-wide chronologies of human biological and cultural evolution in the Pleistocene.

Radiocarbon dating is a radiometric dating method that makes use of the decay of carbon-14 (an isotope of normal carbon) to estimate the age of organic materials, such as bone, teeth, wood, etc. There are three principal isotopes of carbon which occur naturally, viz. C^{12}, C^{13} (both stable) and C^{14} (unstable or radioactive). The concentration of these isotopes in the atmosphere is as follows: C^{12} - 98.89%, C^{13} - 1.11%, and C^{14} - 0.00000000010%. Thus, in nature, for every 1,000,000,000,000 normal carbon atoms (C^{12}) in living material there exists one radioactive carbon atom (C^{14}). The radiocarbon method is based on the rate of decay of the radioactive or unstable carbon-14 isotope (C^{14}). The half-life of C^{14} is about 5,730 years, during which C^{14} is reduced to half of its original amount. Thus, the concentration of C^{14} in the atmosphere might be expected to reduce considerably over tens of thousands of years. However, that is not the case. Because C^{14} is constantly being produced in the lower stratosphere and upper troposphere of earth's atmosphere by cosmic ray activity. Therefore its concentration remains roughly constant in the atmosphere.

In the upper atmosphere the cosmic rays generate neutrons which strike nitrogen atoms resulting in the creation of a radioactive carbon C^{14} atom, through loss of a proton and subsequently an electron.

Cosmic rays Neutron N_7^{14} C_6^{14}+ Proton

Carbon-14 spreads evenly throughout the atmosphere and reacts with oxygen to get oxidized into carbon dioxide ($C^{14}O_2$). It also dissolves in the ocean. Radiocarbon present in molecules of atmospheric carbon dioxide enters the biological carbon cycle. It is absorbed from the air by green plants during photosynthesis and then passed on to animals through the food chain. Radiocarbon decays slowly in a living organism, and the amount lost is continually replenished through food and air. After the death of the organism, the absorption of carbon-14 ceases and there is no replenishment of radioactive carbon (Figure 5). As a consequence, the amount of the radiocarbon in its tissues steadily decreases. Because carbon-14decays at a constant rate, an estimate of the date at which an organism died can be made by measuring the amount of its residual radiocarbon and comparing it to available levels in the atmosphere. The carbon-14 eventually beta-decays into nitrogen with a half- life of 5730±40 years.

Radiocarbon dating works by accurately measuring the ratio of radiocarbon to stable carbon in a sample. This can be carried out in any one of the following three ways: 1) Gas Proportional Counting, 2) Liquid Scintillation Counting, and 3) Accelerator Mass Spectrometry. The purpose in each of these methods is to find out the ratio of radiocarbon to stable carbon in a sample. From this measurement the age in radiocarbon years is calculated. This method can normally provide useful age estimates up to 50,000 years after which the amount of radiocarbon is too little to be accurately measured.

However, using the latest sophisticated techniques this range can at the most be extended to 70,000 years.

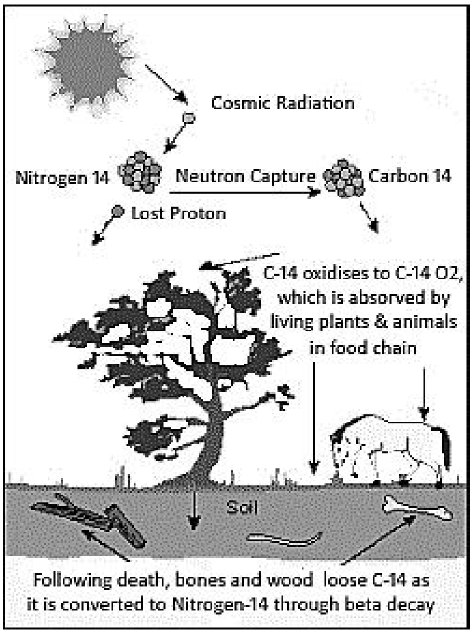

Fig. 5 : Diagrammatic Representation of Carbon Cycle in Food Chain

(Modified from: http://www.theenergylibrary.com/node/11296)

Limitations:

1) Since the method is applied directly to organic material, fossils of any value cannot be subjected to this method as it involves partial or complete damage to the specimen.

2) The range of this method is ordinarily 50,000 years; therefore it is not suitable for older fossils.

3) The assumption that the amount of radioactive carbon in atmosphere is constant is not exactly true because it is known that it was more than 6000 years old . Solar cycles leading to changes in intensity of cosmic radiation or changes in earth's magnetic field may be responsible for these changes. Variations can also occur due to the fossil fuel burning effect (also called Suess effect after its inventor Hans Suess who reported it in 1965) and the nuclear testing above ground that created extra C^{14} (also sometimes called as 'bomb carbon').

4) There is always chance of contamination of the sample with modern materials, such as through rootlet intrusion, and handling of the specimens in the field or lab (e.g., accidental introduction of modern organic material such as tobacco ash, hair, or fibers) can potentially affect the age of a sample.

Despite these limitations radiocarbon remains a very useful technique to date later Pleistocene or younger organic materials.

5.2.2.2 Potassium/Argon Dating Method

Potassium/Argon dating method is one the most widely used radiometric dating methods for dating rocks, especially igneous that have solidified from molten lava. It is an invaluable tool for geological, archaeological and palaeoanthropological investigations. This technique is very useful to archaeologists and paleoanthropologists when lava flows or volcanic tuffs form layers that overlie strata bearing the evidence of human activity.

This method is based upon the decay of radioactive potassium-40 (^{40}K) to argon-40 (^{40}Ar) in minerals and rocks. By comparing the proportion of K-40 to Ar-40 in a sample of volcanic rock, and knowing the decay rate of K-40, the date when the rock was formed can be estimated.

Potassium (^{39}K) is one of the most abundant elements in the Earth's crust. There are three naturally occurring isotopes of potassium namely ^{39}K (93.2581%), ^{40}K (0.0117%) and ^{41}K (6.7302%). Out of these isotopes, ^{40}K decays into two 'daughter elements': stable ^{40}Calcium and ^{40}Ar in an approximate ratio of 89:11. Simply stated, for every 100 ^{40}K atoms that decays, 11 become ^{40}Ar. Argon is a noble gas. When ^{40}K decays the ^{40}Ar that is produced remains trapped in the crystals of the minerals of volcanic rocks. When the magma is molten whatever argon is produced boils off into the atmosphere. However, after the cooling and solidification of lava into rock, the argon produced due to the decay of ^{40}K accumulates within the rock and the radiometric clock of rock begins. As the rock ages, it accumulates more and more ^{40}Ar atoms. The amount of ^{40}Ar atoms is measured and used to compute the amount of time that had elapsed since the solidification of volcanic rock sample.

The half-life period of ^{40}K is 1,300 million years or 1.3 billion years, i.e. in this time the amount of radioactive potassium-40 is reduced to half of its original quantity. Due to its long half-life, this method is very suitable to estimate the age of even planets. However, it may not be suitable for measuring age of rocks younger than 100,000 thousand years as the quantity of argon produced by this time is too little to be accurately measured.

The method involves the melting of the rock samples in a vacuum system in an electric arc at temperatures from 1500 to 2000 °C. The quantity of ^{40}Ar is measured with a mass spectrometer. However some atmospheric argon can contaminate because it is difficult to create an absolute vacuum. Argon roughly forms 0.93 % of the atmosphere. However, we can find the number of contaminating atmospheric Argon atoms because there is a naturally occurring isotope of argon ^{36}Ar that occurs in a ratio of 99.6% ^{40}Ar: 0.34 % ^{36}Ar. By counting the number of ^{36}Ar atoms we can estimate the number of contaminating atmospheric ^{40}Ar atoms which are then deducted from the total number of Argon atoms to arrive at the actual quantity of ^{40}Ar atoms released by the melting of the rock sample. This figure is then used to calculate the age of the rock.

This method has been most widely used for dating early hominid sites where hominid activity is recorded stratigraphically between two lava flows, particularly in East Africa. The most famous of these sites is perhaps Bed I of Olduvai Gorge, which probably represents one of the earliest applications of this method. The method was also used to date the site at Hadar in Ethiopia, which is famous for the discovery of *Australopithecus afarensis,* popularly known as 'Lucy'.

