The Evolution of the Earth and Life
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Cambrian Earth and Life

Welcome to the course Evolution of the Earth and Life. Today, we are going to talk about the life and the earth during Cambrian.

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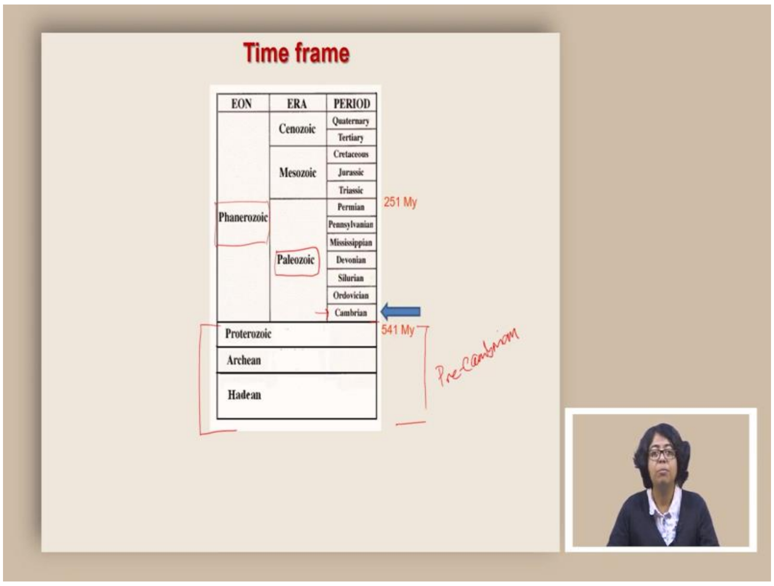

So, the time frame that we are going to be talking about is within Paleozoic. This is the name of the era and it is part of the Phanerozoic and the specific time interval that we are going to be talking about is this period called Cambrian. This starts around 541 million years. Now, these 541 million years is also important to recognize because this divides the Phanerozoic Eon or this separates the Phanerozoic Eon from the earlier Eons - Hadean, Archaean and Proterozoic.

Now, historically people have been interested in Cambrian because people started finding really conspicuous fossils from Cambrian. And Cambrian onwards, they started to look at the fossils and they found many different types of fossils and when they compared it with the rocks before that, they mostly found no fossil. We know that there were fossils in Archaean as well as in Proterozoic but in comparison to the variety of fossils that we get from Cambrian onwards it was absolutely low number when we compared to the before Cambrian time.

As a result, people started to call this entire time as pre-Cambrian. This pre-Cambrian is still a colloquial term to describe the relatively fossil poor part of the earth's history which came before Cambrian. Cambrian is the beginning of Phanerozoic, which means it is the time of life and we are going to see how the world was during Cambrian.

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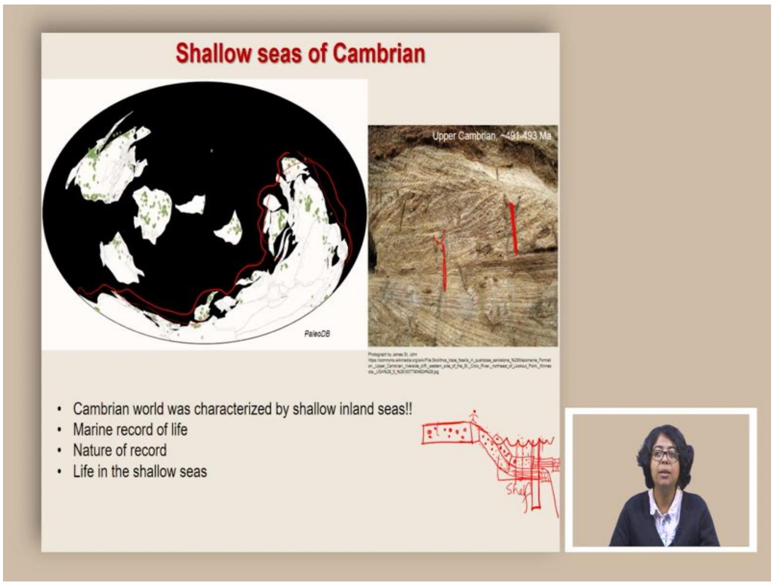

So, paleogeographic reconstruction tells us that this was the configuration of the continents during the Cambrian time. So, what it tells us that there were continents which were relatively large continents and they were not really in the equatorial region always and there are other chunks. If we want to relate it to the present-day continents, it is sometimes difficult to do because some of the parts are really part of two continents nowadays and some of the parts are joined together to make different continents of today.

