Evolution of the Earth and Life
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Cenozoic Climate

Welcome to the course Evolution of the Earth and Life. Today we are going to learn about cenozoic climate. Nowadays, we talk a lot about changing the climate. But it is important to recognize that the climate has also changed in the past multiple times. Today, we are going to focus on some of the issues that may lead to change in the climate, and some of the natural variabilities.

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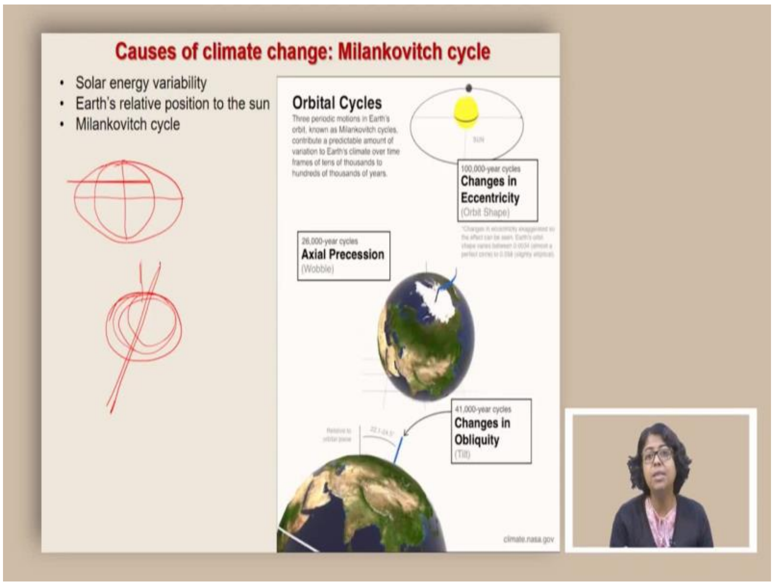

So one of the major changes, natural changes in climate is caused by the Earth's relative position to the sun. And this is in summary called Milankovitch cycle. So it has different aspects to it, let us try to understand a bit about it. So the first one that I am going to talk about is the orbital cycle. So there are three periodic motions in Earth's orbit, known as Milankovitch cycles.

And that contribute to a predictable amount of variation in Earth's climate, over the timeframe of 10s of 1000s to a 100s of 1000s of years. So there are different types of variability in terms of its timescale. So let us go by through one by one. So the first one is the one how the Earth is circling around the sun.

Now, if we look at the orbit, we will see that the orbit actually changes over time. So sometimes it is a completely circular one. Whereas sometimes, it is a bit elliptical one. And depending on whether it is a complete circle versus elliptical one, we will see a difference in the intensity of the seasons. And the changing intensity of the seasons finally lead to an overall change in the climate. And this has a periodicity of 100,000 years. So we will see a change every 100,000 years because of this change in the orbital shape. And this is called the eccentricity the eccentricity basically means how elongated the orbit is, what is the ratio of major and minor axis of the circle that or the ellipse that we are going to talk about.

So when it is equal, then it is a circle, but when it is unequal, then we are talking about an ellipse. So this leads to a variation in climate through time. The second one is called an axial precession. This is something like how our top wobbles when we let it move. So often, the top wobbles like this. And this means that it is coming relatively closer to the Sun in each of these times, depending on exactly what position it is in.

So instead of this axis staying at the same place, it actually has a circular path, which is covered in every 26,000 years. And therefore we can expect some changes in every 26,000 years, in terms of the overall seasonality and seasonality and duration of the season finally leads to the change in the climate.

The final one is the obliquity the obliquity refers to the tilt of the earth. Now, if we look at the Earth, and its axis, it actually makes an angle with the orbital plane and this angle changes. So sometimes it comes closer and it makes a relatively smaller angle sometime around 22.1 degree, but sometimes a relatively larger degree 24.5 degrees, and depending on how tilted it is, or less tilted it is. It is going to determine again, something related to seasonality.

And finally, that will accumulate and change in the climate. So these three cycles are extremely important. And all of these three, reflecting some change in the climate over time, and combinely this is called Milankovitch cycle. The obliquity has a periodicity of 41,000 years, precession has the periodicity of 26,000 years, and eccentricity has a periodicity of 100,000 years.

