Evolution of the Earth and Life

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Discussion on Conceptual Questions

Professor: Welcome to the course Evolution of the Earth and Life. Today, we are going to discuss some of the questions. These are the questions that I got based on the materials that I covered so far. And today Neha is going to help me saying these questions, and I will try to answer those.

Student: So, as we saw in one of your lectures of how rock melts, that fluids play a crucial role in understanding where exactly a rock is going to melt. So, what is the role of water what is its effect on the melting point of a particular rock?

Professor: So, the fluid work as network inhibitors. So, what it does? It stops the materials to go into crystallization. As a result, it tends to be in the liquid phase quickly, and therefore it melts. Somewhat similar analogy would be salt and ice. So, in water, if we add salt, it actually does not crystallize so quickly. And that is why in countries where there is a lot of snowfall, once the snowfall starts, they will sprinkle salt on the ground, so that it does not form ice so quickly. So, it basically inhibits the crystal formation. And water does somewhat similar thing to the rocks.

As a result, what we find that if we are dealing with rocks, which either has hydrous minerals, so that means we are talking about minerals, which have H_2O inside their crystal structure, or it has rocks where there are water filled up between the greens. In both the cases, they are going to melt faster and at a lower temperature compared to rocks which do not have either of these things. So, if we compare the wet rocks versus dry rocks, we are always going to find that the melting point of the wet rocks are much lower than the dry docks.

Student: So, we know that igneous rocks forms from magma. And this magma, the parent magma from which the universe rock forms is homogenous in its composition. So, how does the rate of cooling of magma affect the appearance of an igneous rock?

Professor: So, the appearance has two components. One is the texture. And that means how the crystals look like? Are they big crystals? Are they small crystals? And I am going to explain how that depends on the rate of cooling. So, I guess all of us tried our luck with making ice creams. And we know that when you try to make ice creams in a regular fridge, after it freezes, when you try to taste it, it does not really taste as good as it does in a regular shop.

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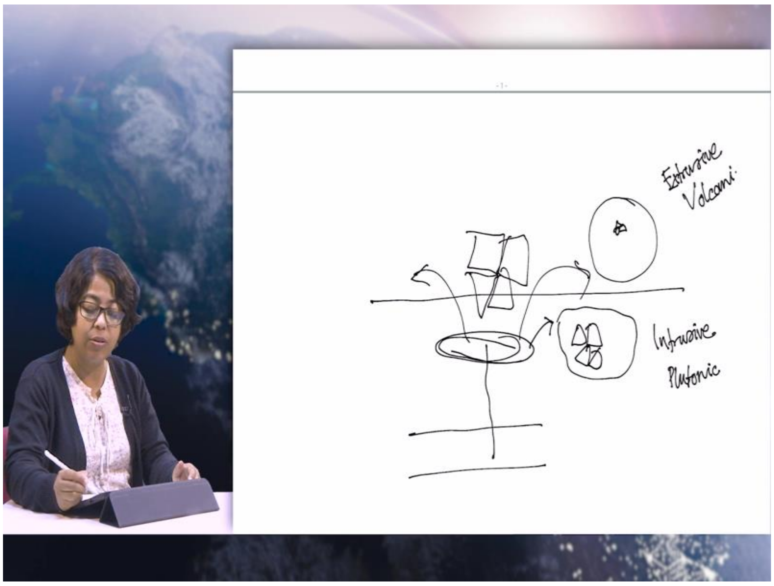

The primary reason for that is if you look at those homemade ice creams that you just tried in your regular refrigerator, they actually have very large crystals. Because the more time you give in terms of bringing down the temperature to a certain degree, it helps the crystals to grow. So, the slower the rate of cooling, the crystals grow larger, and when you are tasting the ice cream it apart from separating part of the milk and icing it also these large crystals that you are tasting. And therefore it tastes a bit gritty and sandy, which is not the best thing.