So, it is not so easy to connect each of these parts to a separate part of the continent. But when we look at the rock record of different parts of continents during Cambrian what we find is the marine rocks especially the majority of them represent shallow marine condition. So, what I mean by shallow marine condition, if we start to walk from the beach and we look at the sea what we will find that the beach has a particular depth or height and then once you go to the sea, it is slightly lower.

But if you imagine yourself walking along this line, what you will find that it basically goes down. It goes down and then it continues for quite some time and then finally it dips down really really deep and this part is called a shelf. This is the part which is called a shelf. This is a relatively shallow region and then this is the slope which goes down and makes it really

really deep part of the ocean. This shallow part therefore includes the entire region and shallow marine successions are the sediments that get deposited around this place and finally convert to rock.

When we look at the Cambrian rock record, we find that there are lots of shallow marine deposits which indicates that probably during this time around this continental configuration there was shallow seas all across this continental configuration and these were really large sea ways but they were not deep enough, they were inundating the land again and again. Now, the question is how do we know that things were inundating and things were shallow? As I mentioned that you will see difference in the sediments.

Now, let us take an example. If we go by this analogy, near the beach we are going to get sediments which are primarily sand, there can be different kinds of sand but it is primarily going to be sand. Then if we go to this deeper part slightly deeper part because it is under water it will also have sand but then it will also have some things which are very fine-grained material, they are coming out of the suspension and they are depositing it.

If they are below the wave surface so we are going to get very fine-grained material. And these are called siltstone or silty material. We will also get things which are only depositing because of the suspension deposits and they are going to create things like shales. Depending on the condition we can also have things like calcium carbonate deposit and these calcium carbonate deposit could be in the form of reef, in the form of organisms which are making their skeleton.

So, this is a general theme of how you are going to see a difference in sediments. Now, let us imagine that the sea level has dropped down. The sea level is now around here and if that is the case then we are going to see a shift of the entire lithology that we see here. So, the processes that operate are always going to be a function of what kind of materials, what is the relative distance from the sea level. So, what we will find that this, if this is a time afterwards we will find sand starting to deposit here and then we will find these very fine particle of silt depositing here, probably we are going to find shales depositing here and then so on and so forth, we may find things even like limestone.

Now, what that means is if we are going up in terms of the rock succession we will see that there is a change in succession, we are getting very fine material to a relatively coarse material and this is generally equated to the sea level drop. The opposite thing can also happen; if sea level rises, then you will get the more coarser materials on top of the finer material. So, these kind of upward sequence change in lithology tells us something about what was the sea level at some time and how that sea level changed.

When we look at the Cambrian succession we find that there are multiple evidences of shallow marine areas and there are changes over time which went back from a lowering of sea level and then increase in the sea level and this oscillated quite some time. So, they are also telling us that during this time sea level rise and fall was very common and they are generally affecting more in the inland seas. These inland seas or shallow seas they are very unlikely thing to see today, we do not really have any example which can replicate the Cambrian time today.

These shallow seas were vast extent of seas which covered half of the continents easily and they really had the similar depth as shelf region but not the deeper part of the ocean. And the record that we see of the animals, primarily come from the marine records. We do not really know whether the terrestrial record exist because the amount of terrestrial material is not much during Cambrian time. More importantly, the groups that we look at we understand that they were primarily marine. Probably, this terrestrial transition happened much later.

Whether they were freshwater groups or not that also is a relatively a doubtful area. We do have some evidence of freshwater transition but again the majority of life was a marine and the land was pretty barren compared to the proliferation of marine life. The second thing that is important that people recognized about Cambrian record is this appearance of burrows. So, what are these burrows?