Limitations:

1) This method is applicable on rocks and not on fossils themselves.
2) This method is more suitable for rocks of volcanic origin and inapplicable to non-volcanic regions.
3) It has to be assumed that all the argon produced due to the decay of ^{40}K has remained trapped within the rock.
4) The method works well for almost any igneous or volcanic rock, provided that the rock gives no evidence of having gone through a heating-recrystallization process after its initial formation.
5) Rocks younger than 100,000 years cannot be dated with this method.

In addition to radiocarbon and potassium/argon methods there are other absolute dating methods such as amino acid racemization, fission-track dating method, palaeomagnetic dating method and thermoluminescence dating method, which can be used to find out the age of archaeological or palaeoanthropological sites.

5.2.3 Amino Acid Racemization

It is based on the fact that amino acids, such as isoleucine, present in bones, teeth or other organic remains undergo gradual change (racemisation) from L-form to D-form over time after the death of an organism. The ratio of the two is measured to indicate age.

5.2.4 Palaeomagneting Dating

The earth's magnetic field varies through time, therefore, the magnetic north pole changes position. At the time of deposition, the ferro-magnetic particles acquire the magnetic field of the day and also align in its direction. The method involves the measurement of the direction of the palaeomagnetic fields of the rock layers of a stratigraphic column and then matching the pattern with a palaeomagnetic reversal patterns of a stratigraphic section whose time relationships are better understood. Usually one absolute date is required to match the undated column with a well-dated column.

5.2.5 Thermoluminescence Dating

Thermoluminescence dating is based on the assumption that the alpha particle radiation from naturally occurring radioactive elements, such as U^{238} and Th^{232}, present in clay and rocks as trace elements release electrons which settle at a higher energy level in crystal lattice defects of minerals that can be freed from their binding by applying energy in the form of sudden controlled heating. This causes the release of electrons that is seen in the form of visible light or thermo luminescence, which can be measured. The older a specimen is, the more are the trapped electrons and greater is the thermo luminescence. It is very useful to date archaeological specimens such as fired pottery.

Check Your Progress

5) Name some of the radiometric dating methods.

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5.3 SUMMARY

Dating methods play a significant role in archaeological and palaeoanthropological investigations by placing the fossils and artifacts in a chronological framework. A fossil or an artifact is much more useful from a palaeoanthropological or archaeological viewpoint if we can find out how old it is. Several dating methods are now available that can be used to date fossils, artifacts or the rocks from which these were recovered. These can be broadly grouped into relative and absolute dating methods. Relative dating methods, such as stratigraphy and fluorine methods, can help us to determine the relative sequence of past events or past objects without actually knowing their precise age.

Absolute dating methods on the other hand provide us exact age of a specimen or an event in years before present. Absolute dating methods can be non-radiometric or radiometric. Dendrochronology, palaeomagnetic dating and amino acid racemisation are some of the commonly used non-radiometric absolute dating methods. The radiometric methods, such as radiocarbon, potassium/argon, fission track methods, are based on the decay of the radioactive isotopes of some elements. Radiometric methods have been effectively used to find out the age of some important hominid sites in Africa.

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5.5 ANSWERS TO CHECK YOUR PROGRESS

1) The two types of dating methods are Relative Dating Method and Absolute Dating Method.

2) Stratigraphy is basically the study of the sequence, composition and relationship of stratified soils and rocks.

3) Absolute dating methods provide a numerical age with reference to a calendric system.

4) Bristle Cone Pine tree (Pinusaristata) has an exceptionally long life and has proved to be very useful to develop tree ring chronologies.

5) Some of the radiometric dating methods are radioactive carbon method, potassium/ argon method, uranium/lead method and fission track method.

UNIT 6 METHODS OF CLIMATIC RECONSTRUCTION*

Contents

Learning Objectives

After reading this unit, you will be able to:

- Understand the importance of reconstruction of climate;
- Discuss the methods of reconstruction of climate;
- Elucidate the reconstruction of climate using botanical evidences; and
- Talk about the reconstruction of climate using faunal evidences.

6.0 INTRODUCTION

Climate may be defined as the mean and range of temperature and precipitation prevailing over a defined area of the globe (Dincauze, 2000a). Climate varies with space and time. Direct measurements of climatic variable provide information up to two centuries only. Dependence on indirect or proxy measures of climate variability is a necessity for

* Contributed by Dr. S.A.Abdul Latheef, Visiting Scientist, Department of Genetics and Biotechnology, Osmania University, Hyderabad.

the reconstruction of the past climate. Measures such as sediment cores, low accumulation ice cores and preserved pollens have limitation in describing climate changes for centennial and often long time scales. Climate indicators such as historical documents, growth and density measures of tree rings, corals, annually formed ice cores, laminated ocean and lake sediment cores and speleothems, were found to describe the year by year patterns of climate of the past centuries (Jones and Mann, 2004). Since evidence on past climate is not directly available, the reconstruction of past climate requires accumulation of evidence from many sources and integration of concepts and techniques of multidiscipline (Dincauze, 2000b). The link between past environment change and ultimate cause is understood by feedback between the environmental system that obscures cause and effect relations of the environment through lag times, discontinuity in spatial and temporal changes, difficulties associated with obtaining absolute dates and variability in environmental changes. Indirect or proxy evidence indicates different causes of change. Information on the cause of change can guide in understanding past environment and environmental changes.

Climate reconstruction is useful to know:

- the earth's response to change;
- to plan for the future;
- to know human response to changes in the past which can assist in predicting the human response to future global change;
- to understand the selective pressures affecting the survival and extinction of animals at a site;
- to provide information about the amplitude of climatic variations at centennial time scales;
- to put the recent global warming under the purview of natural climate variations; and
- to suggest the effect of anthropogenic emissions of green house gases on the global climate (Wise, 2001; Stanford et al., 2009; Storch et al., 2009).

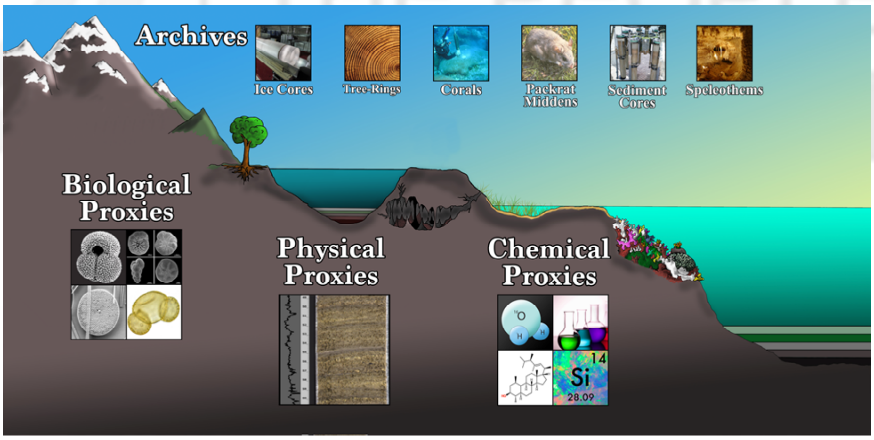

Fig. 1: Proxies of Past Climate

Source: https://www2.usgs.gov/climate_landuse/clu_rd/paleoclimate/

> **Check Your Progress**
>
> 1) Define climate. How climate reconstruction is useful?
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6.1 METHODS OF CLIMATE RECONSTRUCTION

6.1.1 Dating Methods

Dating methods are used to estimate the age of fossils (the remnants of once-lived things) (Standford et al., 2009). Estimation of age gives indirect reference to the climate of the past. Dating methods are classified as either relative or absolute (Price, 2007a). Relative dating methods use stratigraphic relationships to classify younger and older materials. Stratigraphy deals with layers of deposits at archaeological sites and assumes that deeper layers are older than higher layers in a sequence (Price, 2007a). The relative dating techniques consist of lithostratigraphy (using properties of rock layers to correlate across regions), tephrostratigraphy (using finger prints of trace elements in volcanic ashes to correlate time equivalence at different sites), biostratigraphy (using of information of biological organisms found at archaeological sites to make age correlation across sites and regions) and chemical methods (estimate the age of fossils based on the analysis of fluorine, uranium and nitrogen content. The technique is useful to settle disputes on the age of fossils or between fossils and their sediments) (Standford et al., 2009).

