The Evolution of the Earth and Life

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Cambrian Explosion

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

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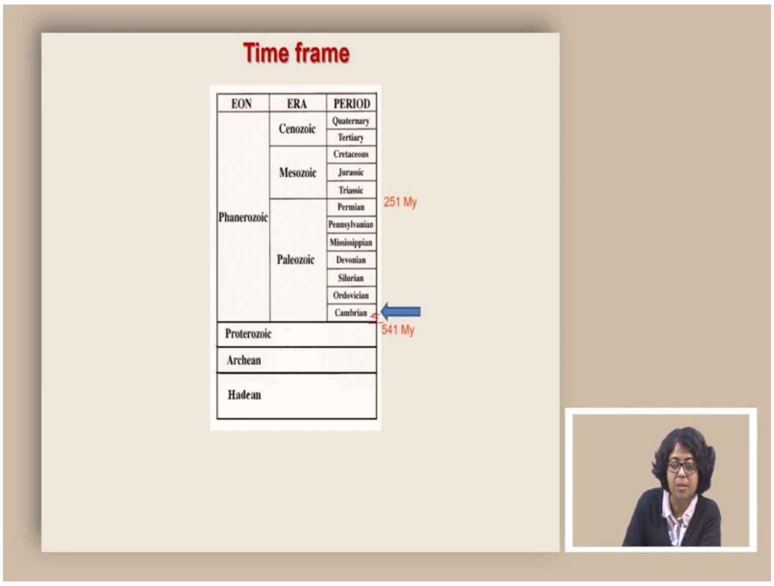

Just to orient ourselves the time that we are talking about is Cambrian, this is the time as part of the Phanerozoic and more specifically it is part of the Paleozoic era. We are looking at the first period of Paleozoic era called Cambrian and the boundary is somewhere around 541 million years.

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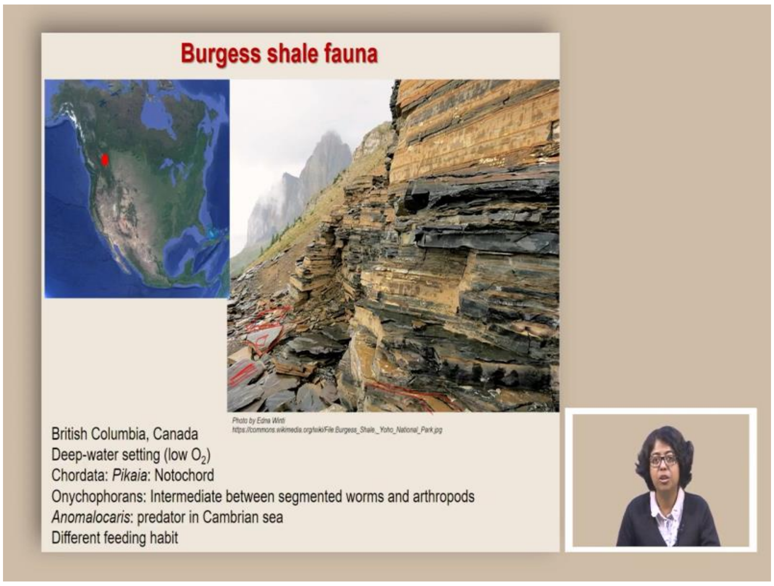

When people started to look for Cambrian fauna, they primarily focused on a particular exposure called Burgess Shale fauna. This is one of the places which showed a very high diversity of Middle Cambrian fauna. There has been records of other fauna too which came after Burgess Shale fauna which are younger in age, but today's class we are going to focus on some of the Burgess Shale fauna. So, this is an area which is in Canada in British Columbia and it shows a relatively deep water setting of low oxygen and if you look at the rock sections they look something like this.

So they are bedded and if you take a block and lightly hammer on it, it basically cleaves, it dissociates as separate plates and majority of the fossils appear on those plates. Now if we look into the fossils, it is basically a diverse organism that we are going to encounter. There is a story associated to it that the first time somebody was venturing into these Burgess Shale fauna, they did not find much because they were looking at the outcrop and trying to find the fossils probably in the outcrop and then their mule or the horse stumbled over a rock and it cleaved apart and it showed them the fossils within the layers of the rock.