This is the burrows that we are talking about, these are vertical burrows, these are animal traces where they lived and how they used these sediments to go down, eat these sediments, extract nutrients from it and these are very common in Cambrian in contrast to the previous rock record of Proterozoic and therefore these kind of change in the rock record which is much more bioturbated or much more carrying, much more trace fossils in form of vertical burrows are a characteristic feature of Cambrian rock record. Now, we will try to understand what these shallow seas do to the life. So, we are going to understand a little bit about the life in shallow seas.

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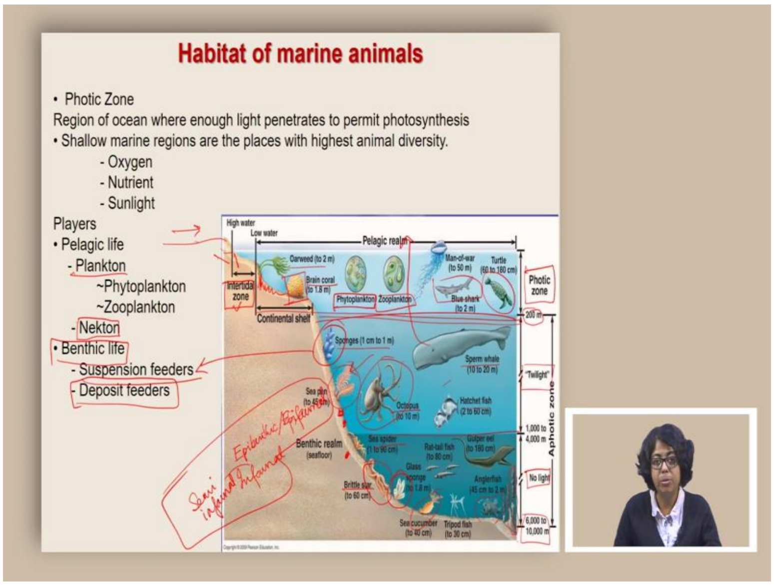

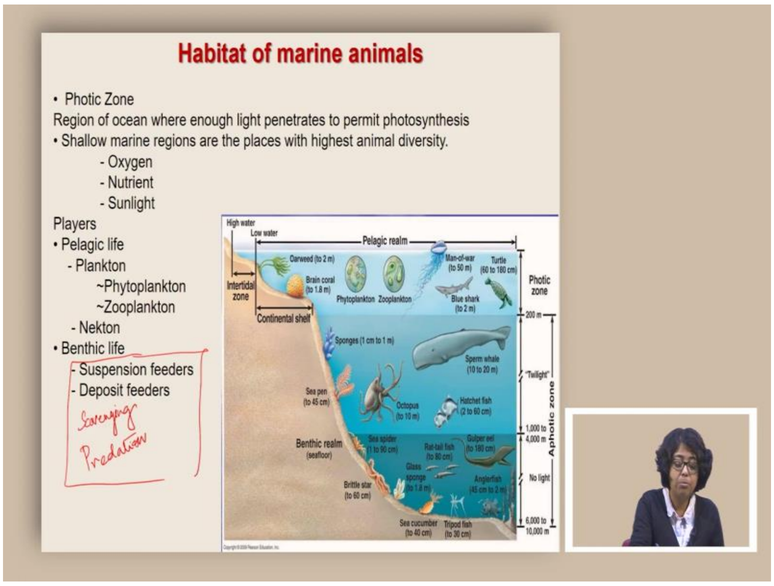

So, we are going to look at the ocean, the ocean of today. So, if we look at the ocean of today, we will find this kind of depth zone and also different kind of habitats. Habitats largely mean what is the environmental condition of a particular organism where they live. So, if we start with again a beach condition and you try to move on and go towards the sea, we will find this there is this place which is called an intertidal zone. This intertidal zone basically means that during high tide this will be inundated and during low tide it would be exposed.