Check Your Progress

2) What is meant by dating methods? How it is classified?

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Absolute dating methods assign the age to the object according to calendar year (Price, 2007a). The absolute methods with age limit ranges in years are: dendrochronology (8000), radiocarbon (100-40,000), radiopotassium (>500,000) argon/argon ($^{40}Ar/^{39}Ar$) (1.6 million years), uranium series (30,000-300,000), geomagnetism & archeomagnetism (approx 2000), theromoluminescence (500,000), electron spin resonance (1,000,000), obsidian hydration (8000) and fission track (100,000-1,000,000). These methods can be grouped into four categories based on the principle. These are: accumulation of layers (dendrochronology and obsidian hydration), radio and non-radioactive decay (radiocarbon, radiopotassium, fission track, uranium series and argon/argon), trapped charges (thermoluminescence, electron spin resonance and optically stimulated luminescence) and magnetism (geomagnetism and archaeomagnetism) (Price, 2007a and Standford et al., 2009).

6.1.2 Instrumental Climate Data Methods

Climate change may be studied by analysing records of common climate elements such as temperature, precipitation, namely, rain, snow and hail, humidity, wind, sunshine and atmospheric pressure, which have been obtained with standard equipments. The most commonly measured element is temperature. Temperature is a valuable climate element in climate observation. Rainfall, however, varies much more widely than temperature over relatively small geographical areas, and over short periods of time. The data obtained by instrumental records are considered to be authentic. The instrumental data comprised of measures of ocean and land regions by thermometer. This method also includes measurements of sea level pressure, continental and oceanic precipitation, sea ice extents, winds and humidity. These data sources can be used to interpret climate changes over approximately 1850 years. The data are subjected to bias such as residual urban warming in thermometer measurements and in case of measurement of precipitation in issues, such as, under catch. Statistical methods are used while interpolating missed data (Jones and Mann, 2004).

6.1.3 Historical Document Records

These records are considered as proxy climate evidences. These records contain information on frost dates, droughts, and famines, freezing of water bodies, duration of snow and ice cover. The data of the records were drawn from Europe, eastern Asia and North America. The data may not be useful for describing global climate variation and must be used cautiously after rigorous assessment (Jones and Mann, 2004).

6.1.4 Dendrochronology

In this method, past seasonal temperatures or drought can be inferred by measuring widths or maximum latewood densities of annual rings of the trees. This method also shows strong statistical correlation with instrumental climate records. Dendrochronology was developed by A.E. Douglass at the Arizona University. This method is useful in areas which have better preservation of timbers and trees mainly in sub popular and mid latitude terrestrial regions. This method is limited to extra tropical species and where cross-dating and chronology development of trees is possible. Trees form new ring each year at the outer edge of the trunk with a darker and lighter part. Wider ring is formed during the time of high rainfall whereas the narrow ring in the summer. These rings exhibit similar pattern in the same species. Small core from trees and old wood is drilled. As width of individual tree ring differs due to the annual growth, part of the sequence of rings from one tree can be overlapped with all or part of sequence from another tree. Connecting older trees and younger trees to this sequence, a chronology can be developed. Matching of new wood to the chronology, the age of the tree can be established. Application of this method is questioned due to recent observations that wood densities change in drought stressed trees at high elevations and also possibly due to high CO_2 concentrations (Jones and Mann, 2004 and Price, 2007a).

Fig. 2: Cross Section of Tree Trunk Showing Weather Changes

Source: http://iedro.org/articles/fall-of-rom/

6.1.5 Coral Records

This method is complementary to dendochronology. Coral records offer the possibility of dating annual and seasonal records and also provide uniform climate information compared to other methods. Using century old fossil records and data of several decades the millennial length of climate can be reconstructed. This method reconstructs the environment using information on coral's aragonite structure such as variation in strontium/calcium ratios, oxygen isotopes, density and variations of the fluorescence. Inability to detect digenetic alterations in the fossil corals is one of the limitations of this method and this limitation may cause bias in coral based past climate estimations (Jones and Mann, 2004).

6.1.6 Ice Core Records

This proxy method is spatially complementary to information provided by dendrochronology and coral records. Ice cores occupy small fraction of global surface. This method provides information about climate change from Northern and Southern hemispheres and alpine regions for over several millennia. Ice core contain isotopes of beryllium and oxygen and volcanic dust. Ice cores are source of information for fraction of melting ice, accumulation of precipitation, composition of chemicals, past radiation and local climatic conditions.

6.1.7 Speleothems (cave deposits)

Speleothem is a structure formed in a cave by the deposition of minerals from water, e.g. a stalactite or stalagmite, commonly known as cave formations. These are secondary mineral deposits formed in a cave. *Speleothems* are typically formed in limestone or dolostone solutional caves. Speleothems provide information on changes of hydrological cycle, atmospheric circulation and past cultural aspects. Speleothems are formed as a product of meteoric water cycle and variations in their growth rates. Various parameters such as growth rates, composition of isotopes, trace elements, organic matter and laminae are studied to gain information on speleothems. These variables are also influenced by temperature, changes in rainfall and ground water residence time. Speleothems are confined to North America, Eurasia, the tropics, Southern Africa and Australia (Jones and Mann, 2004).

Check Your Progress

3) What are speleothems? What information do they provide?

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6.1.8 Varved Lake and Ocean Sediment Records

Varve is a deposit formed when a glacier ends into a lake or an ocean. This is a deposit of a pair of thin layers of clay and silt of contrasting colour and texture which represent the deposit of a single year (summer and winter) in a lake. Such layers can be measured to determine the chronology of glacial sediments. Annual varved or laminated lake sediments such as ice core are formed due to the deposition of inorganic sediments and provide information on climate from high latitude regions. These records also tell about variations in summer temperature when sediment load dominate the deposition process.

Varved sediments can also be found in coastal or estuarine environment. The climatic information of marine environment can be obtained using oxygen isotopes and assembly of fauna incorporated in the sediments. Past century climate information is obtained by employing radiometric dating (Jones and Mann, 2004).

6.1.9 Boreholes

A borehole is a narrow shaft bored in the ground, either vertically or horizontally. A borehole may be constructed for many different purposes. Environmental consultants use the term borehole to collectively describe all of the various types of holes drilled as part of a geotechnical investigation or environmental site assessment. Samples collected from boreholes are often tested in a laboratory to determine their physical properties, or to assess levels of various chemical constituents or contaminants.

Boreholes provide information on temperature variations of several decades from terrestrial (tropical, midlatitude and subpolar) and polar ice caps regions. Changes in ground or ice surface temperature are estimated using subsurface borehole temperature. Ground surface temperature is influenced by seasonal snow cover, land surface changes and season specific factors. Surface air temperature is used to describe large scale climate variations. Discrepancies with other proxy methods in estimating surface air temperature are reduced when spatial sampling biases are taken into consideration and spatial regression is employed for optimal estimates. Ice borehole records also provide information on past temperature changes of polar environment (Jones and Mann, 2004).

6.1.10 Glacial Evidence

In this method, glacial moraine is used as evidence to interpret past climate changes. Moraine is a mass of rocks and sediments carried down and deposited by a glacier, typically as ridges at its edges or extremity. With the study of the position of the glacial moraines, the changes in movements of glaciers, namely, advance and retreat of past glaciers can be inferred assuming that past changes in regional glacial mass balances reflect past climatic variations (Jones and Mann, 2004).

6.2 RECONSTRUCTION OF CLIMATE USING BOTANICAL EVIDENCE

With reference to the plant remains, climate reconstruction is mainly done by two kinds of evidences: macro and micro evidences. Macro evidences are in the form of pieces of wood, seeds, nutshells, fruits, stems, roots, leaves, buds and cuticles. Micro evidences come mainly from pollen, spores, algae, diatoms, phytoliths and calcitic crystals (Dinacauze, 2000c; Price, 2007 b). Besides these evidences, molecular methods such as analysis of DNA of plant remains and chemical analysis of carbonized material found at the archaeological sites are also used to reconstruct the climate.

