Evolution of the Earth and Life
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Appearance of Amniotes

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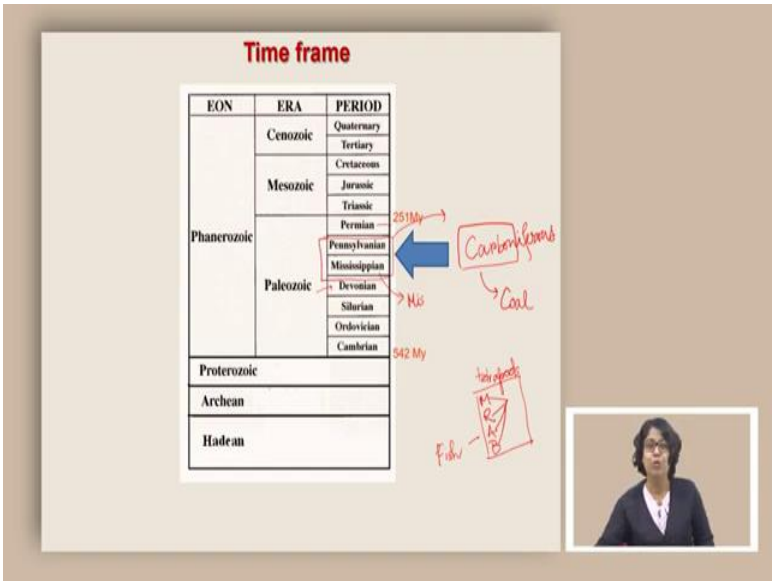

Welcome to the course Evolution of the Earth and Life. Today we are going to talk about a new group amniotes. The geologic timeframe that we are primarily going to be focusing on would be part of the Paleozoic which is called Pennsylvanian and Mississippian both of them together is actually referred as carboniferous now carboniferous gets it is name from this part of it which basically indicate that this is a primary source of coal that we use today.

The reason carboniferous has been divided into these two parts is because they look quite different in the rock sections of the United States of America one part of it is better represented in the state called Mississippi and therefore, it is called Mississippi and the other part of it is better represented in the northern state of Pennsylvania. And therefore, carboniferous is generally subdivided into these two parts called Mississippian and Pennsylvanian.

So, we are going to look at primarily some of the events that were taking place around this time. And finally talk a little bit about some of the events that were taking place in Permian. Now, so far, we have talked about one group that appeared somewhere around Devonian and that was a major transition and we talked about these clades or groups which went from fish to a completely different group of organisms which are called tetra pods.

Now, these tetra pods are the groups which evolved from fish but they were quite different from fishes because they have limbs. We also know that within tetra pods if you look at today's world we are going to find all kinds of groups such as mammals, such as reptiles, such as amphibians, such as birds, all these groups actually fall within the part of tetrapod.

Now, we also know that not all of these are the same they are also quite different. So, now the question is what is the next major event that appeared and which were the next group among the tetra pods? This also brings us to the question the paper the first tetrapod groups like So out of these mammals, reptile, amphibian, and birds, which one was represented by the forest tetra pods that appeared on the earth. So, we are going to focus on certain characters.

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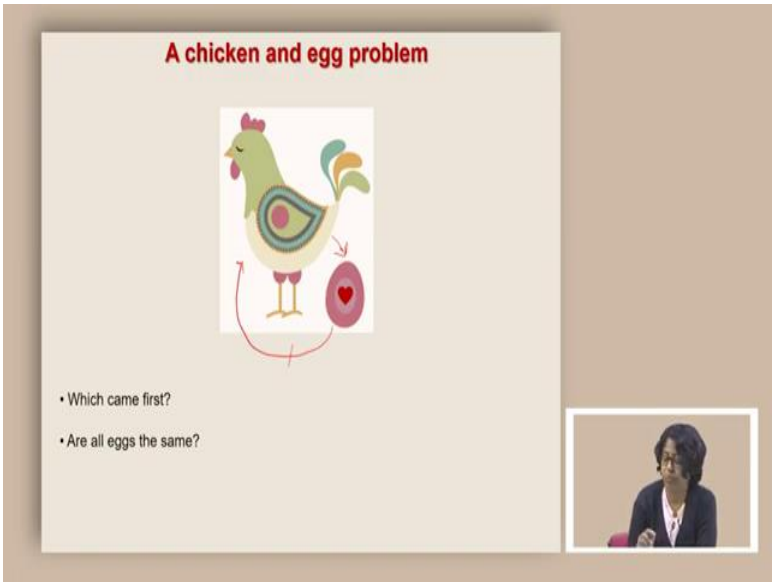

And this will bring us to this controversy that we are all familiar with which is a chicken and egg problem. So, generally, we refer to chicken and egg problem where we really do not know what is the starting point to in the analogy if you are asked that you have a chicken and the chicken lays the egg which one came first it is very difficult to say because an egg leads to the development of a chicken and then finally the chicken lays the eggs. So, it is very hard to break this loop and say which one came first.

