Evolution of the Earth and Life
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Lecture 7
Plate tectonics

Welcome to the course, Evolution of the Earth and Life. Today we are going to talk about Plate Tectonics, so the continental drift idea although it was supported by various observation was rejected because Wegener could not propose a plausible mechanism and because of the lack of suitable mechanism it was rejected, but things started to change during Second World War.

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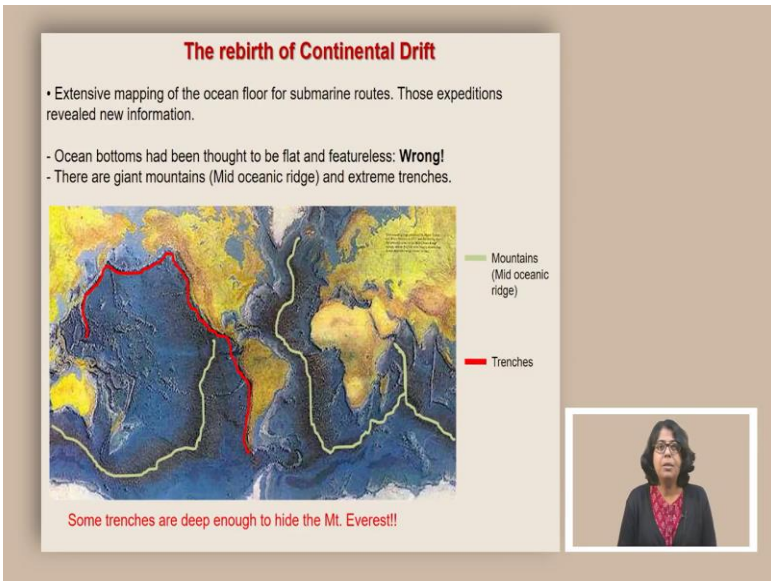

During Second World War people started doing extensive mapping of the ocean floor to figure out the submarine routes and these expedition revealed very new information, so before these kind of expeditions the general idea about the ocean bottom has been that it is flat and featureless, but after these expeditions people realize that it is completely wrong, there are giant mountains which we now know as mid oceanic ridges and very very deep parts of the ocean known as trenches and some of these features are so deep that they can hide Mount Everest so they are deeper than those. And when people started mapping these areas they also started asking this question that what creates these topographies.

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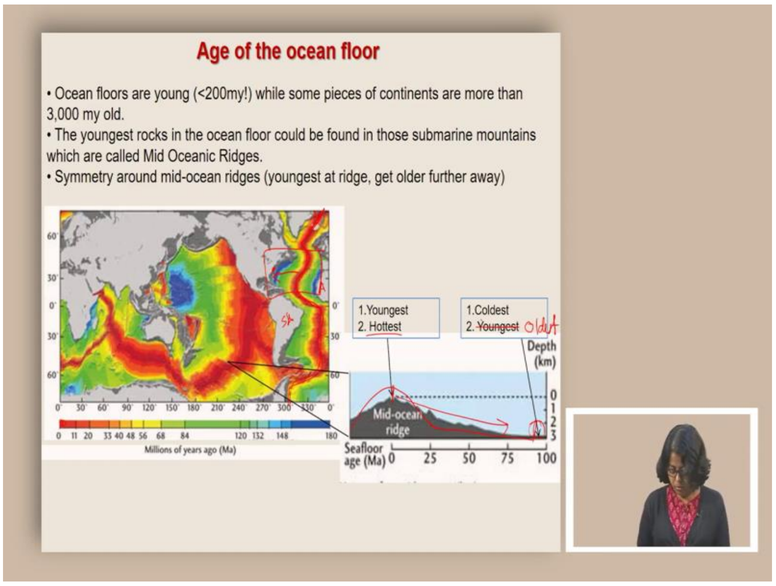

The second aspect that people realized about the ocean floor that the ocean floor has a very unique age distribution, so by this time researchers knew how to date rocks and they could date many of these age, absolute ages of the sea floor rocks and they found that the age distribution of the ocean floor is unique and it has an interesting pattern. First thing that is very unique about the ocean floor is the ocean floors are generally young that means we do not really find any rock that is older than 200 million years below the ocean whereas if we come to the continent we do find rocks that are as older than 4 billion years.

