**Evolution of the Earth and Life**
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**Paleoclimatic Reconstruction**

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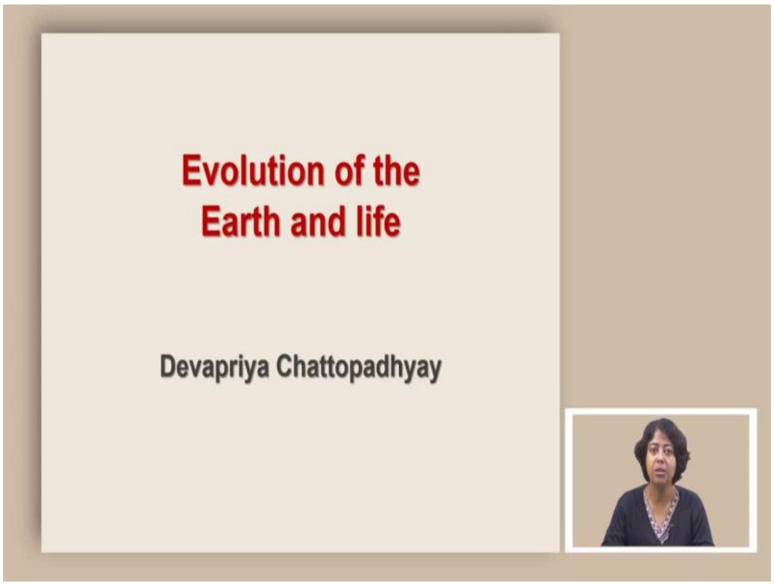


Welcome to the course Evolution of the Earth and Life. Today we are going to learn how do we know anything about the past climate, we are going to talk about paleoclimatic reconstruction.

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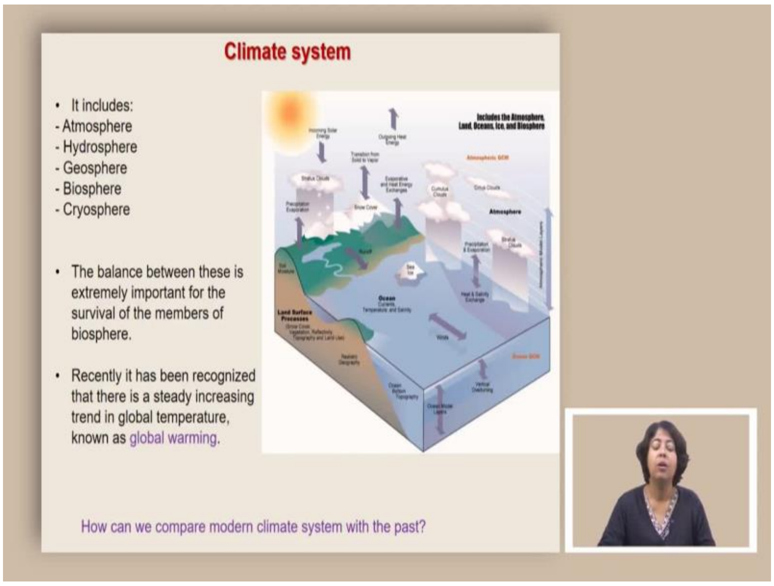


Let us first understand what we understand about climate system. So climate actually is influenced by multiple spheres of the Earth. It includes atmosphere, hydrosphere, geosphere, biosphere, and cryosphere. Now atmosphere is the gaseous layer above the lithosphere that we take our breathing air from. Hydrosphere includes the oceans, the rivers, the groundwater, geosphere, or lithosphere, is the solid rock part that provides the landscape. And also it is connected to the mantle convection.

Biosphere is constituted by all the living organisms, the actually span from geosphere to hydrosphere, to all the way to atmosphere, and then cryosphere is the part which includes all the frozen form of the water. So it includes glaciers, mountain glaciers, as well as continental glaciers. Now, all of these spheres are connected through processes and all these finally contribute to the climate system.

And the balance between these are extremely important for the survival of the members of biosphere. As a result, we are always concerned about the climate system. And this has not been just the concern of today, even in the past time, the biology has considerably changed as a response to change in climate system. Now, the question is, today we are concerned about a major change in the climate, as we all know that there has been a steady increase in the trend of global temperature, we call it the global warming.