But then can we ask this question that are all the eggs same? And if we are particularly talking about these kinds of eggs? Did these eggs come first? Or is it the other kinds of groups that came first? So, roughly calling it a chicken and egg problem. So, therefore, it is important to know are all eggs the same. So, if we are rephrasing this question that whether the chicken came first, or the eggs came first and that is what we are going to focus today.

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So, eggs are not just eggs there are major differences in terms of how eggs are formed how they look like where do they live and how it contributes to the growth of very young individual right after the egg is hatched. So, there are major types of eggs and we are going to subdivide them into two major groups. One group has soft membrane and these are eggs like the fish eggs or the frog eggs that we are familiar with. And they could only survive in water.

The reason they can only survive in water is because they have a soft membrane it has a jelly like substance. And if it is laid on the ground where there is no water, it dries out very quickly. And once it dries out it cannot really lead to the development of the young individual. Not only that if we look at the number of eggs, in each time when a matured individual is laying eggs. For these kinds of fish eggs or frog eggs the number is really, really high at a given point of time a fish can lay 1000 of eggs at a given point of time and that can create a large pool of small individuals.

Now, the question is why so many, part of the reason is not all of the eggs finally lead to the formation of individuals because many of the eggs do not survive. Think about the water where the eggs are being laid, the water has current there are a lot of predictors also in the water. And these water currents can actually move the eggs in different directions sometimes it can get exposed and therefore might not mature into individuals or might not mature into the final stage of embryo.

And these are some of the reasons because which the total number of eggs laid at a given point of time is much larger for these kinds of jelly like eggs the total number of individuals

surviving and going to the matured stage is much smaller than the total number of eggs laid. The other difference or the other characteristic for these kinds of jelly like eggs are that young individual that comes out of those eggs look very, very different from the matured individual.

We are all familiar with fish larval or for the frogs from larval or tadpoles, they do not really look like the adult frogs or fishes. And that is what I meant by that the young individual that comes out of the fishes comes out of these jelly-like eggs are very different from the adult individual. And these are the kinds of eggs which are called a non-amniotic egg.

Now let us take a look at a slightly different type of egg which is called an amniotic egg. Eggs, such as bird eggs or reptile eggs. They have hard shells. And these shells are very interesting because they have a permeable nature we will talk about it in great depth. And these eggs can survive on land they do not require water for survival. And when we talk about groups that leaves such eggs we also know that they do not lay 1000 of eggs at a given point of time that total number of eggs are much much lower.

That also indicates that they must be surviving more. As a result, the requirement for laying a number of eggs is sort of reduced. And hence you see less number of eggs at a given point of time. The individuals which come out of those eggs resemble the adult individual maybe they will have a slightly different size but it would be relatively easy to recognize that it is a young individual of that adult individual. It is not completely different. It is not going to go through a metamorphosis which is common for the fish egg or the frog eggs. These kind of hard shelled eggs which do not require water for their survival and can survive on the land are called amniotic eggs. And it is interesting when these amniotic eggs started to appear.

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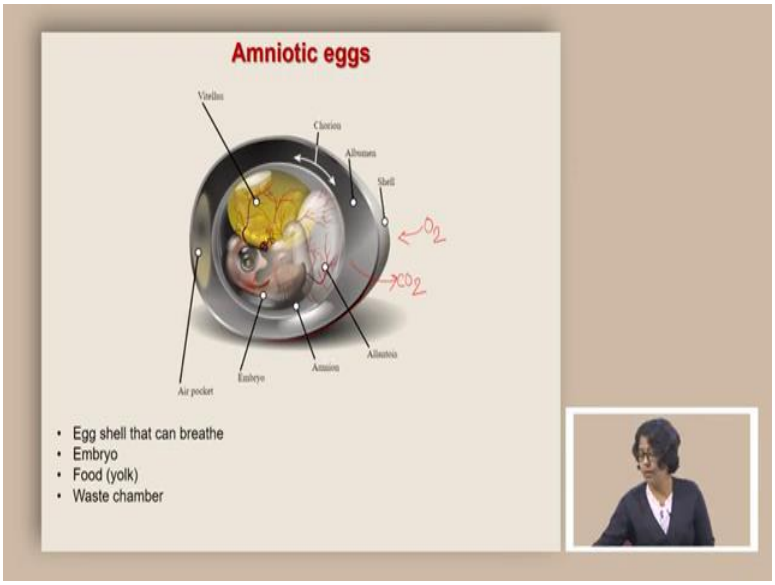

The amniotic eggs are a complex mechanism. It is not as simple as the non-amniotic eggs where it is a jelly like substance which has primarily the embryo. So, once the embryo grows it converts to this form where it can be a fish. I mean, for the frogs it is a tadpole stage. So, the individual sweet coming out of those eggs, those non-amniotic eggs are not matured at all. And they do not have the degree of maturity simply because they do not have food in the egg itself.