Probably it is just a story, but it emphasizes the fact that primarily the fossils are hidden between the rocks. So, unless somebody breaks them apart to look into these surfaces, the fossils are not going to be visible. Now, let us take a look at different types of fossils that we find in Burgess Shale fauna.

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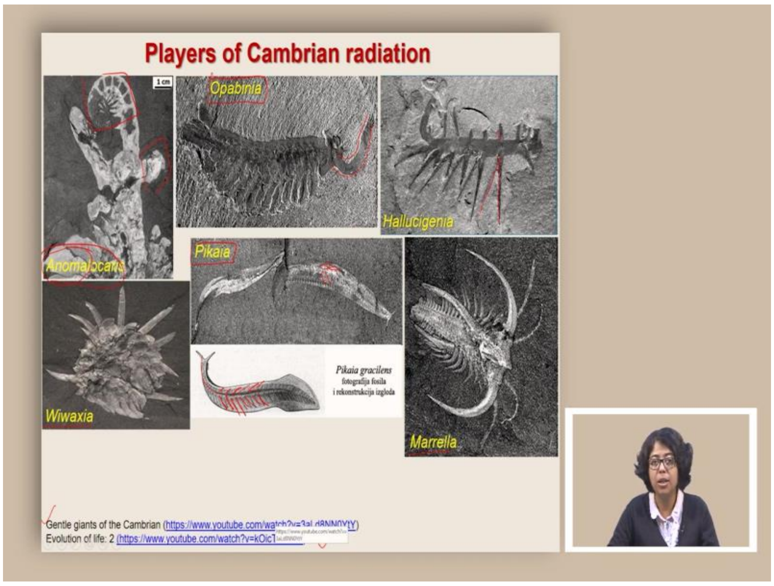

These are some of the classic examples of Burgess Shale fauna and subsequently it has been found from all over the world. So, one of the very common type of Burgess Shale fauna or Cambrian fauna is Marella. It looks something like this, it looks somewhat like an arthropod. And all of the preservation of these organisms in Burgess Shale fauna are through carbonization. Another interesting organism that was found in Cambrian explosion as part of this Burgess Shale fauna is Hallucigenia.

It is an organism which has legs which are very pointed and then there are also spines. Initially it was not very clear in terms of which part is spine and which part is leg, but later after encountering multiple such organisms, preserved organisms, it is now quite clear that they had two series of spines as well as legs. The name goes with this idea that when it was given this name because it looked very different from any organism that we see today, someone thought that you can only imagine such an animal when you are hallucinating and therefore the name goes as Hallucigenia.

There is Opabinia, this is another organism which has multiple appendages and then it has an antenna like thing. Exactly what was the function of it, it is still not clear. There is another organism, it is called Wiwaxia, it has multiple plates. What is the closest living representative of Wiwaxia is not very certain. Then there is an organism called Pikaia, it is a small organism. What is very important to recognize is in this organism, there are interesting patterns of segments or more importantly muscle scars and these are very similar to some of the caudates, early caudates where we find these chevron shaped muscle scars.

Now caudates are the groups where we belong. So, early caudates they did not have the vertebral column and what we find is still this nerve cord is there and there are these muscles which are supporting it adjacent to it and they create this kind of V shaped pattern. In Pikaia we also find that and therefore Pikaia has been attributed the designation of caudates. What that means is our ancestors, the ancestors of the vertebrates were there in the Cambrian fauna. Another extremely important organism in Cambrian fauna is the Anomalocaris.

So, Anomalocaris derives its name from the word anomaly which means something was wrong. So, Anomalocaris was not discovered as the single animal. So, there are different parts of the body which were identified and which were discovered separately and many of them were given specific names thinking that they were individual organisms. Only when a complete Anomalocaris fossil was discovered, people recognized that they actually were part of a larger body and therefore finally the animal was basically named as Anomalocaris. There are interesting resources that you can look at in terms of what kind of organisms you can expect during Cambrian and how they looked like if you look at these resources.