Now, when we try to understand what might be the repercussions of this increase in temperature, we also want to know the long term record of such increase in temperature, what are the other spheres which are going to be effected? What is going to be the magnitude of these effects? So therefore, we are always interested to know how the past temperature record looked like or how the past climatic record look like? But the question is, how do we decipher the climate of the past when we cannot see them?

So today’s focus is going to be different techniques that we use to understand the past climate. We are going to first start with a bit of geochemistry.

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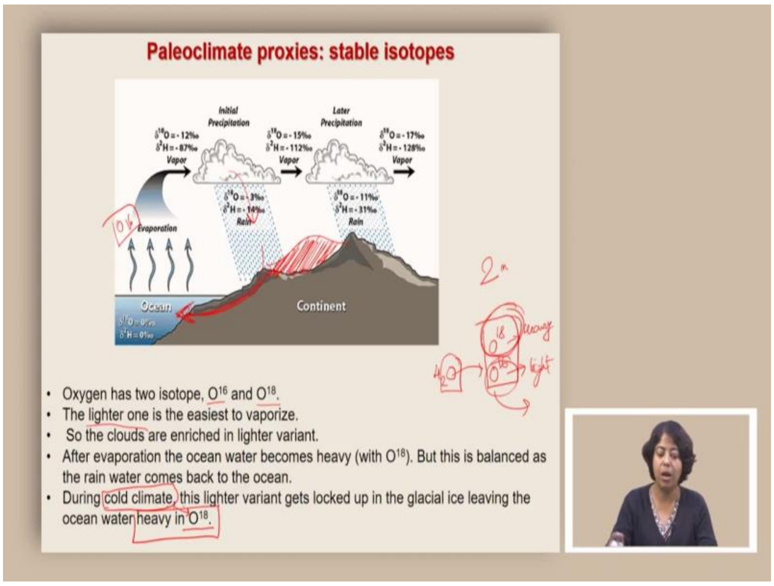


So one of the very important aspects of paleoclimatic reconstruction, or ways to understand paleoclimate or paleoclimate proxies is through using stable isotopes. Now, we know that isotopes are basically different proton neutron combinations of the same element. So, if we have two isotopes of the same element, it means that the proton number is going to be the same, but the neutron numbers are going to vary and therefore, the mass number are going to be different for the same element and there are different kinds of isotopes.

When we thought about or when we talked about the dating. We talked about radionuclides or radioactive decay, where the isotopes are not stable. They decay naturally and they create daughter products from the parent elements. But then there is another variant of isotopes which are stable. So let us take the case of oxygen. So oxygen has two isotopes. which we find commonly in the atmosphere as well as in the ocean, which is O 16 and O 18.

Now, they differ in terms of the number of the neutrons, the proton number remains the same, because the proton number actually collides, the chemical reaction or the behavior of the element neutral number on the other hand, is not going to change their behavior in terms of taking part into a chemical reaction. So, for both O 18, oxygen 18 and oxygen 16 for any chemical reaction, they are going to behave in the same way.

However, because their masses are different, they are going to behave differently, if it goes from phase changes, such as going from let us say solid to a liquid phase or liquid to a vapor phase and things like that. And this is being utilized for understanding past climate, let us try to understand how it can be done.

So, as I mentioned that oxygen at this point we are going to talk about two primary isotopes of oxygen one is O 16 and the other one is O 18. Now, we know that in the ocean, there is water, so, water means H 2 O and this oxygen now has two components one is O 18 and the other one is O 16.

Now, various isotopes will have different proportion in the natural system. So, what we find is not all the isotopes are equally abundant, but they always try to maintain a ratio. Now, among these, O 16 is the lighter one, because it has less number of neutrons, whereas this one is heavy, because it has more number of neutrons. So, the difference between O 16 and O 18 is two neutrons.

Now, because this one is heavy, with the same energy, this will have more vibration, and this will have less vibration. And this is one of the reasons why the lighter one is easiest to vaporize. So every time the water is getting vaporized in the vapor, preferentially the light isotope will go. So, let us say we start with H 2 O and in the oxygen part we have O 18 and O 16 Then when we are looking at the vapor phase, we are going to find that the proportion of O 18 and O 16 has changed, it is going to be more of O 16 Than O 18 compared to the water phase.

