The evolution of the Earth and life
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Lecture 52
Mass Extinctions and Their Impact

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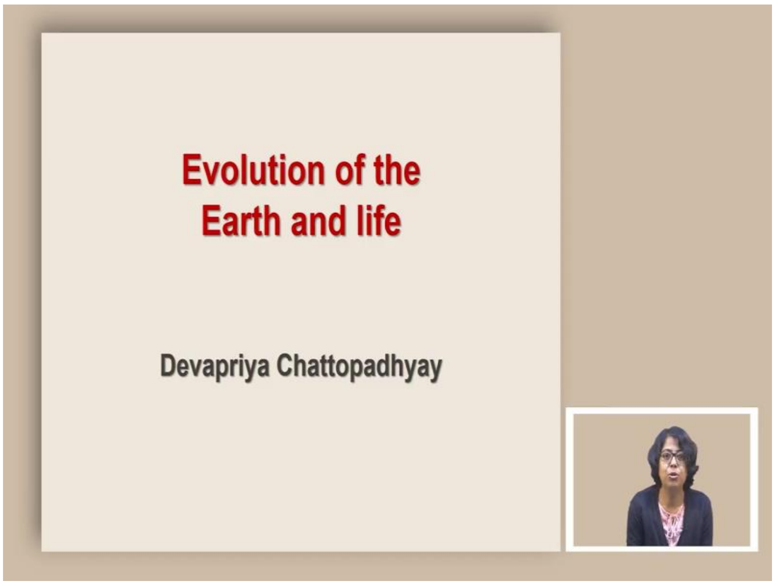

Welcome to the course Evolution of the Earth and Life. Today we are going to learn about extinctions.

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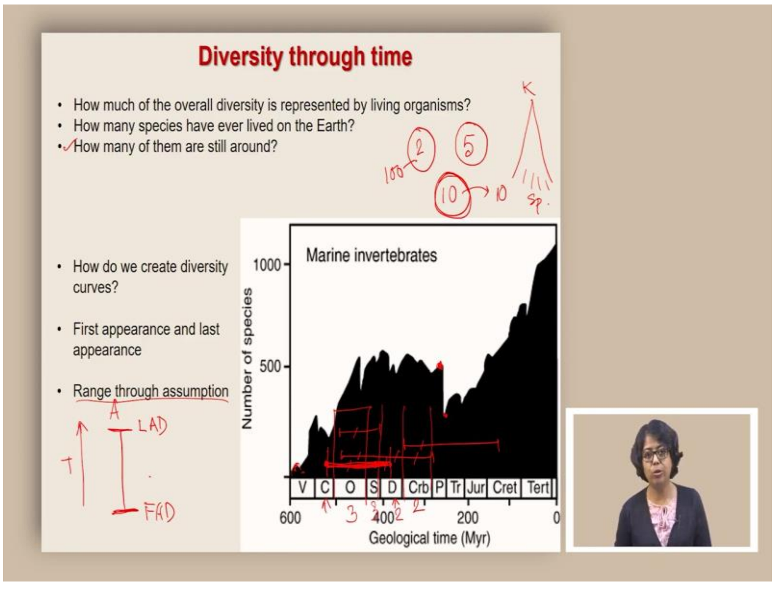

So, let us first try to understand how organisms evolved over time in terms of their number. And that is roughly what we mean by diversity? Diversity means how many different types of organisms are there at a particular time, and how it changes over time is of interest to a number of paleontological questions. So, one way of looking at it is, if you have three places with different number of species, then you can call it species with different diversity.

So, let us take an example. Let us say that we have an area where we have two different species, this one has 5 different species, and this one has 10 different species. In this case, we are going to call this area the most diverse because it has higher number of species. It is important to remember that we are not really talking about the number of individuals, it does not really matter if this particular place has 100 individuals, but only have these two species. It does not matter if this one has only 10 individuals, but each individual represent a different species.

When we are calculating diversity, we are interested not in the number of individuals, but we are interested in the number of species, or genus or family, or any of these groups that are being represented. It is also important because when we think about fossils, or when we are trying to understand the change in community, in the history of the Earth, just observing number of individuals is not really a good idea. Because the number of individuals can change very abruptly, depending on the preservation.

