Evolution of the Earth and Life
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Who are Whales?

Welcome to the course Evolution of the Earth and Life. Today we are going to learn about the development of new group called whales.

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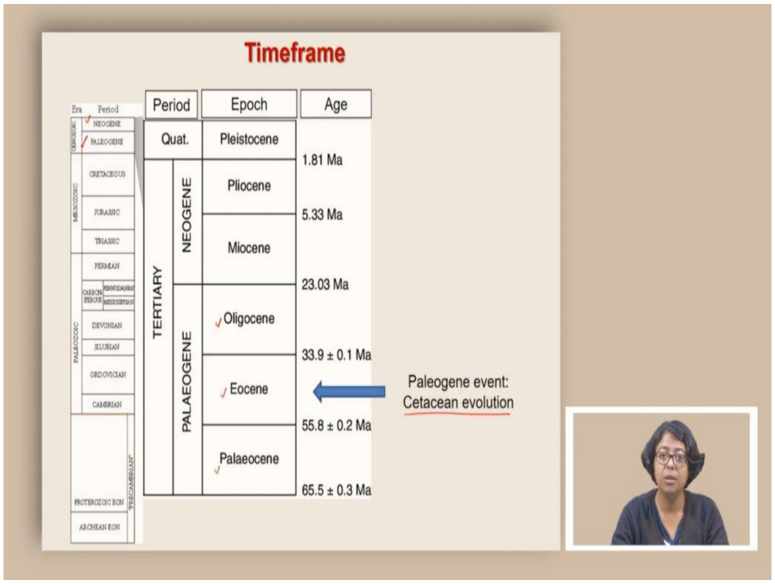

Let us start with the timeframe. As we mentioned before that Cenozoic can be divided into two major periods Paleogene and Neogene. And within Paleogene there are three epochs Paleocene, Eocene and Oligocene. And the major change that we are going to be talking about today appeared somewhere around Paleogene and it is called cetacean evolution. Cetacean are the groups which contains all kinds of mammals which live in the ocean.

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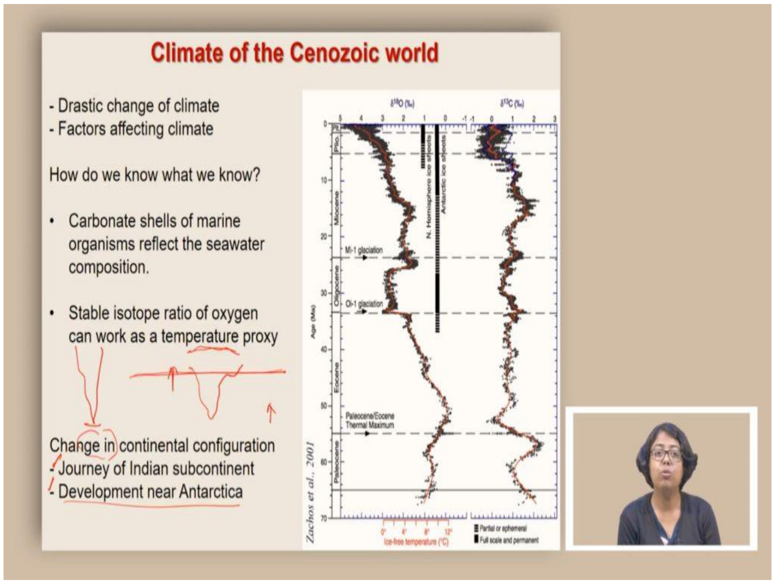

And another point that is very specific to Cenozoic is this drastic change of climate, which changed between cold climate and warm climate. It is also aided by some of the changes in the geography. One of the major change was this journey of Indian subcontinent from a nearly polar region to all the way to the equatorial region. So, if we look at the modern day position of India, what we will find that there is the Tropic of Cancer, which runs pretty much through India at the middle part. And we have Himalayas on the top and this configuration was achieved only during Cenozoic.

During Cenozoic, it basically moved towards the north, and collided with the Eurasian plate and formed the Himalayas. So, as India moved northwards, its all land for now moved with it. So, that is also one very important geographic change that happened during Cenozoic. The second important change that happened during Cenozoic is the development near Antarctica. So, Antarctica as we know is frozen continent today, but it was not as cold as that at the beginning of Cenozoic. At the beginning of Cenozoic, the South America was still had some connection with Antarctica, and this link was lost sometime in Cenozoic, where the ocean circulation changed.

So, these two events greatly impacted the development of various groups during Cenozoic, and we are going to talk about one such group, which is the cetaceans.