And many of those rocks are actually oceanic rocks, we know that they have formed in the ocean so we know that there were oceans, definitely there were oceanic rocks which are older than 200 million years but we find them in the continents, question is why do not we find any signature of these old oceanic rocks under the ocean, where do they go? The second important relationship is that the youngest rocks in the ocean floor are always found in the submarine mountains which are called mid oceanic ridge.

The reason they are called mid oceanic ridge is because they are often found in the middle of the ocean, away from the continents and they form a chain, so if we look at this particular place, this is South America, this is Africa and this is Atlantic and if we trace we will find that these are the regions which shows the development of these ridge and it is fairly continuous and these colours are also showing the age so if you look at this colour, the red colour it shows that it is 0 8 that means the rocks are forming.

So always in the middle of these Atlantic Ocean there are places where the rocks are forming, its molten and therefore its hottest and also the youngest, as we go from this part towards the continent what we find, we encounter rocks that are older and also colder, so as we move towards this direction we find the oldest rock at least in this region, now when we look closely into the mid oceanic ridges what we find again that there is a ridge which is relatively higher topography and as we go away from this ridge it gets colder and also age-wise it is older.

Now, because of this difference in terms of the age it started people thinking that probably the rocks are being created here and somewhat they are being pushed away and therefore the first formed rocks now we are finding here and which are quite old so the age difference between this and this tells you how for how long this pushing process has been occurring and they are very symmetric.

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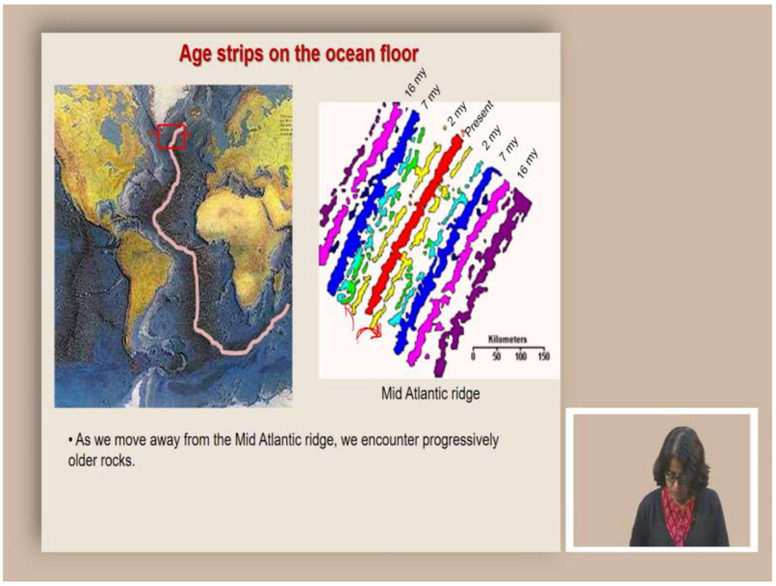

What do I mean by that is if we actually take a look at this particular portion and look at their edges what we will find that the rocks in the middle they have a 0 year age which is present and as we are moving in this direction and in this direction we are encountering older rocks but look at the age distribution they are very similar which again tells you that probably rocks are being created here which we can observe even today but probably they are being pushed away from the centre as new rocks are forming and thereby creating these kind of symmetric pattern.

Now, the question is if we are pushing these rocks from here and these older rocks subsequently get pushed and all the older rocks we are getting somewhere here where do they go eventually because we do not find any rocks which is older than 200 million years, so where does all the rocks which are older than 200 million years go?

