Evolution of the Earth and Life
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Sedimentary Environment and Plate Tectonics

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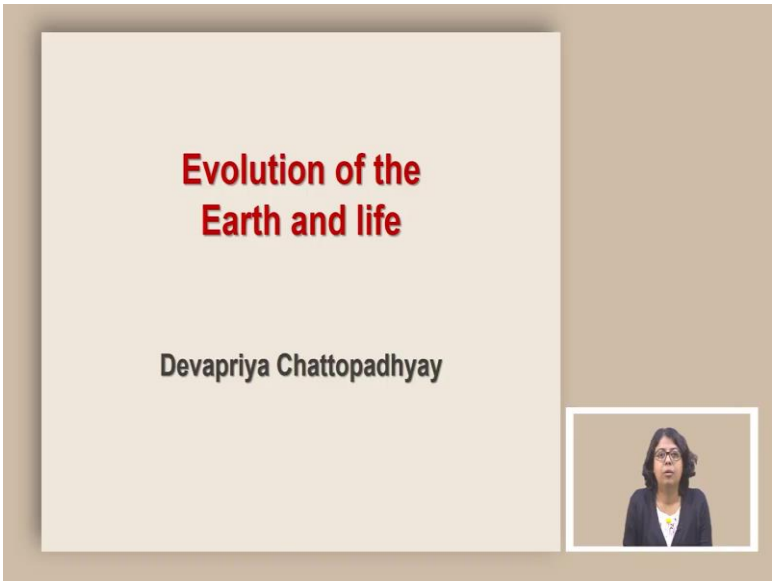

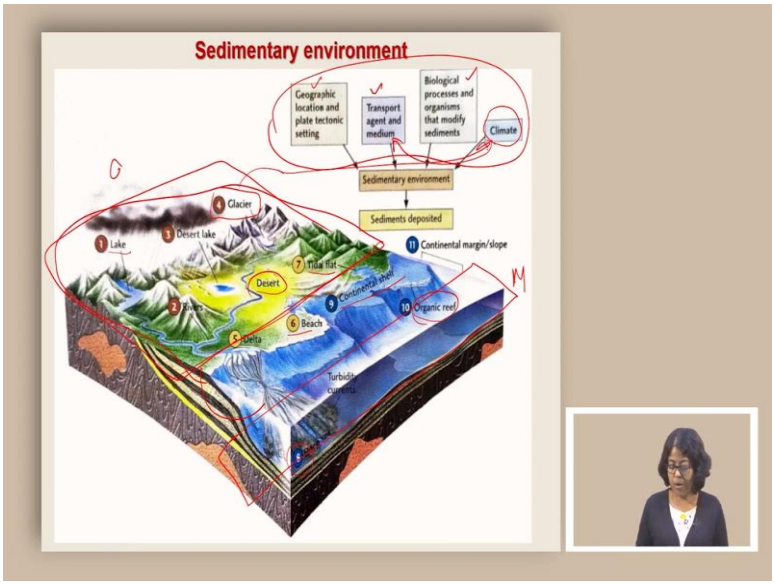

Welcome to the course, evolution of the earth and life. Today we are going to talk about sedimentary environments and how those are related to the overall plate tectonics setting. Sedimentary environments are the overall development of various agents.

So, if we look at this particular picture, we will find that there are things such as lakes. So, lakes are going to generate certain types of sediments, those sediments, if we can identify in the previous record that will tell us to conclude that they were created by the lake processes.

And once we know that, often it becomes really useful to recreate the history of the earth and therefore, identification of sedimentary environment is important.

Now, the sedimentary environment can be controlled and can be impacted by various things. One of them is the geographic location and the plate tectonic setting. The second one is the transport agent and medium. Both of these things are going to tell you something about what kind of rocks you can expect, what is going to be their grain size, what is going to be their sorting? Biological processes that are operating in those areas, as well as organisms that are living in those places and how they modify the sediments are also going to impact the final rock product. And this we will know from fossils.

