Evolution of the Earth and Life
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Lecture 54
K-Pg extinction: mechanisms

Welcome to the course, Evolution of the Earth and Life. Today we are going to talk about different mechanisms of K-Pg mass extinction.

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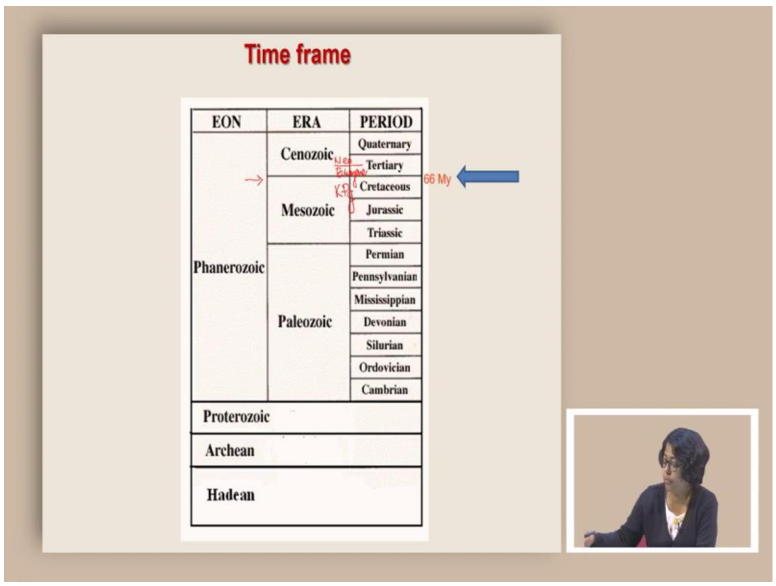

As I mentioned before, we are going to look at the timeframe of Cretaceous and Tertiary, so we are looking at the boundary between Mesozoic and Cenozoic, and because Tertiary is divided between Neogene and Paleogene, this particular boundary is also called a K-Pg boundary. We are going to look at the events that took place during K-Pg boundary, and which may have led to the extinction event that we are familiar with.

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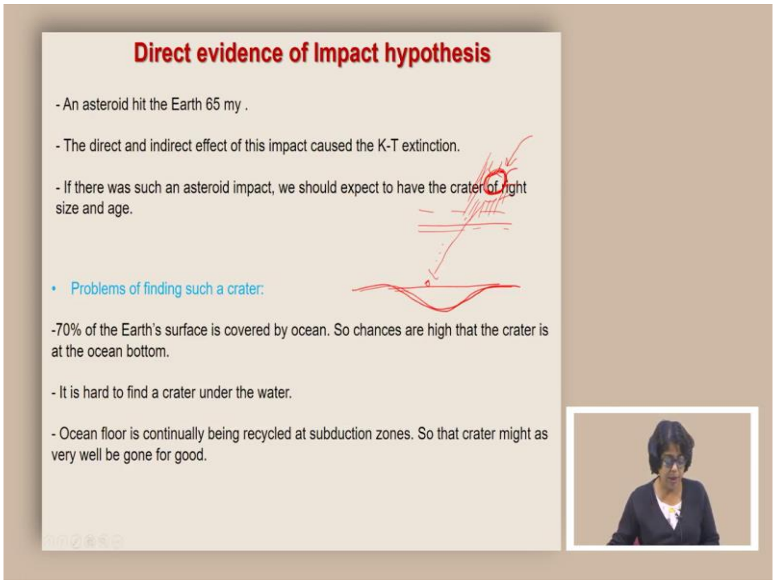