Now, it is important to recognize that they are not independent. So, all of these will appear in their own cycle and they will superimposed on each other. So, eventually when we look at the record of climatic variation over time, we are going to see some of the signatures of all of these cycles.

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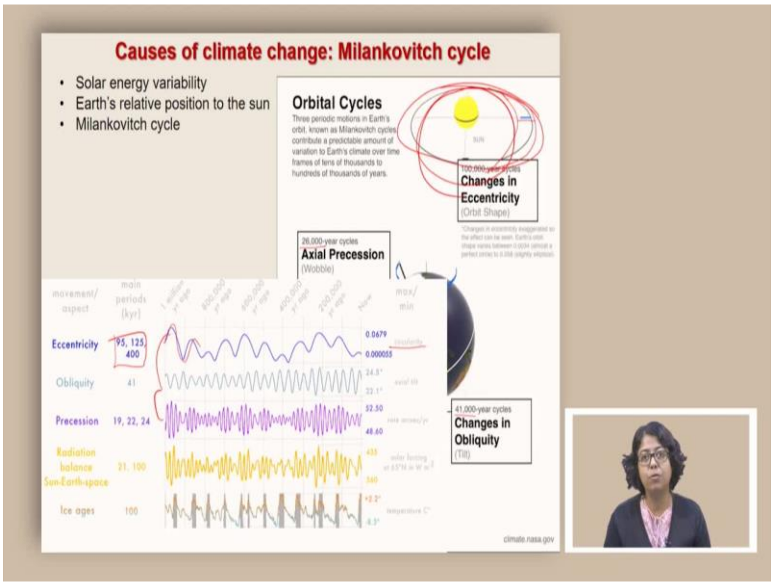

So now if we look at how it looks like it will look something like this, so for obliquity, or for centricity, we are going to see a cycle which looks something like this. And again, the main periods in terms of kilo years, we will we are talking about 95,000 years. And again, the main reason for this is the circularity, as we talked about here that sometimes the axis comes very close to the sun. And sometimes it is actually quite oblique it is sometimes it comes as a circular shape.

And therefore, the changes radiation from the sun is not very much within a single year. But sometimes because of the change in the axis, which looks more, sir. elliptical, the seasonal variation becomes extreme. So that is what the pattern we are expecting out of eccentricity, obliquity on the other hand, as we said that it is going to have a 41,000 years periodicity, we are going to see a change something like this. And it has a relatively small change in terms of the magnitude and also in terms of how frequently it is appearing.

Precession, as we said that it can vary, and somewhere between 26,000 years, so it can be 1922 or 24. And we are going to see patterns like this. And when all of these are super imposing all 3 of them, then we can try to check that over time, how it is going to look like. And what we find is now if we try to look at the overall climate, it often matches with the climate changes in terms of glaciation and deglaciation. So glacial periods and interglacial periods, it often matches. So large scale variability of climate over time, is often explained by this Milankovitch cycle.

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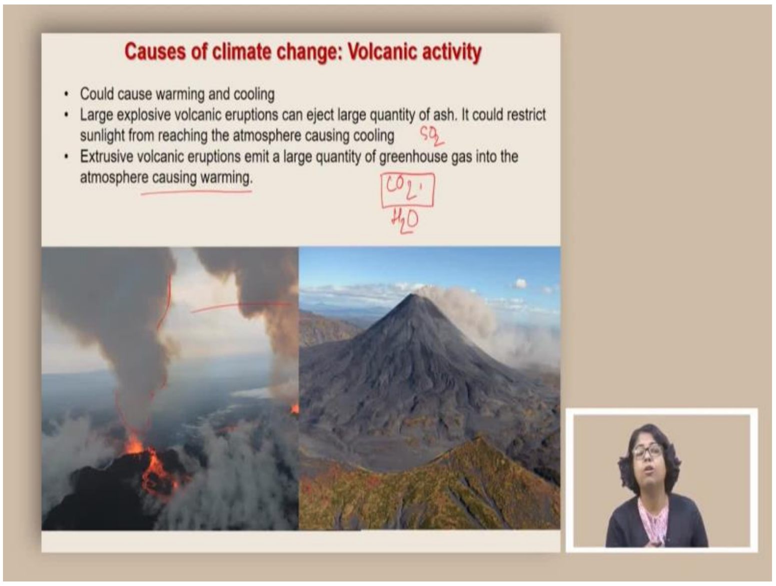

The second important component that can contribute to climate change is the Earth’s inner activity, primarily through volcanism. Volcanism, can actually cause warming as well as cooling, depending on what kind of volcanism we are looking at. Sometimes large scale extrusive volcanism, explosive volcanism, they can erupt a large quantity of ash and these ash could restrict sunlight from reaching the atmosphere and therefore, it can cause cooling.