And other extreme is in really professional setting where people try to make really high quality ice cream, they use liquid nitrogen, so they pour liquid nitrogen and it freezes immediately. And then you get one of the creamiest ice cream because it has no crystals at all. So, from this we know that size of the crystal depends on how quickly something cools down and how slowly something cools down. Now let us take this analogy to our magma chamber.

So, magma chamber is somewhat deep below, and the depth can change depending on which tectonic setting we are looking at. But all the source of those magma is primarily from the upper mantle, which, in terms of its composition is fairly regular and homogeneous. So, when it comes up to the surface, it basically goes through different temperature change, it could still reside in a place, which we are calling magma chamber, which is below the surface. And from here, the magma can be in a liquid form.

Now from here, to this surface, whether it is coming actually outside the surface, and therefore cooling the rock almost instantaneously. Or it is actually forming some part of these, or taking out some part of this magma still under the surface, and creating rock that determines what is going to be the size of the crystal.

So, if we find something, which basically came from inside, but then actually cooled down on the surface, we are going to find very fine crystals. And these are typical things that we generally called extrusive rock. And the ones which are inside the surface hold down much slowly, because the temperature inside is relatively hotter, compared to the outside, this will create something which has a much larger crystal. And these are called intrusive rocks.

There are common names for it also. This one is called a plutonic rock. And the other one for obvious reason, is called a volcanic rock. And these are the main difference in terms of the crystal structure. And that controls how they will appear. This will also have some differences in terms of their composition. But I think right now, we are only talking about the appearance. And this is what controls the appearance of crystal size.

Student: So, related to this explanation, like the extrusion or volcanic rocks have a fine grain structure since they are formed on the surface. So, does the surface temperature of the Earth or the variants in surface temperature due to several reasons affect the crystal structure of these igneous rocks?

Professor: So, it does to some extent, because if we are thinking about a magma, which is coming in contact with very cold temperature, it is going to crystallize much, much faster, compared to not so cold medium.

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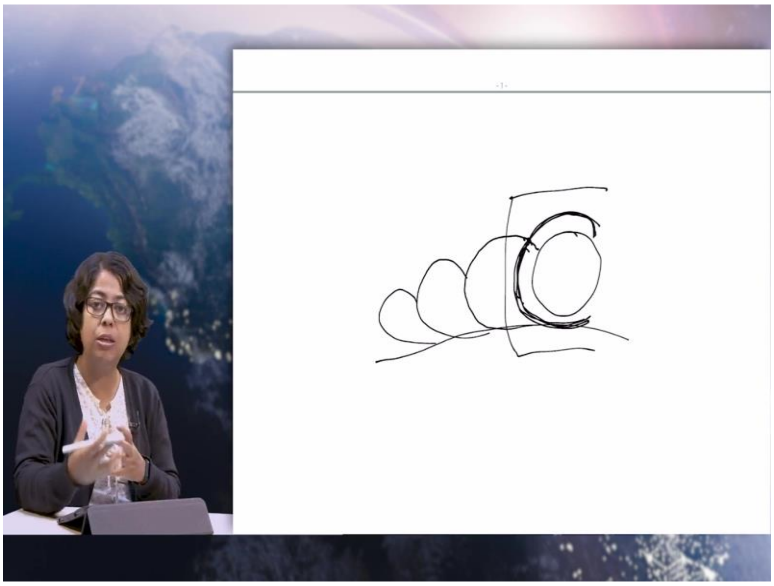

And one such case that we see is when these magma come in contact with ocean water. often what we see, it basically forms our pillow like structure, where the crust of this pillow forms very quickly. And it creates extremely fine grained structure, sometimes even glassy structure, which means it does not even have a crystal, it is so quick. But then once this crust forms, the magma inside is still liquid. And what it will do, it will push this envelope and part of it is going to collapse and it is going to create another blob. So, these are telltale signs that things have formed underwater.