Finally, each of these things, once they form the rock or once they form the sediment, they can be impacted by the climate, not only that, the transport agent and medium often is linked to climate, how they are behaving, how much they are creating the sediments? So, all of these things are eventually guiding what kind of sedimentary environment we are looking at. And therefore, if we can somehow understand or identify this in sedimentary environments from the rock record, it actually gives us clues about all of these factors.

So, therefore, understanding the sedimentary environment is important. Now, there are different types of sedimentary environment that we can talk about. One kind of sedimentary environment that we can classify broadly. And today we are going to talk about the broad sedimentary environmental classification. So, one type that we can see from this picture is where the sediments are basically depositing in the ocean. So, those are going to be the part of this sedimentary environment where it is a marine sedimentary environment.

So, there can be variations within them. For example, there can be development of reefs and sedimentation around reefs, there can be very deep sedimentary places where a lot of sediments which are carried from the continent, as well as in the shallow part, are getting deposited. So, there would be variations, but all of them sort of falls under the overall realm of marine sedimentation. There would be other type, which are happening in the continent.

So, in the continent, we can have all kinds of variations such as rivers, and how they are carrying the sediments and depositing the sediments before coming to the ocean. There can be desert, these deserts are moving sediments quite a bit, primarily through the agent of wind and changing the landscape. So, if we can identify those landscapes and what kind of rocks

would be produced, we can eventually reconstruct a desert in the rock record. And that is why it is important to identify these kinds of sedimentary environments.

Then there are other types of sedimentary environments which are all part of this continent, one lake that I already talked about. Glaciers, how glaciers are moving and carrying sediments with them. And these glaciers and their movement and how much sediments they are carrying, will again be controlled by the climate. So, this entire part whatever sedimentary environment we are talking about are going to be part of the continental sedimentary environment whereas this one is going to be part of the marine sedimentary environment.

But then I left out a bit of it, for example, beach, for example, continental shelf, whereas, there are things called tidal flat. These are places which are basically in between the continental sedimentary environment and the marine sedimentary environment. These are the transitional zones, where you need to understand the processes that are operating in the continent as well as some of the processes that are operating in the marine realm. And they are particularly interesting, because it captures the signal from both of these worlds the continent as well as the marine.

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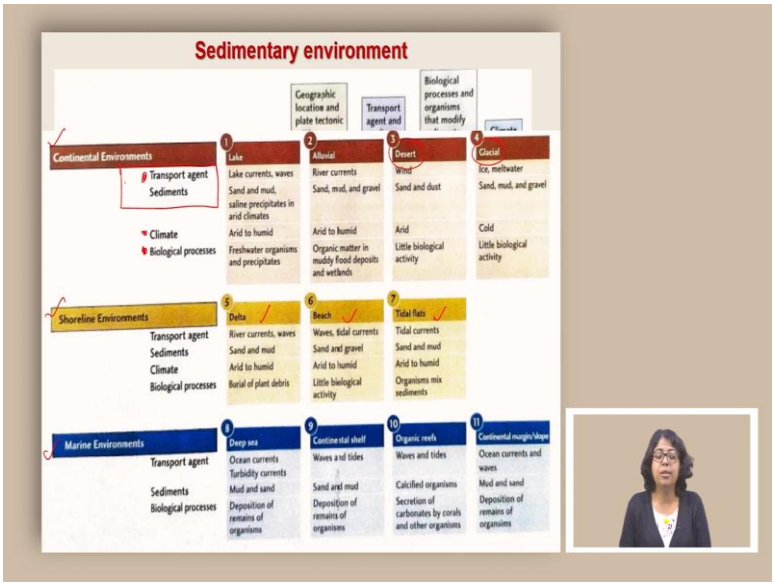

So, therefore, the overall classification has these criteria, where we can look at these major types, one is the continental environment and within continental environment, as you can see, there are various classifications, Lake, alluvial, desert, glacial then there is marine environments, where there can be variations of deep sea, continental shelf organic reefs, continental margin or slope. And then there is something in between which is shoreline

environment or marginal marine environment or transitional environment, where we are going to look at Delta beach and tidal flats.