So, what is being hatched out of those eggs are really, really mature individual then they go through phases which matures them eventually. In contrast amniotic eggs are way too complex it has different chambers. So, it has these egg shell which can breathe what we mean by that it has this permeable layer so oxygen from outside can actually go inside there are gases which can form inside can go outside. So, this shell has this fantastic quality of working as a permeable membrane although it is hard and therefore it protects the inside from desiccation.

So, that means this shell, although it is permeable also although it is allowing the entry of oxygen and removal of carbon dioxide it is not allowing you know water which is inside to go out it is also not allowing any other things such as water to go inside. So, this is a fantastic type of shell which is creating a barrier from the outside world. Now, what is there inside there is the embryo.

This is a typical chicken egg. It has this embryo which can grow. But if it is growing in a closed system that means it requires food. And that food comes from partly the yolk and

other parts albumin also contribute. And then there is another chamber because when it takes the food the food goes through this metabolic pathway eventually creates waste and that waste needs to be stored somewhere. And that is the reason for another chamber often the allantois where all these waste products are getting stored.

So, now we have a system of a closed structure where the embryo can grow for quite some time till it reaches the maturity, it requires food. And the food is already provided it requires part where the waste product can be stored so that it does not mix with the food or create toxicity to the embryo. So, that chamber is already there. There is also a mechanism to keep all of these things into a stable position.

So, this is a perfect solution to be or to have in order to be in on the land for a very, very long duration. And that is one of the reasons why we do not really see amniotic organisms are the organisms which lay amniotic eggs to have very matured kings or very matured juveniles coming out of these eggs. The egg is our process it provides a mechanism by which these organisms can grow inside the egg and that means when they come out they are already matured. And therefore, their mortality rates the probability with which it can die reduces significantly and hence the groups can afford to lay lesser number of eggs.

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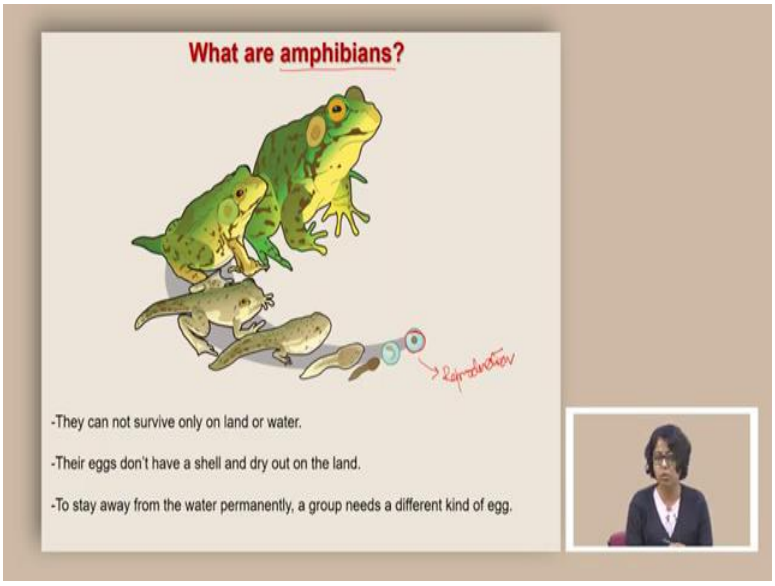

So, now let us try to understand a little bit about what are amphibians. So, when we think about amphibians at least the meaning of the name it sort of says that it can live in water and it can live on land. But the truth of it is it is one animal which cannot live completely on land

it cannot live completely in water it actually requires both. And that is one of the typical character of an amphibian.

If you think about the first transition from the fish to tetrapod starting with euthenopteron going through tiktaalik and finally ichthyostega what we understood that there was a major push to go to the land and the groups which went to the land got a selective advantage. However, they were not completely free from water part of their lifecycle and which is an extremely important part which relates to reproduction was still attached to the water. Without water they cannot reproduce because their eggs are still in that jelly like shape and therefore require water.