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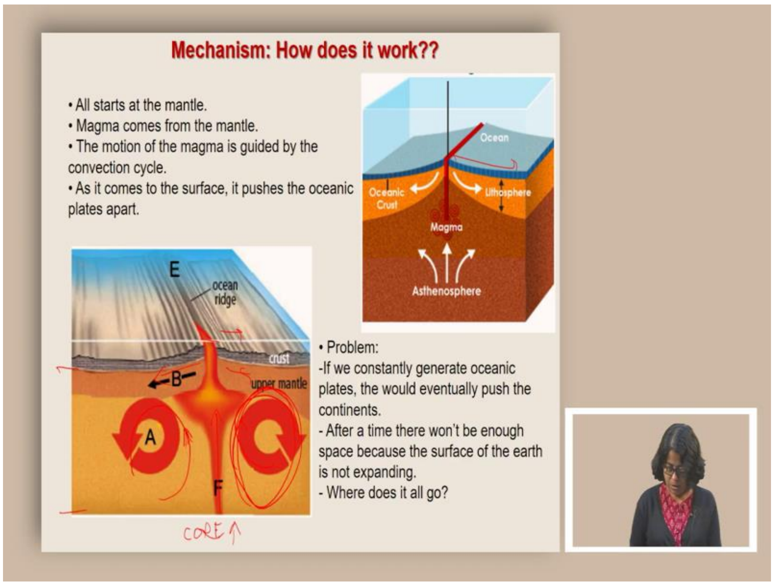

So, that is where people started thinking about a process, so it all starts from mantle, so as we know that crust is the thin layer on top of the earth and below the crust there is mantle it is a solid state of rocks but it can flow, it has high temperature and pressure and the magma comes from the mantle, the motion of the magma is guided by the convection cycle, now what do we mean by that?

This is the upper mantle or this is the overall mantle, now this mantle is hot, in fact we know that there is core below this and core is very hot, core has two parts the outer core is liquid and the inner core is solid. Now, because the outer core is liquid and the entire planet is trying to cool down so because the centre is very hot and outside is cold the crust is cold it is trying to dissipate heat from the central point to outside, now the way to do it is if you have a liquid material then these dissipation occurs through convection.

Now, convection occurs in outer core which is liquid but the mantle although it is solid it can also flow you can think of a very high viscosity materials which can be solid but which still can flow and because of that mantle also has these convections, these convective cells, what we mean by that if there is a heat source then things which are getting hot will get buoyant and hence go up as they go up they lose heat and therefore they lose the buoyancy and then they come down, so this is how sort of the convection works.

And because there are differing convection cells there can be convections which are opposing in terms of its nature and so this is the two places or two senses of direction of convection because of which what we can find is both of these things are quite hot and we are eventually finding the magma rising up, as they are rising up they are basically coming to this place which we call the ocean ridge.

So, it is coming up but because it is pouring down it is creating a new space and this is the ocean oceanic crust, it is also pushing this, this convection also helps to push these things apart and these motion of the magma is primarily controlled by the convection cycle as it comes to the surface it pushes the oceanic plates apart, now what are the problems?

The problem is if we constantly push it and if we constantly generate oceanic plates then it would eventually push the continents, that is understandable, but after a time there would not be enough space because the surface of the Earth is not expanding that means there has to be a place where some of these plates are also vanishing so that the total surface area is constant. And the way to do it is if you can basically bring these plates to a place where it is getting consumed and therefore we do not see them.

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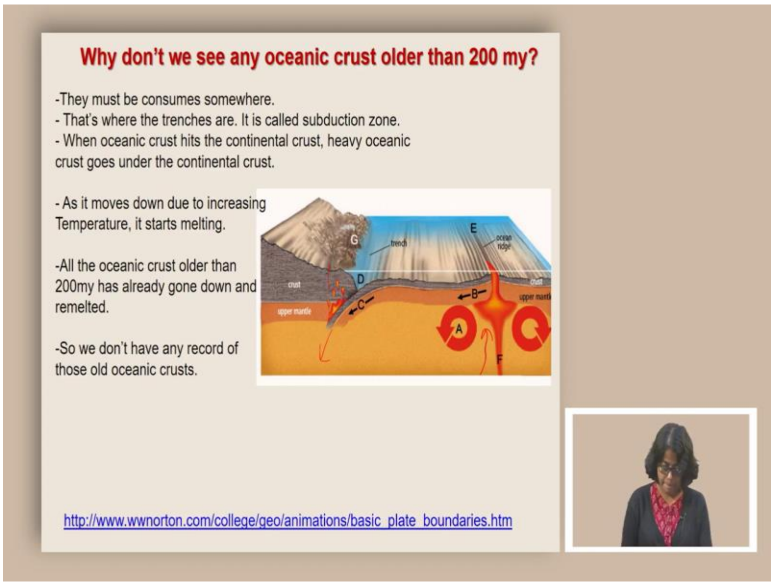

And the place where it happens are the places which are called subduction zone so they must be consumed somewhere as we understood that is where the trenches are, it is called the subduction zone when the oceanic crust hits the continental crust oceanic crusts are heavy and therefore they go under the continental crust and once they go down they face increasing temperature and there would be a point Beyond which it will start melting, as it melts it becomes buoyant and it will also come back up a part of these molten products and it will, it can create a volcano.