Sometimes what happens these ash can actually have a global coverage, and if it covers the entire globe, it will experience a sunlight blockage for a prolonged time. And that can lead to an overall drop in the temperature for over a period of time that spans maybe a few months. And that means the seasonality changes and that can lead to an overall temperature drop.

More importantly, apart from ash sometimes these volcanoes also emit sulfur dioxide and sulfur dioxide when mixed with water. It creates sulfuric acid, and this sulfuric acid could create these droplets and that can spread the overall atmosphere over the entire globe. And that can also vary actively stopped the sunlight to penetrate inside and therefore block it further prolonging the stoppage of the sunlight inside and therefore creating a very cold atmosphere.

There are instances where such a volcanism has been related to regional temperature drop, especially some volcanic eruptions in the Southeast Asia has often been linked to temperature drop in Europe. Because it is a global phenomena and these ash as well as sulfur dioxide vapor, they can travel for a long distance.

On the other hand, extrusive volcanic eruptions often emit a large quantity of greenhouse gas, such as carbon dioxide, methane, water vapor, all of these can contribute to the overall greenhouse budget of the atmosphere and thereby increasing the temperature. So this can also lead to global warming. In fact, in the past history of our planet, there has been multiple situations where there was ice house effect or there was global glaciation. And those glacial cycles were broken, because of massive eruption of volcanism, which emitted large amount of carbon dioxide, water vapor and methane, which finally led to and warming of the environment, and therefore, blocking or stopping this spread of the glaciers.

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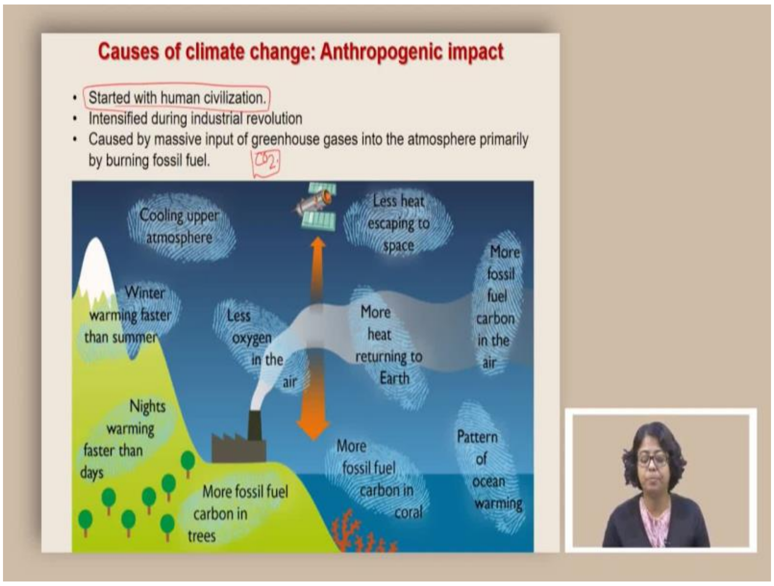

The third one, which we are more familiar with is the anthropogenic impact. This started primarily with human civilization, it is not during only the industrial revolution, but it actually happened before also, even before industrial revolution, because of the burning of plants, it emitted a lot of carbon dioxide, and that led to the overall change in the atmosphere. And it has intensified during the Industrial Revolution.

So, the primary change that we see is caused by the massive input of greenhouse gases, which includes primarily carbon dioxide, but it also has other components a bit of methane. And this leads to the atmosphere, and finally, it warms up the atmosphere and this carbon dioxide, methane and many of these things are produced, because we are burning the fossil fuel.

Now, there are other related issues, which are also coming with these anthropogenic impact. But right now, we are only focusing on the change in the atmosphere and leading to the climate change. Now, it is important to recognize that because this is primarily done because of the human's civilization, this anthropogenic impact is not present in the deep history of the earth. So when we look at the climate change recorded in the past history of the Earth, that tells us something about the natural variability and the natural causes of climate change. And that also helps us to understand how the anthropogenic impact that we see today is adding to those natural changes in the climate.