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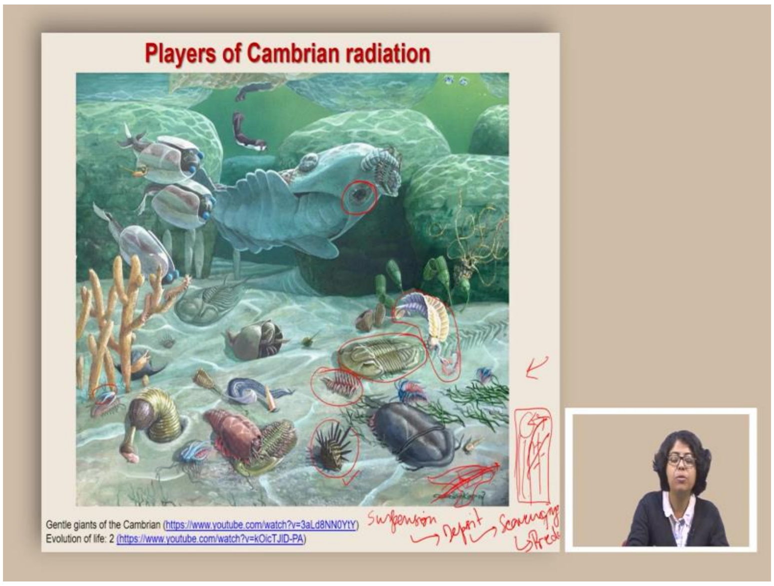

Now, the artist's reconstruction plays an interesting picture and it also shows you some of the scales. For example, the Anomalocaris is really a large organisms, it is easily a few feet long. Then there are organisms such as Vivaxia and organisms like Marella. There are Trilobites that you will find and then you will see Hallucigenia in this. You will see Opabinia. Now, what it tells us is that there were different types of habitats that they were exploring. There were also different types of feeding that we see during this time. And how does feeding affect?

So, as I mentioned that there can be different types of feeding, for example, suspension feeding, deposit feeding, scavenging and predation. And one argument is that there is a process, a natural selection process that you can use to explain how different feeding styles appeared. One such process argues that the first organisms were primarily suspension feeders, especially the groups that we find in Ediacaran. Even in modern day, if you look at some of the very primitive organisms such as sponges, they primarily feed through suspension feeding.

What that means, they take the water from outside through the pores and then take the nutrients from this and then exhale the water out. The other groups show deposit feeding. Deposit feeding is when they eat the sediments and extract the nutrients out of it. The question is, if at the beginning you have all the suspension feeders, how can you convert to deposit feeding?

One of the argument is that some of the suspension feeders were good at handling heavy sediment load. What that means, even when the water is coming, if that water has really high sediments mixed with it, they can take the nutrients with these sediments and absorb this very well and exhale the water along with the sediments. Often, the sediment rich water has the maximum nutrients and therefore the suspension feeders which can deal with this heavy load of sediments can survive better and they will be selected for because of their higher performance.

Now, imagine a group which is a specialized type of suspension feeder which can deal with these sediments, very high amount of sediment mixed with water. That specialized group is not very different from some of the deposit feeders which simply stay in one place and then they take the sediments inside them through the sediment water and their poop contains only the sediments and they absorb the nutrients inside their body. So, you can think of starting from suspension feeding to deposit feeding going through this very specialized class.

From deposit feeding and deposit feeding requires some groups to at least have the proper development of the gut because that through which the sediment is going to go out. Some of these deposit feeders are also very good in detecting sediments where the nutritional level is very high. Many a times they basically search for sediments where dead organisms are depositing because that is where many of the nutrients are stored and they will target those sediments.

So, again we are talking about a specialized class of deposit feeders who can search and eat those sediments which have maximum nutrients in terms of the dead skeletons or dead bodies which are of animals which died in the ocean and then slowly decomposing and going down. Now, a step from there to a group which do not eat sediments but only target this dead organism is not a very far leap and those are the organisms that are called scavengers. So, now you have a system where you can start with suspension feeding and go to deposit feeding to scavenging.