Now, because all the oceanic crust will eventually go through this cycle always the oldest part of it will basically go down melt and once they melt they forget all their history and they become part of the mantle as a result we do not find rocks which are older than 200 million years under the ocean, they might still be recycled and come back as new magma and generate new rocks but it is not possible to trace the connection of the old rocks with these new rocks because they will change their chemical composition, the minerals would be different. So, every time it melts the clock sets to zero and therefore you do not really know when it melted before it started crystallizing, so because of this reason we do not have any record of those old oceanic crusts.

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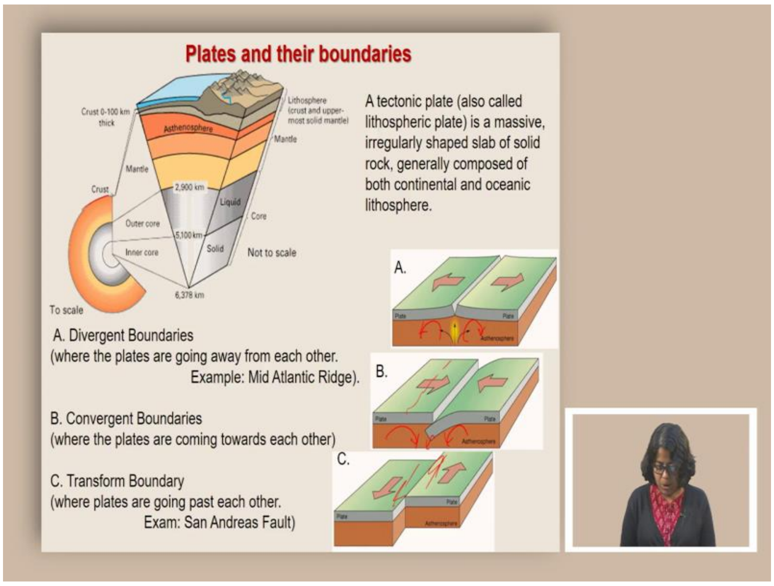

So now, let us take a look at all kinds of plates and their boundaries so as we have understood that if we break down the Earth and look into the deep structure of the Earth what we will find that there is a very thin crust then there is a mantle and then there is a core and this core has a division of outer core and inner core, now the inner core is solid the outer core is liquid, mantle as we talked about that mantle has this property where rocks can flow, now the crust is solid and the crust is brittle so that means they break rather than bend but in the crust we have different types.

So, for example you have an oceanic crust versus a continental crust, a better definition or a better term to describe all of these things is a lithosphere, so a lithosphere is a combination of the crust and uppermost solid mantle so this lithosphere is combining both the crustal part as well as part of the mantle and that is what these plates are and it is also therefore called the lithospheric plate, it can be called a tectonic plate or a lithospheric plate, it is a massive irregularly shaped slab of solid rock generally composed of both the continent as well as oceanic lithosphere so depending on what is the composition we can either call it an oceanic lithosphere or continental lithosphere.

And they are on top of a mantle slab which is called an asthenosphere and the interaction between lithosphere and asthenosphere is key to this movement of these plates, now there can be different kinds of boundaries, one boundary is called a divergent boundary where the plates are moving away from each other, the second one is called a convergent boundary where two plates are coming closer to each other.

Third type is called a transform boundary where the plates are passing each other without converging or diverging and as we understood that they all depend on the mantle convection and how the directions of us neighbouring convection cycles are that is going to guide whether it is going to be diverging boundary versus a converging boundary.

Now, what happens when we are looking at convergent boundaries, when we are looking at convergent boundaries couple of things can happen, one thing that can happen is if the continent and oceanic plates are colliding then because oceanic plates are heavy they are going to go down and melt and go through this cycle, if two oceanic plates are colliding then the older oceanic plates tend to be cold and denser and therefore they are going to go down and melt they can still create volcanoes and those volcanoes will appear in the ocean as volcanic islands or volcanic arcs.