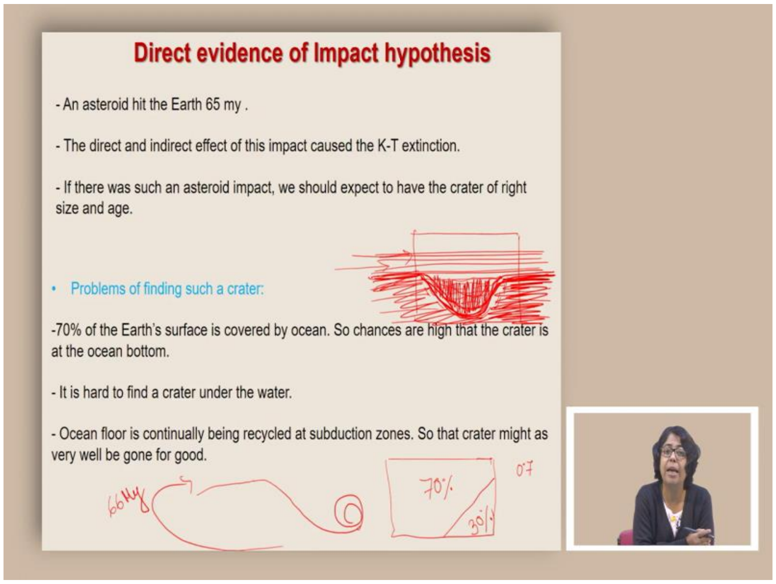

Luis and Walter Alvarez, came up with the idea of an impact hypothesis, which argues that there was a major asteroid hit during 66 million years ago. And because of this hit, there was a major change in the atmosphere and the ocean. These changes led to the extinction event. Although, there were evidences of an impact which were distributed globally, such as tektites and shocked quartz, iridium anomaly.

It was still not very convincing to a number of researchers, because it was still not showing the exact crater which was produced by this large impact. Now, let us understand what do we mean by a crater? So, when an asteroid hits the Earth, it basically comes from the extraterrestrial space, and then because of the Earth's gravity, it comes closer to Earth, enters the atmosphere. Once it enters that atmosphere because of the friction, it starts to burn.

It starts to burn till it reaches the ground. Now, if it is a small asteroid or a small meteorite, probably by this journey before it hits the ground, it will be completely burnt and therefore we will not really find any remnant of this, probably some ash. If it is slightly larger, probably we will find only 10 percent of the original size, and that will still be a relatively small one. Now, if we are talking about an asteroid, which is let us say 1 kilometer in diameter, then it is a large body and even after burning, it is not going to be completely wiped out.

And it will still have a large enough mass which will impact on the ground. So, it will basically hit one part of the Earth and that part will eventually create a depression. Now, the issue is once it creates the depression that depression is not going to be there forever. So, let us try to understand what I mean by that. So, in the ground, once a depression is created because of the asteroid impact, sides of this crater, so this is going to be called a crater, sides of this will show signature of melting, because of this high impact.

Probably a bit far away from it, we are also going to see patterns which are showing impact metamorphism, various patterns in the rock. But eventually there would be time after that where sediments will flow in and fill up this crater. Now, because we know that in the Earth, sediments are always flowing, the sediments are always getting transported, this will be filled up and eventually this part can also be filled up with sediments. These will get compacted, this will turn into a rock.

And now when we are looking at a rock, it becomes very difficult to identify this crater, number one because it is this boundary that we are talking about, which was the crater outline is now part of another rock, which is also solid. So, at best, what we can expect to see is a change in the composition between the rock which was making this part, and the filling up of the sediments. Because the sediment which filled it up are somewhat younger and therefore, and I mean, they made into a rock much later.

So, therefore there can be a compositional difference, and that is the boundary that we can hope to find out. So, this shows you the complexity of finding a crater or pointing a crater on the Earth surface. Now, the question is, do we really find the crater? There can be a possibility where the crater can never be found, because the crater might not exist today. Let us try to understand that point.

We know that the Earth's surface, 70 percent of it is covered with water. It is the ocean. And only 30 percent is the land. And if I simply take the probability of an asteroid hitting, there is a 0.7 probability that it is going to hit the ocean floor rather than on land. The ocean floor is an active place. The ocean floor is something which continuously gets subducted, recycled and eventually creates new ocean floor.

This we know from Plate tectonics. What that means is, as we go towards the older records, we really do not find them under the ocean floor because they have already been consumed. We are talking about a crater, if it hit the water, which is more likely it hit the ocean floor, which is more likely 70 percent more likely than hitting the continental crust. Then we are talking about a crater, which is 66-million-year-old.