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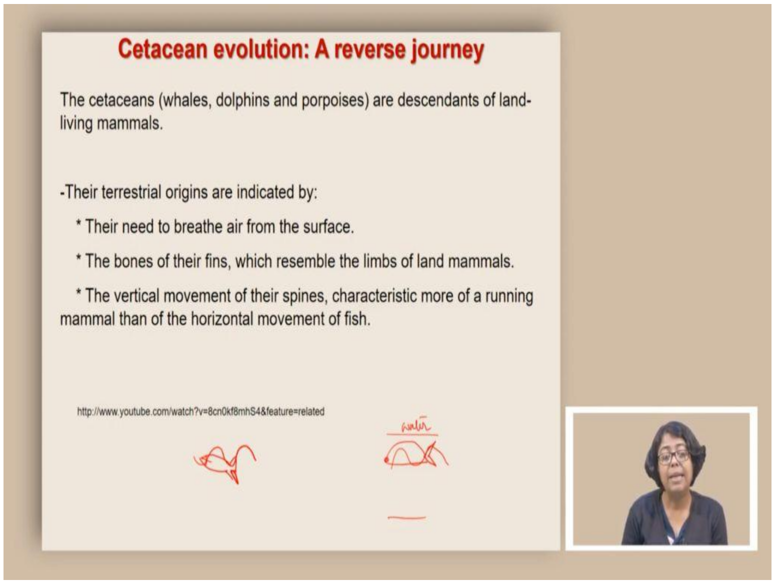

The cetaceans as I mentioned, include whales, dolphins, porpoises, they are descendant of land living mammals. Now, how do we think that they were descendants of land living mammals? Because although they live in water, or although they live in the sea, often they show characters which are very different from other sea living creatures. So, I am sure that you have seen a whale coming to the surface and blowing the water. And that is something which we do not see in any other marine organism. And this also led people to understand that their origin is very different from the other marine groups that we see.

So, the terrestrial origin is indicated by their need to breathe air from the surface, and that is the reason they come up to the surface every once in a while, a whale, or a dolphin, or a porpoise that cannot live inside the water for the entire time. They can live for substantial amount of time, but then they have to surface, because they have to breathe air, and they cannot breathe air from the water, unlike the fishes unlike the sharks. The second point, which is very interesting also is the bones in their fins resemble the limb of land mammals. Generally, the fins of a fish or even a fish which has a musculature like a lobed fin fish, those bones do not look like fingers.

But, if you look at a whale fin, it is actually made up of bones, and which resemble the limbs of the mammals. And that is another indication that they must have been developed, they must have been originated, evolved from organisms which lived on the land. The third point is about how they move. So, if you look at the fishes, these fishes, and if you are looking at them from the top, we will see that the fish movement is somewhat like this. So, we have seen the example of the early amphibians when they moved, and even early reptiles when they moved, it was movement towards the side.

And every time they were moving in one side, they were squeezing part of their body, and that is way the reptiles move, that is the way how the fishes. So, they are always moving and squeezing sidewise. But, when we look at the mammals which live in the sea, and therefore they swim and they move, their movement is very different. So, they do not move like this. If we think about a fish, the fish movement structure is always like this, and therefore, it moves sidewise. But, on the other hand, if you are tracking a whale, it will never seem to move, but, if you are looking at a cross-section, so that means you are looking from top to bottom.

Then, you will see that the movement, the sense of movement is actually like this, but this is the top surface of the water and this is the bottom surface of the water. So, the whales actually move in a very different way than a fish, because part of the body is moving with the water. So, their movement is more of up and down movement, like how a horse moves or how a cheetah moves, rather than a sidewise movement. This is unusual because none of the other fish or water living animal shows these kinds of patterns. So, the vertical movement of the spines, characteristic more of a running of a mammal than a horizontal of a, horizontal movement of a fish indicates that their origin must have been terrestrial, and then they evolved to live in the water. What is the genetic structure tell us?

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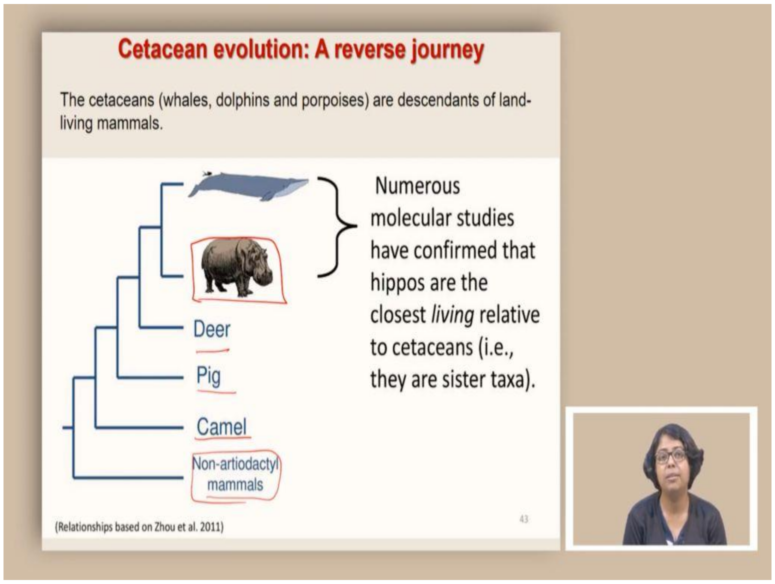

So, the cetaceans have been looked at for quite some time in terms of their relationship with other living organisms. And what they show us is if we plot them in terms of how they are related to other organisms, we are going to find this interesting pattern, where we will see that there are many mammals which are grouped as a specific type. Then, there are camels, pigs deers, but, then when we look at the whales or other cetaceans, they are actually closely related to a living land living organisms. And that is Hippo. Hippo is the closest living organism in terms of its relationship to whales, and that sounds quite interesting, because in terms of its feature, it does not look like a whale.