And so, depending on the tidal range it will be either under water or would be exposed. So, that is what the intertidal zone is. Depending on the slope of the area this intertidal zone could be a kilometer or a few meters. If it is very steep slope then it can be stretched only a few meters in terms of the spatial extent but if it is a very gentle slope then you can have a large area getting inundated and exposed daily along with the tide and that is the character of the intertidal zone.

Then, we have something called a continental shelf. This continental shelf is a shallow area and it will always be under the water, it will not be affected by the tidal range, it will never be exposed during a regular tidal season. It can be exposed because of the sea level drop due to a global change but during daily cycles of tidal range, it will not be exposed, it will always be under water. And this zone is also up to 200 meters, it is also called the photic zone. Because this is the place where the sunlight penetrates the maximum, as a result this is the place where we see majority of the animals and they are surviving and they are utilizing the sunlight.

We find these phytoplanktons, these are microscopic organisms which are primarily producing food through photosynthesis. We also have zooplanktons which are the animal counterpart of these phytoplanktons, these are also microscopic and they are found in plenty in the ocean and they are mostly restricted in the photic zone. We also find other kinds of organisms like the corals, the weeds, often some of the sharks, the turtles, these are organisms which love to be in the photic zone primarily because of plenty of sunlight and also the availability of phytoplankton and zooplankton.

Now, the corals are also interesting because the corals are primarily concentrated in the photic zone because they often have a symbiotic relationship with an algae. And the algae require photosynthesis and therefore they are restricted to the photic zone; below the photic zone these algae will not survive and this algae helps the corals in terms of the food and corals provide in turn the stability, stable habitat. That is why it is a symbiotic relationship and that is why most of these corals we find within the photic zone.

Now, if we go down a little bit from 200 meters to a 1000 meters this is the place which is called a twilight zone. That means the sunlight can still penetrate but it is not going to be as bright as in the photic zone and therefore the composition of animals change. What we are going to find here are sponges, often sea pens, these are things which are related to cnidarians like corals and jelly fishes, we can have octopus, we can have certain types of fish, certain types of whales but often especially these groups which can swim which are often called the nektons, they can go up and down depending on their food availability.

For example, the whales, they occasionally go up to breathe and then come down, often they gather food from here but they prefer to stay within that twilight zone. When we go to the last part, between 4000 to 10000 meters, we get to this zone where there is absolutely no light and then we find another kind of animals which are adapted to this no light condition and these include sea spiders, brittle stars, so again these are part of these echinoderms, these are sea cucumbers, some of the interesting fishes and these kind of fishes are very, very well adapted to this light less condition.

And if you see, you can also see some of these hydrothermal vents. So, hydrothermal vents, the typical depth of it is also around this very deep level and this is a no light place. And the ecosystem around it is very different from what we are finding at the top. Now, what is important to recognize is now if we like to count how many different types of groups are there in each of these depths, what we will find, the majority of the types concentrate in this photic zone and in this shallow region.

And therefore, these shallow marine areas are the most diverse it accounts for the maximum diversity of animals. It also accounts for the maximum of the biomass of the animals that are living in the sea. Now, we are going to look at some of the players that means who are the groups who live there. So, one is the pelagic life. So, the pelagic life means what is in the water. And there can be planktons, these planktons basically mean that they are the floating organisms.

That can be a phytoplankton, that can be a zooplankton but it is primarily floating organisms, they cannot drive themselves to a specific direction, they are mostly floating by the water currents, waves and therefore they can be distributed all across the ocean through the waves and currents. Then, there is something called nektons, these nektons are the free swimmers. They can decide where they want to go and this will include the sharks, other kinds of fishes, turtles, whales, all of these would be part of these nektons.

If you think about the octopus this would also be a nekton. So, anything which can swim on its own and guide their trajectory, where they want to go and swim up to that point, that would be the character of the nekton. A very large group of organisms that we find in the ocean are not really floating in the water or swimming in the water, they live in the sediments. So, those are the ones which are called the benthos. So, the benthos are the animals which live on the sediment water interface and if you look at the ocean water of today, the ocean water below the ocean water there is a thick pile of sediment and that continues all the way from the beach to the deepest level.