Now, the 66-million-year-old crater has a very high probability that it has already been consumed and gone through multiple melting and remelting processes. And when it finally comes back up, it has no record of this crater. This was some of the worries that researchers had at this point, that it might also be possible that, that particular crater that represents the asteroid impact during 66 million years ago is no longer present on Earth's surface.

Secondly, even if it is present, if you are thinking about an underwater crater, which has already been filled up by sediments and then eventually converted into rocks, it is very hard to recognize them through underwater surveys. These surveys would be geophysical surveys to check the contrast in density. So, because of all of these things, for a long time after the proposed impact hypothesis of Alvarez, researchers were not convinced that the crater can be found.

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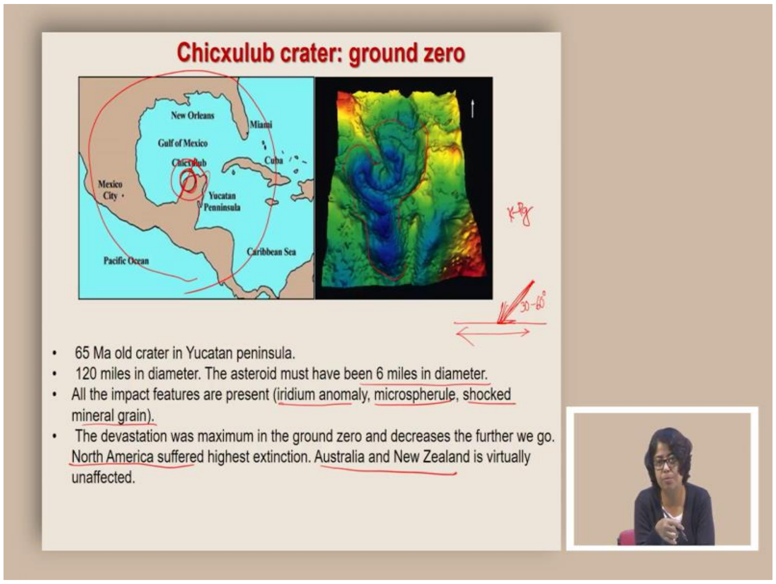

The crater discovery came from the Gulf of Mexico. So, there is a place called Yucatán Peninsula, where during underwater survey of geophysical map, people discovered that there is a crater, which is 120 miles in diameter. And this basically shows an interesting geometry. So, if you are walking on the ocean floor around this part, you are definitely not going to see any crater.

However, the geophysical survey shows that there is a change in the density of the material, which shows that there is a layer which corresponds to an older rock, and this is filled up by younger sediments, and the diameter of this place is very large. We are talking about 120 miles. Now, what might have been the size of the asteroid? Now, there can be different arguments about what can be the size of the asteroid, because the crater that is created by an asteroid also depends on the impact angle.

So, it is possible that different impact angles are going to create different diameter of crater from the same asteroid. So, people have done a number of computer simulations to figure out what kind of impact angles are going to generate what kind of craters, at least what diameter, and therefore corresponding back to an overall range. Another point which helps is there are multiple such craters, not of K-Pg age, but in relatively recent years.

And there you can check whether what was the crater's diameter and what were the impactor. And that can give you a general sense of what is the overall size of the asteroid that are responsible for creating a particular diameter of crater. So, based on these computer simulation as well as available data, people recognize that the asteroid was 6 miles in diameter. And it probably impacted at a high angle, probably anywhere between 30 to 60-degree angle, when it hit the ground, and it hit the ocean floor sediments.

Once it hits the ocean floor sediments, this impact created a number of situations later, and these are going to manifest themselves in terms of a changing atmosphere, ocean as well as biosphere. Also, one point when people drilled through these impact crater in Chicxulub around the same type of rock or corresponding to K-Pg, they also started finding all the evidences of impact such as iridium anomaly, microspherule, shocked quartz, et cetera.

So, it also tells you about the support of impact hypothesis from the crater, which tells you that the crater could not have been created by any other way. It fits well with the diversity change of the organisms and how it is globally distributed. So, if we look at the amount of extinction or the intensity of the extinction globally, we find that majority of the extinction or high rate of extinction, high intensity of the extinction is observed near North America.