There is a third type where continents are colliding, when both the continental plates are coming closer to each other and colliding now because continental plates are less dense they are relatively light it is very difficult to subduct them and therefore they will tend to be rising up and create a collisional mountain.

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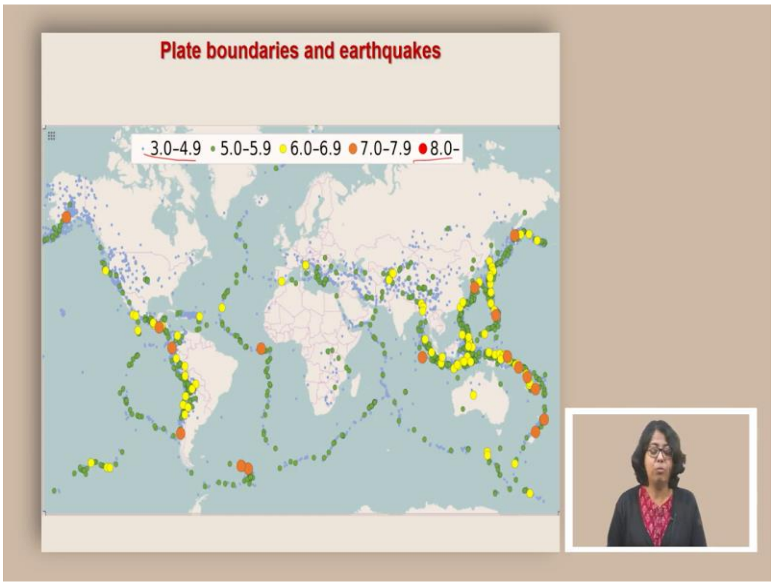

Now, let us take a look at the plate boundaries how would you know that exactly where the plate boundaries are, one of the nice relationships is the earthquake that often tells us about the plate boundaries, because of the plate movement and processes operating at the plate boundaries they create different degrees of earthquake, different intensities of earthquakes and this is a map which shows the distribution of the earthquakes, so some of the earthquakes are very very low intensity, low magnitude earthquakes, some of the earthquakes are very high magnitude earthquakes and they are not randomly distributed they are all distributed in terms of the plate boundaries.

The other aspect of physical process that gives us understanding about the plate boundaries are the volcanism, because for especially for the subduction we know that if an oceanic plate goes down beyond a point it will start to melt and create volcanisms, it could be an oceanic volcanic chain, it could be a volcanic province in the continent but there would be volcanoes associated with it so that also helps us to identify some of the plate boundaries. The other important thing that can tell us about the boundaries are the formation of these rocks through these mid oceanic ridges and those would be other types of boundaries.

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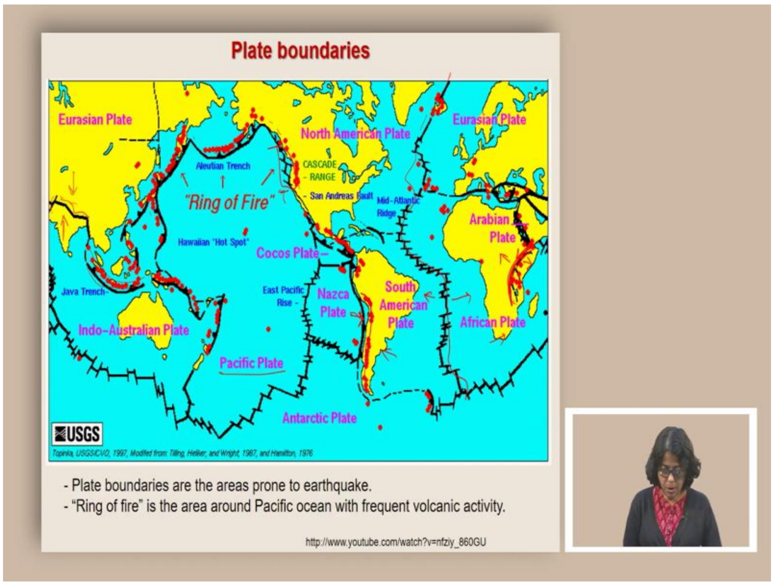

So now, when we put together all of these things we find an interesting distribution of plates so let us take a look at the global distribution of plate boundaries in the areas and which are the areas which are prone to earthquake, which are the areas which are prone to more magmatic activity.

