UNIT 5 ACCOUNT OF PAST CLIMATE

Structure

5.1 INTRODUCTION

You know that climate is average weather, over a long period of time that covers a large area, even the whole planet. The weather represents hour to hour or day to day state of the atmosphere over a particular area. The atmosphere, ocean, snow and ice cover, land surface, rotation and revolution of earth, incoming solar radiation and biota are principal components of the climate and their interaction forms a system termed as climate system. You have already read about weather, climate and climate system while studying Unit 1 to 4 of the course. In fact, it is the climate system, which makes our planet Earth a habitable entity in the Universe.

The climate system evolves in time under the influence of its own internal dynamics like volcanic eruptions and due to changes in the external factors such as solar radiation and atmospheric composition. It is one of the oldest systems of the earth that has significantly contributed to the origin and evolution of life through ages. Earth is a constantly changing planet since its formation of around 4.6 billion years ago and hence, its climate is also witnessing the changes from time to time. We can know about the present climate by studying the components climate system. However, for understanding the current dynamics of climate and predicting its future state, it is necessary to have an understanding of present and past climate. In this unit, we will discuss the climate of the past, sources of past climatic conditions and changes in climate during Quaternary Period, when humans appeared as a dominant biotic element on the earth.

5.2 OBJECTIVES

After studying this unit, you should be able to:

- define palaeoclimate;
- differentiate between climate and palaeoclimate;
- describe the sources of palaeoclimate information; and
- discuss climate change during the Quaternary Period.

5.3 PALAEOCLIMATE

The term palaeoclimate refers to the climate of the past. As we have already stated in previous units that the science of studying the modern climate is termed as climatology. Similarly, the science dealing with the study of past climate is known as palaeoclimatology. The word palaeoclimatology is a combination of the Greek words "*Palaios*" - (ancient) + "*clima*"- (climate) + "*ology*" - (branch of learning) and therefore it refers to the study of the past climate. The scientists who study the past climate are known as palaeoclimatologists. They use natural environmental evidences or their proxies present on the earth's surface such as sediments, sedimentary layers, fossils (coral and tree growth rings), ice cores and radiocarbon to infer the climate of the past prior to the availability of recorded instrumental data of climate.

You may be surprised to know that changes in climate is neither unusual nor a new phenomenon. It is a natural process and Earth has already witnessed several cycles of climate change since its origin. Before discussing the earth's past climate, let us familiarise with the geologic time scale. Like the divisions of our time into years, months, weeks, days, hours, minutes and seconds; the geological time, covering entire span of Earth, is also divided into certain geologic time-units such as eon, era, period, epoch and age (Table 5.1). The duration of a particular time unit of the scale is determined by dating of rocks using radioactive methods. The boundary between two time units largely

corresponds to sudden biotic events like origination or extinction of certain species.

Table 5.1: Summary of the geological time scale showing main time units

Eon	Era	Period	Epoch	Time interval in million years (Ma)
Phanerozoic	Cenozoic	Quaternary	Holocene	0.012 to present
			Pleistocene	2.58 to 0.012
		Neogene	Pliocene	5.333 to 2.58
			Miocene	23.03 to 5.333
		Palaeogene	Oligocene	33.9 to 23.03
			Eocene	56 to 33.9
			Palaeocene	66 to 56
	Mesozoic	Cretaceous		145 to 66
		Jurassic		201.3 to 145
		Triassic		251.9 to 201.3
	Palaeozoic	Permian		298.9 to 251.9
		Carboniferous		358.9 to 298.9
		Devonian		419.2 to 358.9

			Silurian		445.2 to 419.2
			Ordovician		485.4 to 445.2
			Cambrian		541 to 485.4
Precambrian	Proterozoic	Neoproterozoic			1000 to 541
		Mesoproterozoic			1600 to 1000
		Palaeoproterozoic			2500 to 1600
	Archaean	Neoarchaean			2800 to 2500
		Mesoarchaean			3200 to 2800
		Palaeoarchaean			3600 to 3200
		Eoarchaean			4000 to 3600
	Hadean	------			4600 to 4000