So, that is the reason where scientists started to explore more that was the history of the whales and whale development. And majority of this whale research and where whale fossils were found, ancestors of the whale fossils were found, actually are around India, Egypt and Afghanistan, Pakistan. So, this entire region is very rich in the fossils of the whale ancestor.

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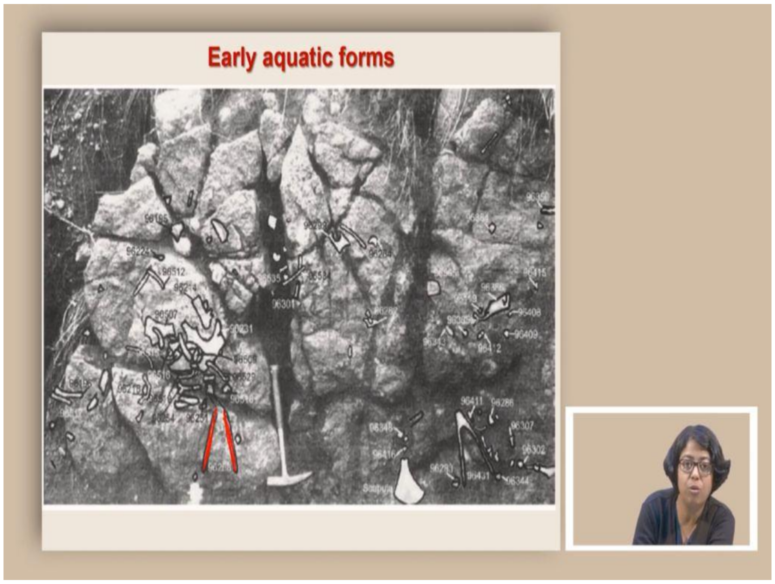

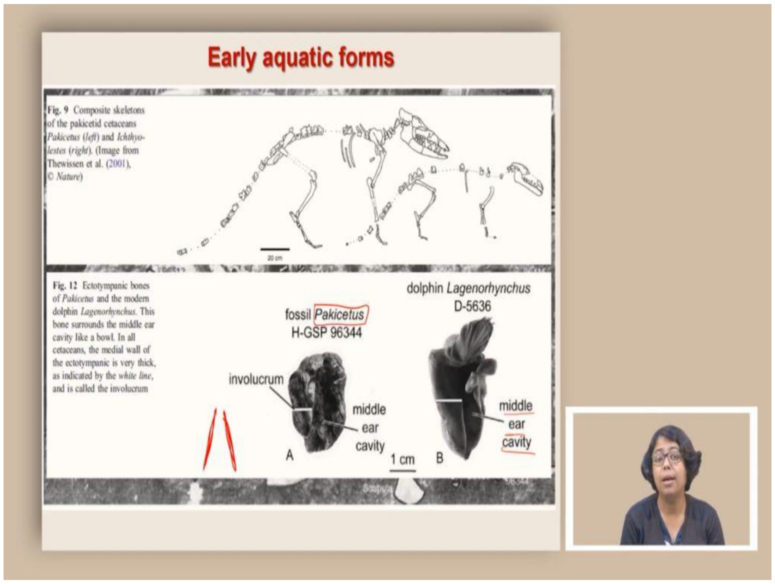

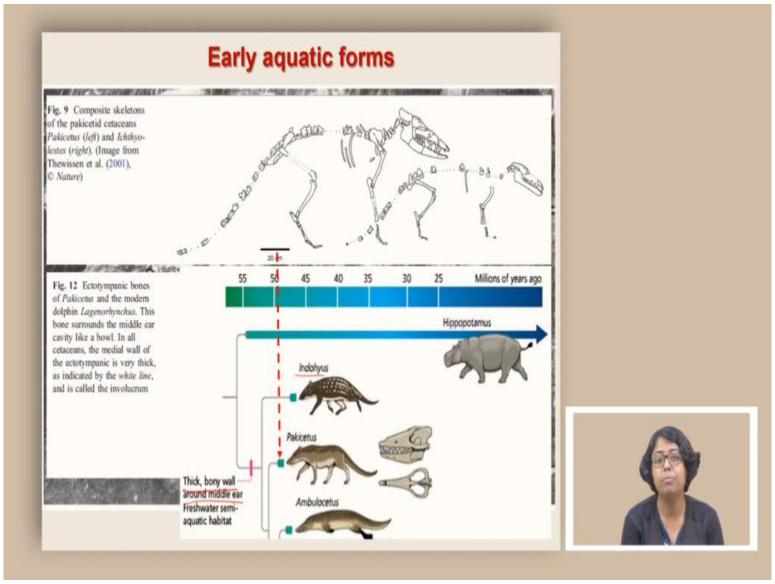

So, it starts with this discovery of an curious looking organism in Pakistan. And once these bones were discovered, so these are bones which were found as part of a rock assemblage, and carefully extracted from these rock. And finally reconstructed as this organism, which looks very different than what we think of a whale. But, this organism shows certain characters such as how their ears are and how their tooth are, which clearly indicates that they have some similarity with the whales, and therefore they are considered as one of the oldest ancestors of the whale. And because it was found in Pakistan, this particular fossil is called Pakicetus.