So first one that I would like to focus are is this area around what is called a Pacific Plate, so Pacific Plate is a large oceanic plate and if you look at these red dots they are showing you some of the volcanic activity some of the earthquakes and often what you are going to find is this area started with these red coloured things, this is also a place which is called Pacific ring of fire, this is the place where this Pacific Plate is going under another plate, a mostly oceanic plates and therefore creating this chain of volcanoes.

And this is the reason because it is a volcanic activity, magmatic activity all around this this is called the Ring of Fire, let us take a look at some of the other examples, for example if we look at the boundary around here this is Indian Boundary where the Indian plate which is a continental plate is moving towards the Eurasian plate so it is also a convergent boundary but it will it is between two continental lithospheric plates, continental plates.

And because the continental plates are lighter it tends to resist the motion of going down as a result we find the development of a large land mass which is a very high land mass which is the Himalayas and as well as Tibet at the back which is probably because of the development of under plating. Now, let us talk about some of the examples here this is a place where one oceanic plate is going under another oceanic plate and therefore they are creating the chain of volcanic islands around the Java Trench.

Let us take a look at a continental oceanic boundary, so this is South American Plate which is a continental plate and this is Nazca plate which is an oceanic plate once it goes down or once it collides with the continental plate this Nazca plate goes down and it creates the volcanoes all around the South American Plate and that is again an example of a convergent boundary where it is a continent ocean plate convergence.

Then there are interesting patterns around here which is in North America, the western part of North America where we do see plate movement but those plate movements are sliding past each other so we actually have a number of transformed walls or all around here, so they are not really diverging or converging they are simply passing next to each other and they can also create continuous events of earthquakes.

Now, let us look at some of the convergent, some of the divergent boundaries, so if we look at this portion, this entire portion is the part where the South American Plate and the African plate are going away from each other and the reason it is going away from each other is because of this Mid-Atlantic Ridge because this is the Mid-Atlantic Ridge where new ocean floor is being created and therefore pushing this oceanic plate and eventually pushing the continental plates too.

Let us take a look at some of the diverging plates right here it is within a continent so within a continent there is this thinning of the lithosphere and then it is diverging in this direction and in this direction, so eventually after probably couple of million years we may find that there is a creation of the oceanic lithosphere right around here and probably the sea water is going to go inside and create a new seaway, these are the continental rift margin again an example of a divergent boundary in the continent.

So, looking at the global distribution of the continents and the ocean and finally connecting it with the magmatic activity as well as the earthquake gives us a fairly good understanding of where the plate boundaries are today and these plate boundaries help us to explain where we can expect prolonged period of magmatism or earthquake, in fact the depth of the earthquake pretty much gives us very good understanding of what is the depth where the plates are going down.

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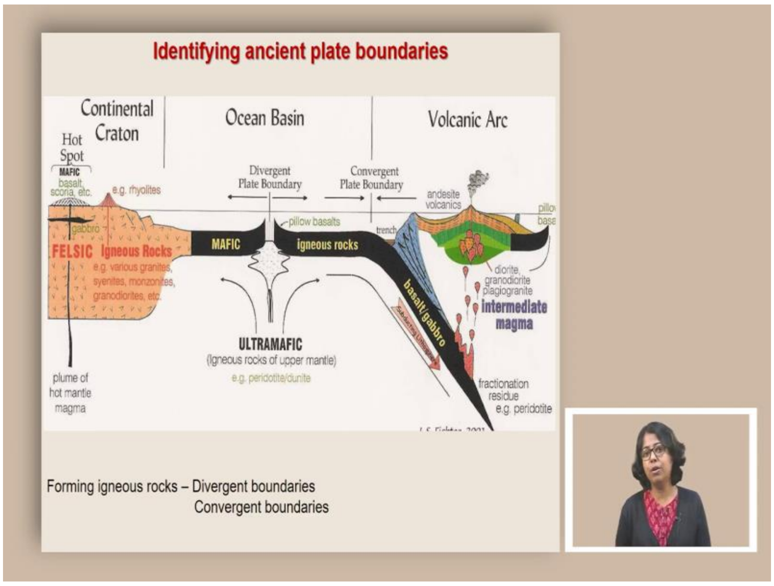

Now, using these criteria it is possible to identify ancient plate boundaries especially if you know what are the rock characteristics that are associated with each of these types it is possible to extract information from old rocks to understand what was the plate boundary and if we reconstruct that that leads back to Wegener’s original idea which tells us that yes there was a time where Pangea existed and then eventually these continents fragmented and moved in different direction.