Now when we think about the surface temperature variation in general, yes, it is true that Earth's surface temperature has varied quite a bit fluctuating from probably in very cold times, where it can go to subzero to hotter times which vary, the average temperature can go to well around 30 degrees.

But when we are talking about overall change in terms of the crystal structure, and as the magma cools, it is such a large temperature change, this molar temperature variation on the surface does not make a big difference, especially apart from the outside crystal formation, because inside is still hot and it has its own way of cooling down and that rate of cooling is not always dependent on exactly what is the temperature of the outside surface. So, that is why we often see changes in crystal structure as we go from the exterior to the interior of the rock, depending on how they formed.

Student: Now a couple of questions on plate tectonics, like you have mentioned about the formation of oceanic and continental crust. But these two are of different densities, like the oceanic crust is more denser than the continental crust. But how come these two crusts of different densities have been formed from the same mantle?

Professor: I think that is a very interesting question.

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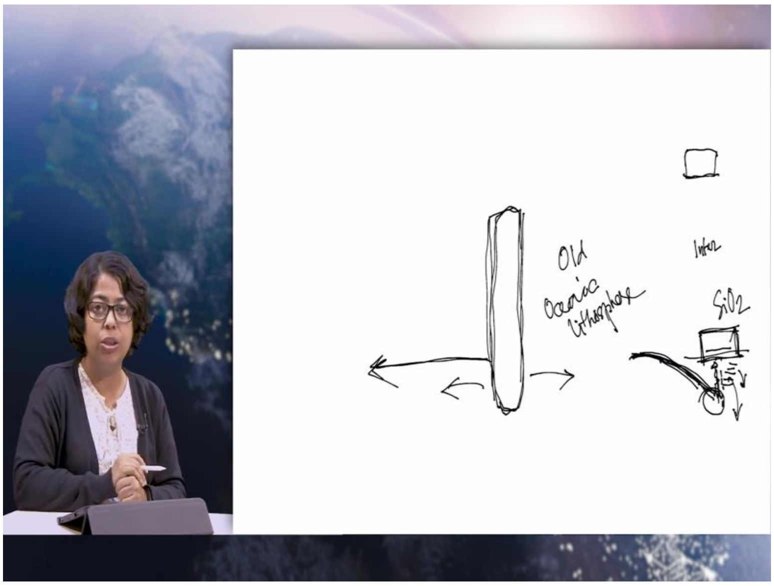

And the primary reason for this difference is how they are forming, and what are the main crystal structure and what are the minerals that are in it? So, when we think about oceanic crust, it is primarily forming in this divergent boundaries. So, what are these things? These are divergent boundaries, where the sense of direction is away from each other, and the new plates are forming. And when the new plates form, it is basically it is the magma which is coming very close to the surface and creating this new piece of crust.

Because it is not differentiating so much, it is primarily going to have the salty composition, it will have because if we recall the Bowens reaction series, the first few things that is stabilizers, they will have a high content of metal ions. And all of these things are going to produce this oceanic lithosphere or oceanic plate.

Now, this one is not very well differentiated in terms of from the magma, it has not gone through a lot of fractional crystallization. And therefore it is going to be more heavy in terms of its overall composition. And it is going to have a dominance of those minerals which are sort of above in the Bowens reaction series, which have slightly higher metal ion content generally heavier.

And as it cools down and moves away from it, because of the heat, this has a higher volume, and this is also relatively less dense compared to other oceanic crust, and as it goes away from the source of heat, it will condense it will cool down and therefore also become slightly more denser. And as a result, old oceanic lithosphere or old oceanic plates are always denser.

Now let us come to the development of continental crust. Continental crusts formed through a relatively more complex process. One way where it starts is those convergent boundaries, especially the subduction zones. So, if you are looking at a continent ocean boundary or an ocean-ocean boundary, and there is a subduction zone, what happens this plates, the subducting plate, generally an oceanic plate, it goes down up to a point where the temperature and pressure combination is ideal as well as it also has some of the hydrous minerals which are contributing the water from it, the sediments on top also has water therefore, reducing the melting point all of these leads to the melting of some of these places.