5.4 GLIMPSE OF EARTH'S CLIMATE THROUGH AGES

The rock record of the earth contains numerous clues of the past climate which shows that climate of the living planet earth is not uniform throughout its history, since time of origin nearly 4.6 billion years ago to present. As discussed before, fossils (tree rings, plant leaves, pollens and coral skeletons), ice cores, sedimentary layers and sediments are main substances containing proxy data for palaeoclimate. Further, the study of this proxy data also reveals that past climate of the earth had often altered by solar intensity, volcanic eruptions, lithospheric plate motion, weathering reactions as well as fluctuations of greenhouse gases and temperatures. Additionally, the changes in oceanic circulation patterns, cyclic variations in Earth's orbit around the Sun, extra-terrestrial (meteorite) impacts and biologic evolution also influenced Earth's past climate. It may be noted that the past climate of the earth is defined in term of non-glacial (infra- and inter-glacial) and glacial periods. Let us discuss the climate during Precambrian and Phanerozoic times.

5.4.1 Climate during Precambrian

During the Precambrian time (4.6 billion years to 540 million years ago), Earth's climate was warm and concentration of greenhouse gases like carbon dioxide, methane and water vapour were very high. The concentration of carbon dioxide was more than 18 times than its present levels and methane was above 1000 ppm. The oxygen was not present in the early atmosphere. After millions of years of the formation of the earth, temperature came down to certain degrees and water vapour of early atmosphere produced rains. As a consequence, the earth was provided with basic necessities such as soil, water and air for origination of life. It was around 3.5 billion years ago, the early forms of life such as cyanobacteria made their first appearance on the surface of the earth. These bacteria made their own food by using sun energy as a source of energy and released oxygen as a by-product of photosynthesis process. As a consequence, around 600 million years ago, enough oxygen was present in the atmosphere that led to development of multi-cellular organisms. The non-glacial and glacial stages have been recorded in Precambrian history of the Earth. The evidence consisting of sedimentary rocks formed by glaciers show that Earth was very cold possibly near to freezing point, during the latter part of the Precambrian times (Ruddiman, 2018). Four ice ages are known from the Precambrian: first ice age occurred in the Archaean eon around 2500 million years ago and three ice ages in the Proterozoic eon between 900 and 600 million years ago (Barry and Chorley, 2010).

5.4.2 Climate during Phanerozoic

In the Phanerozoic eon (540 to 0 million years ago), the concentration of carbon dioxide fluctuated greatly and decreased from 6000 ppm to reach its current levels. The carbon cycle greatly shaped the Phanerozoic climate and as a result diverse variation occurred in multi-cellular organisms and land plants (Beerling and Berner, 2005). It is noted that the climate shifted frequently between icehouse (glacial and non-glacial) and greenhouse conditions and temperatures greatly influenced by the natural processes including breaking and re-union of continental landmasses as well as extra-terrestrial impacts during the Phanerozoic time. The five great mass extinctions such as End Ordovician, End Devonian Permian/Triassic boundary, End Triassic and Cretaceous/Tertiary boundary had been recorded in the Phanerozoic history of life. All these mass extinctions are directly related to the wide spread changes to the past climate. Mass extinction is a phenomena where sudden and permanent loss of large number of species or groups of organisms on earth's surface. Three major ice ages are documented from the Phanerozoic eon, which occurred in the Ordovician period, during Carboniferous-Permian periods and Late Cenozoic era (Barry and Chorley, 2010).

5.5 SOURCES OF PALAEOCLIMATIC DATA

It must be noted that for studying modern climate, the climatologists (also known as climate scientists) can get a century old data. Can you think this data is sufficient to know the climate of the whole Earth, which is nearly 4.6 billion years old before present? The answer is certainly not. Therefore, the palaeoclimatologists used climate archives or proxies to unravel the past climate of the earth. The climate archives comprise earth's material and old documented records (e.g., historical records) that hold physical characteristics of the past environment. While studying climate archives, the climate of the past can be reconstructed. The main types of climate archives are:

- Historical data
- Archaeological data
- Geological record

5.5.1 Historical Data

It represents first source of information for reconstructing the past climate. It consists of documentary data. The logs of the farmers', diaries of travellers', ancient inscriptions, newspapers, paintings, artistic depictions, reports of the early weather observers and other public records are the sources of historical data. Apart from these, the legal document, written account, tax, economic and pictorial records containing information about land uses, landscape, societal collapse, construction material and biodiversity also provide important clues for reconstructing past/ancient climate. Additionally, any records consisting of information on the timings of forests and flowering of trees, occurrences of snowfall, rainfall, drought, famine and flood as well as migration of birds are also parts of historical data. Historical data provide both qualitative and quantitative information of the past climate. This data provide climatic information of the events recorded by the humans, for example, the Mesopotamian civilization of the Middle East, was considered to be the one of first civilizations to record events.