And many of the organisms, especially the organisms which are stationary, that means they cannot move, they are the eggs simply get attached to the sediment and they grow there or animals which have limited mobility they can only swim a little bit but not far, these kind of animals prefer to stay close to the sediments. And these organisms can be further subdivided into different groups - one group which lives right above the sediments, these are called epibenthic organism, then there can be something which are inside the sediments, always inside the sediments, they are called the infonal, this can also be called an epifonal.

And then there are other organisms which are sometimes above the sediments, sometimes inside the sediments but more importantly they are always in the part of their body is inside the sediments and outside a part of it is outside, sometimes they are called semi infonal. And these organisms make up an important component of the entire marine system and marine ecology. They often have skeletons, these skeletons contribute to the sediments of the ocean and therefore the benthic organisms are one of the most important component of the entire marine ecology.

And these organisms can feed in different ways. So, one way they feed is called suspension feeding. Suspension feeding means when they take the water inside and then absorb the nutrients and throw out the rest of the water, that is called suspension feeding. We find sponges to do this suspension feeding. Then, a lot of animals which are benthic also have something called deposit feeding. The deposit feeding includes the animals which eat the sediments and then extract the nutrients out of these sediments and then release these extra sediments and these are called deposit feeders.

One example would be the worms. These worms which live in the sediments, they constantly eat sediments, extract the nutrients out of it and then take out the extra part of the sediments and these sediments again mix. So, sea cucumber is an example of these kind of deposit feeders; snails often do that, so there are different kind of animals which do deposit feeding but these are not the complete one, there are other types of behavior in terms of feeding. The other type of feeding is the scavenging.

The scavenging means it basically goes to dead organisms and eats them and then finally, there is something called predation, that means the organisms target specific groups and eat them, attack them, kill them and eat them, that is what predation means. So, these are the major types of food collection behavior in the marine realm and we are going to see what was the change during Cambrian.

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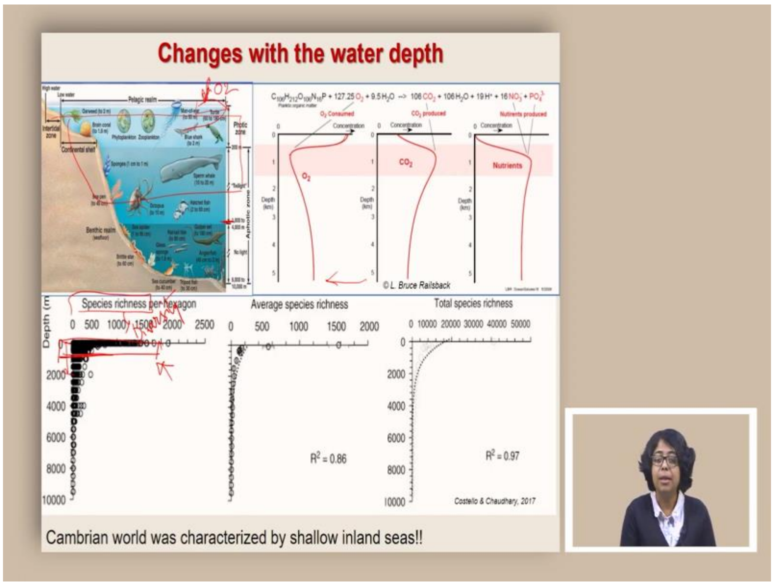

We are going to look at some of the changes with the water depth. We already mentioned that the shallow region has the highest number of groups and the reason for that, one is definitely that the sunlight can penetrate but there are other things too. For example, if we look at the oxygen concentration, what we are going to find that the oxygen concentration is very high towards this part because the oxygen is basically coming from the atmosphere and the atmospheric oxygen goes to the ocean through diffusion, it is a slow process, so it cannot really penetrate very deeper part of the ocean and therefore, the concentration actually goes down as we are going with depth.