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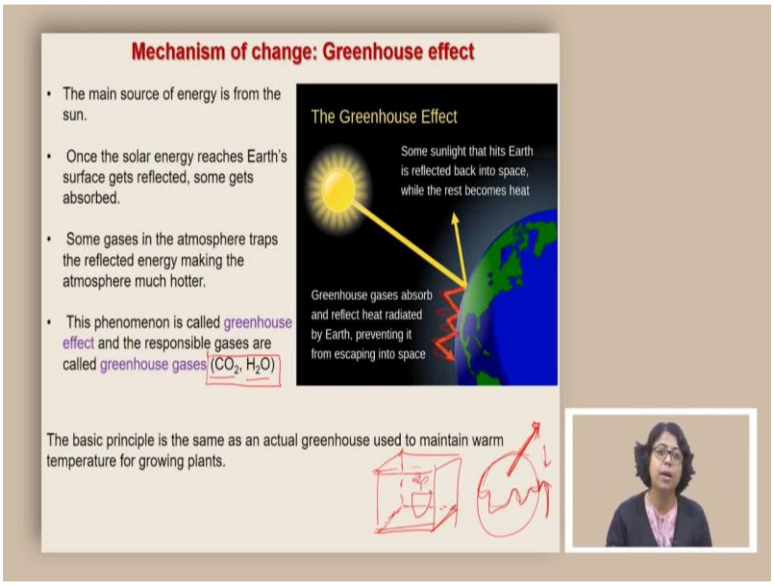

Now, once any of these factors are working, be it the Milankovitch cycle. Milankovitch cycle primarily governs the climate primarily by the distance from the Sun in different ways in different cycles. But apart from Milankovitch cycle, the other two factors that we talked about, one is volcanism, the other one is anthropogenic impact.

Both of them primarily contribute to changing the climate by changing the composition of the atmosphere. So we talked about changing the composition of the atmosphere through volcanism, or through anthropogenic impact. And one of the ways of doing it is by adding carbon dioxide and water vapor.

Now carbon dioxide and water vapor they are in gaseous form. And the main source of energy for the entire Earth is sun once the solar energy reaches Earth surface, it gets reflected, and some gas is absorbed. Some gases in the atmosphere traps the reflected energy, making the atmosphere much hotter. So it is almost like reflected part is never going back, it is basically keeps on hitting the surface again and again. And that is what cumulatively increases the temperature.

And this phenomena is often called a greenhouse effect. And the responsible gases are called greenhouse gases such as carbon dioxide, water vapor, methane, because this principle has been adopted by people in the colder region, to grow vegetables and fruits and flowers, they use to construct a glass house, because glass also has this property where it traps the heat and does not let it go out.

So therefore, once they created this greenhouse, and they can basically plant things, and because the outside temperature is very cold with the plants will otherwise die, if it is kept in this glass house, then they grow. And they flourish because of this extra heat that is trapped inside the glass. And this is generally called the greenhouse. And just to take that analogy, for the atmosphere, this particular phenomena is called a greenhouse effect.

Now, it is important to also recognize that this is greenhouse effect, and the opposite of it is often called an ice house effect. What it means is, if you have a reduction in the amount of these gases in the atmosphere, then the atmosphere will also have this tendency of not trapping any temporary, any heat inside and therefore becoming cold. In fact, many of the planets, which are at the same place, or which could be around the same place as earth, of the same size, might not have the exact same temperature, because earth has a temperature, which Earth has an atmosphere, which can trap the heat and therefore keep the Earth warm.

If there are other planets, which are at the same place, and do not have the atmosphere, we will find that they are much colder than the Earth simply because they do not have this insulating effect, and they do not have this greenhouse effect that is provided by the Earth's atmosphere.

Now, when we were talking about the ice house effect, there is another important component that we should remember that once because of the cold temperature, the ice forms and in the earth, part of it becomes glaciated, these glacial mass also reflects back the solar radiation. So therefore, part of the solar heat, sun's energy is reflected back. As a result, it also becomes cooler.