5.5.2 Archaeological data

Archaeology deals with the study of the past human cultures. It focuses on how people lived, worked, traded and moved in the past. The specialists of archaeology are known as archaeologists. They use archaeological data to know how the life style of prehistoric human is influenced by the climatic conditions. It is to be noted that archaeological data is considerable older than that of historical data, because archaeological data comprise a time of ancient cultures that are reconstructed on the basis of scientific analyses of numerous soil layers preserving human artifacts. In other words, archaeological time is based on the remains of human life and hence, not based on the record kept by humans as in the case of historical data (Krebs, 2007). An archaeological site is a place, where the evidences of past human activity are preserved and

such evidences are a useful source of cultural and non-cultural (also described as environmental conditions) information, which together constitute the archaeological data (Reitz et al., 2008). The branch of archaeology dealing with the reconstruction of the past environment including climate is known as environmental archaeology. The following kinds of data, which may be useful of Palaeoclimatic study, are recovered from an archaeological site:

5.5.2.1 Rock layers, Minerals and Soil data

The chemical, physical and geological characteristics of rock layer, mineral and soil samples from any site provide many clues of the past climate. The grain-size analyses of sediment layers help to know the medium (wind, water, floods or glaciers) of their deposition and thus, useful to reconstruct the past climatic condition. The sequence of sediment layers of near shore archaeological sites give information of the sea level changes as they contain distinct layers of sediments deposited under marine to freshwater conditions.

5.5.2.2 Plant and Animal remains

The plant remains comprise any type of plant materials like wood, mature seeds, pollen, spores, fruits, flowers, leaves, stems, roots, bark, epidermis, fibers, stomata, starch grains, phytoliths, resins, lignin and lipids associated with any site. The animal remains comprise bones and teeth of mammals, fish skeletal remains and shells of invertebrates (molluscs, echinoderms, crustaceans, insects, foraminifers and protozoans). As we know that plant and animal life are largely controlled by climatic conditions, as a consequence, their remains will help us to known their food source and to reconstruct the climatic and environmental conditions of the past. The carbon, nitrogen and oxygen isotopic analyses of bone and shell remains give information about palaeodiets (terrestrial/aquatic), palaeotemperature (i.e. temperature of past) and seasonal patterns. The existence of mammoth (elephant) remains consisting of skins and bones clearly specify a cold climate. The presence of floral remains largely consisting of bouquets of wild flowers in the burial sites provides information about climate conditions prevailed at the time the society lived there. The sudden natural burial of a site preserving prehistoric humans and domesticated animals may have pointing towards the flooding phenomenon, which is related with rainfall and yield important clues of the past climate.

5.5.2.3 Artifacts

These are objects created, modified and used by humans. The various forms of pottery (intact or broken), tools made of stone, wood, bone and metal (arrow-heads, mace-heads and spears), decorative objects (jewellery and *figurines* or statuettes) and personal objects (clothing) constitute artifacts. It is considered that prehistoric humans used nearby available material for creating or manufacturing the artifacts. Thus, their study shed light on the

past climate. For example, the presence of broken, blacked and burned clay pots in association with ash layers in an archaeological site is an indicative of the warm climate.

5.5.3 Geological Record

Geology is the science that deals with the study of the earth with reference to its origin, evolution, age, structure, composition and processes operating on it since its formation (about 4.6 billion years ago). The scientists who study the earth's materials are known as geologists. The earth's material consisting of different types of rocks (igneous, sedimentary and metamorphic), fossils, sediments and soils that are available to them (geologists) for study. This material is also termed as rock record and yields many proxies or indirect evidences to reconstruct the timeline of the earth's climate during the geological past. It may be noted that the geological record is much older than that of historical and archaeological data. The 4.6 billion years long history of earth witnessed numerous intervals of short and long term climatic fluctuations, which left many climatic proxies or natural archives preserved in the rock record. Some of the most important natural archives are sedimentary rock types, fossils, and ice core and cave deposits.