How do we know an organism whether it is lives on the land or lives in the water? One important indicator is this middle ear cavity, so, the ear region has to be adapted to the life. So, the way we hear on the air is very different from the way an organism hears in the water, because the water has a completely different density, viscosity compared to air. So therefore, if an organism is living substantial amount of time in the water, the ear region has to change. And that is one of the clues that tells you whether an organism lived substantial amount of time in the water, and for Pakicetus that was the case.

But, otherwise, it looks like a terrestrial organism. There are other groups which have been discovered as fossils, which also shows some similarity with the development of the whales. So, before Pakicetus, there was Indohyus which looks absolutely a terrestrial organism, but it has some similarity with Pakicetus. Within Pakicetus, we see some changes in their ear region, and also partly nose region and we will talk about it. But, then we also started to find more water living organisms. So, the important character that combines all of these groups, which we think are quite different from other regular terrestrial organism is this thick, bony wall around the middle air region, which indicates a freshwater semi-aquatic habitat.

So, probably these organisms did not live in the water for the entire time. They were semi-aquatic, meaning they lived on the land, but they also lived in water for some time. If you think about otters, they are something like that, they often live on the land. But, they also live in the water for some time during the day, or during the entire duration of life.

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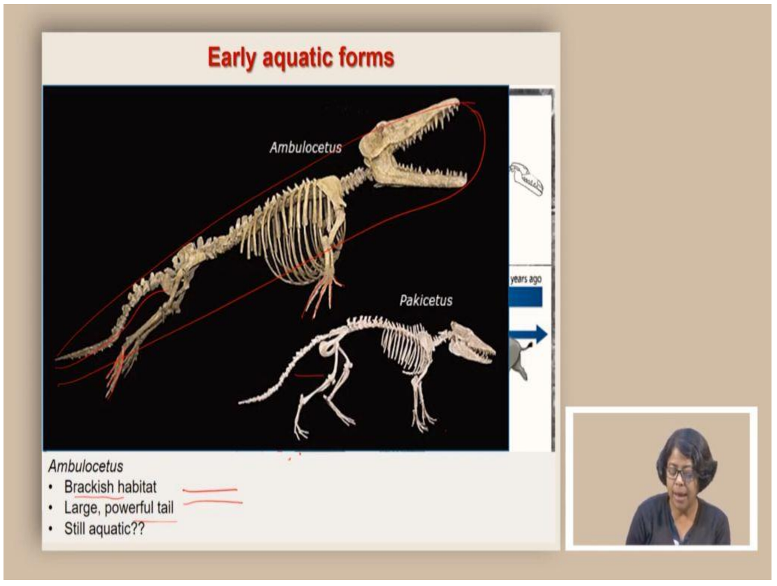

Among these early aquatic forms, as we said that Pakicetus it is, it was quite clear that they lived a substantial amount of time on the land. Ambulocetus is not the case. In Ambulocetus, we started to see significant changes. One changes if you look at the digits, the digits are much longer, and such longer digits are very good for swimming. And if you look at this one, especially the pelvic region and the digits and the limbs, it is also adapted for swimming. Now, where did they live? We think again, with the help of the rocks that they were found from, they lived in brackish water. So, that means it is a place which is close to the ocean, but not open ocean.

The ocean water comes, stays there, evaporates a lot, and therefore it becomes highly saline water. And once in a while, they go there and maybe they were also swimming. They had large powerful tail, and this is again to maintain a balance, and we still see this general shape of the animal which is good for swimming, because it has an elongated body. Now, how do we know whether they lived in aquatic environment which means a freshwater environment versus Marine? So, when we think about an animal being an animal which can live in water, it makes a big difference whether live, they live in the ocean versus they live in freshwater.

Because, the body structure not the bones but the kidney has to filter out the extra saline water. And therefore, the animals which live generally in the ocean, they cannot survive always in the freshwater, and the freshwater animals cannot survive in ocean water, unless they have these specific adaptations. So, Pakicetus, we knew that they were semi-aquatic, but, Ambulocetus, because it started to show a signature that they were spending significant amount of time in the water. It is worth asking this question whether this water was a freshwater or a marine water.

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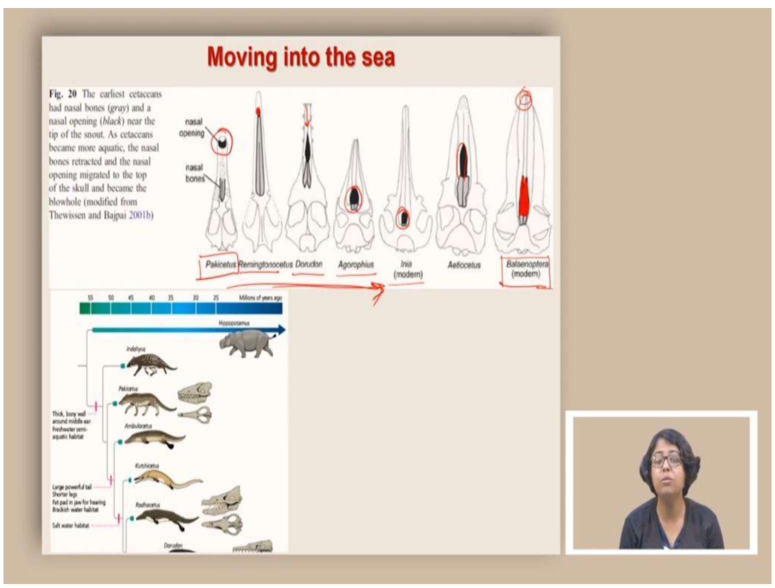