Now, the question is, what should we look at? So, there are primary things that we should look at number one is transport agent of sediments, who are the agents who are carrying these sediments. The second one is climate, where can we expect them to form for example, let us say if you are talking about the glacial environment, it means we are looking at a climate which is cold, because otherwise it cannot form. For example, if we look at the desert, we are immediately talking about a climate which is very arid, otherwise it cannot form.

The third one important aspect is biological processes, that in these areas, what kind of organism should we expect, because if you know what kind of organism you can expect, you can predict what kind of fossils or the remnant of the past organism you should expect. So, by looking at these transportation agent, climate and biological processes, you can really recreate the environment of the sedimentation.

And once you have recreated the environment of sedimentation, then you should look spatially in terms of walking around the same time, but in different parts, how all of these are coming together and telling you the same thing or are there variations in sedimentary environment as you are moving spatially.

So, that is a general goal of recreating a sedimentary environment so that it can tell us something about the past history and we can use it to understand the Earth processes better. Now, let us concentrate on this part, first, transportation agent of sediments, how do we recreate the transportation agent of sediments? What are the clues that we should look for?

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So, as I mentioned before, that determining sedimentary environment is important. And one of the major clues of determining sedimentary environment is the transportation agent. And this transportation agent, when we are trying to think about it can be a variety of things such as rivers, winds, glaciers, it could be carried by gravity, which we call mass wasting. But for today's lecture, we are going to concentrate on the major transportation agents such as reverse, wind and glaciers.

Now, here I have given pictures of three different deposits from all over the world. And clearly the rocks look very different and they represent different transportation agents. So, when we are trying to figure out which transportation agent is responsible for developing a rock, we should concentrate on grain size, grain shape, sorting and sedimentary structure, I will come back to this part slightly later, but let us first concentrate on these grain size means, how big or how small a particular grain is, because we are here primarily talking about Detrital sedimentary rocks, it is important to talk about the grain.

The grain size will depend on the energy of the medium, energy of the transportation agent. So, let us compare the wind versus a glacier. Wind is the energy of the wind is much lower compared to the energy of the glacier. As a result, the wind really cannot pick up a boulder and carried on the other hand, the glacier can pick up a boulder and carry it, how about very fine grained material, the wind can carry very fine grain material such as let us say sand, very fine grained sand, but, for the glacier, because it has very high energy, it can also pick up a sand grain and carry it.

So, in glaciers we are going to find very large boulders as well as very fine sands. In wind, we are going to find only very fine sands and not really big boulders that tells us something about sorting. Grain shape also gives us a number of clues because wind is going to carry very fine particles and it is directed in different directions probably you are going to find very round shaped grain of these fine particles.

Whereas in glacier, when it moves, part of it is always in the contact of the base and part of it the rocks which are at the bottom, they are going to be scriped because they are always at friction with the base level. Therefore, one part of it will be polished but not the rest of the things. So, the grain shape is going to be can be quite irregular to polished in one surface but not in the other ones.

So, these are some of the examples which can easily tell you the difference between a rock that is produced by movement of glaciers versus a rock that is produced by sediments that were carried by wind. Every transportation agent such as rivers, such as these winds, such as the glaciers, such as the ocean wave will have such telltale signature. Another important aspect apart from size, shape and sorting of the grains is sedimentary structures.

Sedimentary structures mean what kind of pattern you are seeing in the rock record that tells us about the mechanism of grain movement. So, for example, if you look at this particular picture, the first picture we know that these are rock record these are primarily record of a river. Now, if you look at the very top portion of it, you will see that rocks are parallel in terms of their bedding, bedding means where the sediments are depositing.

So, all the sediments if they are falling down of the suspension or they are of the same size and they have been carried in one direction, they can create layers like this and because these boundaries of these layers are parallel, they are called parallel bedding or plane bedding. So, these parallel beddings are giving you at the top, but then we come here and look at things which look quite different. We see patterns like this. These are patterns which are called cross stratification. One way of looking at it is how they are forming in the plane bed.

So, there can be situation where because of the energy there is a lot of sediments which are piling up and as they are piling up, they are going to create this mound like shape, but in this part of the mound, there will be suspended materials which are going to gently fall over. So, they are going to create a pattern, which starts with coarse grain to very fine grain in only this

part. But then because of the energy, which is pushing this part of it can again create another such mound and create something like this.