Now, in a natural normal setting, this evaporation is going to take place. So the evaporation will create this vapor and the vapor is going to have slightly more, O 16. And this is going to form the clouds, the clouds will eventually rain. When it rains again, this finally comes back to the continent, and again goes back to the ocean and the balance is maintained.

And finally, the ocean water composition remains the same because even though preferentially O 16 is going up, it is coming back through the cycle and therefore the balance is maintained. Now let is imagine a scenario where the rainfall is not really coming back to the ocean. When can it happen? It can happen when the rain water finally freezes as ice on top of the continent. If that happens, then it is not coming back to the ocean. And the evaporation still continues and the ocean is preferentially losing the O 16.

So as a result, what will happen? The ocean water will have more proportion of O 18 during the times when there are lots of ice on the continent, compared to the times when there was no ice on the continent. And that gives us a very nice way of identifying what were the times that there were continental glaciers versus what were the time when there was no continental glacier.

And that is the primary principle, people used to understand that the cold climate, the lighter radiant will be locked up in glacial ice, leaving the ocean water heavy in O 18. And therefore, cold climate have been associated with rich O 18 signature from the ocean. And this can be used by looking at the ocean water.

Now the question is, how do we know about the ocean water? The ocean is a large reservoir, it gets mixed always. So it is not so easy to know, what was the ocean water of let us say a past time, you cannot really separate out the water of today from the water that is recycling maybe for the last 5 million years. So how do we then know which water to look at and we are going to look at some of these signatures.

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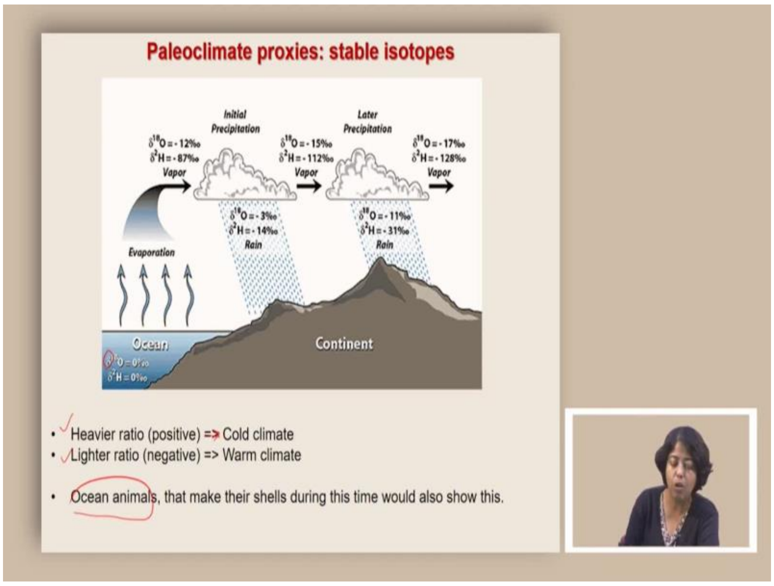


So again, that if we are finding a heavier ratio, that indicates a colder climate, and if we are looking at a lighter ratio, that indicates a warmer climate. Now there is a way of writing it, including this delta notation. But for now, we are simply going to use this general idea that heavier ratio means it is a colder climate, and lighter ratio means it is a warmer climate. Now the question is, how do we find those water, which existed, let us say a few million years ago?

The answer is very rarely do we find that water. But what we find is animals, which used that water to create their shells, ocean animals often make their shells out of the elements that are already in the ocean. And therefore they basically take this isotopic signature with their shell. And now if we can look at those shells of those particular times, that will tell us something about this heavier ratio versus lighter ratio. And then we can talk about what was the condition like when those animals were living and we are going to spend some time talking about each of these types of animals.

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So, there are different ways of looking at it. One way of looking at it is to look at the ocean sediments. ocean sediments will also contain the crushed up shells of ocean animals and the isotopic signature of those crushed up shells from the ocean sediments can also tell you something about the condition long in the long past.