So, in order to reproduce they cannot live completely away from water they need to come back to the water to lay eggs. And therefore, if you think about amphibians, they cannot really live in places which are very very much away from the water bodies. So, it can be a pond, it can be a river, it can be the ocean, but it has to be some regular source of water body. And that restricts how far they can go. And that was the case of the groups that first ventured into the land among the vertebrates. The first tetra pods were all amphibians they move to the land but for their reproduction they still had to come back to the water body.

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And with the advent of newer eggs we started finding a different group appearing. So, now if we look at these classifications again we know that all of these groups are bordered by this red color are called tetrapod and within tetrapod there is a small subset which includes reptiles, birds and mammals, they are surrounded by this blue box. They are called amniotic

because they are eggs do not require this water for survival as well as their eggs are not jelly like that we have seen for amphibians and fishes.

So, the next group that started to appear from the tetrapod broad group of tetrapod was these amniotes. And by that logic we can basically say that if you think about the eggs definitely the eggs came first. But when you were talking about the birds or chicken that came later so if we are specifically talking about just eggs and chicken I would argue that the eggs came first and then the chicken. But typically, we are talking about non-amniotic eggs coming first and then appearance of amniotes.

Now, as I mentioned that the first evolved tetra pods were amphibians. Although they were the first to venture land they could not move away from water. And that is one of the important aspects to remember when we look at the fossil record of these first tetra pods also we find that they are mostly restricted near the water bodies.

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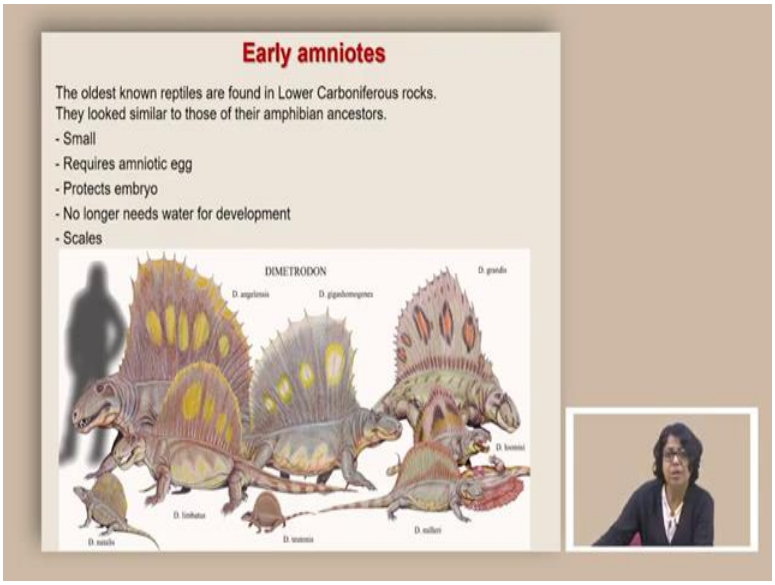

So, now we are going to focus on the early amniotes. So, now we are talking about a group which is part of the tetrapod but no longer an amphibian. And what was the character of those groups? Who do they represent? So, we know that the early amniotes We started finding the record of early amniotes from lower carboniferous rocks they looked quite similar to the those of their amphibian ancestors.

However, there are some striking differences. When we think about the ichthyostega which was an amphibian which was an ancestral organism it was quite big. However, the early amniotes that we started looking at because we they are small. They also had amniotic eggs

and one of the ways of knowing that they were amniotic or early amniotic is by two factors. One is the preservation of the eggs. Because unless it is a hard shelled or thing it is not going to get preserved. So, preserved eggs sort of indicate that it was in the appearance of amniotes.

But the second most important thing is if we started finding amniotes or even these tetra pods in places which are far away from the water body or water source, that indicates that they must have been quite independent of the water source for their reproduction and then only they can spread their ranges and survive in places which is not in association with water. And they can only do it because they are embryo were protected by this shell.

They do not require water for the development because apart from only the eggs in non-amniotic organisms the non-amniotic eggs require water but it is not just the non-amniotic eggs which require water. It is also the first formed individuals like the tadpole or the fish larval all of them require water they are not free from water at that stage it is only when they mature they can go out for the case of amphibians where they can live on land till they need to reproduce.

The other important criteria that we started finding in amniotes in earlier amniotes are the presence of skills which are not present in the tetra pods which unknown amniotic. So, this probably should give us a fairly good idea that who they were who were the first amniotes they were the reptiles.