5.5.3.1 Sedimentary rock types

The sedimentary rocks are formed by the slow processes of deposition of sediments carried by rivers and streams into oceans and other water bodies (e.g., rivers or lakes) and after millions of years, the soft sediment got consolidated into stratified (layered) hard rocks. These rock bodies constitute the sedimentary rocks. Many climatically sensitive sedimentary rock types provide natural climatic archives as described below:

- **Glacial features:**

Some glacial features like striae, tillites and moraines are easily recognised in the field and serve as useful climate archive for cold, glacial climate of high latitudes and elevations. As the glacier moves, it erodes/breaks rocks lying at its base and transports them in the direction of flow, leaving behind deep scratches in the underlying rocks, which are made by rock fragments carried by glaciers and are termed as glacier striae. As the glacier advances, it drops a mixture of sediments consisting of boulders, pebbles, sand and mud, which later get settled by melt water of the glaciers and this heterogeneous mixture is known as till and when it lithified is known as tillites. As glaciers further advances, they form ridge-like deposits composed of unsorted mixture of fine rock particles to great boulders derived from the glacier are known as moraines. The drumlins, kames and eskers are other glacier features that also provide Palaeoclimatic information.

- **Rock-types**

Some specific sedimentary rocks such as **calcretes**,which represent calcium

carbonate accumulations, form due to the near surface evaporation of groundwater and **evaporates (**composed of rock salt also known as halite and gypsum) formed by evaporation of surface water can help to identify mid to low latitudes regions with arid, dry and warm climates. The **sandstone** resulted by lithification of desert dunes, is characterised by large scale cross-bedding tells us about desert likes condition and wind direction. The **varves** are lake deposits, consisting of alternating layers of coarse and fine grained sediments that have deposited in lakes. The lake receives coarse-grained sediments at the time when sediment supply is high possibly in summer season and fine-grained when sediment supply is low in winter season. Therefore, alternating coarse and fine grained layering of sediments are considered to be associated with cyclic seasonal variation. The **limestone** (carbonate) rocks rich in coral remains indicate warm water (tropical ocean) having temperature ranging from 21 to 29°C. The **coal-bearing sedimentary rocks** are indicative of humid tropical settings. **Laterites** are brownish to red nodular soils rich in iron, aluminum and manganese usually formed in hot and wet tropical climatic regions experiencing high rainfall.

5.5.3.2 Fossils

These are remains of the ancient life preserved in the sedimentary rocks. As we know that some organisms particularly animals and plants are highly dependent on environmental conditions and many of them are narrowly adapted to specific climatic conditions. As a consequence, their fossils provide valuable clues to know the climate of the past. The fossils of **reptiles** (e.g.,lizards or snakes) are good indicators of a warm climate because they cannot live in cold climate as their body is not able to maintain constant warm temperatures. The fossils of **plant cycads** indicate tropical and subtropical ancient climate because modern cycads occur in these climatic zones. The margins of plant leaf are excellent indicators of past climate, for example, fossil leaf with smooth margins are good indicators of tropical climate whereas leaf with toothed or lobed margins indicates cold climate.

The study of growth rings in trees and corals tell us about past seasonal variation. The trunk of a tree and skeleton of a sea coral contain numerous almost circular growth rings. In each season, a new ring adds and preserves weather conditions of the particular season. As they grow, many rings are added, which reflects season history of the area during the period of a tree or coral growth. The study of growth rings in a tree for inferring climate is known as **dendroclimatology**. The study of coral's growth rings is termed as **coral clock**. Based on growth rings of corals it is inferred that Earth's rate of rotation is decreasing slowly from ancient times due to the gravitation pull of the moon.

5.5.3.3 Ice Cores

They include cores of ice obtained from perennially cold areas where no or little melting occurs such as the Polar Regions, northern Greenland, high

mountains of the Andes and the Himalaya by drilling glaciers and ice sheets. The ice cores obtained by drilling are used to study air bubbles, water and material trapped in them such as ancient atmospheric oxygen, hydrogen, carbon dioxide as well as dust and ash particles by various methods. Ice cores are useful source of past climate data of thousands of years ago.