On the other hand, because one species is often represented more than one individual. Counting, at least at the level of species is much more robust when we try to understand how different things were. And that is why people have been studying species diversity. There are times when people can study even at higher taxonomic level, what that means is, species is a part of genus, one genus can have multiple species.

Now, multiple genera can make up one family. So, there is a hierarchy setup, where it can start with the kingdom and then towards the very base of it, you have species. Now, we are going to try to understand how the number of species changed over time. And for that, we need to understand what were the different species at a particular time. And that is once we know that we can create something called a diversity curve. And this is one of the examples of diversity curve.

Now, let us try to again understand how a diversity curve can be made. So, first thing that we have to understand is when we are thinking about a particular species, in the geologic record, there would be one point of time when the species appears, and then there would be another point of time where the species disappear. The species may even continue till today in that case, it has never disappeared. But in a normal case, many of the species appear and then after a point of time it disappear.

Now, when an individual dies, we call it we call that event as death. When a species disappear we call that event, an extinction. And we will come back to it in a more broad definition, what is the definition of extinction? So, why do we consider that this is complete disappearance for that you need to have data from all over the globe to ensure that the species really disappeared from all over the globe. And it is not simply absent in one particular spot.

So, if we compile all the data and eventually look at the range of the species, that means how long it survived, it will give us these kind of patterns. If I draw a plot, where this is the time so with time, the species appeared at a particular time, and then it disappeared at a particular time. And it is present throughout and this one is called the first appearance, datum or this is the point at which the species appeared first.

And this is the point where the species disappeared, and therefore last appearance, datum or LED. Now, because we are talking about time, it does not have to happen that in the fossil record, we are getting all the specimens of this particular species A throughout the time, what do I mean by that? Let us now take an real example.

Let us say we are starting from Cambrian this is this time, and we are looking at Devonian this is this time. And we are looking at a species, which if we go through all the rock record, then we will find the species A to be present here. Then for some reason, we do not find them in Ordovician, but we find them in Silurian and then also in Devonian, but we do not find them beyond this. So, how would we interpret this data? And how would we put these definitions such as FAD and LAD.

Now, because we it is a global compilation, and we have looked at all the record of fossils, the first time we are encountering this particular species is in Cambrian and therefore, we are going to call this as the FAD of species A, because beyond Devonian we are not finding it. So, we are going to define Devonian as that LAD of this particular species. Now the point is, we said only about Silurian where we are finding this species. What about Ordovician? Was the species there? Now there is a question which is which we have to answer from more from a point of view of biology.

So, if the species disappeared here and again reappeared, that means all the individuals of this species died after Cambrian and then somehow appeared again in Silurian. What are the chances of this phenomena happening? So, if you actually calculate the chances, it would be similar to finding same genetic code for two completely unrelated people. So, let us say completely unrelated means they are not identical twins. Completely unrelated people, showing you the same genetic makeup is very, very improbable. It never says that it is the chances are 0, but it is the number is so low, it is close to 0.

Similarly, the chances of a species disappearing, that means all the individuals of that species dying. And then again, after some time, the same species appearing with the same genetic makeup is very, very low, the probability of it is very, very low. It is so low, it can be approximated to 0. And hence, we assume that the species must have been there. It is just not preserved. It is just not sampled. And this assumption is called a range through assumption.

And therefore, what we do whenever we get this FAD and LAD of a species, we extended throughout saying that we really do not have to find the record of this species presence in all the time bins in between, as long as they are present here. And as long as they are present here, we assume that they are present throughout this time, even though we are not finding their fossil record.

Now once we do that, it also gives us very good estimation of how many species were there. So, what we do, we go through all literature, we go through all fossil occurrences, and try to compile all kinds of range through plots, or all kinds of ranges of species. Now, if you plotted all kinds of ranges, then at a given point of time, let us say in Ordovician, you can calculate how many species were there. So, in this case, let us say you calculate there is one here, there is one here and there is one here. So, that means, there are 3 species here. So, four Ordovician, you can write three.