6.2.1 Macrobotanical Evidence

This type of evidence can be observed visibly without the help of any gadgets. Histosols are best preserver of macrobotanical materials. Histosol is a soil consisting primarily of peat, organic materials; found mainly in geographically high latitude areas or other marshy wetlands, bogs, swamps in the form of coprolites (fossilized excreta), carbonate crusts, packrat middens (debris pile constructed by a wood rats), food stores and artefacts. These are sources of macrofloral evidences. Macrofloral remains are better preserved when these are carbonized, mineralized and deposited in anaerobic conditions. These remains are also kept in frozen environment and in permanent dryness conditions to prevent exposure from air and bacterial decomposition. These may also preserve dietary as well as climatic evidences.

Carbonized material preserves the massive tissue such as wood, seed, stems, tubers, roots, some fruits, nuts and rarely the fibres. Analysis of carbonized material reveals information on contemporary climate, duration of usage, function carried out at the sites, activities held, nature and timing of abandonment. Off-site macro fossils preserve parts of plants and provide information on local environments. The macro plant remains obtained can be interpreted in terms of non-cultural (natural contexts) and cultural (use of plants, size, diversity and quality of environment) contexts (Dinacauze, 2000c).

6.2.1.1 Methods Used for Identification of Macrobotanical Remains

Macrobotanical remains are identified by botanical keys and herbarium collections prepared for the region. Charred samples are characterized using carbonized specimens prepared for the purpose. Scanning electron microscope is used to identify the macrofossils. Macrobotanical evidence provides information on the species and context of plant remains. When sample is correlated with spatial coordinates, its context of origin and depositional environment can be interpreted.

Interpretation of macrofossil remains rely on the analogies with modern flora and vegetation and paleoenvironmental inferences drawn from many sources. Saturated plant remains and associated evidences collected from pond margins and bogs supplement the data. Macrofossils can be characterized up to the species level. Large wood specimen data may aid in the interpretation of forest decomposition, dendro-chronological and dendro-climatalogical evidences. Macrofossil data provide sound evidence for local plants and association with other plants but they may not be statistically representative of their source population (Dinacauze, 2000c). Macrobotanical remains inform about the presence and percentage of different species in an archaeological site which is useful to understand the human diet, season of occupation and the environment of site (Price, 2007b).

6.2.2 Microbotanical Remains

Microbotanical remains are helpful in knowing the information on the species of plants, origin of agriculture and climatic change as samples are sourced from stratigraphic sequence. Besides microbotanical remains, genetic analysis of corn revealed the information on changes at the sequence level and their location (Price, 2007b; Dinacauze, 2000c). Spores, pollen, diatoms, phytoliths and grains of starch are the sources of microbotanical remains. These are used to reconstruct vegetational history of a region on the basis of pollen spectrum. Climatic change of the Holocene time of Europe had been reconstructed by microbotanical analysis. Eco factors of Mesolithic culture was known by this method.

6.2.2.1 Spores

Spores are flattened, oval, circular or triangular in shape. Spores are bigger in size than pollens. Spores are asexual reproductive cells of the non-flowering plants belonging to plants like mosses, ferns and fungi. They have capability of inducing the growth of a new plant. Evidences on spores are found from Silurian period whereas early Cretaceous period provides information about pollen.

6.2.2.2 Pollens

Pollens are male gametes and carried by winds or insects inducing pollination to fertilize the female germ cells to produce the seeds. Pollen can be used to identify the genus or species of plants. Lake and pond sediments, peat deposits and soil are the best sources of preserved pollen. Anaerobic, acidic and completely dry conditions help in better preservation of pollen. Pollen association with archaeological sites can be used to gain information on past vegetation, climate and environmental (precipitation) conditions.

Pollen records fail to represent local diversity of plants and biased of size and direction and altitude of vegetation associations in the study area.

6.2.2.3 Phytoliths (plant rocks)

Phytoliths are silica bodies found in vascular plants. These are diagonistic specially at family level in angiosperms. They abundantly found in all organs of palms (Arecacceae) with highest concentration in leaves. Phytoliths are preserved in the soil for thousands and millions of years. These provide information on taxa in time and space. They are found in different shapes such as dumbbells, saddles, bowls, boats and pyramid and found to be characteristic of some plant taxa. Phytoliths are separated from other sedimentary components by heavy liquid flotation and centrifugation. Analysis of phytholiths provides information on the distribution and usage of plants as well as climate type.

6.2.2.4 Diatoms

These are aquatic unicellular microscopic algae that produce oxygen abundantly. They are found in marine and fresh water environments. Using microscope they can be identified up to the species level. Analysis of diatoms provides information on climatic conditions to supplement the archaeological record.

6.2.2.5 Grains of Starch

Starch is a complex carbohydrate found in seeds, bulbs, tubers of plants such as arrowroot, cassava, barley, maize, millet, oat, potato, rice, sage, sweet potato, taro, wheat and yam. Starch is better preserved in deposits and can be an aid in the identification of genus and possibly the species. The variables such as size, shape, optical and chemical properties are analyzed for starch identification. Study of fossil starch reveals information on diet and environment of past human beings and their cultures.

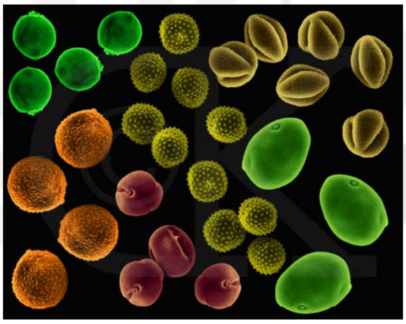

Fig. 3: Pollen

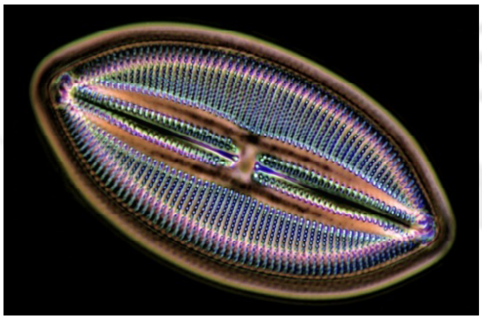

Fig. 4: Diatom

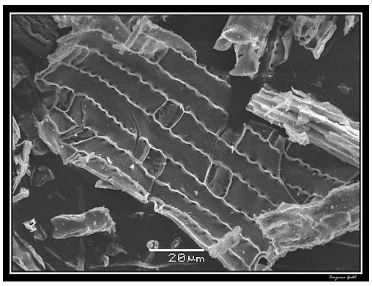

Fig. 5: Phytolith

Sources:

https://www2.estrellamountain.edu/faculty/farabee/biobk/BioBookflowersII. html
https://sites.google.com/site/botany317/session-2/eukaryotes/session-3/heterokonts/diatoms
https://en.wikipedia.org/wiki/Phytolith

6.3 RECONSTRUCTION OF CLIMATE USING FAUNAL EVIDENCE

Ecofacts or biofacts are organic materials found at an archaeological site that carries archaeological significance. These are animal bones, charcoal, plants, and pollen. Animal ecofacts available at archaeological sites are bone, teeth, antler, ivory, hides, hair, scales and shell. To better understand the interaction between humans and animals in the past, archaeologists study remains of all animals. In majority of cases, only bones or some part of bones are found at the archaeological sites. Study of animal remains reveals information on man and animal relationship. Animal biofacts provide knowledge about how animals were killed, how many animals were present at the assemblage and how much meat contributed to the diet. These remains also provide information on ratio of adult to juvenile and male to female animals, seasonal or selective hunting of animals, tools used to kill animals, domestication process of animals and age and sex determination of the animals. Animals provide important clue for past environment. For example presence of woolly rhinoceros and mammoth in any deposit indicated cold climate (glacial).

Fig. 6: Faunal Remains Found at Rich Neck Slave Quarter

Source: https://www.nps.gov/ethnography/aah/aaheritage/images/bones.jpg

Check Your Progress

4) What are the major sources of animal remains? What information do they provide?