But unlike Wegener's idea now we know that this supercontinent did not appear just once there were multiple such super continents and fragmentation events throughout the history of the Earth and using this plate tectonic framework we can explain many of the events of the Earth, development of different rock types throughout the Earth's history and regionally where we are expecting what kind of a rock and why they are there.

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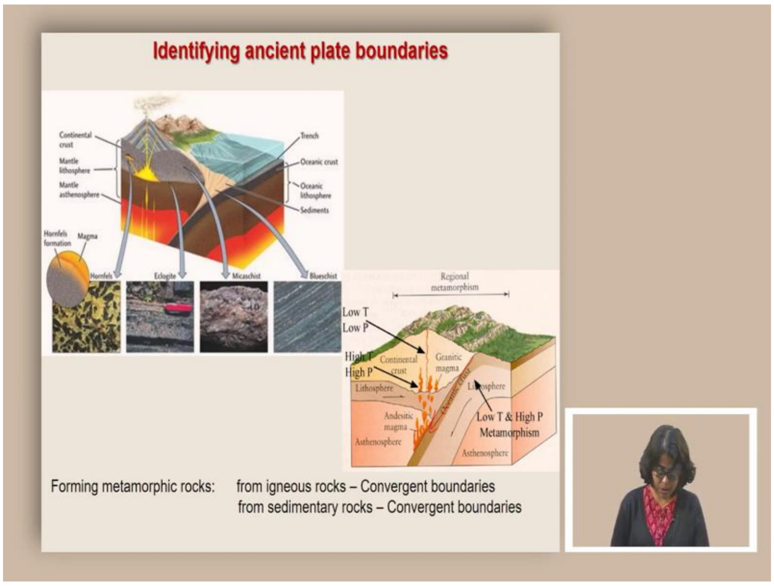

We can also identify using plate boundaries using types like metamorphic rocks where the subduction basically generates different temperature and pressure profile some of the temperature and pressure combinations do not lead to melting but change in the rock and that is what lead to different kinds of metamorphic rocks, so looking at both igneous rock as well as metamorphic rock gives us understanding of plate boundaries.

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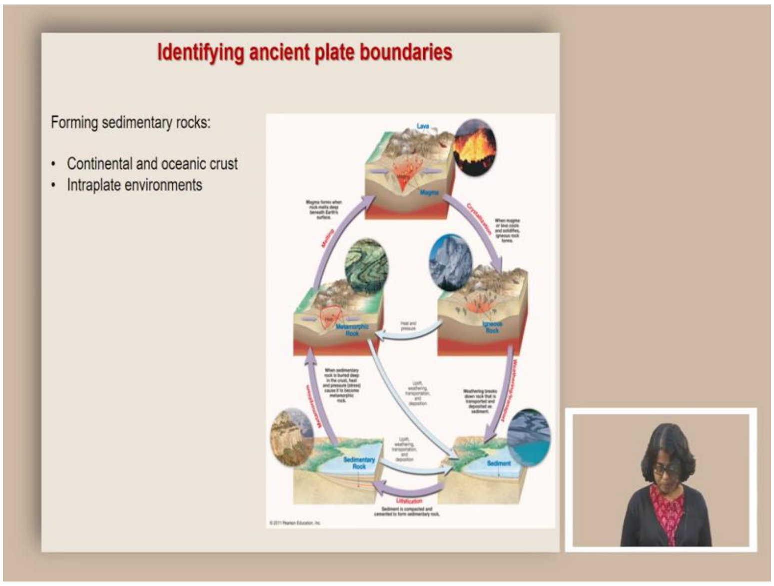

Sedimentary rock also tells us something about the plate boundaries because plate boundary also involves a massive pile of sediments which goes down, there can be plate boundaries where these massive pile of sediment basically buckle up and create mountain chains such as Himalayas, so these kind of things are very important to reconstruct the history of the Earth, sedimentary rocks can also form in intraplate environment and then it becomes even more important to recognize those because they can tell us how the environment was where it is not being affected by direct tectonics.