Now, some of these scavengers are also groups that do not completely wait for an animal to die. They often go for animals which are in the process of dying, sometimes they can attack as a group and that is what we know as predators. And this is important that these feeding styles are not very distinct; you can actually argue for a natural selection which can produce all types.

But when we are talking about predation, in order for a group to be a predator they have to be mobile, they have to be large enough so that they can eat and overpower the other groups and they should have also have a good skeletonized body because skeletonized body helps in terms of movement, also in terms of being agile and biting off and basically targeting specific preys.

And all of these characters we started seeing during Cambrian. Anomalocaris has this mouth region which was ideal for catching and eventually piecing things into smaller bits which can be digested further. The trilobites were ideal in terms of deposit feeding because they were constantly scooping sediments and eating nutrients from it. There were suspension feeders too, Vivaxia is probably again a deposit feeder.

So, now we have an Cambrian ecosystem where you see not only appearance of skeletons, you also see appearance of complex ecological structure; some of the groups are suspension feeders, some of the groups are deposit feeders, some of the groups are scavengers and predators and this kind of complex ecological trophic structure started to appear in Cambrian.

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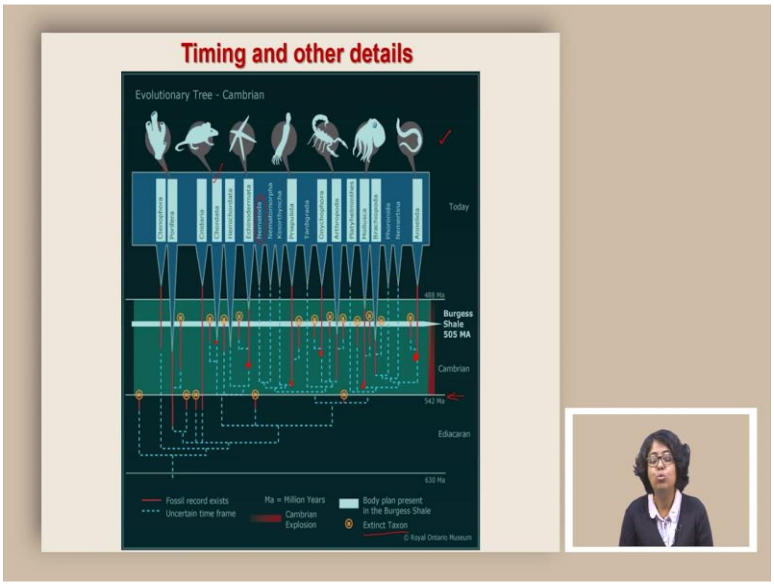

Now, when we look at the organisms that appeared during Cambrian, we find an interesting pattern. So, this is the Cambrian boundary and when we look at these groups, these are extinct taxon. So, any group from Ediacaran which shows this mark, it shows that they are extinct group. But then these are the groups that we find today and among these groups if we now trace back how many of them had their ancestor during Cambrian what we will find is majority of them appeared during Cambrian.

So, be it the sponges some of them claim that they can even have a longer time when they appeared, it could be even prior to Ediacaran. But let us take a look at the Caudates which includes us that definitely had their origin around Cambrian. If we look at the Echinoderms they had their origin in Cambrian; if we look at some of the worms, we find their origin to be in Cambrian; if we look at the Arthropods, they started in Cambrian. If we look at the mollusks different types of mollusks they appeared in Cambrian; some of the Anelids, again another type of worm they appeared in Cambrian.

So, now we have an ecosystem of today and majority of these groups actually appeared in Cambrian and one important point to remember there are things like Nematodes, these are other types of worms. So, the groups that we really cannot connect to Cambrian many of these groups also have soft bodied organisms and because soft bodied organisms do not get preserved so well we really do not know whether they appeared in Cambrian or not. It could very well be that they actually appeared in Cambrian but did not get preserved. So, therefore it is important to recognize that Cambrian contributed to the majority of the phylum that we see today.