But then, there are other organisms which secrete calcium carbonate shells. So these are some of the foraminifera, these are microorganisms, these are single celled organism, these are bubble shaped, these are called planktic foraminifera. And that means if we are looking at the ocean, these are the deeper zones and this is the water column. The plankton organisms are basically floating in the water column. Those are called planktic. And then there are organisms which are always on top of the sediment surface.

So these sediments are basically in between the ocean floor and the water and the organisms which are living on the sediment surface. These are called benthic organisms. And these benthic organisms have different forms. So in this case, these are benthic forams. Now both planktic forams and benthic forams many of them have their shells that means they are external skeleton made up of calcium carbonate.

Now, if we look at the calcium carbonate, it actually has an oxygen in it. And this oxygen basically comes from the ocean water. In fact, we will see that the entire thing comes from the ocean water, but this oxygen basically retains the same signature of the time of the ocean water composition. And as we know that the ocean water composition in terms of their isotopic composition, they will reflect whether it was a cold time, or a warm time. So if you know which time these foraminifera represents, you can look at their shells, extract calcium carbonate, look at the oxygen isotopic composition of that calcium carbonate. And that is going to tell you what was the condition like of the ocean.

The same thing can be done for benthic forams also. Now, because planktic forams are living in the water column, they are going to tell you something about the water column composition, whereas benthic forams are going to probably tell you something about the sediment water interface, a slightly deeper part of it. And because these forams are very sensitive to depth, not all forams live at the same depth.

If you know something about their biology and ecology, you can go to even further detail of which depth of water is showing what kind of isotopic signature, then you can reconstruct almost the entire part of the ocean and different depth at different places of the earth. And talk about the global climate pattern, especially reflected from the ocean water chemistry.

Now, the other way of looking at it is not to look at isotopes, but only to look at the community. So, these organisms are also sensitive to temperature sensitive to ocean chemistry, how much acidic it is how much alkaline it is, and because of smaller changes in the ocean chemistry, they will die or they will shift their habitat.

As a result even if you are not looking at their isotopic composition, just by looking at which species are there at a particular rock record, it is going to tell you something about the overall pattern of the ocean water condition. So that often is quite useful to know about ocean water current conditions of the past.

Now forams are not the only microorganisms that are used to learn about the past ocean, there are other organisms such as radiolaria. These radiolarians often have their skeletons which are made up of silica $SiO_2$. And they give us slightly different information because often they form in very deeper part of the ocean. Then we have some things which are called diatoms. Again, they live in different depths. So combining foraminifera, radiolarians, diatoms, you can actually reconstruct the history of the ocean and as it changed over time, some of them reflecting climate change some of them reflecting changes in the circulation, all of these can be reconstructed back using these microfossils.

Now, so far, we have talked about the marine conditions. And there are ways to do it for terrestrial conditions to spores and pollens, which are basically the seeds of different types of plants. They have very high preservation potential, so that they have a thick coat on top of them often made up of complex proteins or carbohydrates, and therefore they do not break, they get fossilized. And if you find those spores and pollens, they tell you something about the composition of the plants that were living during that time on the land.

That tells you something about the paleoclimate because certain plants live in certain temperature conditions. If you are finding the signature of let us say palm trees in the present day arctic, that basically means at some point of time, the rocks from where we were collecting these spores and pollens. Those rocks deposited in a condition which was not so cold because very cold climate will not support up growth of a plant like palm.

On the other hand, you can have pollens of plants, which are highly adapted to extremely cold climate and that will tell you something about the cold climate. If you are finding signatures of plants such as cactus that tells you something about the growth of plants in a very dry condition. So spores and pollens not only tells you about the temperature, it also tells you about precipitation and the overall condition on the land.

Even spores and pollens can tell us something about some more detail, if we are looking at their isotopic signature, but it is not going to be always the oxygen isotope. There are other stable isotopes that one can use to learn more about the terrestrial condition.

Now, let us try to think about even in deeper sense, how much resolution can we get when we are talking about the Paleo temperature or paleo salinity? Is it for a million years that we are going to get an understanding of whether the temperature was high and low? Or is it going to be as precise as a month, so that for that, we are going to look at some other organisms.