And the answer to that lies in how do we figure out the composition of the water. Now, how do we know that they spend significant amount of time in water, and part of the answer comes from the nasal bones and nasal opening. Now, if we look at the modern kind of whales, what we see that the nasal opening is right on top of the skeleton. Primary reason for this is basically they only they need to have a contact with the surface, and because they are floating like this, the top of the surface is on top of their skull. And that is the only place where they want their nasal opening. If the nasal opening is somewhere here, that means they the water might go inside which is not the best design.

But, if an animal is living on land partially, then it is understandable why they might have a nasal opening even here, what we have. Now, if we look at different kinds of organisms, which are somewhat of a transitional form from modern whales and from Pakicetus, what we will see is some change of these nasal opening and their placement. And that tells us how well adapted they were to live in the water. So, if we look at Pakicetus, it has this nasal opening at the front. If we look at the second organism, which is also related to Pakicetus, it is still at the front. Dorudon has shifted it towards the top.

Another organism we find it on top, the modern Inia, we have on top another organism and top so, these are selective patterns. And it shows the more aquatic habitat, more time spent in water than land, and this is fully aquatic or fully varied. But again, as I am saying that all of these are giving you indication that they could live in water, but not what kind of water. And to know what kind of water, we need to see the oxygen isotope of the bones and the tooth, because oxygen isotope value tells us whether it is freshwater versus marine water.

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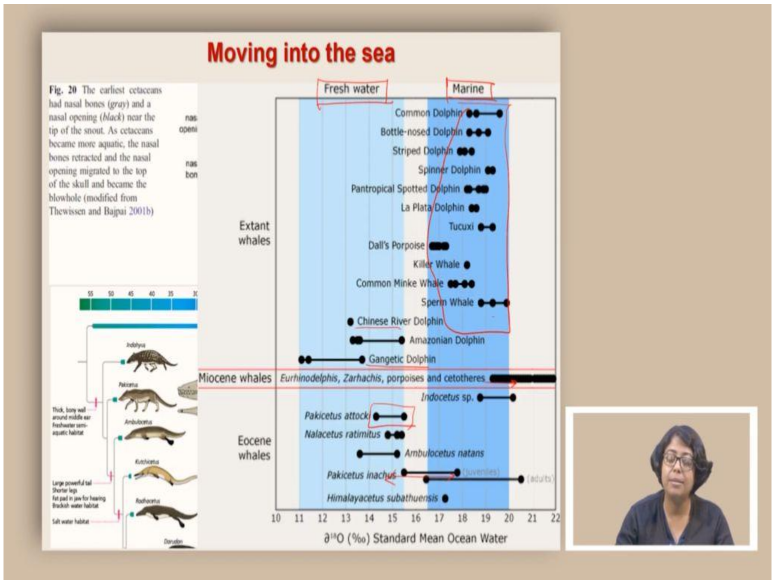

So, if we do that, what we will find is an interesting pattern. What we find is that if we plot the oxygen isotope, this is the area which will be indicated as freshwater, and this is the area which will be indicated as marine. And now, if we look at the Pakicetus, then we will often find that there can be some changes. And if we look at the modern ones, all of them are exclusively marine. But then, we have some groups of Pakicetus, which we find in the freshwater, some groups which are somewhat in between. So, it starts from the freshwater, but then can also have a marine signature. But after the Miocene, especially the during the Miocene, we started to see exclusively marine whales.

And in today, we basically have whales and dolphins primarily in marine, except for some examples of Gangetic dolphin or Chinese River dolphin. Majority of the cetaceans that we see today are marine and that started to happen somewhere around Miocene. And we can say that with enough confidence primarily because of their oxygen isotope composition found from their teeth and from their bones. So, now we have varied pattern of ancestors of whales.

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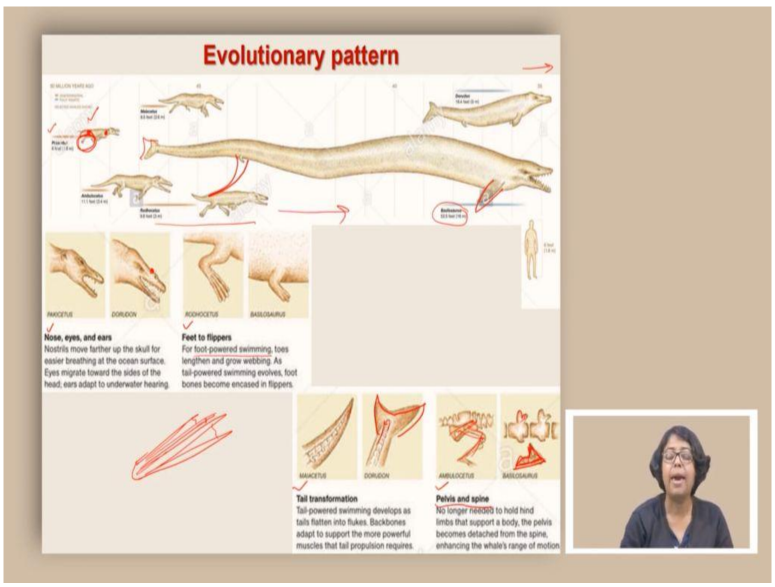