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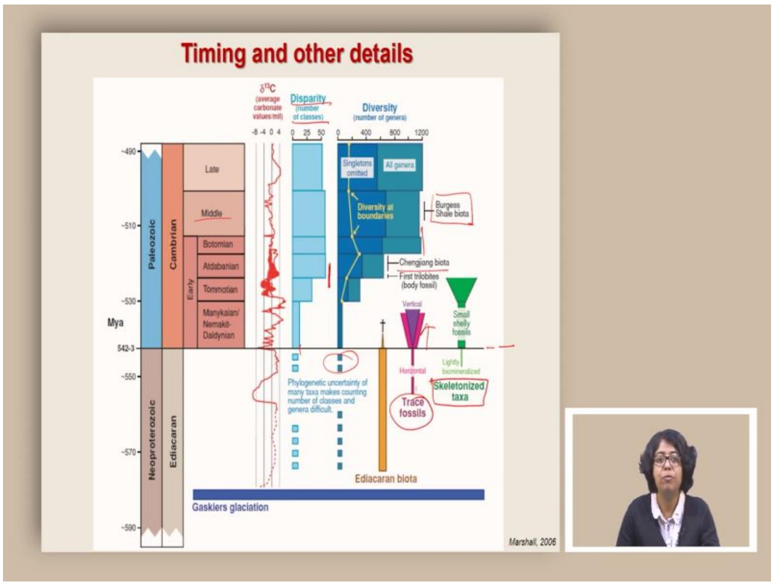

Another type which is important to recognize is the pattern of the activity of animals before and after Cambrian. So, this plot shows the Cambrian boundary which is around 552 to 553 and then we look at the Burgess shale fauna which is definitely a middle Cambrian part but there are other times or other fauna such as Chengjian fauna from biota, such as Chengjian biota from China, these are showing even earlier times of Cambrian, there are very good Cambrian deposits in England and all of them are showing very characteristic pattern of fauna.

First character is their skeleton, the skeletonized taxa started to diversify the moment we go into Cambrian. The second very important point is the trace fossil. So, even in Ediacaran we have these horizontal trace fossils but when we go into the Cambrian, the first thing that we find is we started finding vertical burrows. Vertical burrows immediately mean that they were processing these sediments differently. Generally vertical burrows are always a characteristic of animals which are deposit feeders.

So, the rock record also shows these kind of changes in the ecological structure especially in feeding yield. We already talked about the disparity, the number of classes and we see there is a high level of the number of class increase. So, we have gone from somewhere around 5 to 50 somewhere in the middle of Cambrian. The diversity also increased significantly when we go from Ediacaran to some of the times in the middle Cambrian.

Now, was it something to do with the skeletons? Because we have to keep this in mind that skeletons make it easier for organisms to get preserved. In Ediacaran because their things were not skeletonized, probably it was less they did not have similar durability like the Cambrian fossils. But on the other hand, Ediacaran was the time when the sediments were not disturbed by the deposit feeders and Cambrian is the time when there were enough deposit feeders which were constantly turning the sediments.

So, it is hard to say how much of this diversity is caused because of the appearance of skeletons and therefore creating a better fossil record. However, that argument does not explain why the disparity is so high. So, the disparity is typical signature of Cambrian fauna especially middle Cambrian fauna which cannot be explained just by preservation or better preservation or appearance of skeleton.