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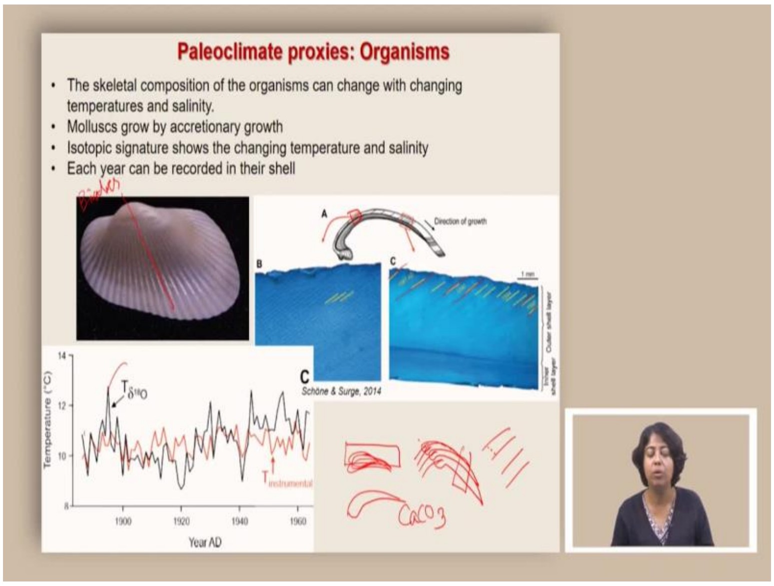


So for high resolution studies, people look at marine molluscs to understand the changes in temperature salinity, for very precise times. So these are called bivalves. These are marine organisms, although sometimes you can even get them on the land in freshwater, but majority of them are found in marine water. Now, they also have calcium carbonate shells.

But interestingly, these mollusc grow by accretionary growth. What do I mean by that? If I cut a section around this, what I will see that initially, the bivalves have, will look like this. So this is basically two valves that they have. But then as they grow, they are going to grow even more. And therefore, it is going to look something like this. So now let us concentrate only on one shell, how it will grow, it will look something like this in the first time, then it is going to grow like this, then it is going to grow like this. And so on, and so forth.

So what it means that every time it is adding a new layer, so if I am now looking at this part, it is going to tell me a sequential pattern of changes. Now, how long does it take for them to grow like this? So people have studied modern bivalves, and they have found that some of them actually grow annually. And because of their annual growth, you can actually find yearly record of these kinds of growth.

Now, can we go even farther? Well, it is possible because if you have a growth like this, and each of these are basically indicating year, and if you sample between them, that is going to tell you something about what is happening within a year. So, then, you can come up with a very, very high precision changes in oxygen isotope through time. So, what people have done, this is a picture that they have taken one part of this bi valve from here and one part from here.

Now, if you look at this part, you see they have grown longer and therefore you see even higher spacing. So, once they have dated it, they found that each of these layers are representing different years. So if you can look at these years, this one represents 1597. This one represents 1590, this one represents 1587 and so on and so forth. So, these are very precise, yearly measurement.

Then, you can do the same thing with the isotopes because bivalves also have calcium carbonate shells, and they are secreting it from the ocean chemistry. So they also keep the signature of ocean. Not only that, when the bivalves actually grow their shell, it matters to them, whether it is a cold condition or it is a warm condition. So even If the seawater chemistry is the same in terms of isotopes, depending on whether it is a cold temperature versus warm temperature, they are going to preferentially take oxygen, one of the isotopes of the oxygen.

As a result, they themselves are good proxies of the paleoclimate. So using these isotopic signature of the bivalves shown and search, they have reconstructed this pattern of temperature. So what they have done, they have measured all these isotopes, and using the ratio and their relationship with temperature, they have reconstructed it. That is what the black lines are. And the red lines are actually showing what was measured during this time, because these are 1587 and 1580s there were records instrumental records of temperature, and therefore they could match these things.

And what they are finding that they are fairly accurate. So what if we are talking about a time, let us say 1000 years ago, or 20,000 years ago, where there was no instrumental record where nobody was measuring it, we can use these bivalve shells. And we can look at their isotopic composition through these growth bands and get a very, very good accurate estimate of temperature fluctuation, and sometimes salinity fluctuation through time, which is as precise as taking the measurements every month or every year.