And once it melts, it becomes more when to have more volume, it tries to rise up. This rising up will have a relatively longer history of fractionation. Secondly, the composition of this plate, which has a lot of hydrous minerals, which has sediments, these are also contributing to deciding what is going to be the final rock composition.

And what we find is because of these relatively longer path where there are multiple phases of this fractional crystallization, where the magma as it reaches to the top becomes very light in terms of the color as well as its composition, that it will be primarily composed of things which are towards the lower part of the Bowens reaction series. So, it will have a relatively high amount of silica whereas the other minerals, which are relatively high temperature minerals have already settled down.

So, this gives results into the formation of a rock, which will be dominated by quartz or feldspar some of the mica and relatively low proportion of the high temperature minerals. And this also means that they will have a igneous composition which is sort of intermediate. That means it has a high component of felsic minerals and not so much of mafic mineral. And generally, these felsic minerals are also going to have a lighter density. So, this is one of the reasons why you will have the continental crust to have a lighter density compared to the oceanic crust.

Student: So, the density of a plate can be used as a parameter to calculate its age, right?

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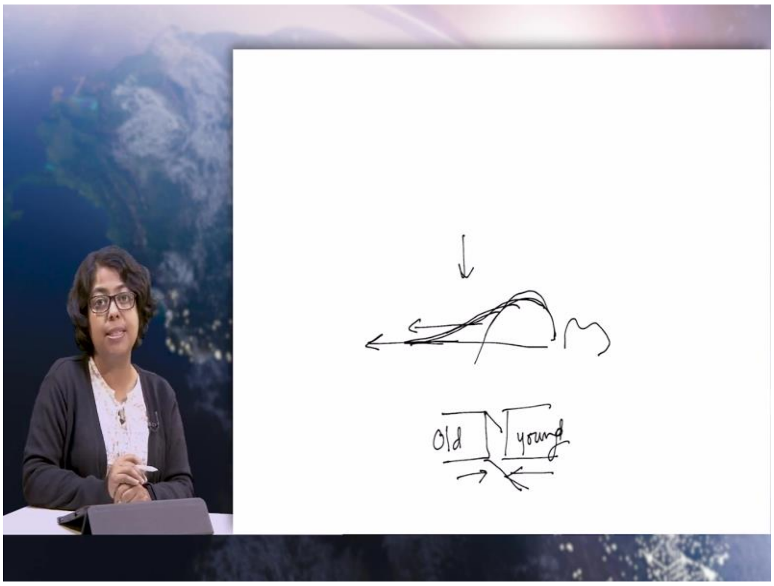

Professor: It is true especially for oceanic crust because as I say that oceanic crusts are less dense and because of their high volume and high heat content near the mid oceanic ridges where they are forming. As we move away from that, and as these rocks basically get pushed, because of the new formation of rocks, they also get colder, and therefore, they become more dense. The overburdening pressure of the water as well as the sediments also play a role.

So, to a first approximation, as the oceanic plate becomes older, also becomes colder and denser. Therefore, if there are two oceanic plates in our convergent boundary, one is old and one is young. The older plate is always going to go down compared to the younger plate because of this density difference.

Student: One of the strongest evidence for these plate tectonics are the seafloor readings. So, how did the magnetic reversal of the work lead to these sea floods readings?

Professor: Well, technically, the magnetic reversals did not lead to seafloor spreading, but they have a relationship of how we understand the seafloor spreading or how we document the seafloor spreading. So, let us try to understand how it happens. We know that magnetic reversals mean Earth’s magnetic pole keep on changing. It does not have a very well documented periodicity or a regular periodicity. But we know that it has changed multiple times in Earth's history.