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Bones are counted to know the origin of bones from particular site and using the type and size of the bones, the animals are sorted. The sorting can aid in the identity of animal such as mammal or rodent. The species of the animal is characterized by comparing the archaeological material with published guides and keys. Using bones animal can be identified up to the genus or family level. At a given archaeological site, the animal remains can be identified depending on the conditions of preservation, fragmentation and deposition and the certainty ranges from 5%-40%. To know how many animals of each species were present at particular site, measures such as NISP (number of identified specimens) and MNI (the minimum number of individuals) are used. Age and sex determination is done for predominant species and to know seasonality of the site. Sex determination is done based on size, using certain bones (pelvis), antlers, tusks, horns and teeth. The variables which are taken into consideration for determining the age at death includes size of bones, the degree of ossification of bone, number and condition of teeth. In case of herbivores, age of the animal is confirmed by using tooth wear, annual growth rings of teeth, and *cementum annuli* of teeth (annual deposits of cementum around the base of teeth). Determination of season of residence from animal remains may reveal information on the pattern of settlement, and subsistence followed by the people of the past.

The study of the biological, chemical, and physical processes that change organisms after death, leading ultimately to their preservation as fossils is known as taphonomy. The initial phase in this process is removal or decay of the organism's soft parts by scavengers or microbes. Analysis of taphonomic changes may help in reconstructing the post-mortem processes that provide information on site formation processes and the paleoenvironment.

Bones were used by human beings for a long time. Upper paleolithic culture of Europe yielded evidence for the use of bones for making various tools such as needles, disks, plaques, hoes, weapons and, ice skates/ bone and antler were used for making hair combs; bone and ivory for making jewellery etc. Terrestrial gastropods provide data on land use and plant succession at local level. Shells are indicators of local habitat, climate and season of habitation at the site. Proportion of shells at a particular site provides information on the local water conditions and the study of ratio of oxygen isotopes reveal about changes taken place in water temperature over the time. Molluscs add one growth ring every year and the study of growth rings informs the seasonality of the site. Scavenger crabs are better indicators of temperature and moisture. Bivalved aquatic crustaceans are useful in knowing the water quality and the human land use practices. Beetle assemblages provide information on the past temperatures. Large animal remains reveal information on gross regional climate, meso-scale habitats and relative dating. Insect remains are employed for interpretation of season and duration of exposure of pit fill and bivalve growth ring to date the shell deposits (Price, 2007c; Dinacauze, 2000d).

Anaerobic, arid, alkaline or mineralizing environments preserve the animal remains for long time. Artefacts, butchery cuts, footprints, animal burrows, dens and nests are the sources of trace fossils. In the absence of animal remains, the analysis of available residues provides information on animals at the archaeological contexts. Analysis of carbon isotopes improves our understanding on the components of diets of animals and climate variation. Nitrogen isotope throws light on the ratio of meat to plant foods whereas determination of trace element concentration inform on the dietary composition, trophic level, animal ranges and paleoclimate (Dinacauze, 2000d).

6.4 SUMMARY

Climate may be defined as the mean and range of temperature and precipitation prevailing over a defined area of the globe. Direct measurements of climatic variable provide information up to two centuries only and dependence on proxy measures of climate variability is a necessity for the reconstruction of the past. Proxy or indirect evidence indicates different causes of change, understanding on the past environment and environmental changes.

Dating methods are used to estimate the age of fossils and are classified as either relative or absolute. The relative dating techniques consists of lithostratigraphy, tephrostratigraphy, biostratigraphy and chemical methods. Absolute dating methods assign the age to the object according to calendar year. These include dendrochronology, radiocarbon, radiopotassium, argon/argon, uranium series, geomagnetism and archeomagnetism, theromoluminescence, electron spin resonance, obisidian hydration and fission track.

The instrumental data can be used to interpret climate changes for approximately 1850 years. Historical records contain information on frost dates, droughts, famines, freezing of water bodies, duration of snow and ice cover. In dendrochronology method, past seasonal temperatures or drought can be inferred by measuring annual ring widths or maximum latewood densities. Using coral records data of several decades and century fossil record, the millennial length of climate can be reconstructed. Ice cores are source of information for fraction of melting ice, accumulation of precipitation, composition of chemicals, past radiation and local climatic conditions. Speleothems provide information on changes of hydrological cycle, atmospheric circulation and past cultural aspects. Annual varved or laminated lake sediments provide information on climate from high latitude regions and variations in summer temperature when sediment load dominate the deposition process. Boreholes provide information on temperature variations of several decades from terrestrial (tropical, midlatitude and sub polar) and polar ice caps. In glacial evidence method, glacial moraine (a large mass of dirt and rock carried by the glacier) evidence is used to interpret past climate changes.

Mainly two kinds of evidences in relation to plant remains such as macro (pieces of wood, seeds, nutshells, fruits, stems, roots, leaves, buds, cuticle) and micro (pollen, spores, algae, diatoms, phytoliths and calcitic crystals) remains are taken into consideration for inferring past climates. Macrobotanical evidence can be observed visibly without the help of any gadgets. These evidences are identified by botanical keys and herbarium collections prepared for the region. Macrobotanical remains inform about the presence and percentage of different species in an archaeological site which is useful to understand the human diet, season of occupation and the environment of the site.

Spores, pollen, diatoms, phytoliths and grains of starch are the sources of microbotanical remains. Spores and pollen are used to identify the species of the plant. Analysis of phytholiths provides information on the distribution and usage of plants. Diatoms are aquatic unicellular microscopic algae and provide information on climatic conditions to supplement the archaeological record. Starch is better preserved in deposits and can be an aid in the identification of genus and possibly species. Study of fossil starch reveals information on diet and environment of past human cultures.

Animal ecofacts are available at archaeological sites in the form of bone, teeth, antler, ivory, hides, hair, scales and shells. To better understand the interaction between humans and animals in the past, archaeologists study remains of all animals. Using bones, animal can be identified up to the genus or family level. Age and sex determination is done for predominant species and to know seasonality of the site. Animal remain characterization begins with sorting of pieces and fragments. Anaerobic, arid, alkaline or mineralizing environments preserve the animal remains for long time. Artefacts, butchery cuts, footprints, animal burrows, dens and nests are the sources of trace fossils. Some animals act as index fossils for specific time and climate.

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6.6 ANSWERS TO CHECK YOUR PROGRESS

1) Climate may be defined as the mean and range of temperature and precipitation prevailing over a defined area of the globe (Dincauze, 2000a). Climate reconstruction is useful to know:

   - the earth's response to change;
   - to plan for the future;
   - to know human response to changes in the past which can assist in predicting the human response to future global change;
   - to understand the selective pressures affecting the survival and extinction of animal at a site;
   - to provide information of the amplitude of climatic variations at centennial time scales;
   - to put the recent global warming under the purview of natural climate variations; and
   - to suggest the effect of anthropogenic emissions of green house gases on the global climate.

2) Dating methods are used to estimate the age of fossils (the remnants of once-lived things). Estimation of age gives indirect reference to the climate of the past. Dating methods are classified as either relative or absolute. Relative dating methods use stratigraphic relationships to classify younger and older materials whereas absolute dating methods assign the absolute age to the object according to calendar year. For further details kindly refer Sub-section 5.1.1.

3) Speleothems or cave formations are secondary mineral deposits that are formed in caves in the forms of stalagmite and stalactite as a product of meteoric water cycle and variations in their growth rates. They provide information on changes of hydrological cycle, atmospheric circulation and past cultural aspects.

4) Major sources of animal remains are bone, teeth, antler, ivory, hides, hair, scales and shell. Study of animal remains reveals information on how animals were killed, how many animals were present at the assemblage and how much meat contributed to the diet. These remains also provide information on ratio of adult to juvenile and male to female animals, seasonal or selective hunting of animals, tools (streaks or chops) used to kill animals, domestication process of animals and age and sex determination of the animals. Some animals act as index fossil for time and climate.

UNIT 7 CENOZOIC ERA WITH SPECIAL REFERENCE TO QUATERNARY PERIOD

Contents

Learning Objectives

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

- Know the chronology and position of Cenozoic Era in Geological Time Scale;
- Understand different periods of Cenozoic Era;
- Study various glaciation and inter glaciation phases; and
- Discuss the causes of Pleistocene climatic change

7.0 INTRODUCTION

The Cenozoic Era is also known as Caenozoic or Cainozoic. Cenozoic literally means 'new life' after the Greek roots '*kainos'* meaning 'new' and '*zoico'* meaning 'animal life'. The Cenozoic Era is of substantial interest for anthropologists since the evolution and diversification of fossil primates, including humans, took place during this era. Besides primates, a significant portion of the evolution and radiation of various groups of mammals also happened during the Cenozoic. It is for this reason that sometimes the Cenozoic is also termed as the 'Age of Mammals' who were the dominant animal life of earth during the Cenozoic Era. The era began about 65 million years ago and continues into the present. The existing locations of the continents and the distribution of current flora and fauna acquired its present-day configuration during this time period.