So, beyond 1 kilometer, we have a very low oxygen concentration. Then, the oxygen concentration does not go back to the same level but it kind of grows a little bit because it gathers more oxygen through other currents which bring oxygen from the surface. The second one is the carbon dioxide concentration also is low in the surface shale area and then it concentration increases. The nutrients that are produced, we also find that the nutrient production is also increases somewhat around the shallow region and therefore, this shallow region is one of the places where we have majority of life gathering.

What happens if we look at it today? If we look at it today in terms of species richness, that means, if you take an area and count how many species are there, so this is a good proxy for diversity. If you look at the species richness of an area what we will find that within the first 1000 to 2000 meters which is again this is the region that we are going to talk about, we have the maximum species richness. Again, that tells us that the shallow region is extremely important in terms of giving how many species are there.

And now we have to remember that the Cambrian world was characterized by shallow inland seas. So, now if you have a lot of shallow inland seas that will automatically give you a really high diversity of organisms. So, initially people thought that the reason we find so many different types of fossils during Cambrian is also a result of the fact that Cambrian was a time when we have shallow inland seas, but looking into the Cambrian fossils tell us a slightly different story.

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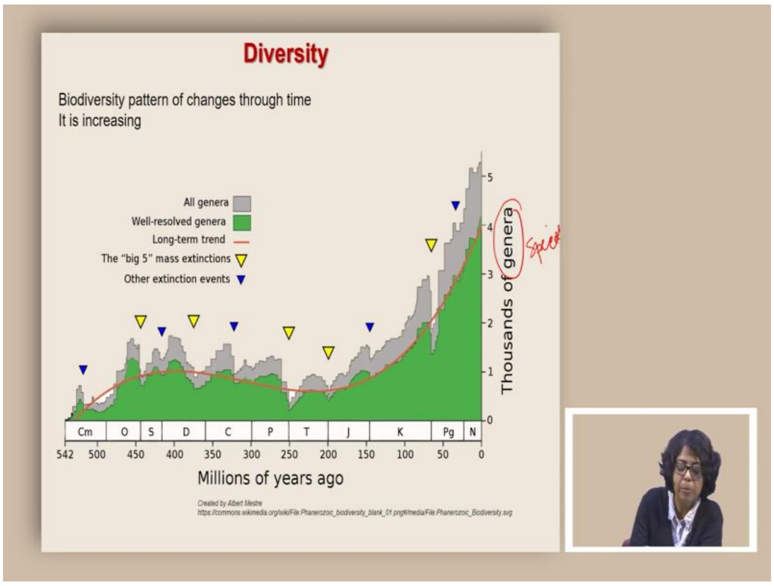

So, as we mentioned that diversity basically means that you are counting how many different types are there, but generally when we look at let us say the genera or species, it generally is the count of how many different species are there, how many different genera are there. And if you look at the present day understanding of overall biodiversity through time, we will see this pattern which shows us that it is actually increasing over time.

Now, if we zoom in to Cambrian, we actually see that there is a very nice increase and then there were subsequent drops and so on and so forth, but initially there was a very high increase. So, is it the only thing that makes Cambrian very unusual that it had a very high diversity? Actually no. there can be different types of diversity.

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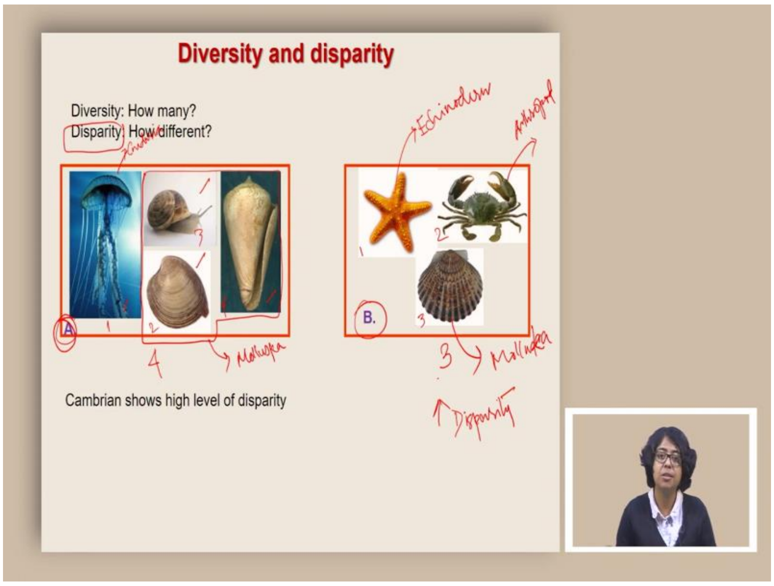