Whereas, Australia and New Zealand is often showing a virtually unaffected pattern. So, we do not see a very high degree of extinction in Australia and New Zealand, which is something what we expect if the Chicxulub crater was the ground zero. This is where the impact happened, then areas nearby are going to be affected more and New Zealand and Australia are far away from this, and therefore we can expect to see a relatively lesser degree of extinction.

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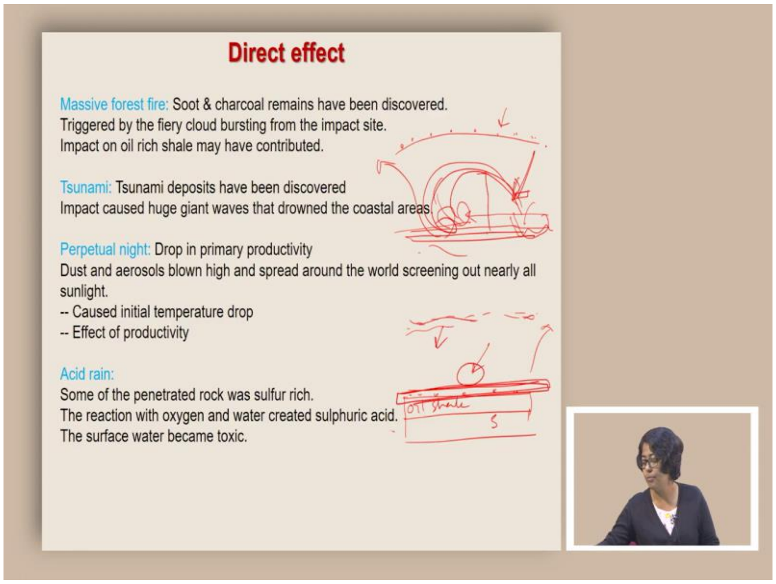

Now, what were these direct effects? So, we are going to go through some of the observations and then the interpretation. So, number one was massive forest fire. The observation was that we found soot and charcoal remains from this K-Pg boundary. Now, how can you create soot and charcoal? Charcoal primarily develops when there is a massive forest fire. But soot can be developed if there is a forest fire, but it can also be developed if the impact actually triggered or hit an oil rich rock. Because then it starts to burn and creates this soot.

So, one idea is that because of the impact, number one, it started a fiery cloud, which started to burn nearby forests and finally led to this development of charcoal and soot. But another contribution of soot came from the oil rich shales which were impacted. And therefore, they immediately start to burn and create this soot.

The second one was tsunami. So, tsunami deposits have been discovered and the idea is that if there is a high velocity impact on the ocean flow, then it creates a wave, which finally leads to tsunami. Tsunamis are the large waves which impacts mostly the shallow water coastal region. And as it comes from the deeper part to the shallow region, the amplitude of the waves increase and this is the part where it becomes most destructive. Again, this fits well with the idea of an impact where because of the impact the ocean floor starts to have a wave which ripples through and creates these large tsunami waves near the coastal region and create tsunami deposits.

Perpetual night. This was effect of couple of factors, primarily because of the ejector. So, once it hits the ocean sediments, it was an ocean sediment and underlying was a rock. These ocean sediments are going to go airborne and they are going to create all these debris which are in the atmosphere. Now, these debris mixed with soot, they are going to create a situation where the sunlight cannot penetrate.

This happens often during nuclear experiments because that also takes this ejector in the atmosphere. There are a lot of aerosols and dusts which goes to the atmosphere quickly and therefore does not allow the sunlight to come in and therefore there would be a relatively quick drop in the temperature at the beginning. And it will also block the sunlight and therefore, initially there will not be enough sunlight, so therefore perpetual night.

Now, if that happens in a natural scale, these perpetual nights are going to impact the plants. Plants need sunlight to have photosynthesis and then to survive. So, without that, they are going to die. And they are the primary producers. When we look at the ocean, the ocean's primary producers are these phytoplankton.

They are also going to die, simply because they are not getting enough lights. So, dust and aerosol blown high and spread around the world would eventually create drop in the sunlight, it will basically block all the sunlight. And this would lead to an initial temperature drop. And secondly, it is going to impact the primary productivity.