The era began at the end of Cretaceous, the last phase of the Mesozoic. The end of Cretaceous was marked by large-scale extinctions, when the non-avian dinosaurs, along with several other types of fauna, were completely wiped out. Several types of ecological niches vacated by the reptilian extinction were gradually occupied and exploited by the mammals, which flourished, diversified and came to dominate Earth's faunal life.

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During early part of the Cenozoic, Earth was largely populated by small fauna, which also included small mammals. However, over a period of time the mammals diversified and radiated taking advantage of the absence of dinosaurs who had dominated the earth during the Mesozoic Era. The mammals occupied almost all the ecological niches, which were earlier the domain of the dinosaurs. Over time, a few of the mammals greatly increased in size and grew much larger than even some of the largest mammals of today, such as whales and as elephants. Of all the twenty orders of the class mammalian, of special interest for an anthropologist are the primates, which also evolved, diversified and radiated along with other mammals during the Cenozoic Era.

7.1 POSITION OF CENOZOIC IN THE GEOLOGIC TIME SCALE

The Cenozoic Era is the most recent of the three major subdivisions of animal history. The other two are the *Mesozoic* and *Palaeozoic* Eras. Before we discuss the Cenozoic, it would be useful to understand, in brief, the various divisions of the earth's geologic history and the position of Cenozoic in it. The history of the Earth is divided into parts based on certain geologic or faunal/floral events. The generally accepted divisions are eon, era, period, epoch, and age, as progressively smaller units of geological time. The major divisions of time are termed eons. In succession these are: *Hadean*, the *Archean*, the *Proterozoic* and the *Phanerozoic*. The first three of these can be collectively called as the Precambrian super eons. Eons are further divided into *eras*. The eras are in turn divisible into periods, epochs and ages. The various divisions of geologic time, along with their ages, and the position of Cenozoic in it are depicted in Table 1.

7.2 CHRONOLOGY OF CENOZOIC ERA

From an anthropological perspective, Cenozoic Era is very important because, the entire primate evolution and subsequently the human evolution occurred during this Era. Besides primates, the evolution and radiation of mammals, birds and most flowering plants and grasses took place during this phase of Earth's history. The Cenozoic is divided into three periods, namely the Palaeogene, the Neogene and the Quaternary, and seven epochs, viz. Palaeocene, Eocene, Oligocene, Miocene, Pliocene, Pleistocene and Holocene. The Cenozoic is sometimes called the 'Age of Mammals', because the largest land animals,the mammals appeared on earth during that time. The Palaeogene is subdivided into three epochs: the Palaeocene, the Eocene and the Oligocene. The Neogene is subdivided into two epochs: the Miocene and Pliocene. The Quaternary is divisible into two epochs: the Pleistocene and the Holocene.

a) Palaeocene Epoch

The Palaeocene is the first epoch of the Cenozoic, which began at about 66 million year before present (myr). It begins at the end of Cretaceous when large-scale extinctions of life occurred. *Dinosaurs* on land, large swimming *reptiles* in seas, nektonic *ammonites* and most microscopic planktons died out at the end of Cretaceous leaving many ecological niches vacant for evolution and radiation of mammals, which had existed for more than 100 million years before the Cenozoic Era. Palaeocene saw mammals growing bigger and occupying a wider variety of ecological niches. The mammals were small rodent-like to medium-sized mammals. Fossil evidence from the Paleocene is scarce. Small early primates, plesiadapids, marsupials and monotreme mammals were present.

b) Eocene Epoch

The Eocene began at around 56 myr ago and ended at around 34 myr ago lasting

Table 1: Position of Cenozoic in Geological time scale

Eon		Era	*Period*	Epoch	Major Fauna	Age (myr)
PHANEROZOIC		CENOZOIC	*Quaternary*	Holocene	Ice Age recedes, present interglacial begins. Rise of human civilization; domestication of animals and agriculture. Stone Age cultures give way to Bronze Age (3300 BC), Iron Age (1200 BC), many pre-historic cultures world-wide and industrial revolution.	0.0117
				Pleistocene	Pleistocene megafauna first flourishes and then becomes extinct. Anatomically modern humans evolve. Emergence of human stone-age cultures. Quaternary Ice Age continues with glacial and interglacial phases.	2.58
			Neogene	Pliocene	Several of the existing genera of mammals present. Hominids appear and diversify. Cool and dry climate.	5.3
				Miocene	Horses and mastodons diversify. Modern mammal and bird families become identifiable. First apes appear. Grasses spread.	23
			Palaeogene	Oligocene	Rapid evolution and diversification of mammalian and other fauna. Major evolution and dispersal of flowering plants	34
				Eocene	Archaic mammals flourish and continue to evolve; several "modern" mammalian groups appear. First grasses appear.	56
				Palaeocene	Mammals diversify into a number of primitive lineages. Many modern plants appear. Indian plate collides with Eurasian plate ~55 myr. Himalayan orogeny begin	66
		MESOZOIC		Cretaceous	Many new types of land dinosaurs evolve (*Tyrannosaurs*, duck-billed and horned dinosaurs). Flowering plants proliferate. Monotremes, marsupials and placental mammals appear. Primitive birds continue. At end of Cretaceous, major extinction wipes out dinosaurs and many other reptiles.	145
				Jurassic	Many types of dinosaurs. First birds and lizards. Small mammals common. Gymnosperms and ferns common.	201
				Triassic	First mammals and crocodiles appear. Reptiles dominant on land, seas and in the air. Modern corals and teleost fish appear. Many large aquatic amphibians; ammonoids very common.	252
		PALAEOZOIC		Permian	Synapsid reptiles become plentiful, amphibians common; cone-bearing gymnosperms replace earlier flora.At ~251 myr, major life, including trilobites, graptolites, blastoids, extinct.	299
				Carboni-ferous	Amphibians diversify, first reptiles and coal forests. Winged insects radiate, first land vertebrates. Early sharks diversify, echinoderms abundant; trilobites and nautiloids decline.	359
				Devonian	First clubmosses, ferns,seed-bearing plants (progymnosperms) and first insects (wingless) appear. Trilobites and armoured agnaths decline, jawed fishes and early sharks rule the seas. First amphibians still aquatic.	419
				Silurian	First vascular plants. First jawed fishes and many armoured jawless fish in seas. Corals, brachiopods, crinoids, Sea-scorpions abundant. Trilobites and mollusks diverse.	444
				Ordovician	Invertebrates diversify. Early corals. bivalves, nautiloids, articulate brachiopods, trilobites, ostracods, bryozoa, many echinoderms. First green plants and fungi on land.	485
				Cambrian	Major diversification of life. Most modern phyla appear. First animals with hard parts. First chordates. Trilobites, worms, sponges, brachiopods present. Prokaryotes, fungi, algae go on.	541
PRECAM-BRIAN	**Proterozoic**	*In upper part, fossil of complex multicelled organisms. Stromatolite fossils common. First multicellular organisms (~1200 myr). First Eukaryotes (~2000 myr).*				2500
	Archean	*Simple single-celled life (prokaryotic life such as bacteria and blue-green algae). Oldest probable microfossils.*				4000
	Hadean	*Formation of Earth. There is no evidence for life in this Eon. Oldest known rocks 3500-4000 Myr.*				4600

Modified after Cohen et.al. (2013).

nearly 22 million years, the longest of all the epochs of the Cenozoic Era. For most of the Eocene Epoch, the global climate was warm and rainy. Among the mammal groups that first appeared in the fossil record during this period are the perissodactyls, artiodactyls, proboscideans, rodents, and many primates. Adaptive radiation of adapid and the omomyid prosimians took place during this epoch. It is thought that the intense global warming allowed warm-adapted mammals to migrate between continents via land connections at very high latitudes. Early perissodactyls, such as the horse relative *Hyracotherium*, appeared right at the very beginning of the Eocene. By the end of the epoch, the planet was much cooler and the rainforest-like habitats that covered much of the continents gave way to more open woodland.