In that case again, this part is going to give you this contrast between very coarse grain slightly coarse grain rock, very fine grain rock because of the suspension. So, now, over time, you can see these kinds of layers, and these are the layers that you are seeing here. So, these are called cross stratification, and these are sedimentary structures, and they are capturing the movement of such mounds, it can be a ripple, it can be a dune, depending on which kind of agent we are looking at.

So, these kinds of sedimentary structures are also very important in recognizing what was the transportation agent? For example, in this case, these are typical stratification that we can expect only in the fluvial regime or when the rivers are the primary agents of transportation.

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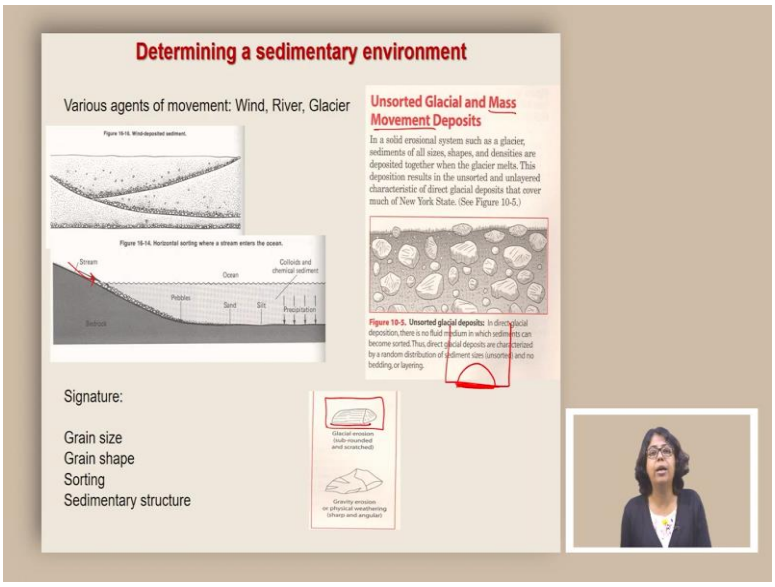

So, in summary, we can have various agents of movement. And if you are thinking about River, the stream can push these sediments and you can have a difference in terms of the grain size. And eventually you can develop different kinds of grain size partition.

You can also have change in grain shape, for example, these can be a glacial erosion marker, because this part is very flat and often polished, because it is getting scratched when the glacier is moving, and with contrast to the glacier, if this is the glacial mass, this is where this rock is and therefore, this part of the rock or the grain gets polished very quickly, there can be wind deposits too.

And these kinds of wind deposits will also have very fine grained sedimentation because winds cannot carry a lot of heavy sediments. If we think about the glaciers in glaciers, we can find things which are again quite poorly sorted, there will be very fine grain, but there will be really, really large pebbles and boulders, sometimes it may be confusing, which are the remnants of glaciers versus which are the remnants of mass movement or mass wasting, where gravity pulls everything down.

But in those cases, because it is like sliding along a slope, the gravity mediated mass wasting, you are not really going to get any rounding of the grain whereas for glaciers, we can have some polishing in one side. So, one of the signature that can help you to tell apart which is glacial and which is mass wasting is that in gravity or physical weathering or mass movement, you are going to get very angular grains without any polishing whatsoever.

Now, using all of this important information, it is possible to come across or develop really important conclusions about overall pattern of sedimentary deposits. And we are going to look at one such example.