So it is important to remember that ice house effect and overall drop in the temperature if it leads to development of glaciers, they will further lead to a drop in the temperature. And in Earth's history, it has been observed multiple times that there are times of global glaciation. And one of the ways of breaking that cycle of going to colder and colder temperature is through volcanism, which can add greenhouse gases in the atmosphere, and therefore make the atmosphere hotter, so that it is balanced by this loss of the heat through albedo effect.

So this is one of the ways of balancing the temperature in that most fear, and also one of the mechanisms of climate change.

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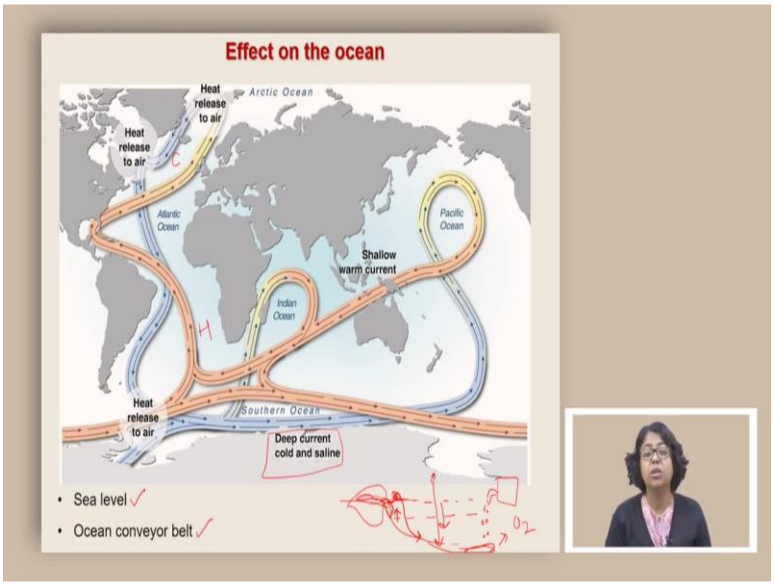

Now what happens if things get colder or things get warmer, one important effect is on the ocean. The first thing that we are familiar with is the sea level. Now once you have the coast and then the level drops, we have a sea level where we can observe the sea water. Now this sea level fluctuates a little bit depending on which part of the day we are looking at whether it is being affected by the tides, and all of these will finally reflect in the changing the sea level.

But very importantly, if that global temperature changes, it also affects the sea level, one of the ways that it can happen is when the temperature rises, the water becomes hot, and if something gets hotter, the volume expansion happens. So, therefore, that contributes to the overall increase in the sea level.

The second point that contributes to the sea level is there a lot of water, which is locked up as ice in the continent, and once you start melting them, you are adding extra water to this sea level to this sea volume, as a result, the sea level is going to rise. So, this is an important concept that to remember that with increasing temperature, the overall sea levels should rise the overall in start sea level, and partly because of the volume expansion, partly because of the addition of extra water through melting of the ice.

And once we do that, that means we are also inundating lots of lands, which were otherwise above the sea level. And because we are increasing the sea level, the sea water is basically going to retake this part of the land. And therefore, organisms which were living here will die. As a result of this increasing sea level.

The opposite is also true when the sea level drops, the marine organisms if they were living here, they will be exposed, and they will also die. So, sea level is a critical point, which is reflecting the change in the climate, and therefore, has an important implication on the overall bio biodiversity of the earth.

The second important component is that ocean convection system. So, the ocean is not a static body, the ocean water, it constantly moves, and there is a pattern in which it moves. And the pattern is primarily guided by the temperature as well as the salinity of the water. So, if we look at the convection, the heated water in the tropics, they basically go into a long journey to the colder region.

And once they go to the colder region, they lose the heat and therefore, they become cold, they become dense, and therefore, the sink inside, this is also a part where they also take a lot of oxygen in it, because they are when they are at the surface they can take oxygen and also salinity plays a role.

And once they become cold, they becomes dense. And this oxygen rich, cold water dives down in the ocean section. So we can think of as surficial ocean current, it basically goes down, but then it goes through a journey, which covers the entire world. And this is one of the major sources of oxygen in deep water ocean.

Now, if we change the temperature, for example, if we make it very cold, then often what happens this convection does not work, because it is cold, we do not have this gradient of heat hot versus cold, because the entire thing is getting cold and we do not see these oxygenated water going down.