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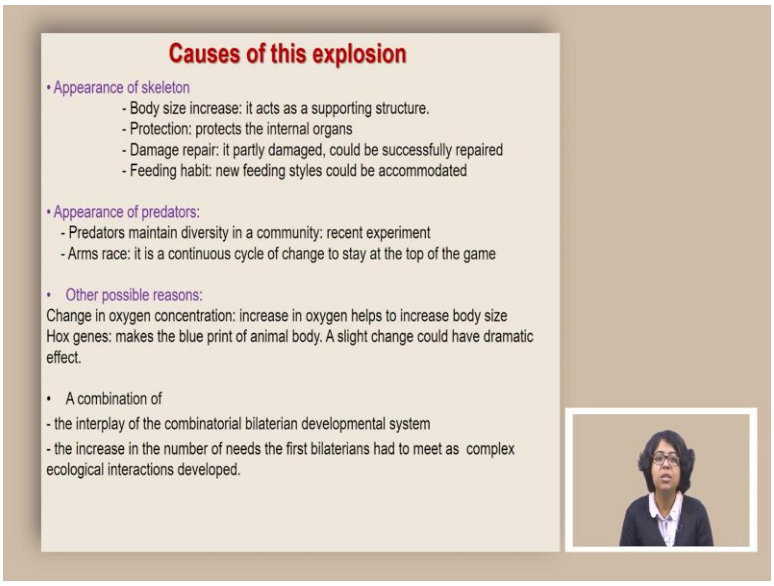

So, the cause of these explosion is really complicated. One thing is for sure that the appearance of skeleton made a major change. Body size increases, it acts as a supporting structure. So, without the skeletons there is it is not possible to have very large body size. The protection is very important, the animals can be protected, the internal organs can be protected because of the appearance of skeleton. The third thing is the damage repair. An organism actually lives longer.

If it does not have a skeleton, any part of the body if it is perforated, if it is attacked, if it is eaten, the entire animal dies. But if it has a skeleton especially segmented skeletons often the skeleton even if part of the skeleton is broken it can repair the skeleton and therefore it adds to the longevity of the animal. Finally, the feeding habit. New feeding styles could be accommodated. Without the skeletons as I mentioned that it is difficult to have predators without the skeletons.

The second part of the explosion was that the appearance of predators. Predators maintain diversity in a community. There are some recent experiments where it has been shown that if you introduce a predator in an ecosystem, you suddenly started to increase the variation in the groups but more importantly certain types of variation get selected for simply because the predation acts as a major evolutionary trigger and it is a very high selective pressure.

So, because of the selective pressure even if the variations were existing before they were not basically getting selected for or selected against and therefore the moment predators are introduced groups tend to show more higher degree of selection pressure and that leads to higher diversity. And once it starts, it goes on. It continues a cycle of change through the presence of the predator and that is often called an arms race.

Other possible reasons it is it does not explain why the explosion was there during this time but it explains how can you find or how can you develop so many body types at a very short time span. One idea is that the change in the oxygen concentration actually aided the increase in the body size. So, the oxygen concentration during protozoic was quite high and it continued to increase all the way up to cambrian and with this increasing oxygen level, it is easier to increase the body size.

The moment you have larger body size you also require skeleton and then the entire process continues. The second point is how can it be done requires this understanding of Hox genes. What it argues that there are genes which are called regulatory genes. Instead of those genes doing a particular purpose or solving a particular issue they basically regulate other genes. So, if you change the Hox genes, it is possible to have multiple changes occurring at the same time because they regulate other genes.

Now, the question is why do not we see such changes today? Because after Cambrian, probably after Paleozoic we do not see development of new phylum. So, Hox gene must be operating even today. Then why cannot we have developments which are creating new phylum very distinct phylum adding to the disparity? Then the logic is that once a layout is created, then changing the genes will lead to some organisms where two functions are conflicting and therefore it will become a non-viable organism and they are not going to survive.

And as we went with time, the complexity of the genetic materials and their pathways increased and therefore it is not possible to do it now. Even if it happens once in a while they are not going to survive to reproduce and continue with that lineage. So, finally the cause of the explosion is at the interface of many things; probably it includes the appearance of skeleton, increase in the oxygen and also the appearance of predators, all of them contributed to this highly complex ecosystem appearing and maintaining its diversity.