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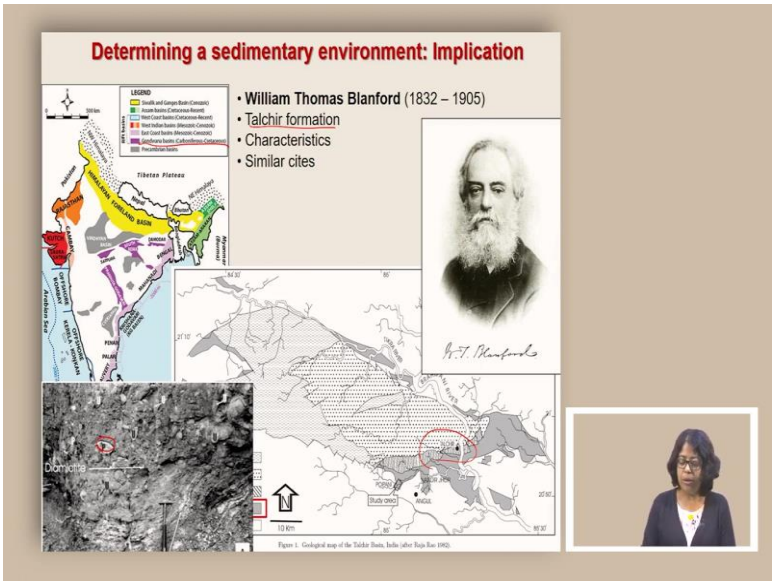

So, William Thomas Blandford was a geologist and he was looking at different Indian rocks and he came across a particular rock in the eastern part of India in Orissa, which he called Talchir formation, these are rocks which are found near this place in Orissa. And you will always find very big, large rocks as part of these Talchir formation. And some of these rocks also have something called striation marks.

In terms of the overall age, which is determined by some other methods, these rocks are part of these Gondwana basin, which basically means that these are the rocks, which formed anywhere between carboniferous and cretaceous time.

Now, they have striations and it is not from only one place, they are actually spread across various different parts of India, where you can find similar looking rocks. And these rocks have these kind of pebbles, and then quite big ones. And many of these pebbles and big boulders actually have marks on them.

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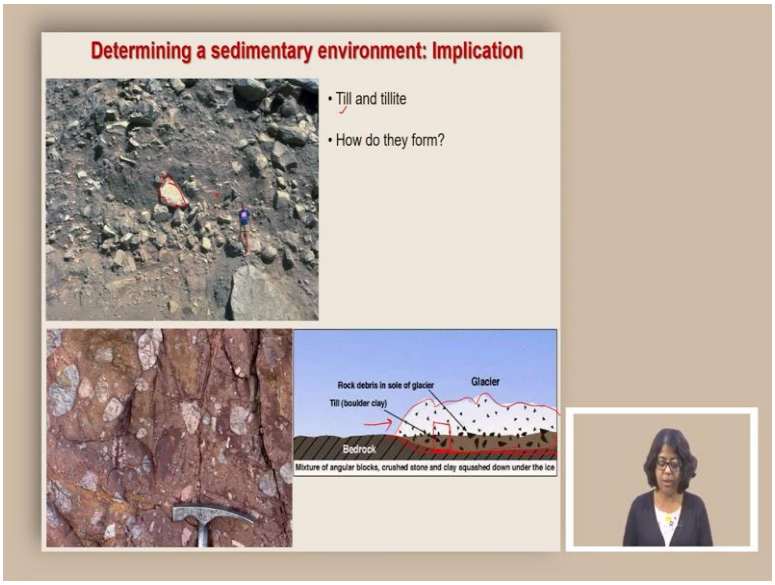

The first understanding of such striation marks tells us something about the glaciers. So, if we look at the modern day glacier, we know that when a glacier moves, it has a pattern of how it is basically taking the rocks. So, there would be very angular rocks at the base of it, and they are called the tills. And then there would be some rocks which are not so big or not, so angular towards the top. And some of these would be crushed down, we will have some of the polished surfaces. But because this entire thing is moving, often, the rock which is underneath, we will have the marks of these, glacial rock scratching over them.

And that is what we call glacial striations. On the other hand, if you just freeze this part, you are going to see a rock, which has a lot of big boulders, and tiny sand sized grains, as well as angular parts. And this is what is called a Glacial Till. And if you convert it to a rock, then it is called a tillite. And this is an example and you can also see some of the striation marks here.