5.5.3.4 Cave Deposits

These are calcium carbonate deposits consisting of speleothems (stalagmites, stalactites and flowstones) formed in a limestone cave and are a potential indicator of non-glacial terrestrial climate. The speleothems are secondary mineral deposits formed from groundwater within underground caverns. The speleothems possesses different types of annual laminas and preserve the seasonality. The oxygen and carbon stable isotopic analyses of each laminae tell us about the past rainfall, vegetation and other climatic factors. Cave deposits provide Palaeoclimatic evidences of around 30,000 years before present.

The reconstruction of the past climate involves the understanding and study of natural archives and the methods employed in their analysis. So, it is not necessary that our interpretation of proxy data is not always accurate. We should be aware about present day climatic relationships of various geological climate proxies and it will help us to overcome the difficulties associated with each climate proxy described above while inferring climatic information of the past.

Check Your Progress 1

Note: i) Use the space given below for your answers.

ii) Check your answers with those given at the end of the unit.

1) What is palaeoclimate?

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2) Which type of palaeoclimate does tillites indicate?

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3) Fossil leaf with smooth margins indicates ---------- palaeoclimate.

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5.6 CLIMATE OF THE QUATERNARY PERIOD

The Quaternary is the youngest period of the Cenozoic era and is divided into two epochs such as Pleistocene and Holocene (Table 5.1). It is a period of greater climate changes since the past 60 million years (Bradley, 2015). The climatic history of Earth since 2.58 million years ago to present is very dynamic because the large portion of the earth's surface particularly Northern Hemisphere, parts of Antarctica and high mountainous regions, repeatedly witnessed widespread glaciations. Therefore, this period is referred to as "the Great Ice Age". This age is not over yet, in fact, we are living in the inter-glacial (warm) stage of this age. The oxygen and carbon isotope ratios, growth rings in trees, cave and glacial features, lakes and dune deposits, microfossils, pollen grains and ice cores are climate proxies that are commonly utilised to reconstruct the climate of the Quaternary period.

5.6.1 Pleistocene

The Pleistocene epoch starts from 2.58 million years ago and ends at 11,700 years ago. Commonly, Epoch is a subdivision or time-unit of the geological time scale. The study of various climate proxies of the Pleistocene epoch clearly shows that it was a time of radical climate changes and emergence of humans (http://content.inflibnet.ac.in). At the close of the Pliocene and the beginning of the Pleistocene, there was shift in global climate at around 2.5 million years ago, as a consequence, climate became cooler and the genus *Homo* (i.e. humans) evolved from australopithecine (ape- and human-like primates) ancestors in response to climate change. In addition, the beginning of the Pleistocene is also marked by the first appearance of other mammalian genera: *Bos* (bovid), *Elephas* (elephant) and *Equus* (horse) (Mathur, 2005). The climate of the Pleistocene is characterised by an orderly sequence of inter-glacial–glacial–inter-glacial periods. During this epoch, the cold climate intensified, which led to the development of extensive ice sheets and mountain glaciers in high latitude and high altitude regions of the earth. It includes larger part of the Northern Hemisphere (USA, Canada, Greenland, Europe, Asia and northern Russia), Antarctica, South America and mountainous areas of the Rockies, Alps, Himalaya, Kilimanjaro and Mount Kenya. The maximum Pleistocene glaciations occurred in the Northern Hemisphere. Therefore, the massive ice sheets covering the parts of Eastern North America, Western North America, and Northern Europe are termed as

the Laurentide ice sheet, Cordilleran ice sheet and Scandinavian ice sheet, respectively. It is interesting to note that during the Pleistocene epoch nearly 30% area of the earth's surface was covered by the ice sheets and glaciers, and around 20 alternate cycles of glacial–inter-glacial stages have been documented. The cold interval when glaciers are very extensive is known as glacial stage, and warm and dry interval between two intervening glacial stages when glaciers are less extensive is termed as inter-glacial stage.

In the Pleistocene, the tropical regions received maximum rainfall and experienced humid climate. The period of maximum rainfall is known as pluvial period and intervening period of dry climate between two successive pluvial periods is described as inter-pluvial period. The pluvial periods as stated above experienced maximum rainfall, caused the flooding in the rivers and streams and formed extensive flood plain deposits consisting of layers of sand, silt and gravel. It is observed that glacial–inter-glacial and pluvial–inter-pluvial intervals are interrelated. The deciduous and coniferous forests were more common during the warm period; however, grasses, lichens and mosses dominated land during the winter period.