And therefore the organisms which are living very deep part of the ocean, they are not going to get enough oxygen because the oxygen from the atmosphere actually cannot go directly to the bottom part of the ocean. And this is called ocean anoxia. So often, if the temperature is too cold, and it is a completely glaciated part of the earth, this convection gets impacted.

Now, it is also claimed that if you increase the temperature that also impacts this conveyor belt and the strength of the conveyor belt reduces. So any change in the temperature will impact the sea level as well as ocean conveyor belt.

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Then there are other aspects which leads a runaway effect. So if there are warming it often leads to more warming. So there is something called Fire ice. It is originally thought to occur only in the outer regions of the solar system where the temperatures are low and water ice is common. But then, researchers started to find it even in the deep parts of the ocean. These are methane hydrates.

In colder climate methane gas gets trapped within water crystal structure, and it forms a solid, which looks similar to an ice, but it is actually methane and therefore it can catch fire. And they are common in shallow and deep building deposits, they have been identified in different parts of the earth. And with increasing temperature, they melt and release the gas.

Now we know that methane is a very, very potent greenhouse gas. So if the temperature increases for other reasons, and that starts to also melt these methane hydrates, we are adding more methane to the atmosphere, which will create that atmosphere even hotter. So, warming often leads to more warming, and primarily through these hydrates and release of methane into the atmosphere.

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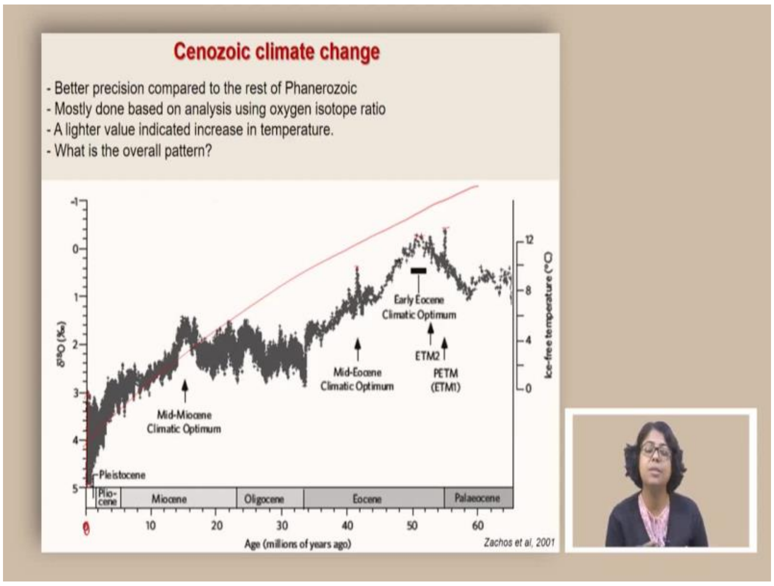

Now using all of these understanding letters, try to look at the Cenozoic climate change, we look at the Cenozoic climate change, because we have much better precision compared to the rest of Phanerozoic. It is mostly done based on the analysis using oxygen isotope ratios of the marine organisms so that we understand the marine changes in temperature better.

As we know, a lighter value indicates an increase in temperature. So now if we look at the temperature, this is what we see today. This is modern day and there is a large spread that we can see. But if we look at the temperature somewhere in the beginning of Cenozoic, it is actually showing a much higher temperature.

And what it is telling us that overall the temperature is actually coming down. And that is why we recognize that we are actually living in glacial time. It is not greenhouse time, it is actually a glacial time that we are looking at.

Another important point in the Cenozoic history there are times of extremely hot climate. One such thing is called a PETM Paleocene Eocene Thermal Maximum. But there are other ones also we chose very high temperature early years in climatic optimum mid miocene in climatic optimum. So these are really high points.

And people have been curious to understand what may have caused them and how the world changed during this time. Because if we are facing a very large climate change towards global warming, these can tell us something about how the overall system changes.