At the major transitions that we are going to look at, are these three things. One is the nose, eyes and ears, second is feet to flippers, third is tail transformation, and final is pelvis and spine. So, this is a picture which shows various ancestors of whales starting from Pakicetus to all the way of modern whales, so modern whales would be somewhere here. And there are in between forms, not all forms survive today. So, for example, there was a form called Basillosaurus which were really big, and it was elongated, probably lived in restricted environment. It was marine, but we do not see anything which is similar to this today. Now, what are the changes that we have seen going from Pakicetus to a modern whale? One important thing is the nose.

The nostrils started to move on the top of the body rather than towards the sides. The second thing were the eyes, the eyes also started to become more on the sides towards the top. Then, what we started to find in Pakicetus? The ear region adapted to the underwater hearing. The second important transition that marks the transition from Pakicetus to modern whale is the transition from feet to flippers. So, if we see these foot, generally when there are land living organisms, we will see their digits as relatively small. But, for foot-powered swimming, toes need to be lengthened.

So, they should have digits which are long and pointy, and that basically helps them to flip around and have more force for swimming. Often, these are webbed, so that means the digits have a small skin layer, which kind of makes all of these as a single flipper rather than multiple digited stuff. As the tail-powered swimming evolves, foot bones becomes encased in flippers. So, they are primarily generating the force from the tail as well as these flippers, and this we started to see in Basillosaurus, in Dorudon, and many other individual groups in between. The tail transformation is also very interesting.

If we look at the Pakicetus, it has a single tailbone and this tailbone has a pointy end towards, and you will see that these are often characters of the territorial realm. But again, tail-powered swimming develops as the tail flattens to flukes. So, if we look at the modern day whales or any other fishes, we actually see things like this, or somewhat asymmetric, and this helps them to swim. And it also tells us in terms of the tailbone, that when this pattern started to appear. And this backbones adapt to support more powerful muscle that tail propulsion requires, becomes another indication of how well adapted they were in terms of the aquatic living.

Final point in terms of morphological change is this pelvis and spine. So, the pelvis which is basically the lower limbs for us, for an organism like this, it is the hind limb. This is no longer required in terms of walking on the land. And in order to walk on the land, we need to have this pelvis joint and the front limb joint. But, if this is no longer needed, these digits and these limbs can be detached from the spines, and that is what we find that in some groups, this is still attached with the spines, the limbs are still attached. But, as they progressed, this particular limb, the hind limb becomes non-functional.

They are not aiding in terms of swimming, because swimming the front limb as well as the tail becomes the most important thing, and having a long hind limb actually can create problems. So, eventually what we see are these kinds of detached hind limb bones, and the spines have interesting developments, which become more helpful in terms of their motion. And these all together shows us the overall morphological transition from Pakicetus, which was a semi-aquatic organism living on the land, sometimes living in the water to a completely aquatic marine organism, which are the whales.

And this is the overall evolutionary transition that we see during the course of Palaeocene, to Eocene, to Miocene. Now, the question is what were the other organisms on the water which were also probably competing with them? Now, if we think about the water, the water was primarily dominated by the fishes. Now, fishes have these bony fishes versus cartilaginous fishes, among the bony fishes, we have the refined fish, we have the lobed finned fish, but as we have seen that the refined fish is dominate. Apart from these bony fishes, there are cartilaginous fishes, and a major group of cartilaginous fishes that we know today are the sharks.

And these sharks were abundant during Cenozoic, and they were probably the primary competitors of these evolving whales, as they were moving into the water.

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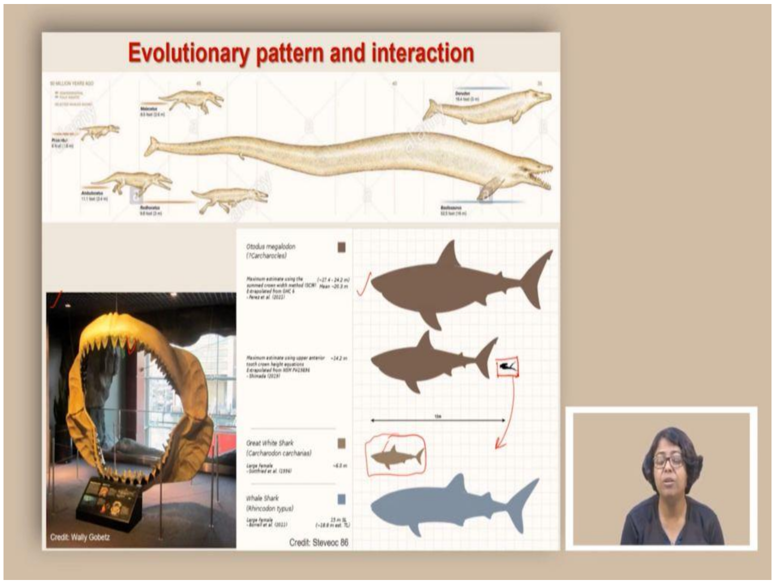

And the whales also changed over time. So, this is a modern human being in with respect to the scale, and this is a great white shark. If I have to compare even the biggest shark which is called a whale shark, it is really big with comparison to a human being today. But, when we compare it with some of the extinct sharks, even a great white shark looks quite smaller to these Megalodons. This is a picture of a megalodon jaw and its teeth displayed in a museum. So, these were really large sharks, and clearly, they were one of the highest predators in the water, in the marine realm.