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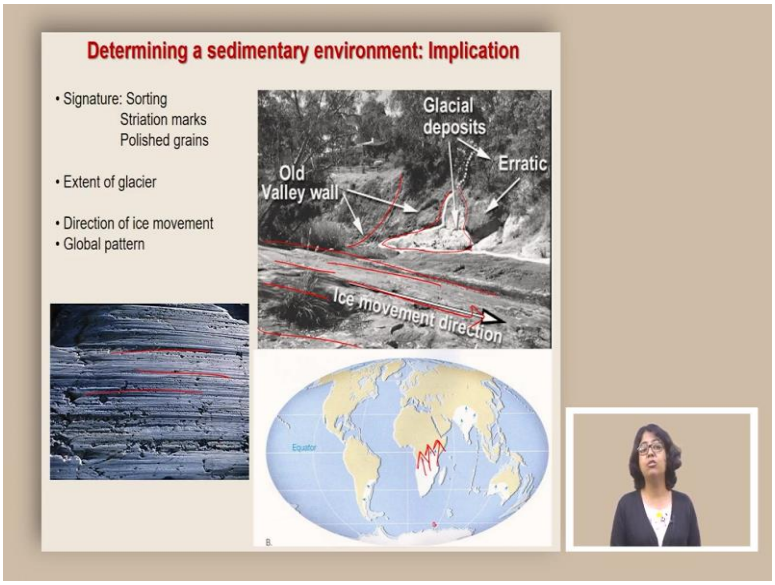

Now, the question is, if you find such a rock, then it definitely tells you that there was a glacial. And these are some of the example that not only do you find these glacial you know, deposits like these huge rocks, you also get a valley through which the glacial moved, and the base surface where the glacial actually moved, you will have these striation and these striation are marks like these, we are finding all of these enthalpy of formation, not only that, it also tells us something the ice movement direction, which direction did the ice the glacier actually moved? So, all of these things are telling us that in India, there was a time when we started finding glacial deposits, in places where we do not see glaciers today.

The second point is it is not only from India, we are actually finding it from all over the world around the same time. And the direction of the ice movement, if you have to put it basically shows that all of them are kind of showing that the glacier actually is moving sort of away from a central point. And if we arrange them in today's world, it will look like that everything all the glaciers are moving towards close to the equator. Now, the question is, how do you explain the evidence of such large scale glaciers from the tropical region?

For example, Africa is a tropical country, India is almost like a tropical country. And these are the places where you are getting old rocks, which are showing you at that point of time around Permian or around this when the Gondwana rocks are, what the Gondwana rocks are representing. There was vast glaciers and all those glaciers are showing same sort of direction of where they were moving. When you put together all of these things, it actually fits nicely with the idea of a supercontinent, which was predicted by Alfred Wagner. When he proposed the continental drift theory.

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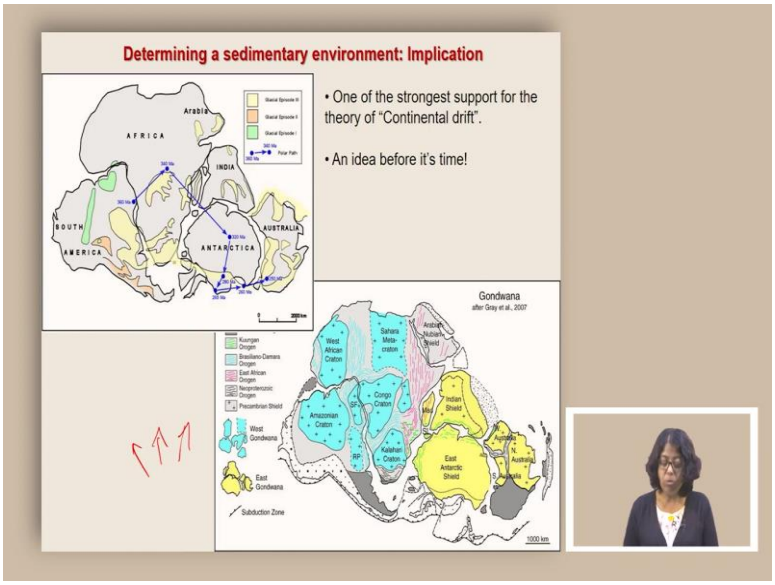

So, if we put all of these things together, it basically shows that there were different glacially episodes and many of these continents what we see today, in the tropics, were not really in the tropics. They were close to the pole and you see different times of glacial movement, these glaciers were not altitudinal glacier, these glaciers did not form because the land was high up like modern day Himalayas, these glaciers formed because the landmass was very close to the pole. And in general, it was cold. And that was kind of confirmed by the glacial movement directions from the central point in continents, which are really separated by miles today.