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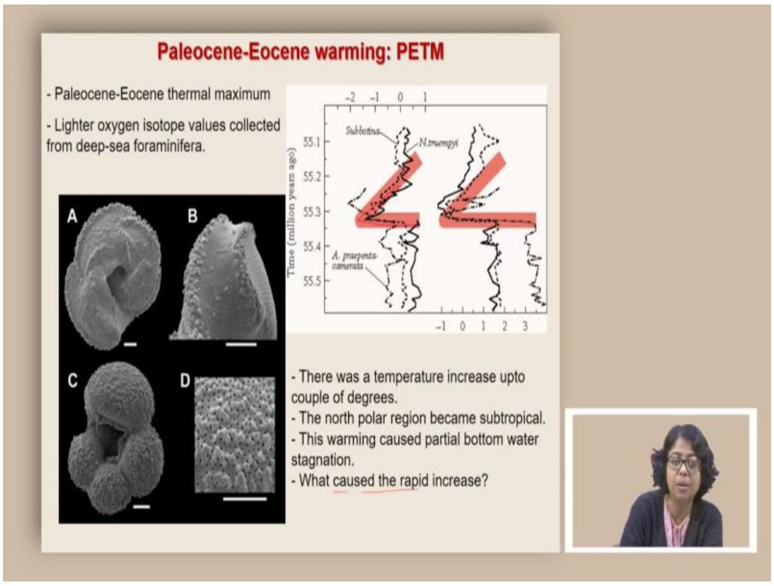

So Paleocene Eocene Thermal Maximum is one event in a Cenozoic, which shows our lighter oxygen isotope value collected from the deep water foraminifera, which indicates that it was a very, very high temperature, the temperature increase was up to a couple of degrees and the North Pole region became almost subtropical.

The warming caused partial bottom water stagnation and therefore, we do not see a very nice circulation pattern, which has been recognized from other isotope signatures. Now the question is what caused the rapid increase? Now one idea is probably the initial part of it is connected to these Milankovitch cycle or other points.

But eventually, once the start of the warming happened, it could lead to these methane hydrates release and methane released to the atmosphere eventually finally culminating into a very, very high temperature change, very large warming event. And that is what creates this kind of a peak in the Paleocene Eocene time.

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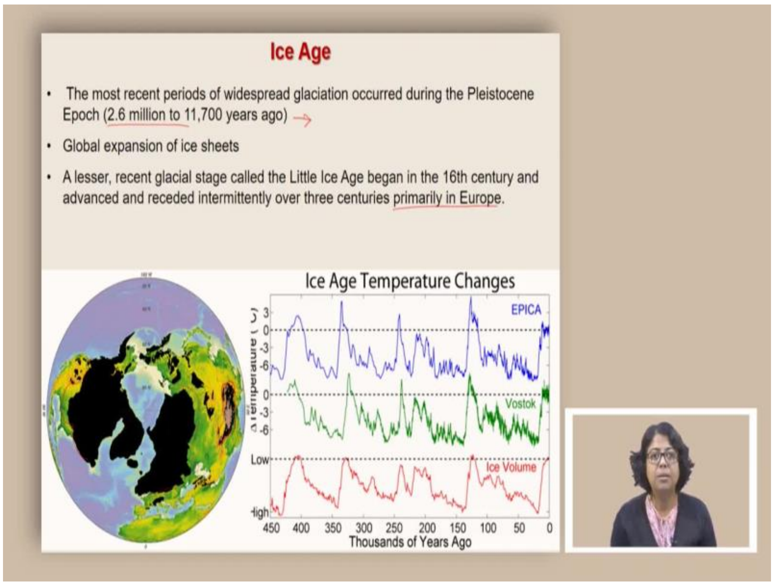

In contrast, a very recent event actually shows us a completely opposite pattern. The most recent period of widespread glaciation occurred during Pleistocene epoch, which ranges between 2.6 million years to 11,700 years ago. This is basically a time when we see a global expansion of ice sheets. This is a globe where the black apart show the extent of the glaciers. And what we see that the northern part of North America is covered by the glaciers. A large part of Europe is also covered by glacier, the Himalayan region, as we see, it is covered by the issues.

So overall contributions of the continental glaciers are large, and signatures from the paleoclimatic reconstruction, either from the ice core, or other proxies also show that there has been major changes in the climatic condition. And it is primarily a very low temperature, and varying between glacial and interglacial period.

So this is the peak of the glacial period. And then it constantly goes back between glacial and interglacial period. This ice age also had a major impact on the type of mammals that were found around this time. A lesser or more recent glacial stage was found in Europe, and which is called a little ice age, which began in 16th century, and it advanced and receded relatively in short period of time within three centuries, and it impacted primarily Europe.

So there are already documented ice ages in the last part of the history of the Earth, that we are studying.