Let us take an example. So, for example if we look at picture A and ask this question how many different types are there, then we will count, this is a jellyfish, this is a snail, this is a clam, this is again another snail; and if we want to count how many species are there, it would be 1, 2, 3 and 4, so the total species richness is going to be 4. Here if we do it, it is 1, 2 and 3, so the total species richness here is going to be 3.

But if we now look that how different they are, then we are going to come up with a very different understanding. If we look at picture A, we basically see that there is a jellyfish which represents this phylum called Cnidaria, but now if we look at the other 3, although they are different species but they belong to the same phylum called Mollusca. So, in some sense they are not very different even though their species are different, but when we look at this picture, picture B, one is a starfish which is an echinoderm; then there is another one which is an arthropod, it is a crab and then there is another one which is a Mollusca.

So, this picture, although it has a relatively small number of species, they are showing extremely different groups and therefore, even though the diversity here is high, this is low because this is 4, this is 3, if we define something called disparity, that means how different things are, this one will have a high disparity compared to figure 1.

And when we look at Cambrian fossils, what we find, it is not just diversity, it is not just how many different types are there, it is how different they are and we find that Cambrian shows the high level of disparity. In fact, throughout the ages, Cambrian shows the highest level of disparity when it comes to the phylum level changes.

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And that is what is the key of Cambrian explosion. So, this major change in the organisms that we started to see in Cambrian has been termed as Cambrian explosion. It includes the appearance of large body and preservable forms because they also include skeletons. We find extremely distinct body plans, very different representing different phylum and therefore very high level of disparity. We find appearance of extensive skeletons.

So, skeletons before that were only restricted to very small organisms, we found small shelly fossils before that but not large scale skeletonized large organisms, we started finding that in Cambrian. Appearance of groups like echinoderms, arthropods, chordates, these are groups that we see even today and all of these groups seem to appear together at the same time. Cambrian showed an enormous amount of disparity, appearance of groups that continued till today and appearance of skeletons.

You also see that it also showed appearance of new type of feeding styles. What caused them? This is an open question. Some arguments are about a biotic environment including these shallow marine environments with high nutrients, high sunlight. Some arguments are along the line of genetic or developmental capacity and finally some arguments are along the line of ecology where biotic environment or biotic interaction led to these kind of changes.

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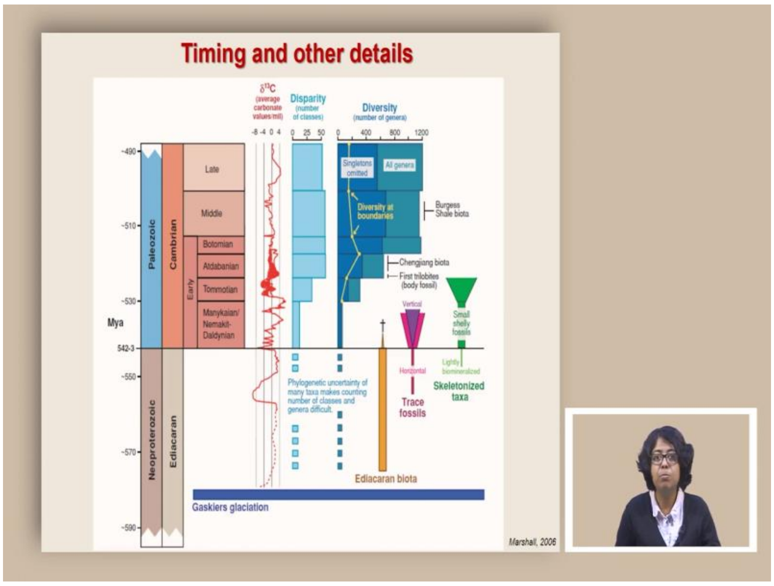