So it does not only give us an average temperature or salinity value, it also tells us something about how the change in temperature and salinity was within a year during that time. So therefore, this is considered as a highly precise high resolution paleoclimatic proxy. Can we do something similar for the terrestrial region, terrestrial region means we are talking about the land.

Now as I say that these bivalve some of the bivalves also grow in the land, but they do not grow on dry land, they can only grow in a pond or a river. But what if we are interested in let us say, the rainfall or the temperature on the land, not just in the river or in the pond?

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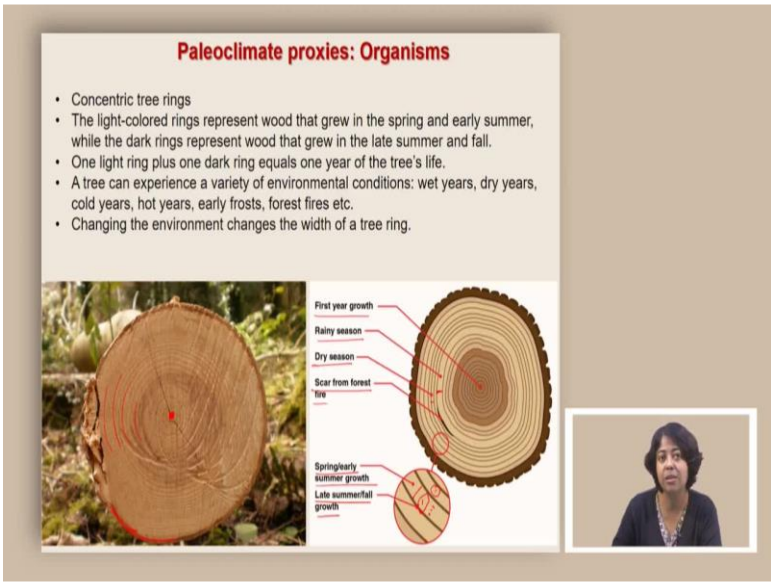


There, we can use tree rings. So just like these bivalves that tree rings also grow, and every time they add more material. So if you have ever taken a look at the tree, a cut tree, you will see that there are concentric rings within the tree. And what these concentric rings tell you is basically how they grew.

The trees grow from the center to the side, so the center is going to be the first year of growth, and the sides are going to be the last part of the growth, it is if it is still living, that is the part which is going to show you the most recent time of growth. But if you are looking at a dead tree, then this was the last time it grew. And therefore, that ages of the tree or if we are talking about the absolute ages, this would be the oldest part and this would be the youngest part.

Now, there is a variation in terms of color of these concentric rings. The light colored rings represent wood that grew in the spring or early summer, while the dark color represents the wood that grew in the late summer or fall or autumn. And one light colored ring plus one dark coloring equals one year of trees life. So if we know that, then we can basically count how many this pair we can find in the tree. And that is going to tell you exactly how many years they lived.

Not only that, the tree can experience a variety of environmental conditions within a year. Sometimes it is a wet year. Sometimes it is a dry year, within the year it can be a heavy rainfall, it can be low rainfall. And even without isotopes. If you simply look at the tree ring width they are going to tell you something about the growth pattern and you can infer something about the environmental conditions. So you can infer some things like wet years versus dry years versus cold years versus hot years, early frost, forest fire, for example.

So for example, in this tree ring, it is a cartoon showing the pattern. This is the first year of growth. This one, you can see, it is a very wide ring. This is showing a rainy season. On the other hand, if you see the small ring, small width, it is showing a dry season. And this one is basically a scar. And this scar is from the forest fire, because the tree was damaged, and it was not growing. And often it incorporates that signature in the growth pattern.

Now, if you look at in more depth within this, the changes in the dry in the dark color shows the late summer or fall growth, which is relatively small, whereas the bigger part of it is basically spring or early summer growth. And this combined is going to give you one year resolution, and this would be another year, and so on and so forth. So you can count those numbers. And that is going to tell you exactly how long a tree has lived.