So, starting from this, sedimentary deposits, or sedimentary environment, or reconstructing the sedimentary environment, actually tell us a lot about the past history of the earth. And it was one of the strongest support for the theory of continental drift. Now, if we actually think about that, at the past time, there was these continents which were together, and then it broke apart because of the drifting because of plate tectonics. How do we find the development of new sediments? Where does these sediments deposit? What are these sediments representing? So, now we are going to talk about sedimentary basins.

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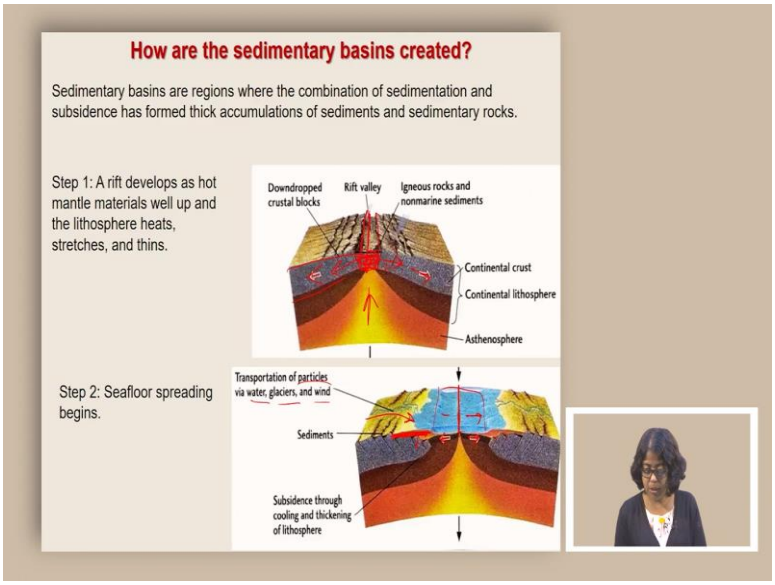

So, sedimentary basins are regions where the combination of sedimentation and subsidence has formed a thick accumulation of sediments and sedimentary rocks. And the sedimentary basins are the primary areas where eventually you can find very important energy resources such as coal petroleum, so it is important to know how these sedimentary basins form and how sediment get deposited. And they are very well linked to the plate tectonic process. So, everything starts with the lithosphere. First step is a rift. A rift means a thinning of the lithosphere.

So, a rift develops as hot magma material comes up, and the lithosphere heats, stretches and thins. So, as we know that lithosphere, or this part of the crust, the topmost part of the crust, is quite rigid, it has a thickness. And when the magma basically comes on the top in contact of this, this becomes really hot. Once it hot. Once it heats up, it basically expands in volume, it loses its density, it starts to flow, and it becomes quite thin. And that is when the Rift Valley starts to develop.

This can happen under an oceanic plate, it can happen under a continental plate, whatever it is, it is going to happen, it is going to make this part of the crust very thin. Now, once it thins up, it is also going to push the rest of the material towards the other direction because it needs to expand.

Now, if we start thinking about a continental plate or continental lithosphere, when it thins, it is basically going to push the other flanks of the continental lithosphere, towards different direction. And this rift valley is going to widen up once it widen up, and because it is thin, it

is also going to have a narrow place, which is lower from the surrounding area of those lower elevation water will come lower elevation areas are the oceans.

So, from the oceans, the water will basically come and fill this rift valley. And that is when the seafloor starts to spread. Again, as I said that it can be to start with it can be a continental lithosphere it can be an oceanic lithosphere. But then, because it gets filled up by water, technically and also, the new magma that is creating this floor in this new place is going to be an oceanic crust. It is going to be formation of a new ocean.

And again, the continental blocks or the existing lithospheres are going to be pushed in two different directions. And you can see that they are basically getting compressed and because they are heavy and they are already sediments on top of it, they are also going to thicken up.