c) **Oligocene Epoch**

The Oligocene Epoch extends from about 34 myr ago to about 23 myrs. A cooling trend is prevalent throughout Oligocene. Mammals such as horses, deer, camels, elephants, cats, dogs, and primates began to dominate continents, except in Australia. Early forms of amphicyonids, horses (*Miohippus*) canids, camels, tayassuids, protoceratids, and anthracotheres appeared. In late Oligocene there was an expansion of grasslands and prairies that was linked to the expansion of grazing animals. Earliest new world monkeys, early anthropoids (*Parapithecus, Apidium, Aegyptopithjecus*), known largely from Egypt, emerged.

d) **Miocene Epoch**

The Miocene Epoch is the first *geological epoch* of the *Neogene* Period and it extends from about 23 myrs back to 5.3 myrs ago. It was a time of warmer global climates than those in the preceding Oligocene or the following Pliocene. The *grasslands* continued to expand and forests continued to decrease. During later part of Miocene, mammals were more modern, with easily recognizable canids, bears, procyonids, equids, beavers, deer, camelids, and whales. Apes arose and diversified during the Miocene, becoming widespread in the Old World (e.g. *Gigantopithecus, Sivapithecus, Dryopithecus*). A large number of ape species existed in Africa, Asia and Europe during this time. The first hominins appeared in Africa at the very end of the Miocene, which included *Sahelanthropus* and *Orrorin*.

e) **Pliocene Epoch**

The Pliocene epoch is the second epoch of the Neogene Period, which began about 5.3 myrs ago and extended to about 2.58 myrs back. During the Pliocene, continents continued to drift toward their present positions and Africa's collision with Europe cut off the remaining part of the Tethys Sea and formed the Mediterranean Sea. During the Pliocene, climates became cooler, drier, and seasonal, similar to modern climates. In Eurasia, primate distribution declined. Elephants, gomphotheres, and stegodonts were successful in Asia. Horse diversity declined, while cattle and antelopes were successful. During Pliocene, hominids became increasingly well-documented in the fossil record (e.g. *Ardipithecus ramidus, Australopithecus anamensis, Australopithecus afarensis, Australopithecus garhi, Australopithecus africanus, Homo habilis*).

f) **Pleistocene Epoch**

This epoch is the first epoch of the Quaternary Period that started about 2.58 myr ago and lasted up to 11700 years before present. The Pleistocene was a relatively short span of geologic time, which was a time of great global cooling, commonly known as "Ice Age". During the epoch, immense glaciers and ice sheets occurred at the North and South Poles and at all high altitudes. The cold periods or glacial were interspersed with warmer phases or interglacial. The evolution of anatomically modern humans (*Homo sapiens*) took place during the Pleistocene, who then spread to different parts of the Earth. In addition to the woolly mammoth, mammals such as sabre-toothed cats (*Smilodon*), giant ground sloths (*Megatherium*) and mastodons roamed the Earth during this period. By the end of this epoch, a major extinction event of large mammals (e.g. mammoths, mastodons, sabre-toothed cats, ground sloths, cave bears, etc.) occurred (probably due to over hunting by humans and climate change) and continued into the Holocene.

g) **Holocene Epoch**

Holocene is the second of the epochs of the Quaternary Period that started about 11,700 years ago and is continuing. It is a period of warming in which the global climate became warmer. During this period many mega mammals, such as like woolly mammoth and woolly rhinoceros, became extinct. Humans developed agriculture and domestication of animals, which was followed by bronze and iron ages, development of civilizations, urban centres, governments, rapid population growth and the development of industrial revolution in 19th century.

Check Your Progress

1) In how many period and epochs Cenozoic era can be divided?

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7.3 QUATERNARY PERIOD AND PLEISTOCENE GLACIATIONS

Quaternary Period of the Cenozoic Era is the youngest period of the geological history of earth. It consists of two epochs: the Pleistocene and the Holocene. Pleistocene Epoch is unique in Earth's history as it has witnessed very cold conditions also known as glaciations or ice ages. One of the striking features of Pleistocene was the slow lowering of temperature of earth culminating in what is known as Ice Age. In fact it was not a continuous ice age but a series of very cold periods interspersed with warmer phases. The cold phase is generally termed as a glacial phase while the warmer phase known as interglacial phase. During Pleistocene, ice sheets expanded, from out of Antarctica and Greenland, and higher altitudes in the mountains. During the coldest phase, the glacial conditions prevailed as far south as 39° latitude north. Countries which now have a temperate climate then experienced the arctic cold of polar region and were covered under ice sheets.

After several years of work, the scientists have been able to show that there have been at least four major glaciations with several interglacial periods when ice retreated during the Pleistocene Epoch. Within the span of the glaciations, there were some warm periods, called Interstadials, when ice retreated. At its maximum, the great ice sheets covering northern Europe and most British Isles were nearly two miles thick. It extended over whole of Scandinavia, the Baltic Sea, and far into Russia and Germany. Less extensive glaciers covered the Alps, the Himalayas, the Pyrenees and other high mountainous areas. During glacial maxima, the sea level fell by as much as 500 feet as much water got locked as ice. A glacial phase may be defined as a cold period of increased precipitation leading to snow formation at higher altitudes and its accumulation at poles and solidification into ice and leading over time to the formation of glaciers.

Penck and Bruckner distinguished four glaciations and three interglacials on the basis of their work in the Alps. The glacial phases were named by them after four small rivers which flowed down the side of Alps into the Danube Basin. The Alps glaciations and their estimated ages are given in Table-2. A pre-Gunz glacial phase, termed Donau, has also been identified in many sub-polar regions,, occurring during the Villafranchian Age of Pleistocene (Bhattacharya, 1990).

Table 2: The four glacial phases of the Alps

Sr. No. of Glacial Phase	Glacial/Interglacial Phase	Approximate Age (Years Before Present or BP)
	Post-Glacial Phase	10,000 BP
4th Glaciation		100,000 BP
	Riss-Wurm Intergllacial	
3rd Glaciation	Riss Glaciation	200,000 BP
	Mindel-Riss Interglacial	
2nd Glaciation	Mindel Glaciation	400,000 BP
	Gunz-Mindel Interglacial	
1st Glaciation	Gunz Glaciation	600,000 BP

7.4 EVIDENCES OF PLEISTOCENE GLACIATIONS

A glacier is a permanent (relatively speaking) body of ice, consisting largely of recrystallized snow that shows evidence of downslope or outward movement due to the pull of gravity. The main evidences of the occurrence of glaciations are as follows:

1) *Moraines*: Moraines are the debris produced by the erosional activity of a glacier. It consists of non sorted random mixture of different sized fragments of angular rocks in a matrix of fine grained, sand- to clay-sized fragments that were produced by abrasion within the glacier and have a form different from the underlying bedrock. Depending on their position in relation to the glacier, moraines can be Ground Moraines, Medial Moraines, Lateral Moraines and End Moraines. Moraines are definite evidence of the presence of glaciers and glaciated conditions. Other evidences of glaciers are U-shaped Valleys, hanging valleys, erratic, etc.

2) *Sea Level Fluctuations*: During glacial periods much sea water was tied up in glaciers so sea level was lower. During interglacial periods, sea level was higher due to release of water by melting of the ice.

   i) *Evidences of Lower Sea Level*: During low sea level or glacial phases, the level of sea was much lower than the present level.

      a) Submerged organic remains of land plans and animals

b) Submerged deltas

c) Anomalous faunal distribution

ii) *Evidences of Higher Sea Level:* During interglacial phases, the ice sheets melted and sea level rose higher than the current sea level.

a) Fossil bearing marine sediments

b) Cliffs by waves of sea.

3) *Loess*: It is a wind blown deposit found in the periglacial zone. The deposit is of material coarser than clay but finer than sand. It is caused by the presence of a glacier nearby.Examples are of Loess deposit in Danube River valley and those in Kashmir valley. The latter is known as Kaerwas locally.