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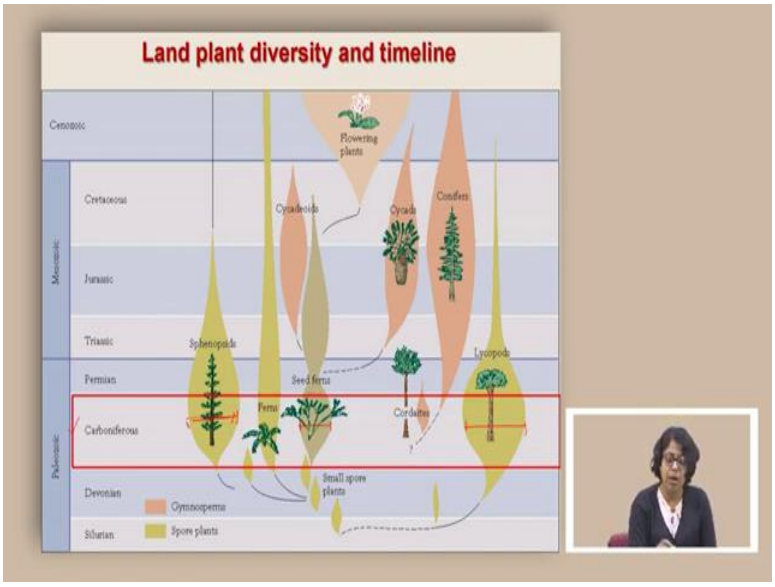

Now, the question is that why would this kind of a lifestyle would have been beneficial. One idea is that it was also related to the changes that were happening around them. So, one

important aspect to recognize is what was happening in carboniferous. So, if we look at this diversity diagram of plants we will find that during carboniferous there were a lot of plant groups with started diversifying and we find these very broad diversity patterns we chose that their diversity was quite high. And not only that there are new groups which appeared in carboniferous.

Many of these groups that we look at they are woody plants and they made large forests. These forests were places where the upper part of it had this big canopy. But many of these plants were also dying. And therefore, they created these woody Flore where there are small insects which were there. And this is the perfect place for any group to have enormous amount of nutrition and food if they can stay away from the source of water. And that is one of the selective advantages for groups which could utilize this part.

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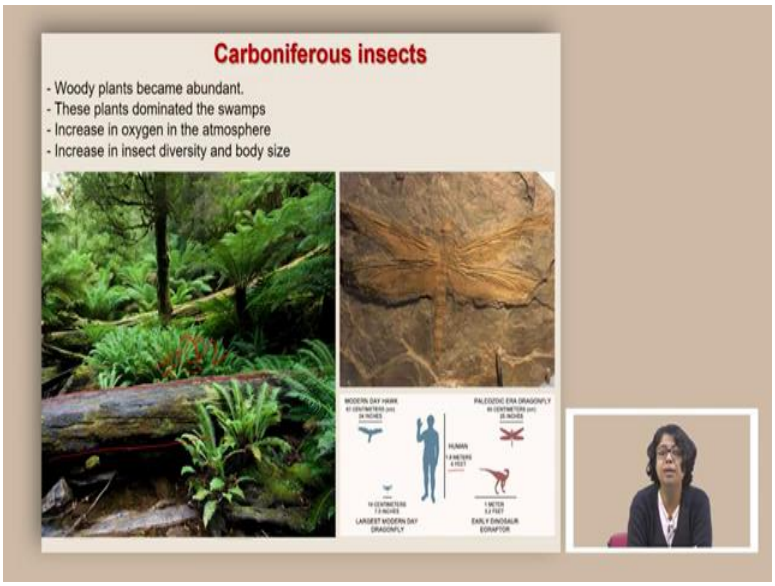

Another interesting point for carboniferous which is related to these plants is the level of oxygen. So, woody plants were very abundant in carboniferous and if we look at one of the Carboniferous forests it would have looked something like this. Where you can see there are lots of large plants but at the ground also there are different kinds of plants. There are woody barks that are lying and lead.

And because these kinds of plants were abundant these plants often dominated swamps but swamps are places where because of the vegetation it constantly consumes oxygen and therefore the swamps become relatively anoxic and in those anoxic places if the plants keep on getting buried eventually we will find all these woody material and accumulating and those woody materials are not oxidizing because of lack of oxygen.

So, those woody materials are not really converting to carbon dioxide this carbon of it from the woody plants are actually staying there. Not only that because of the overbought thing pressure of sediments these will be compacted and eventually produced a coal. This was one of the reason because of which we start finding very high production of coal corresponding to this time.

Apart from development of coal this is a time when there were lots of plants and plants release oxygen. So, this also led to the increase in oxygen concentration in the atmosphere. Now, increasing oxygen in that post we are also helps also support the growth of insect body size. So, we find around this time large insects and these insects such as these dragonflies have meter scale wingspan.