Geologically, the Pleistocene epoch has been classified into three subdivisions: Lower, Middle and Upper. And, each of these subdivisions had experienced episodes of glacial–inter-glacial. Four glacial and three inter-glacial stages have been documented in the Pleistocene (Table 5.2).

Table 5.2: Glacial–inter-glacial periods of the Pleistocene

Epoch		**Glacial–inter-glacial stage**	
		Europe	**North America**
Holocene		Inter-glacial	Inter-glacial
Pleistocene	Upper (12,600 to 11,700 years ago	Wurm Glaciation	Wisconsinan Glaciation
		Riss-Wurm inter-glacial	Sangamonian inter-glacial
		Riss Glaciation	Illionian Glaciation
	Middle (78,100 to 12,600 years ago)	Mindel-Riss inter-glacial	Yarmouthian inter-glacial
		Mindel Glaciation	Kansan Glaciation
		Gunz-Mindel inter-glacial	Aftonian inter-glacial
	Lower (2.58 million to 78,100 years ago)	Gunz Glaciation	Nebraskan Glaciation
Pliocene			

The four pluvial periods such as Kageran, Kamasian, Kanjeran and Gamblian have been recorded from Africa and their occurrence were corresponding to the occurrences of Gunz, Mindel, Riss and Wurm European glacial stages. Many mammalian fauna such as woolly rhinoceros, woolly mammoth, Columbian mammoth, cave lion and rein deer adopted the cold climatic conditions.

5.6.2 Holocene

The Holocene is the current or recent interval of the geologic time scale (Table 5.1). It starts with the end of the last Pleistocene major glacial stage, about 11,700 years before present and continues to the present day. It is subdivided into three ages (Table 5.3). It is relatively a warm period during which human influences had been significantly altered the Earth system particularly its environment. Initially, humans altered Earth's environment by hunting, cutting down trees, farming (agriculture) and latterly, by establishing civilisation, building towns and cities, industries with burning of fossil fuels, extracting natural resources, and finally, by establishing huge networks of transportation and communication systems (Stanley, 2009). It is noted that humanity has broadly influenced the Holocene environment of earth, therefore, it is sometimes also known as Anthropocene. The term Anthropocene is an informal name and till date Holocene is a valid epoch.

Table 5.3: Holocene Time Scale

Period	Epoch	Age	Duration in years
Quaternary	Holocene	Meghalayan (Late)	4,200 to present
		Northgrippian (Middle)	8,200 to 4,200
		Greenlandian (Early)	11,700 to 8,200
	Pleistocene	Upper	12,600 to 11,700

The Anthropocene refers to 'Age of Man'. In simple words, the Anthropocene can be described as the geology of humanity, which focuses on the cumulative role of humans as geologic and geomorphic agents in altering the Earth's environment by multiple ways such as through agriculture, mining, industrialisation, urbanisation or globalisation. The word Anthropocene was extensively used in the scientific literature of China during the 1990s in informal way. In 2000, Paul Crutzen and Eugene Stoermer formally presented Anthropocene and also discussed it in the context of geological time scale. The Anthropocene is less popular concept as compared to the global warming (Syvitski, 2012). The Anthropocene is still an informal time unit and its beginning is still a matter of debate, but many workers believe that it began with the Industrial Revolution in Europe around 1800 years before present (Zalasiewicz and others, 2019).

The Holocene epoch is very important for us because it shows how Earth's environment reached to its present form. It also experienced varied cycles of

climate change (Table 5.3). It should be noted that radiocarbon dating method (Carbon 14) with half-life 5,730 years serves as an excellent method for dating Holocene sediments and organic remains. The Early Holocene (11,700 to 8,200 years before present) was a time of global warming and moist conditions prevailed in tropical dessert areas. About three episodes of high sea level elevation were recorded during this interval based on remains of reef-building sea corals. The dry interval of the Early Holocene is described as Boreal period and wet as Atlantic period (Table 5.4). The Middle Holocenewas a time of high warming and global temperature rose by 4° to 5° C. During this interval, Arabia and India experienced higher monsoon circulation (Mathur, 2005). During the Early and Middle Holocene between 9,000 and 6,000 years before present, many continental glaciers disappeared. The dry and warm climate of the Middle Holocene is termed as Subboreal environmental period (Table 5.4). The Late Holocene (4,200 years before present to present) witnessed rapid warming and cooling intervals. Between 1445 to 1700 AD, the Arctic region covered by ice and many glaciers advanced which gave rise to Little Ice Age. The record shows that climate is fluctuating in the Late Holocene. The wet and cool climate of Late Holocene is named as Subatlantic environmental period.