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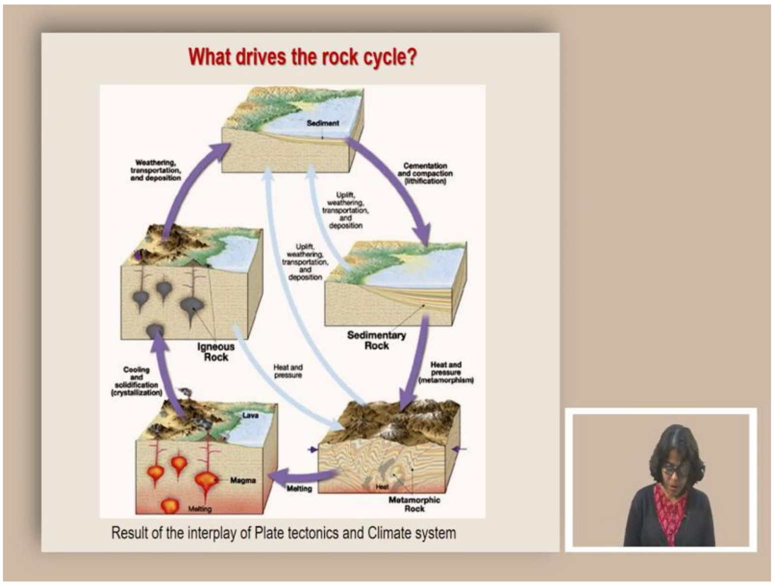

So finally, if we think about the rock cycle it is driven by tectonic activity, things which are connected to the mantle convection and then also connection with the climate because atmosphere has a major role to play how quickly the rocks are getting eroded and weathered and therefore finally how the rocks are going to convert from one to the other and how they are going to maintain their topography is result of two factors, one is plate tectonics and the other one is climate system.

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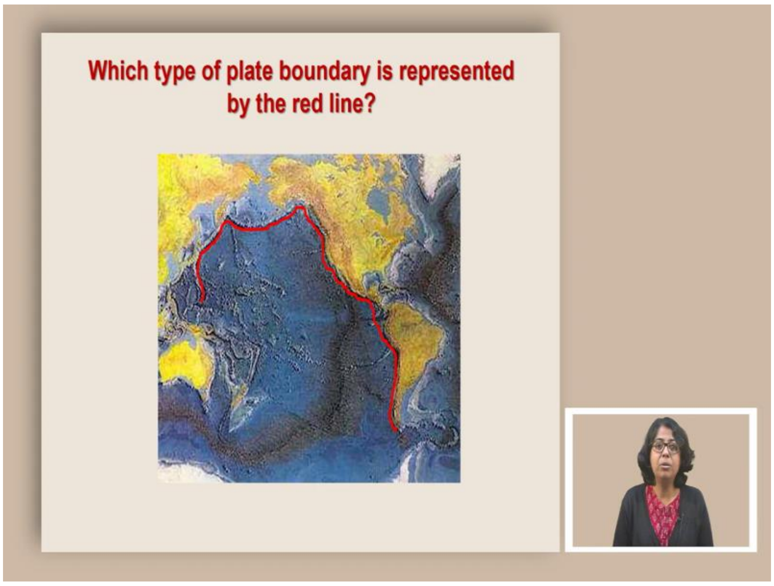

So, here are some of the resources that I have used to make this slide and in summary I would say today we learned how the plate tectonics idea works, what are some of the evidences of plate tectonics, what are different plate boundaries that one can observe on the surface of the Earth.

We also learned how plate tectonics and tectonic boundaries are related to earthquakes and volcanism, finally how the topography is generated through plate tectonics and how they are modified by a combined role of plate tectonics as well as the climate system. So, in summary the Earth is a very connected system and finally what we see on the crustal level is a result of these interactions. Here is a question for you to think about. Thank you.