So, this is a human for scale who is 6 feet human. And if you contrast it with the dragon fly you will find that this dragon fly was pretty similar to a large Hawk that we can see today. So, it was pretty large and similar to our modern the large bird. And these were sustained simply because the oxygen level in the atmosphere was quite high it is higher than the present a oxygen concentration.

Now, this means that the entire ocean, the entire land floor forest floor has all kinds of organisms not only these flying insects but also crawling insects which are large but which can be pursued and can be attacked by the predictors and those predictors. If they are agile and the that helps a lot. And these areas are often away from the water. Even if they are closer to water the water is a swampy water where there is not much oxygen. If the water does not have enough oxygen it is not good to lay eggs in those water especially the non-amniotic eggs the non-amniotic eggs also require a bit of oxygen. And if the water is completely anoxic it is going to kill those eggs.

So, therefore if there is a group which can lay eggs on the ground where the oxygen level is very high in the atmosphere. That helps because the oxygen can permeate through the hard shells of amniotic eggs. But if it is unknown amniotic eggs which are laid on the water and the water is anoxic it is not going the non-amniotic eggs are not going to survive. So, this particular situation worked in favor of groups which laid eggs on the ground and had a hard-shell. Moreover, the early formed groups which can survive like this they were also small and they had plenty of food sources those foods wall primarily the litter-based insects.

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So, the main advantages of early formed reptiles over amphibians were that they had advanced jaws. So, they can go after our predictor go after a prey primarily these insects and then they eat them they their jaw had higher pressure they also had bleed like appearance of tooth which are good for slicing which we do not find so often among the amphibians. Now the question is why do we find very small amniotes at the beginning so as I mentioned that unlike the amphibians that were found in the fossil record at that point of time which were large the reptiles are the first amniotes they were really small.

The reason behind this is for small groups it is actually easier to hide and often to regulate their body temperature. Because these are all cold-blooded organisms and they can hide into this empty bark of the tree or hollow space. says of a decaying tree. Sometimes when the sun is up they can do pushups just like this sailfin lizard does even today and create enough heat to sustain them for quite some time.

And also, when they are small they it is easier for them to chase these insects, which are also living through these white dense forest flow. So, all of these things probably favored the small non-amniotic appearance in the initial phase which were basically reptiles. Now, during the end of Permian, the reptiles started diversifying. In fact, we will see that the number of reptiles were quite high and their size also started to increase. And they were taking all the ecological roles which were initially taken by the amphibians.

And this has an extreme manifestation even today. So, even today if we look at the diversity, we will see that the reptilian diversity is much higher than the amphibian diversity. Not only

that, in today's world the amphibians are primarily restricted near the water and they are always of the smaller size. In fact, one argument is that all the larger amphibians were wiped out, because the larger size was not supported in this competitive scenario where they were constantly competing against the reptilian groups for the same ecological dish.

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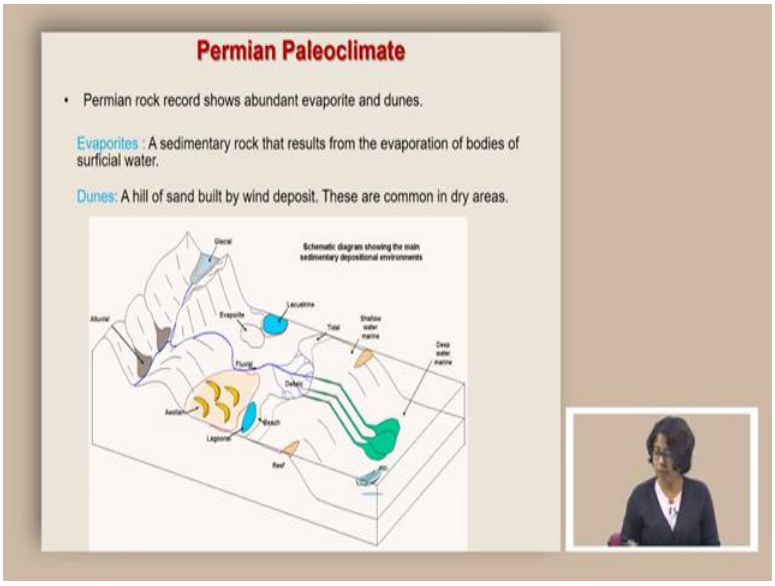

Another point of this very high reptilian diversification near Permian may also be related to some of the paleo climatic change during Permian. Now, Permian rocks, rock record shows abundant evaporites and dudes so let us try to understand what these are so evaporites are sedimentary rocks or that results from high degree of evaporation of water bodies and these water bodies could be restricted water from the ocean it could be a leak it could be anything as long as the degree of evaporation is very high and therefore leaving behind are highly saline condition and eventually development of evaporites these are specific crystals they will often have salt crystals or highlight.