The last direct effect was an acid drain. Now, as I mentioned that the part where the asteroid hit, it has all these sediments, which basically blown to the air and created these aerosol dust layer in that atmosphere. But then it also had the rocks underneath and many of these rocks, some of them were oil rich, oil rich shale, and some of them were also sulfur rich. And sulfur, once it goes into the atmosphere along with oxygen and water, it can make sulfuric acid.

And this sulfuric acid becomes important part of the atmosphere. It rains back down with a significantly acidic composition. And this acidic rain which is high in sulfuric acid, is going to impact the chemistry of the surficial ocean. So, the top part of the ocean will become acidic because of this rain. And that will kill all organisms that live in the ocean surface. The ocean surface organisms, include the larva and the eggs of various organisms, including amphibians, including some of the fishes. So, all of them are going to be impacted because of this sulfuric acid rain.

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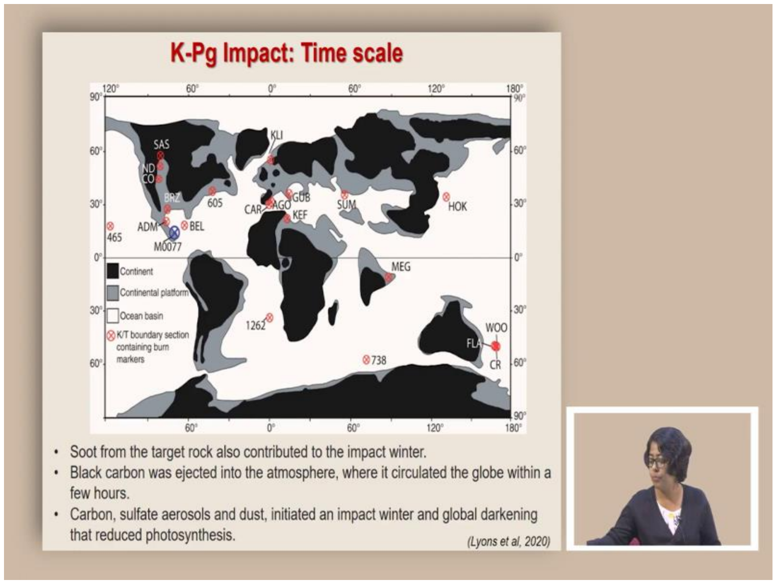

Now, exactly how these things impact? This is a good illustration. So, this is a global map and the red crosses are showing the K-Pg boundary sections which contain burn markers. What it means is this group investigated the rocks and looked at the markers. Those markers are showing you the pattern of burning, and they clearly show that it is a remnant of soot. Now, this actually tells us that the soot from the target rock also impacted the early winter.

So, it is not just the forest fire, it is the black carbon that ejected because of this impact burning and went into the atmosphere, covered the entire globe. And within a few hours of this impact, it already started blocking the sunlight. And carbon, sulfate, aerosols and dust, it started this initial impact winter and global darkening that reduced the photosynthesis. So, this started happening within a few hours of this impact and continued for over a few months.

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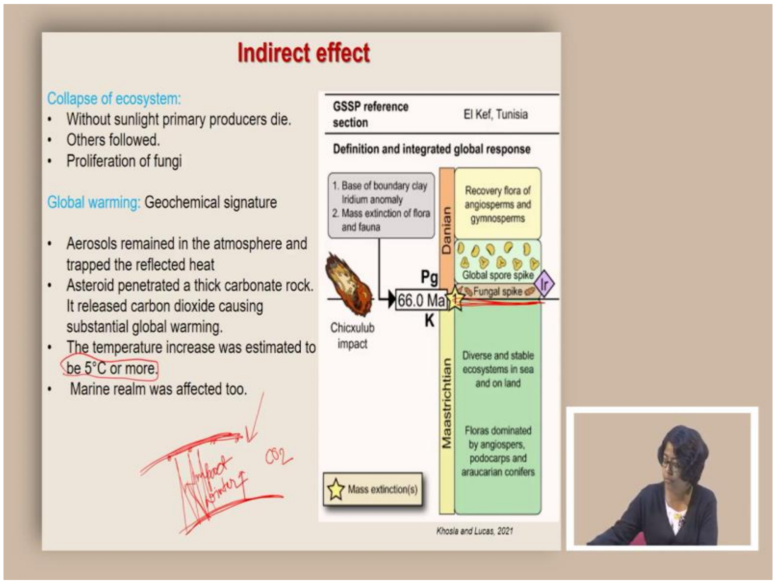