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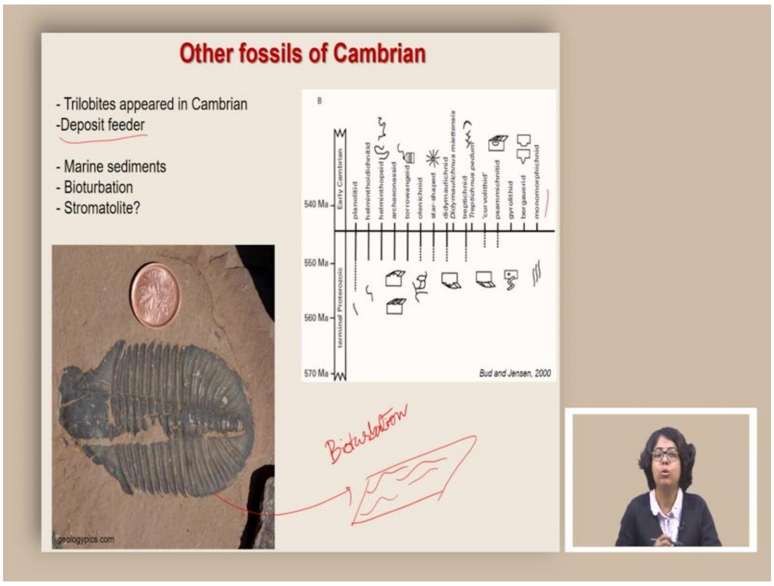

The other fossils of Cambrian apart from the groups that we talked about are trilobites. Trilobites are very important fossils of Cambrian and they were deposit feeders. There was a time when Cambrian used to be equated with the appearance of trilobites because they were very common, they were very distinct and they are extinct form, so there was a lot of interest about trilobites. And these trilobites were deposit feeders and they lived in different depths of the ocean and because they were deposit feeders they were constantly turning the sediments and that is what we called bioturbation.

Because of this bioturbation, organisms which used to live on the sediment surface especially things like microbial mat, they no longer could exist because they were constantly being eaten by groups such as trilobites who are deposit feeders. And that is why if we look at the organisms and kind of burrows and trace fossils before and after Cambrian, we see a very distinct pattern; certain types did not appear till Cambrian and certain types actually are not found beyond Cambrian, primarily because of the appearance of these deposit feeders which constantly ate sediments and repurposed it.

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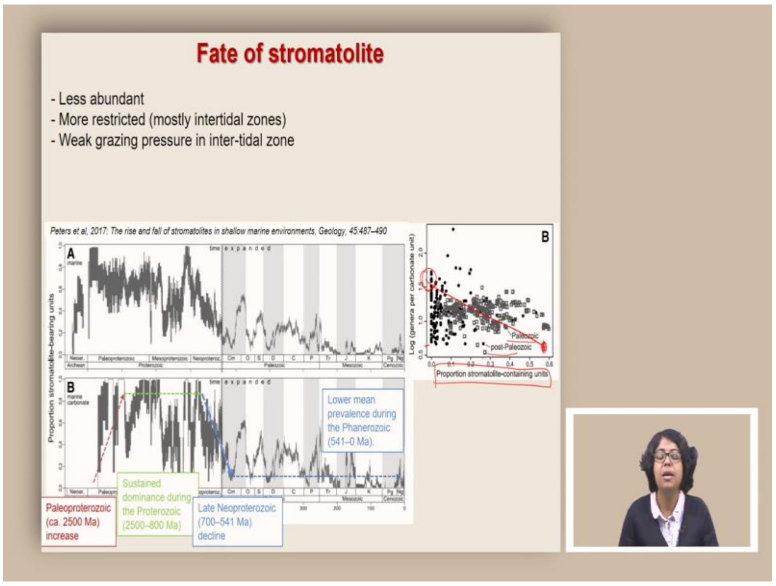

So, the stromatolites who were so abundant during protozoic and also at times in Archaean, they started to drop after Cambrian. In fact, we can still find stromatolites, it is a trace fossil of these cyanobacteria, it is not these trace fossils are not that they cannot be created or it is not even that the organisms responsible for creating stromatolite are extinct but they have become very rare. So, if we plot all the stromatolites that we find in Cambrian and proportion of stromatolite bearing units throughout the Cambrian and afterwards, so this is post-Paleozoic and this is Paleozoic.