The second important aspect of these Permian rock record is the presence of dunes structures. Now, dunes are a hill of sand which is built by the wind deposit and they are generally more common in dry areas. So, if we look at this diagram of sedimentary environments what we will find that often places like here where it is quite dry there is no water input and probably the wind is basically making it wide dry we will find these dunes these dunes can move back and forth depending on the wind direction. Next to it we are also finding evaporate so there can be a lake but part of the lake could dry out and eventually creating a rock section or sediments that have all these minerals which produced because of the high degree of evaporation.

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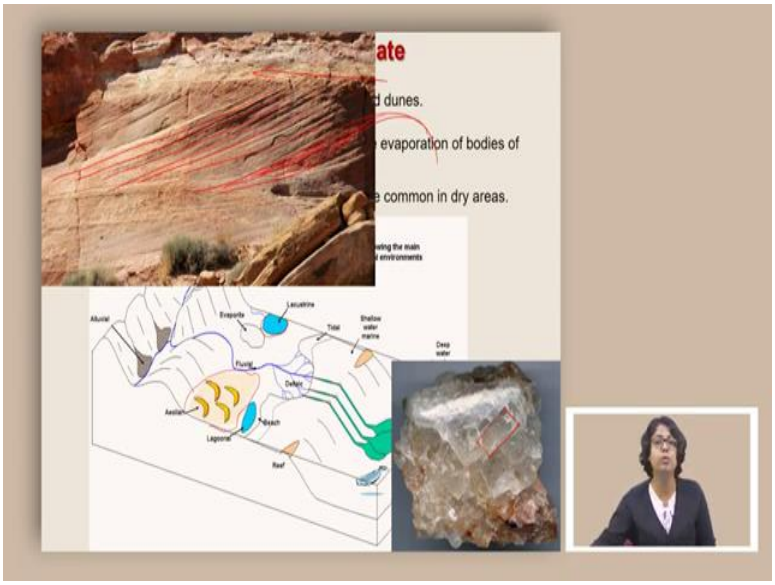

Now, when we look at the rock record it looks something like this. So, this is a typical high lite crystal that produced because of high degree of evaporation. And this is how the dune migration looks like in the rock record. So, if you think about it the dunes are actually probably something like this. But then as the wind current flows in this direction they migrate.

So, every time they migrate they create a different layer. And these layers get present predated and because the previous layer gets solidified you will find different layers and these kinds of layers are telling you the wind direction also. And these features are always telling you about relatively dry condition. So, now the question is that why do we find so many appearances of these dry condition markers in Permian and the clue is in the Paleo geography that means what was the condition of the continents.

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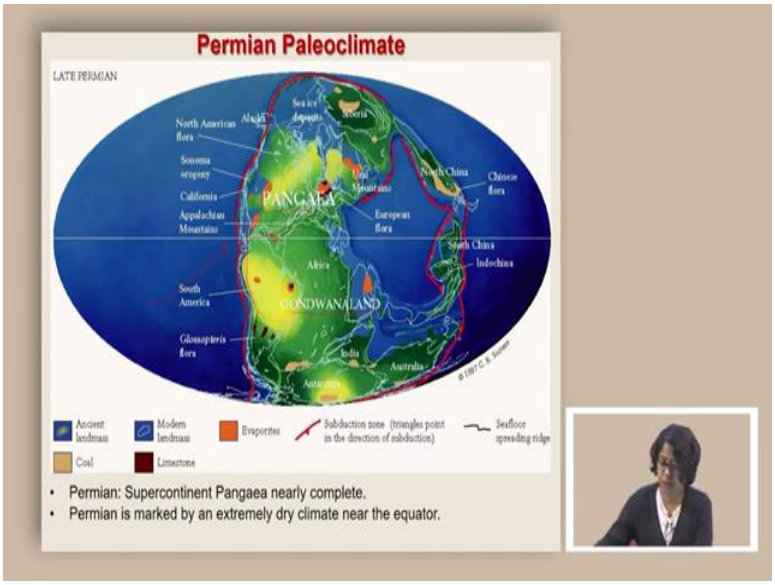

If you look at late Permian, we will see that the entire equatorial region is covered by continents. And this is the part which we often say the Gondwanaland as well as Pangea to it is mega continent it is a super continent. Now, when you have these super continents especially near equator it creates a very dry condition towards the center of it because the water which is being carried the water vapor which is being carried by the wind starts to precipitate towards the side of it by the time this wind goes to the center of these continents, they do not have enough water washer from which it can precipitate it can form rain as a result the central part of it becomes very dry it becomes very arid.