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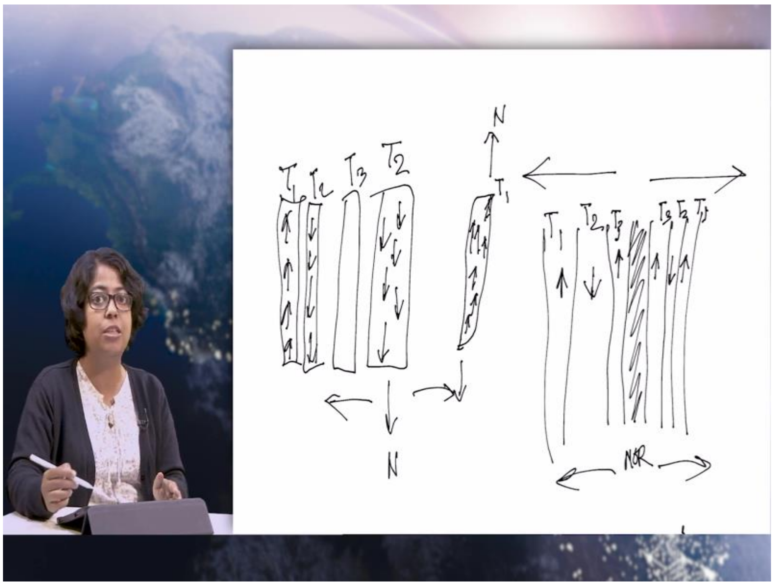

So, let us take a situation where it is aligned to today’s magnetic pole. And the North is aligned to the north of today’s magnetic pole. In that case, when a rock is forming in the mid oceanic ridge, when it is already in a molten phase, the ferromagnetic minerals are going to align themselves according to these polarity. And it is basically going to show you the magnetic pole orientation of that particular time, let us call this one as T 1. But then, as we know that the sea floor is being created on a regular basis, so now we are talking about a few million years later, when what we are going to call T 2.

Now T 2 is let us say we are talking about the present mid oceanic ridge somewhere here. So, that means T 1 with respect to T 2 has gone in this direction as well as in this direction because it is symmetric, and it spreads in both the direction and it is showing this polarity because that is the polarity of the time when this particular floor was created. In time T 2 because of the reversal it has changed. So, now the polarity is somewhere here. This is again a magma which is cooling down and the ferromagnetic minerals are going to orient themselves based on the polarity of that point.

And therefore they are going to orient themselves something like this. But T 2 is again going to move on because there would be a production of let us say something called T 3. So, it is going to have something like T 3. And these T 2 are going to be represented here where it is a different polarity. So, because this process goes on, what we are going to find is at any given point of time, if we are looking at a mid oceanic ridge, as we are moving away from this mid oceanic ridge, we often see these rocks, which will show you change in polarity. So, they are representing basically T 1, T 2 and T 3 the same way in this part. And this is the present day formation.

This is symmetric, because the seafloor in this case is producing symmetrically, it is sort of moving away from the central point. And every time it is moving away, it is basically carrying its polarity signature when it was a liquid and transforming into a solid. And that is why you have these polarity reversals preserved in the rock symmetrically in two different directions from the mid oceanic ridges, and when we calculate the polarity, from the rocks, the Paleo magnetic polarity, we are going to observe something like this, the one that I just talked about that it could be something like this, this and again this. So, the same way that we said here, it is going to look something like this, this and again this.

So, magnetic polarity change is not creating seafloor spreading, the documentation of magnetic floor magnetic pole change is supporting the idea of seafloor spreading, it is documenting the spread and the rate of the spread also, if you know how these polarities have changed over time.

Student: Now thinking about the plate boundaries, how do these interesting structures like Hawaiian structures, like Mauna Kea, are exactly formed?

Professor: So, the Hawaiian structures are actually forming in the middle of a plate and what is making them very, very interesting.