Table 5.4: Holocene climate (modified after Mathur, 2005)

Epoch	Glacial stage	Environmental period	Age based carbon 14 method (in years before present)	Climate
Holocene	Post glacial	Subatlantic	2,500 to 0	Wet and cool
		Subboreal	5,000 to 2,500	Dry and warm
		Atlantic	8,000 to 5,000	Wet and warm
		Boreal	10,000 to 8,000	Dry and warm
Pleistocene	Late glacial			

In nutshell, we live in the Holocene. This epoch possesses relatively high sea level, minimal ice covers (which are still extensive in Polar Regions and high elevation of the mountainous regions), mid-latitude deciduous forest and huge expansion of human population (Bloom, 2009). The modern and industrial society of humans have continuously been altering earth's environment by burning fossil fuels and adding high concentration of carbon dioxide as a byproduct of fossil fuels combustion into the atmosphere. It is altering the climate system and, thus, causing the global warming.

Check Your Progress 2

Note: a) Use the space given below for your answers.

b) Check your answers with those given at the end of the unit.

1) The Pleistocene epoch starts from …… and ends at ……. .

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2) List the four Pleistocene glacial and three inter-glacial stages of the Europe.

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5.7 LET US SUM UP

In this unit, you have learnt the following:

- Palaeoclimate is the science dealing with the study of past climate.
- Palaeoclimatologists used climate archives or proxies to unravel the past climate of the Earth.
- Historical data, archaeological data and geological record are the main climate archives
- The logs of the farmers', dairies of travellers', ancient inscriptions, newspapers, paintings, artistic depictions, reports of the early weather observers and other public records are the sources of historical data.
- Rock layers, minerals, soil, remains of plant and animal, and artifacts are the main sources of archaeological data.
- The geological record consisting of sedimentary rock types (sandstones, evaporates, calcretes, tillites), fossils, ice cores and cave deposits yield clues of past climate.
- The Pleistocene epoch starts from 2.58 million years ago and ends at 11,700 years and it is period of extensive glaciations particularly in the Northern Hemisphere, Antarctica, South America and mountainous areas of the Rockies, Alps, Himalaya, Kilimanjaro and Mount Kenya.
- Four glacial and three inter-glacial stages are known from the Europe and North America during Pleistocene epoch.
- The Holocene is the epoch where we live. It starts with the end of the last Pleistocene major glacial stage, about 11,700 years before present and

continues to the present day.

- The Holocene is relatively a warm period during which humans have significantly altered the Earth's environment.
- The "Anthropocene" refers to 'Age of Man' describes geology of humanity and focuses on the cumulative role of humans as geologic and geomorphic agents in altering the Earth's environment by multiple ways.

5.8 KEY WORD

Proxy: A proxy climate indicator is a record that is interpreted, using physical and biophysical principles, to represent some combination of climate related variations back in time. Climate-related data derived in this way are referred to as proxy data. Proxy data can be calibrated to provide quantitative climate information.

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5.10 ANSWERS TO CHECK YOUR PROGRESS

Check Your Progress - I

1) The term palaeoclimate refers to the climate of the past. The science of studying the modern climate is termed as climatology, similarly, the science dealing with the studying of past climate is known as palaeoclimatology. The word palaeoclimatology is a combination of the Greek words "*Palaios*" - (ancient) + "*clima*"- (climate) + "*ology*" - (branch of learning) and therefore it refers to the study of past climate.

2) Tillites are lithified glacial deposits and indicate a cold glacial climate.

3) Tropical

Check Your Progress-II

1) 2.58 million years ago; 11,700 years ago.

2) The four European glacial stages are the Gunz, Mindel, Riss and Wurm. The three inter-glacial stages are the Gunz-Mindel, Mindel-Riss and Riss-Wurm.