So, one understanding that we should develop is this is the time when there is a large-scale drought or formation of dry areas worldwide. And there are two groups, we have these amphibians we also have these reptiles one is completely dependent on water in terms of their reproduction, and the other one is free from water as long as the reproduction is concerned, the selective advantage is going to go towards the reptilian group because of their independence of the water body in terms of their reproduction. So, probably this also played a major role in the eventual diversification of reptiles and restriction of amphibians into relatively narrow ecological niches.

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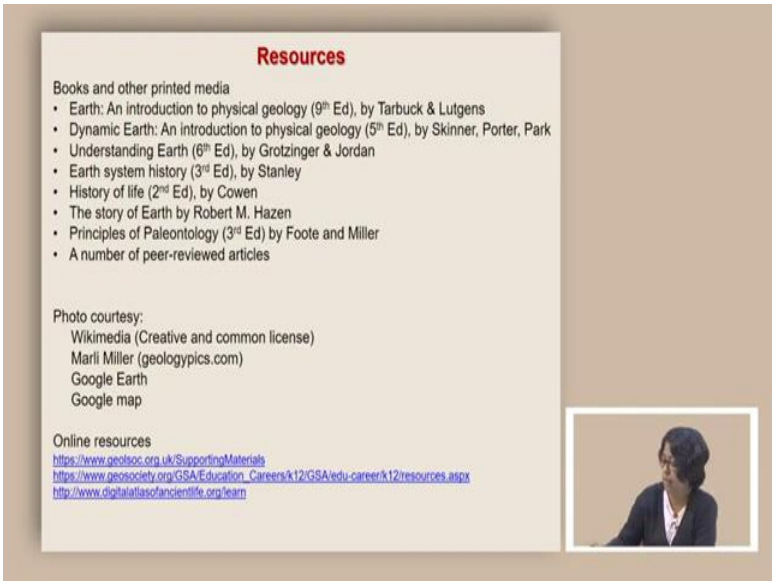

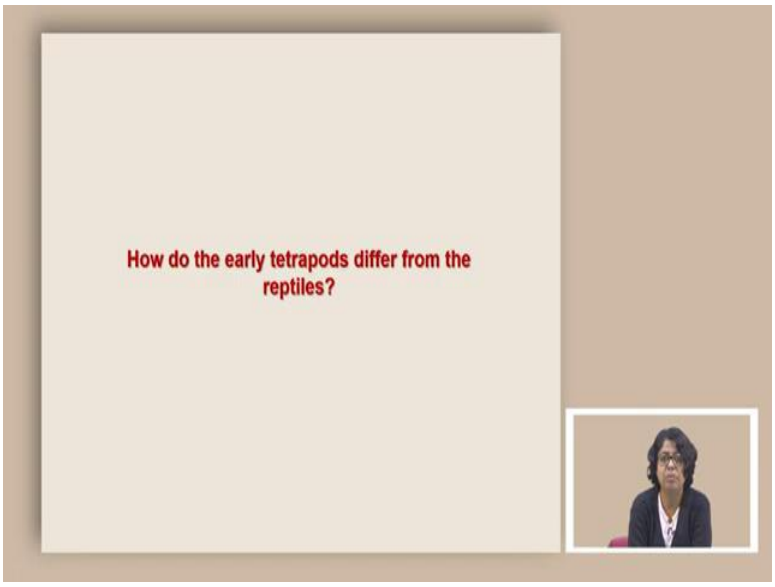

So, in summary today we learned some of the events that took place during carboniferous we learned how a new group evolved out of tetrapod and that group is amniotes. These amniotes have a different kind of egg which has a closed structure which can support the young individual inside and therefore the young individual can grow for longer time and when it is hatched, it becomes a much more matured individual compared to the non-amniotic eggs.

The non-amniotic eggs require water throughout. Even after hatching the young individuals require water for prolonged time. So, the development of amniotic eggs led to the development of this new group called amniotes, which includes reptiles, birds and mammals. We think that the first formed tetrapod was an amphibian and the first formed amniotes was a reptile conditions in carboniferous were helping the reptiles to become dominant primarily

because the condition was very oxygenated in the atmosphere but at the same time the swamps are the water bodies had a relatively anoxic condition.

So, that water lead in water will suffer because of lack of oxygen, whereas the oxygen permitted through the amniotic eggshells will have plenty of oxygen. Increasing oxygen during carboniferous also led to the diversification of different kinds of insects, which can work as a food source for the early from reptiles. Finally, the Permian dry arid climate also favored the proliferation of reptiles and amphibians became very, very restricted to near water areas and they are always of small size in present day. Here are some resources that I used to make the slides and here is a question for you to think about. Thank you