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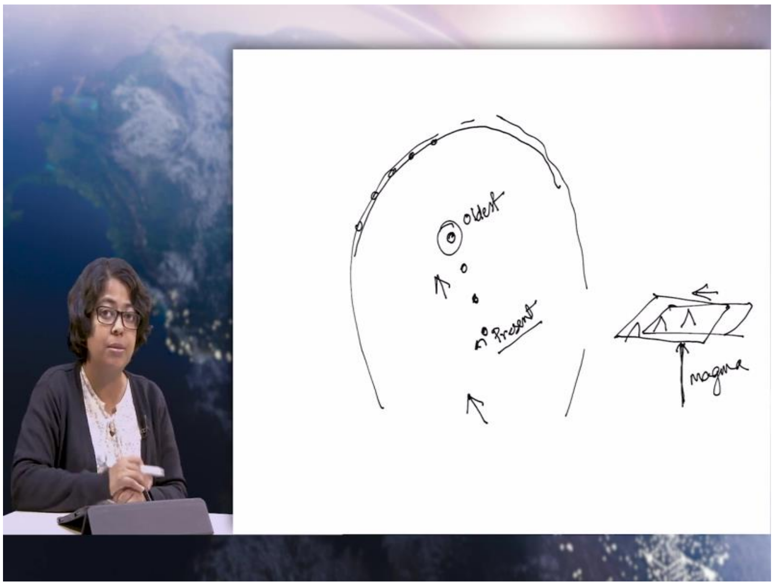

If you think about the boundary, it is actually part of the Pacific plate, so it is not sitting in any plate boundary. So, it is the middle of this plate where we see these series of volcanoes, Mauna Kea is one of them. Interestingly, what we find is, this is the present day, where we find the volcanism, and there are volcanic islands, which are arranged like a chain. And these are the oldest because you can also date them. Now, what it means is, this one is presently erupting. So, that means the magma is coming from this part. But these ones erupted. But right now, it is not erupting. And it is completely dead in the sense that it does not really have any remnant magma underneath.

So, this led to the understanding of something which is called a hotspot volcanism, which argued that if you are looking at a cross section, it is the single source point of a magma, which is coming from the mantle. And this is not really like the large scale convections, it is almost operates like a single source. Now when you have a single source, yes, there would be a corresponding volcano right on top of it. But at the same time, the plate if it is moving, then you are going to shift things in different direction. So, you are going to create another volcano in this progression. So, there can be series of volcanoes, which are showing different times when they were formed.

Similarly, here, we find that this is the present day active volcano. On the other hand, these were volcanoes which erupted but now they are not there, which indicates that if this is a single source, that means the plate movement is in this direction, because this place was on top of these single source at some point of time, but then they were moved. And therefore you find these development of these chain like structure of these volcanoes, but not all of them are active.

This is different from the chain like structures of volcanoes that we find at the boundary of the plates, where we actually find most of these volcanoes to be active. This one is always going to show you one active and the other ones as remnant organisms.

Student: And how exactly does a transform plate boundary arise? Is it due to convection currents in the mantle, or there is some another reason for it?

Professor: There is no other specific reason it is also connected with the plate tectonic boundaries.

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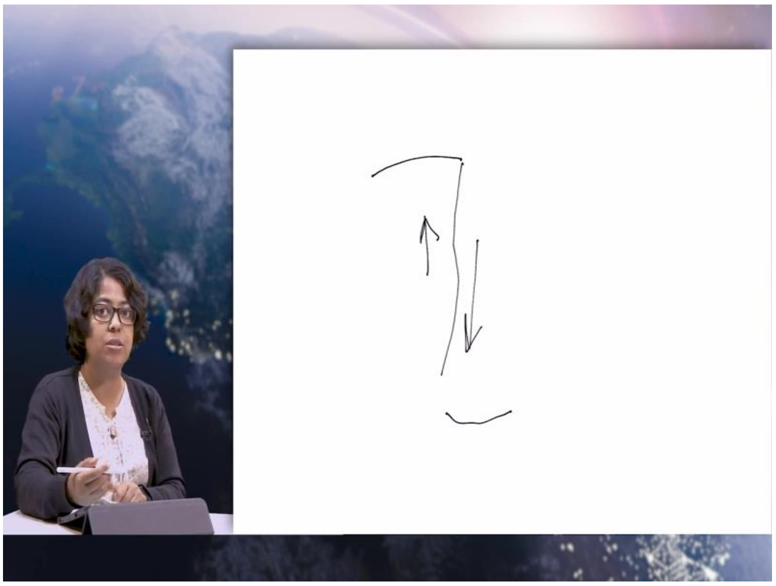