And as it turns out, some of the trees can live for more than 500 years, sometimes 1000 years. And that means you have a continuous record of that many years. And you can look at the detailed record of the terrestrial realm. Now, people have started looking at the isotopic composition within the tree rings, and find out similar patterns that we were talking about for the bivalve shells, or the microscopic organisms from the sea. So using isotopes, again, it is possible to recreate the terrestrial conditions.

Now we are going to talk about another very interesting source of paleoclimatic information. And that is from the ice.

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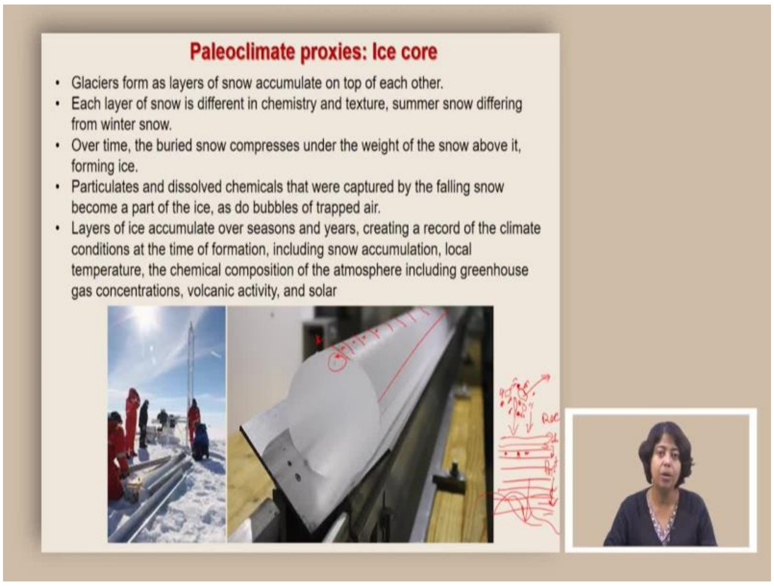


Now, glaciers form as layers of snow accumulate on top of each other. Now, when the snow falls, it is basically some flakes and they are quite light in nature. But each layer of snow is different in chemistry and texture. Summer snow differs from winter snow. And over time, the buried snow compresses under the weight of the snow above it, and therefore creates layers.

Now, every time it is basically creating these layers, new snow is falling down. And because they are very light, and there are gaps in between, they also incorporate air bubbles. And these air bubbles are representing the atmosphere outside. Sometimes they even take particulates and dissolved chemicals that are capturing that are being captured with the falling snow.

If there is a fire maybe far away, but it is being carried and there is soot in the air, sometimes they get trapped within the snowfall. And eventually that is going to be part of this compressed snow layers that we are going to eventually look at. So what scientists do, they drill a core in the ice layer and eventually recover that core and that core will look something like this ice layer. And then they see really section it and try to understand how the composition changed over time.

Now how do we know about the age that initial formed snow it is easier to figure out the age because as we say that the summer snow is differs from the winter snow and if you know how it differs, then every pair sort of represents one year and then we can go with the depth counting more number of years. So we go from recent to past.

But as we go deeper into the ice core, because these ice also deforms and it sometimes it flows. It is difficult to go on with this easy way of figuring out the age. But there are good models which basically tell us exactly how till the age is going to differ as things are going to deform, what is the flow rate. So using that you can still figure out what are the ages of specific layers or at a specific depth, what is the age that you are expecting.

Now, once we know the ages, then every composition of these different parts of the snow tells you a different story, you can look at their isotopic composition, that is going to tell you directly about the sea water composition, if it is falling into sea, or if it is in connection with the sea, if it is a sea ice. It can also tell you something about the atmospheric condition because it traps the bubbles. And these bubbles are representing the atmosphere. So you can melt part of this ice, release these bubbles and analyze the composition of those bubbles to get a first hand look at the atmospheric composition.

Not only that, as I mentioned that they also trap other particles. So that tells you something about the conditions. During that time how the wind was blowing from where it was blowing, to where there are cases, where some of these ice cores were recording particles which were flown from all the way from Sahara.