Indirect effects are a more long-term effect. So, direct effects, we understood what happened in a few hours to a few months, but indirect effects lasted for millions of years. And the first one was the collapse of the ecosystem. So, we already understood that without the sunlight, the primary producers die. If the primary producers die, the consumers who rely on them, who eat them, they also start to die. Once they die, the predator, carnivores who eat these consumers, they also start to die.

So, the sunlight pretty much supplies the energy of our trophic system, of our ecosystem. And if you block the sunlight, then the entire trophic system collapses. In fact, there are some arguments which says that the relatively smaller organisms, which do not require a large amount of food, they may have survived. But especially the large groups such as big dinosaurs, they needed a large amount of food and the collapse of the ecosystem really impacted them badly and they started to die.

And this is also the time when, because the primary production went down and things started to die, we see proliferation of fungi. So, during this boundary, we started looking at the pollens and there is a fungal spike spores, which indicate that there was a lot of fungi growth. And the fungi live best in damp environment, they do not require sunlight, they actually require only the rotting biological organisms. So, they started growing on them and that also supports this idea of the ecosystem failure at that point of time, due to lack of sunlight.

Although, at the initial part there was this blockage of sunlight and therefore impact related winter where the temperature decreased. It finally reversed within a few years because there was a global warming. And the reason is that these aerosols which were blocking the sunlight, they were also trapping the reflected heat. So, when the sunlight comes, it heats up the surface. And then the surface radiates the heat and it basically goes away.

But if it is blocked by these aerosols, which are trapping the heat, this heat basically starts to warm up that atmosphere between these areas. So, there is no way of relieving these radiated heat. More importantly, this asteroid impacted a thick layer of the carbonate rock, and because of this impact and because of the burn, it also produced a substantial amount of carbon dioxide. So, if we compare it with today's world and what is happening around us, we also know that the carbon dioxide level is increasing.

And because of this increased carbon dioxide level, which is a greenhouse gas, it also traps heat. And once it starts to trap heat, it also increases the global temperature. And that is what happened because of the impact. So, some estimates say that the temperature increase was around 5 degree centigrade or more, which is a really large increase. And it was not only impacting the atmosphere, it was also impacting the land, as well as the ocean.

Because the atmosphere also speaks with the ocean circulation. If the atmosphere is impacted, the ocean circulation is also impacted, and that is what happened with the increasing temperature which impacted the global circulation. And therefore, many of the groups which were living in the ocean, they started to die.

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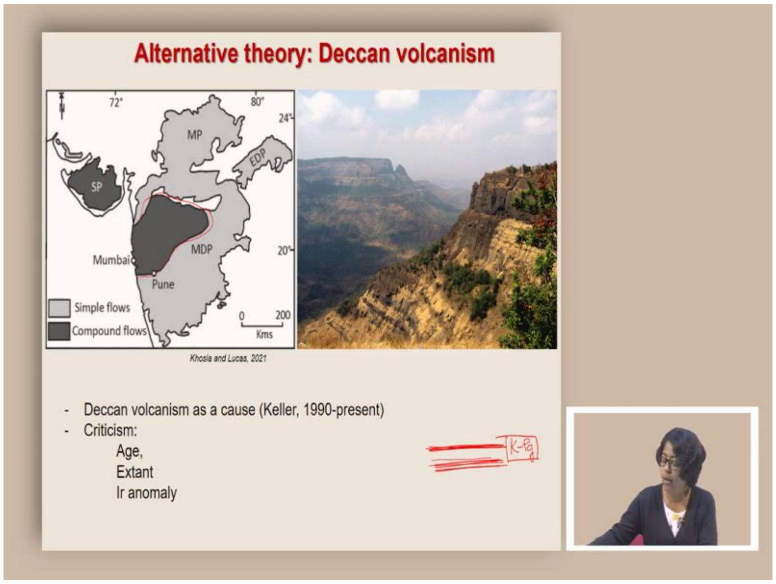

Now, apart from the impact hypothesis, there is another hypothesis, which is Deccan volcanism where they argue that Deccan volcanism also contributed significantly in this K-Pg boundary. Gerta Keller proposed this idea, and has been showing lot of evidences of how the Deccan volcanism impacted the K-Pg boundary mass extinction. So, the argument is that during this K-Pg boundary, even before that, there was a volcanism, a massive volcanism, which covered part of India. And this volcanism also emitted lot of gases.