And once the whales became more marine, they definitely were competing for the same resources. And then a geographic change happened and then associated climate change happened, which favored one group but not the other.

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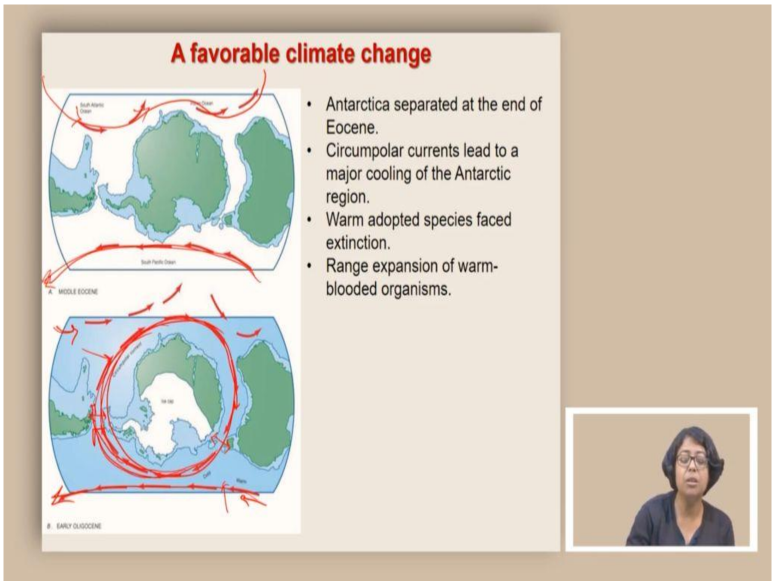

So, Antarctica is a continent that we know today that they are completely isolated from all other continents, and this is the configuration we are more familiar with. So, this is the Antarctic Peninsula. And if you look at it from the bottom most part of the globe, then you will find Australia here, and this is the tip of South America. Now, this is the configuration in early Oligocene. But, if you go back in time, and if you look at middle Eocene, things were quite different. Australia was somewhat connected to Antarctica, but more importantly, the South American tip was also very close to the Antarctic Peninsula.

As a result, the ocean currents were basically not moving around Antarctica, but going in Indian Ocean. And there was this South Pacific Ocean where the currents were also moving like this. What it means is the water which were the tropic is somewhere here. The tropical water which is warm was constantly circulating around Antarctica, and the same is true for South Pacific. The cold water was going to the tropics and getting warmed up, and then coming back. So, because of these warm input near the Antarctica, the Antarctica was not really as cold as today.

But, things started to change during early Oligocene, where this distance become greater and this distance become greater. Once these distances become greater, primarily for tectonic reasons, the ocean current no longer went the way they were going in middle Eocene, they started to go for a circumpolar current. So, basically moving from this part to going through the South American tip, and again coming back like a full circle. And now this area then stopped getting any warm input from the tropical zone, it was cold. This was the warm pool that it was initially receiving, now, it basically bypasses it and goes all the way to the tropics.

So, it was not, it is not contributing anything to the Antarctica. As a result, we started to see the development of large ice cap of Antarctica around this time. So, what will happen to the Antarctic species once it starts to become really cold? Because of this development of circumpolar current which is cold, and it becomes colder and colder, because it is not getting any warm input. Once Antarctica starts to become very cold, the warm adapted species will start to go extinct. And that we actually see in Antarctic record, that many of the groups that have crabs of snails, they started to disappear right around this time.

The range expansion of warm blooded organisms. What it means is, once it becomes very cold, what kinds of organisms can live there? The organisms have to be able to control their body temperature. And we know that the organisms the those organisms are primarily warm blooded. There can be very large cold blooded organism by, and they can tackle their temperature. But primarily, the warm blooded organisms or endotherms are very good in controlling their temperature. As a result, all the warm blooded organisms will try to expand their range from the regions close by, because they can survive, whereas, the other groups which cannot control their temperature will not be able to survive there.

So, this is a point where the advantage was towards the whales because they are warm blooded organisms, they are mammals. They can generate their own body heat and keep them warm, and additionally, they have a very thick fat layer and that keeps them insulated. On the other hand, their competitor the sharks, they are cold blooded organism, and it becomes difficult for them to maintain the temperature, if the overall temperature becomes so cold.