So the wind direction movement can also be tracked using these ice cores. So these ice cores can tell us a lot of information, such as the time of formation, including snow accumulation, local temperature, the chemical composition of the atmosphere, including greenhouse gas concentration, volcanic activity, and some of the solar wind activity. And these are extremely important information to gather because they are in pristine condition, they are not being affected. Although we cannot find them going back in time maybe a few billion years. But for relatively recent history for a few 1000 years. These are one of the most detailed record and paleoclimate proxies than what then that one can use.

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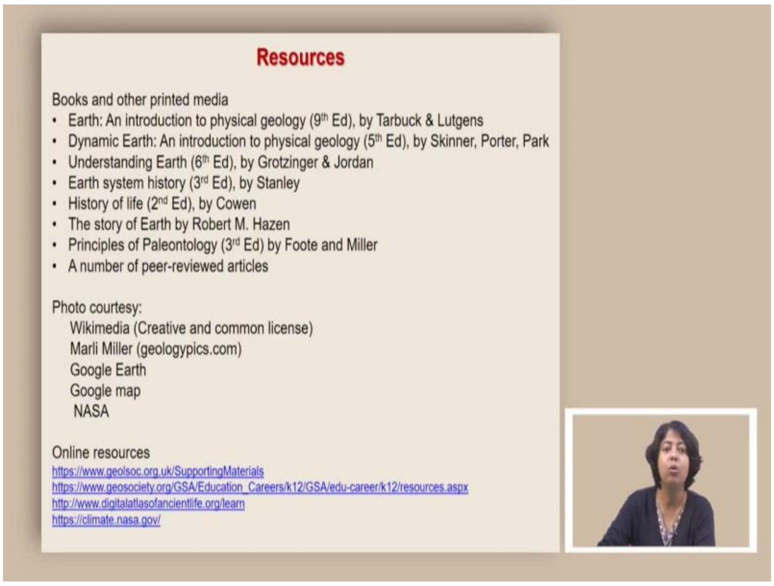


So in summary, today, we learned something about how do we learn about climate of the past. We learned that organisms change as a response to the change in the temperature. We also learned how we can use stable isotopes to learn about the chemistry of the ocean, and how that chemistry is related to temperature, the cold times versus the warm times.

We also learned that using some organisms which grow annually, like the bivalves, we can get a very high resolution record of the paleoclimate, from the ocean. For the terrestrial realm, tree rings can provide equally impressive record. With the help of isotopes, it can be even more detailed and tell us something about the precipitation, the temperature, forest fires, and many more.

Finally, using ice cores, and trapped air bubbles within it and other particulate matter within it, we can reconstruct the paleoclimate up to a few 1000 years at a very, very great detail. And these all contribute to our understanding of the past climate. Here are some of the resources that I used for reading the slides.

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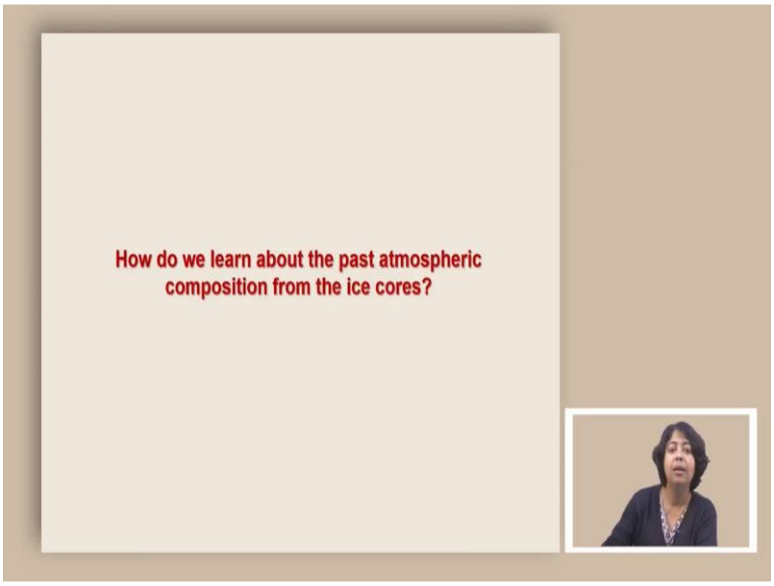


Here is a question for you to think about. Thank you.