But if we plot that along with how many groups we are finding in those sections, in those rocks, we are going to find a negative correlation. What that means is that when there are lot of groups in the same formation we are going to find if there are less number of groups then we are going to find a high number of stromatolites and this indicates that these high number of groups and low number of groups are basically equating or telling you something about the deposit feeders. So, if there are lot of deposit feeders these microbial mats cannot be produced and therefore they are not going to build the stromatolites. If you remove these grazers or the deposit feeders, then the microbial mats are going to get produced and they are going to eventually convert to stromatolites.

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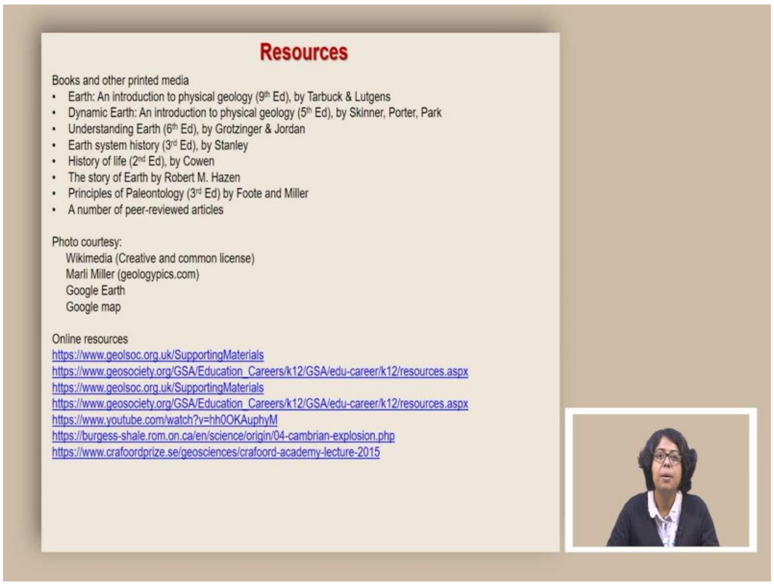

So, in summary in today's class we learnt about what was Cambrian explosion. We learnt specifically about Burgess shale fauna and what are the different types that one encountered in Burgess shale fauna. We also learnt about different ecosystems especially the feeding structure within the ecosystem and then we learnt what kind of different feeding styles we started to see in Cambrian which was not present before. Finally, we learnt because of the Cambrian explosion what was the fate of stromatolites which were so common in archaea. We learnt about some of the causes of Cambrian explosion also. Here are some of the resources that I used for making the slides.

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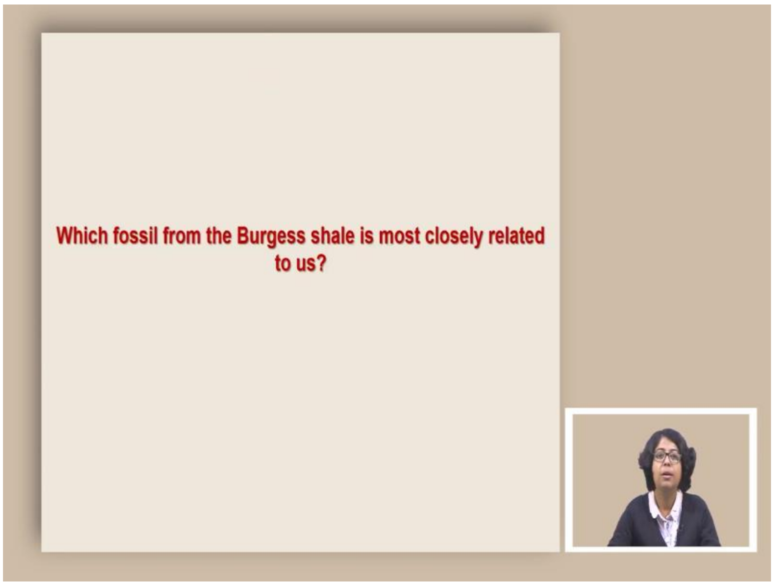

Here is a question for you to think about. Thank you.