So, when we look at the Cambrian explosion and try to understand what are the things that we are seeing, we find this interesting pattern that there are lots of things that we start to see during Cambrian. One important point is this very very highly mineralized pattern skeletonized taxa. We started to get trace fossils of vertical burrows and we also started to see extreme level of disparity as well as increase in diversity. Altogether it makes Cambrian an unusual time with a high degree of diversity and disparity of the animal kingdom and that is why it is called Cambrian explosion.

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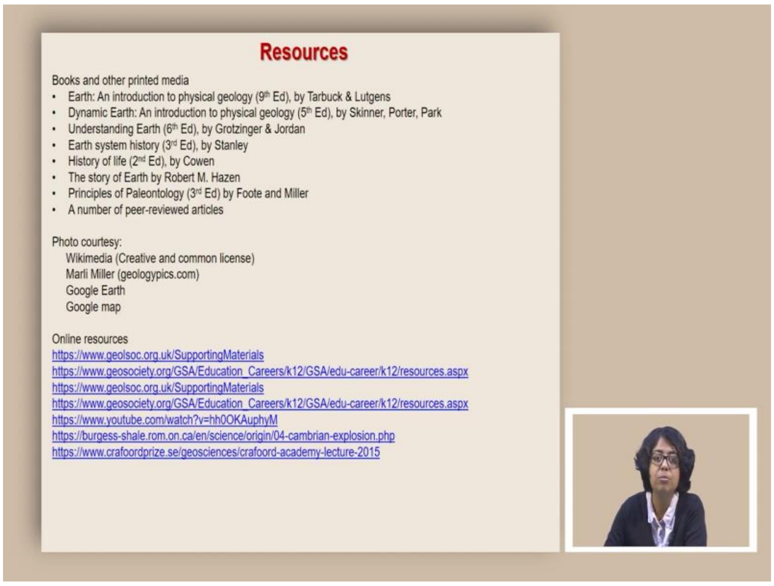

So, in summary, in today's class we learnt a bit about how the world was like during Cambrian. We also learnt about what are some of the advantages of shallow marine region, what kind of nutrient oxygen and carbon dioxide we can expect in these kind of shallow seas. Then, we learnt about Cambrian explosion and what were the characters of Cambrian explosion that made them different from the previous rock record. Here are some of the resources that I used for this making the slides.

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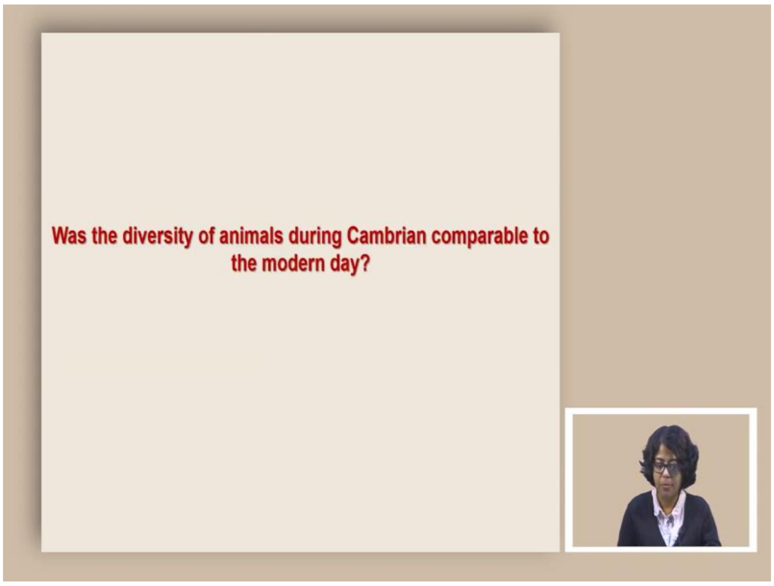

Here is a question for you to think about. Thank you.