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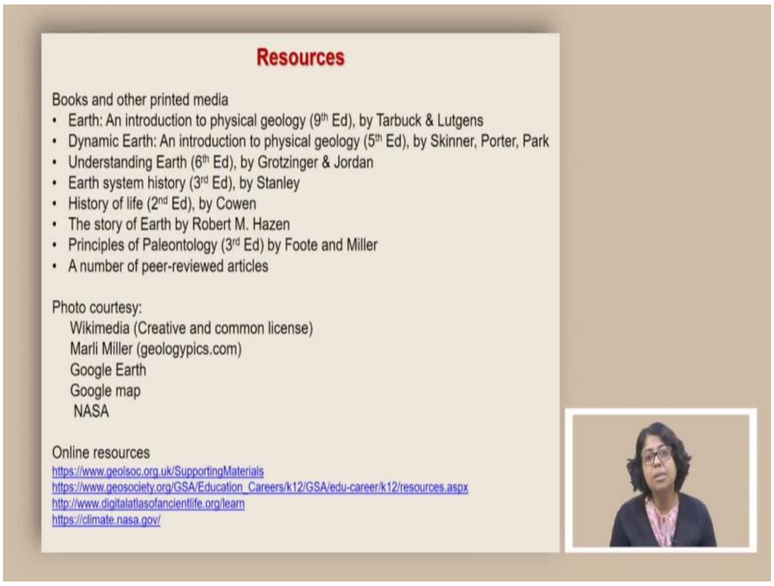

But now, we are in our time, where we know that things are changing significantly. And it is not because of the glacial period, although we are actually sitting in as part of glacial and interglacial period, it is not because of that it is the change in the overall atmospheric composition, which is creating the overall change in the temperature, the global warming.

So in today's class, we learned something about the natural variabilities of the climate that has different periodicity. Some of it can be explained by Milankovitch cycle, which explains how the earth seasonality can change depending on the its position in the orbit, or its wobble, or it is tilt of the axis.

It can also change because of the change in atmospheric composition, that can be brought by the volcanism that can also be brought by anthropogenic activity. Finally, using the Paleo climatic reconstruction proxies, we can look at the changes in the climate in the Cenozoic and which shows that there were times of Cenozoic, especially Paleocene Eocene where the temperature was really high, much higher than what we are experiencing today.

At the same time, overall, the last million years have experienced very cold climates, including the Pleistocene glaciation and the little ice age which happened in around 16th century. But the today's rise in temperature is primarily caused by the anthropogenic impact, which is changing the atmospheric composition, and once changes happen in the temperature, it leads to changes in the global circulation pattern of the ocean and the sea level, which finally leads to a disturbance in all the groups that are living in the sea, as well as impact the groups that live on the terrestrial realm. Here are some of the resources that I used for the slides.

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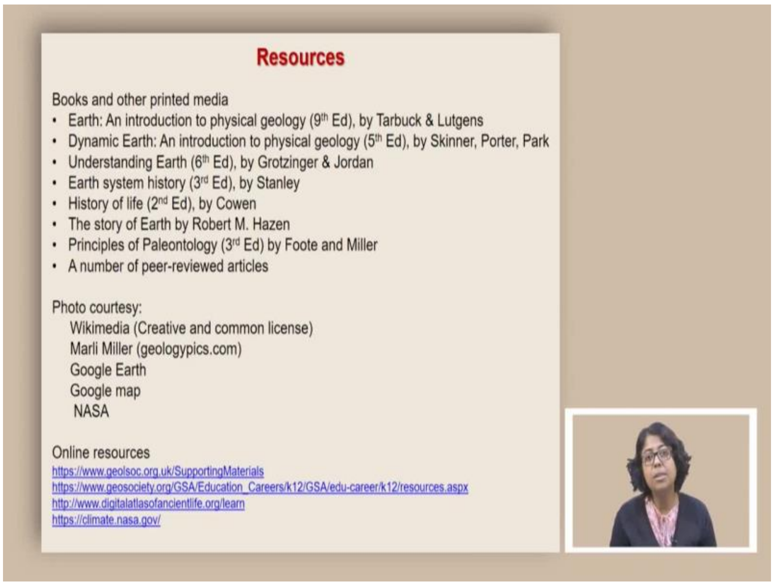

And here is a question for you to think about. Thank you.