But the general idea is that you can imagine situations when one plate is moving in this direction, probably because there is a subduction zone, the other plate can have a completely different orientation, because maybe it is connected to another subduction zone or convergent boundary because of which it is moving in this direction.

Now, when these two plates are next to each other, they can create a sense of motion, which is opposite to each other. And these are the places where you primarily get the transform faults, or transform boundaries.

Student: So, coming to the last question of our discussion. So, has the number of tectonic plates increased over a particular geological time? And how do we predict the future plate tectonic configurations?

Professor: This is really a great question. And we really do not know all the answers to it. First of all, there are multiple cycles of plate fragmentation.

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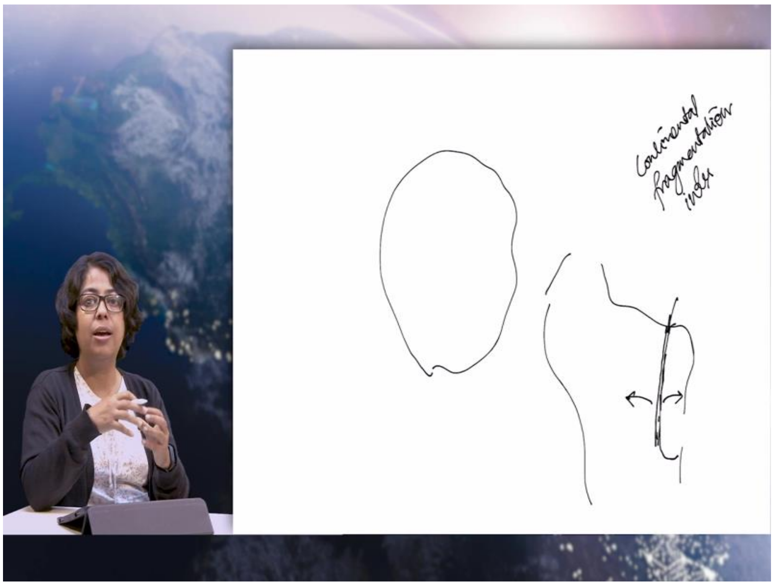

And it is, there are times in the geologic past, where we have a formation of large continents, and therefore the number of plates were relatively low, or at least for the time being, it created a large landmass. And at the same time, there were times when it was fragmented more than what we see today. So, the change in the number of plates have been going through the times, there is something called a continental fragmentation index, which keeps track of how many plates were there at some point of time, and it keeps on fluctuating. Now the question is, can we predict what is going to happen in future?

Well, there are some places where it is clear that they are creating newer configuration. For example, if we look at the African plate, and especially towards the eastern side, there is a formation of a rift. So, what it means it is actually a divergent boundary information. So, once it is fully formed, it is going to create a boundary which is going to develop new sea floors. And probably the water is going to come inside and it is going to separate out probably from part of African mainland that we see today.

So, there are various such things that are happening today, which is going to change the configuration of the plates over time. And but to predict exact position, it is often difficult because it is first of all, it is happening on a curved body. Secondly, there are multiple plates, which are also engaged into it, and the final result could be quite complex.

Thank you Neha for the questions. We are going to cover more questions like these in the coming weeks. Thank you.