Where are they getting these sediments from? These Sediments are coming from the transportation of particles by a water glacier and wind from the continents. So, all these sediments on top of these existing lithosphere are making them heavy and they are kind of going down, they are becoming thick and this is the part where the oceanic lithosphere is forming, and as they are forming, they are pushing these plates away from each other.

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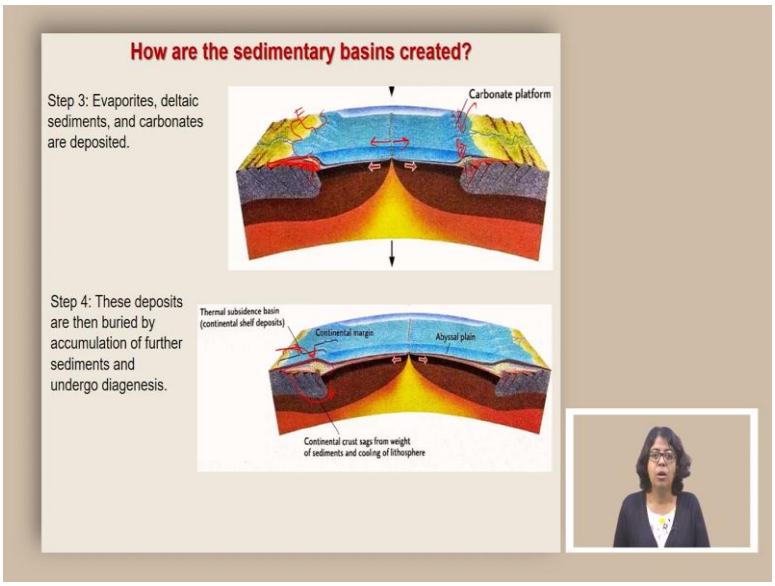

In the third step evaporites and deltaic sediments and carbonates are going to deposit. Again the ocean floor is forming here, they are pushing the existing sediments these things are basically have the sediments on top, but because these ocean is spreading, these are the places which are closer which are not very deep, these are the places where many of the organically generated limestone deposits will start to develop, for example, coral reefs, they are going to

develop somewhere here, you can find lots of organisms which make calcium carbonate shale living here and producing coquina.

Some of these places can have development of chalk if the right kind of organism is living there. So, these kinds of things are going to happen, if part of this ocean is also you know, separated from the overall oceanic circulation, they can create the development of evaporites. And all of these things in terms of the cross section, they are getting deposited here. And therefore, they are also making the lithosphere very thick, the older lithosphere very thick, and it is kind of getting heavy to.

Finally in the step 4 these deposits, the deposits that we talked about here, some of these are coral reefs, some of these are evaporites in different places, they are going to be buried because of the accumulation of harder sediments, because sediments are still coming on the top. And therefore, it is going to make it heavy and this entire part is basically going down because of the overburdening pressure and as they are going down, they are going to undergo relatively higher temperature and compaction which means pressure, they are going to go into this phase which is called diagenesis.

Diagenesis is the process by which the sediments convert into rock. And this is how the sediments which are being produced by different agents now getting sedimentation is happening or deposited in places which are lower in the ocean floor will finally convert to sedimentary rocks through diagenesis and compaction. And this process repeats itself again and again every time there is a rifting every time the plate tectonic works. So, understanding sedimentary environment and using them to recreate the past plate tectonic boundary conditions is very important to reconstruct the history of the earth.

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So, today, what we did? We summarized a lot of processes. So, in today's class, we learned how to reconstruct the sedimentary environment using different criteria, such as the grain size, shapes, sorting and sedimentary environment, sedimentary structures. Once you have created these sedimentary environments, it is also possible to reconstruct specific times in the earth's history and understand the global environmental pattern.

Sometimes it leads us to understanding of change in climate, sometimes it tells us something about the global pattern of plate movement, plate tectonics. And we also learned how to create these sediments and convert them into sedimentary rocks through the processes of sedimentary basin formation by plate tectonics. Here are some resources that are used for the lecture. And here is a question for you to think about. Thank you.