These gases can lead to global warming and eventually create mass extinction. So, some of the arguments against that include the age. So, the Deccan volcanism, as it turns out, is slightly older than exact K-Pg boundary. So, it appears somewhere below K-Pg boundary, it happened all the way in the Cretaceous. And therefore, how it can impact the K-Pg boundary extinction at that specific age is remains unclear. Whether the extent to which we find the Deccan volcanism, volcanics today in India was enough to create a global warming is also a debatable point.

The last point is, these volcanic events are difficult to relate to the global iridium anomaly that has been found with K-Pg boundary. And therefore, today's understanding supports this idea that there was an impact hypothesis, and there are enough supports for the impact hypothesis. So, there was an impact by the asteroids, but this asteroid impact caused the extinction of the organisms, which were already somewhat strained by some of these volcanic events which were happening before. So, it combines the effect of both Deccan volcanism, as well as the impact hypothesis to explain how the K-Pg mass extinction took place.

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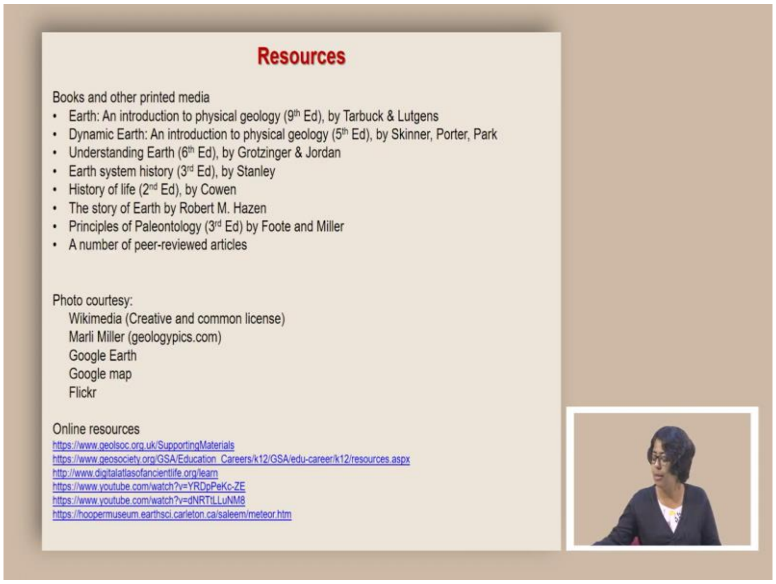

In summary, today, we learned about the different hypothesis of K-Pg mass extinction, how it could have been caused and what were the progression of different events. We also learned about one of the direct evidences of impact in the form of a crater, which was discovered in Yucatán Peninsula. It was marine crater, so the asteroid impacted the marine rocks and sediments. Eventually leading to some of the direct effects such as forest fire, soot, increase in the sulfur dioxide concentration in the atmosphere, and eventually sulfur rain, acid rain.

It also led to a drop in the sunlight penetration because of the aerosol and dust in the atmosphere. And that led to the death of the primary producers. For a long-term effect or indirect effect, these kind of collapse of primary producers led to the development of fungi and overall collapse of the entire ecosystem, which probably led to the death of organisms.

This impact also led to global warming on a larger time scale after this very short impact winter. The reason for such global warming is related to the fact that the impact hit rocks, which are carbonates, which with the chemical composition releases carbon dioxide, a greenhouse gas. Finally, we also learned about Deccan volcanism and how that could have contributed to the mass extinction of K-Pg boundary. Here are some of the resources that I used for the slides.

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And here is a question for you to think about. Thank you.