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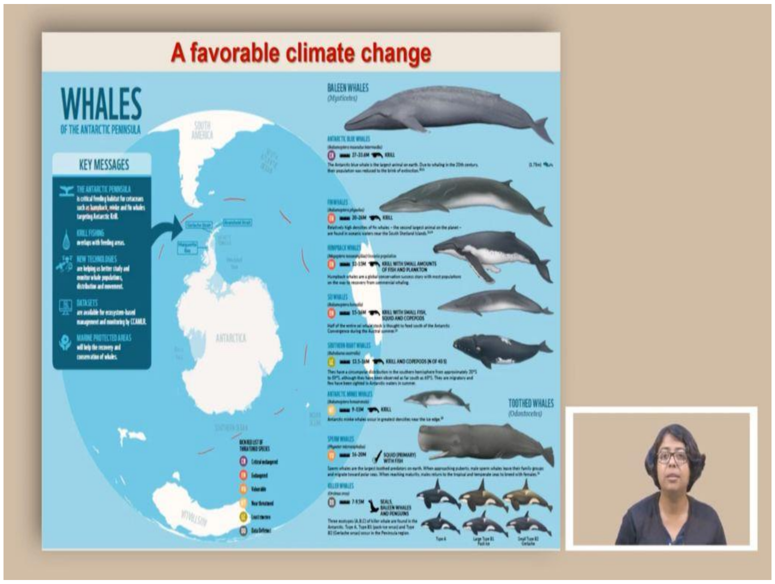

And this led to a development of an environmental exclusion. So, the Antarctic Peninsula becomes one of the places where we started to see humpback whales, various kinds of whales and baleen whales. So, if you look at the development of all of these whales, all of these we started to find in Antarctica, and this region which is very cold today. And they enjoy the selective advantage because they are not really competing with any other groups. There are enough resources in the form of krills or shrimps, or zooplankton, which are never being used by any other group because it is so old.

And the general fishes and the sharks generally avoid such very cold environment, simply because they will freeze and they cannot regulate their body temperature.

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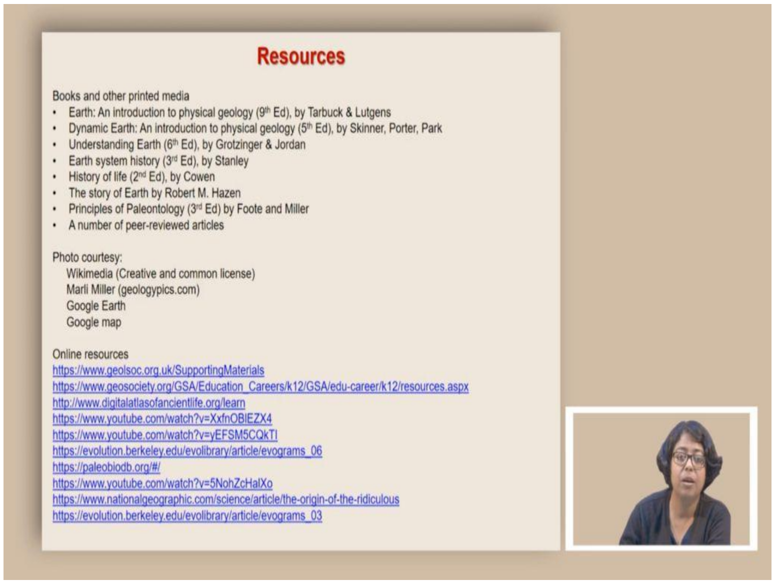

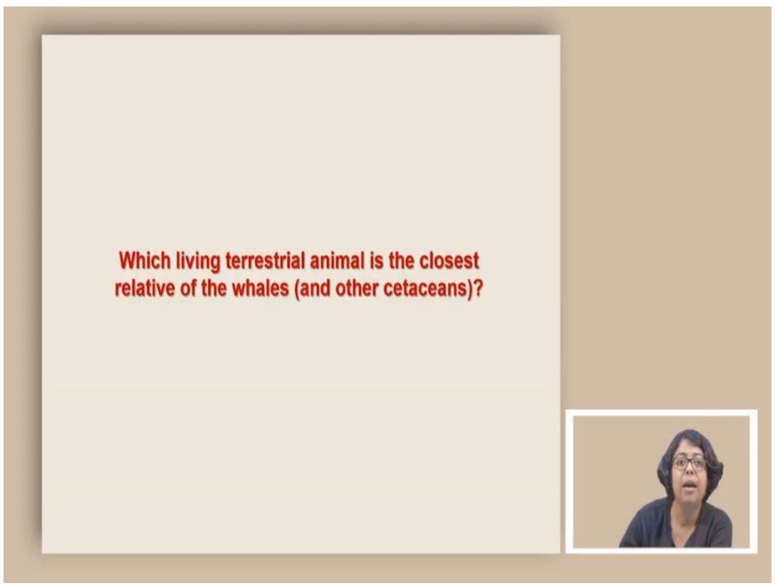

So, in today's class we learned how the whale ancestors came into being, and how whales started their journey from land. We learned which are the present groups, which are related to the whales. We learned about an organism called Pakicetus, which was semi-aquatic, and showed characters which are very terrestrial like. But, also showed patterns which indicate that they lived in the water. We understood the transition from freshwater habitat to marine habitat among the whales, before becoming fully marine whales that we see today. We also learned how environmental changes near Antarctica, led to the selection of whales dominating that ecosystem over the large sharks that were there during this time.

Here are some of the resources that I have used to create the slides. And here is a question for you to think about. Thank you.