4) *River Terraces*: River terraces are the remnants of earlier floodplains that existed at a time when either a stream or river was flowing at a higher elevation before its channel down cut to create a new floodplain at a lower elevation. A river terrace is a bench or step that extends along the side of a valley and represents a former level of the valley floor. A terrace results from any hydrological or climatic shift that causes renewed down cutting. A terraces can also be left behind when the volume of the fluvial flow declines due to changes in climate. When there is more water the river volume increases and its erosional activity is enhanced. It deepens its bed thus forming a terrace. It is understood that terraces also indirect evidence of glacial and interglacial periods. Glacial periods have been reported to be associated with aggradation and interglacial periods with incision (De Terra and Patterson, 1939).

Check Your Progress

2) What is meant by moraines? What do they consist of?

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7.5 PLUVIALS AND INTERPLUVIALS

When the arctic temperate and sub-temperate regions were experiencing glacial and interglacial phases, the tropical and subtropical regions were passing through pluvial or wet and inter-pluvial or dry periods. These have left their evidences in the form of river terraces and lake deposits.

1) **River Terrace:** A river terrace also provides evidence of pluvial phase followed by an inter-pluvial phase. It is also formed in the same principle as mentioned above. The deposits are marked by alternating deposit of gravel and silt. With higher amount of rainfall volume and velocity of water in the river increases. The rocks and other materials carried by river are turned into gravels. With the onset of dry condition, that is with reduced amount of rainfall river loses its capacity to carry loads and instead of gravels silt is deposited. Examples may be given of the

Subarnarekha, Luni, Narmada and Kortaliyar river terraces from East, West, Central and Southern part of India respectively.

2) **Lake Deposits:** In the interior of various continents there are several lakes which provide evidence of pluvial and inter-pluvial periods. During pluvial phase (wet phase) these lakes have been expanding and during an inter-pluvial (dry phase) the lakes have shrunk. These lakes have been expanding and shrinking thus submerging and exposing the surrounding areas and life forms. African lakes provide ample evidence of three pluvial expansions of lakes when lakes Nakuru, Elementaita and Naivasha in Kenya expanded to form a single lake during a pluvial phase.

7.6 CAUSES OF PLEISTOCENE GLACIATIONS

The exact reason behind Pleistocene glaciations is difficult to pinpoint. However several explanations have been given in the past to explain the reasons for their occurrence. These can be grouped into two types of theories: Astronomical and Geographical (Plate tectonic).

A) **Astronomical Theories**

Several astronomical theories are available for the cause of Pleistocene Glaciations.

1) *Increased concentricity of the earth's orbit*: This theory has its basis in a theory known as Croll's Hypothesis. In the 19th Century, James Croll published an article entitled "on the eccentricity of the earth's orbit and its physical relation to the glaciations" showing the calculation of how the gravitational pulls of the sun, moon, and planets subtly affect the earth's motion and orientation. This theory depends upon two phenomena:

   a) Eccentricity of Earth's orbit

   b) Precession of equinoxes.

   The change in earth's orbit, which is now nearly circular, from more elliptical to less elliptical has been periodic. So when the orbit is more elliptical, Earth may have very long and intense winters and short but very hot summers, having a cumulative effect leading to, over a period of time, into growth of glaciers and a glacial phase. The opposite would happen when the orbit becomes less elliptical or circular. Croll's theory was further developed subsequently by Milutin Minankovitch, a Serbain geophysicist who calculated these irregularities in Earth's orbit said that it would come across the climatic cycles known as Milankovitch's cycles. It has been postulated that the eccentricity of earth's orbit fluctuates with a periodicity of 92,000 years and the precession period (variation in the way the Earth wobbles on its axis) shifts in every 21,000 years.

2) *Variation in the angle between earth's axis and plane of orbit*: Another explanation that has been given to explain Pleistocene glaciations is the variation in the angle between earth's axis and the plane of its orbit. The period of this motion is believed to be 40,000 years. At present the angle is 23°, 27´, and it is known to have varied between 21°, 39´ and 24°, 36´. The increase of obliquity of this angle intensifies seasonal difference, by taking northern hemisphere away from sun, resulting in cooler conditions. It has been estimated that a change in the plane of Erath's orbit by 1° may cause a change of 5°C, which may be sufficient to bring glacial phase.

3) *Change in the intensity of solar radiation*: It has been suggested that the solar

heat received by earth from sun is not constant and may have considerably diminished during glacial phases. It was postulated by Huttington that there are periodic recurrence of sun spot cycles which may be glacial and interglacial. This is also known as 'Huttington's Hypothesis'.

Check Your Progress

3) What is 'Huttington's Hypothesis'?

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B. **Geographical Causes**

1) *Changes in earth's Atmosphere*: Atmospheric Factors- the composition of the Earth's atmosphere - can be studied from air bubbles trapped in ice in the polar ice sheets, by studying drill core samples. The study of these ice core samples have revealed that:

   i) During past glaciations, the amount of CO_2 and methane, both greenhouse gasses that tend to cause global warming, were lower than during interglacial periods.

   ii) During past glaciations, the amount of dust in the atmosphere was higher than during interglacial periods, thus more heat was likely reflected from the Earth's atmosphere back into space.

2) *Changes in Oceanic Circulation*: Small changes in ocean circulation can amplify small changes in temperature variation produced by astronomical factors.

3) *Tactonic Causes*: The continental uplift in late Pliocene or early Pleistocene, leading to upliftment of mountain chains like the Alps, the Rockies and the Himalayas, caused an increase in the average height of continents. This could have lowered the surface temperature, more so at higher altitudes and latitudes, thus precipitating colder or glacial conditions.

Thus we see that there are several theories for the occurrence of glacial phases during the Pleistocene. However, no single theory or cause can on its own explain it. It is possible that a combination of factors may have given rise to Pleistocene glaciations.

Check Your Progress

4) How did the continental uplift affect glaciation?

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7.7 SUMMARY

Earth's history is divided by the geologists into several phases. The Cenozoic Era is the most recent of the three major subdivisions of animal history. The Cenozoic is divided into three periods, namely the Palaeogene, the Neogene and the Quaternary. The Cenozoic is sometimes called the 'Age of Mammals', because the largest land animals, mammals, appeared on earth during that time. The Palaeogene is subdivided into three epochs: the Palaeocene, the Eocene and the Oligocene. The Quaternary is divisible into two epochs: the Pleistocene and the Holocene. Pleistocene is the first epoch of the Quaternary Period that started about 2.58 myr ago and lasted up to 11,700 years before present. Holocene is the second of the epochs of the Quaternary Period that started about 11,700 years ago and is continuing. It is a period of warming in which the global climate became warmer. Pleistocene is a period of climatic fluctuation. On higher latitude and altitude climate alternated between cold and warm phases, because of change in snowline. These phases are known as glacial and interglacial respectively. In the tropical and equatorial regions climate fluctuated between wet and dry condition, because of difference between average annual rainfalls. These are known as pluvial and interpluvial periods respectively. Evidences of glacial phases are found in deposits of moraines, loess, sea level changes and river terraces. Evidences for alternating dry and wet conditions are also found in river terraces, alternating deposits of gravel and silt and in changes in lake water level. Causes of climatic fluctuation are explained by various theories, namely, astronomical and geographical. Quaternary is most important for archaeological anthropology. During this time bio-cultural evolution of man had taken place. It provides understanding for the environment and time dimension which caused the changes in man and his culture.

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7.9 ANSWERS TO CHECK YOUR PROGRESS

1) The Cenozoic is divided into three periods, namely the Palaeogene, the Neogene and the Quaternary, and seven epochs, viz. Palaeocene, Eocene, Oligocene, Miocene, Pliocene, Pleistocene and Holocene.

2) Moraines are the debris produced by the erosional activity of a glacier. It consists of nonsorted random mixture of different sized fragments of angular rocks in a

matrix of fine grained, sand- to clay-sized fragments that were produced by abrasion within the glacier and have a form different from the underlying bedrock.

3) According to the 'Huttington's Hypothesis' solar heat received by earth from sun is not constant and may have considerably diminished during glacial phases. It was postulated by Huttington that there are periodic recurrence of sun spot cycles which may be glacial and interglacial. This is also known as 'Huttington's Hypothesis'.

4) The continental uplift in late Pliocene or early Pleistocene, leading to upliftment of mountain chains like the Alps, the Rockies and the Himalayas, caused an increase in the average height of continents. This could have lowered the surface temperature, more so at higher altitudes and latitudes, thus precipitating coder or glacial conditions.