Now, let us say we are coming to Silurian. In Silurian also, we are counting 1, 2, and 3. So, here also you are counting 3, let us say we come to Devonian, we are finding only 1 and 2. So, we are writing 2. Here in carboniferous, we are counting 1 and 2. So, we are writing 2. So, if I keep on doing it, it will give me numbers for each time bin. And then we can plot those numbers and connect the dots. And that will give us this diversity curve through time. So, there are different ways of plotting diversity curve. But this is the basic structure of any diversity curve.

So, then what do we learn from diversity curves, diversity curves, tell us how abundant the species were at a given point of time. So, now if I look at this particular plot, it is going to tell me that it is kind of increasing here, then it is dropping here. So, the number of species here was higher than the number of species here or in other words, if I consider the number of species here, this is higher than the number of species here. So, it gives you a temporal pattern of how species have changed over time.

This can also be used to calculate how many, I mean, what is the number of all species that have ever lived on the earth? And we are going to see how we can do that, if we can do that. And if you can also answer this question that how many of those species are still around, then, by subtracting it, it will tell us how many of the total species are not there. So, we are going to do this exercise.

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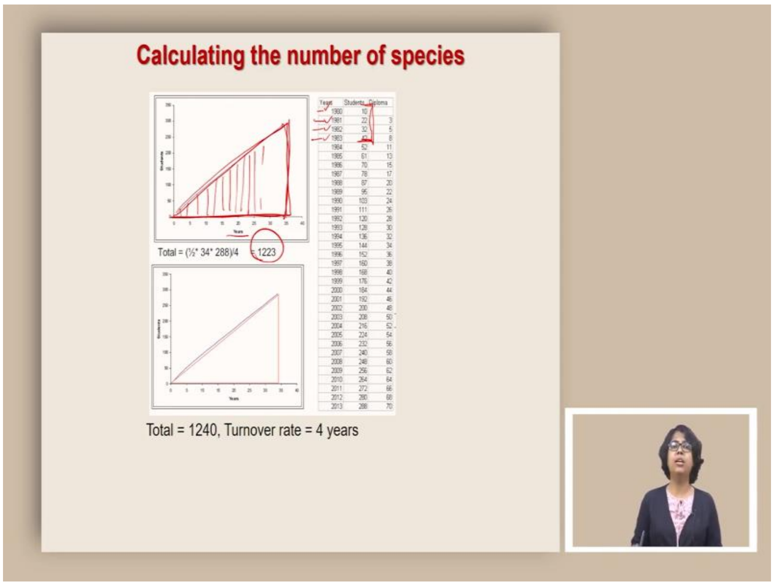

So, let us take an example of a college. And in this case, the college has a 4-year program, where every year there are some students who are coming to the college and after 4 years, they are basically getting a diploma and they are leaving. Now, if you ask this question that over 35 years, how many students have ever gone into this college? How do we answer this question?

Well, one way of answering this question is you basically look at the number of students and getting diploma and then you are basically calculate the total number of students, but please remember, when we are calculating for each of these years, you are also calculating the same student couple of times, because let us say we are looking at some students entering a 1980. They are going to be in their first year, in 1980, second year in 1981, third year in 1982 and fourth year in 1983.

So, if you are counting these four numbers, you are basically counting the same student multiple times, and therefore that would not be a good idea. And hence, it has to be normalized somehow. What I mean by that, you have to account for the number of students whom you counted multiple times in this case, four times. There is another way of looking at this problem and sort of approximating how many students were there during this entire time. And how do we do that?

So, what we can do? We can basically plot the number of students versus year. And if we plot that it, we are going to get this kind of a line, which basically shows that it is kind of increasing. And then how many students ever entered into college, if you were counting them only once would be the area under the curve. And how do we calculate this area under the curve, because it is a simple triangle shaped thing, we can approximate it in terms of the area under the curve as half of the base times the height.

But please remember that we are counting the same student multiple times, in this case, at least four times, because we are assuming that majority of the students are staying in the college for 4 years. And therefore, we are basically counting them 4 times the same students, we are counting 4 times. So, whatever is the total number that you are getting, by calculating the area under the curve has to be divided by 4 to get the real number.

And this is the real number of the total number of students who ever entered this college between these years. This comes very close to the actual calculation if you do that. And this becomes very handy when we are trying to estimate something like the diversity curve, and when we are trying to estimate that how many species have ever lived on the earth.

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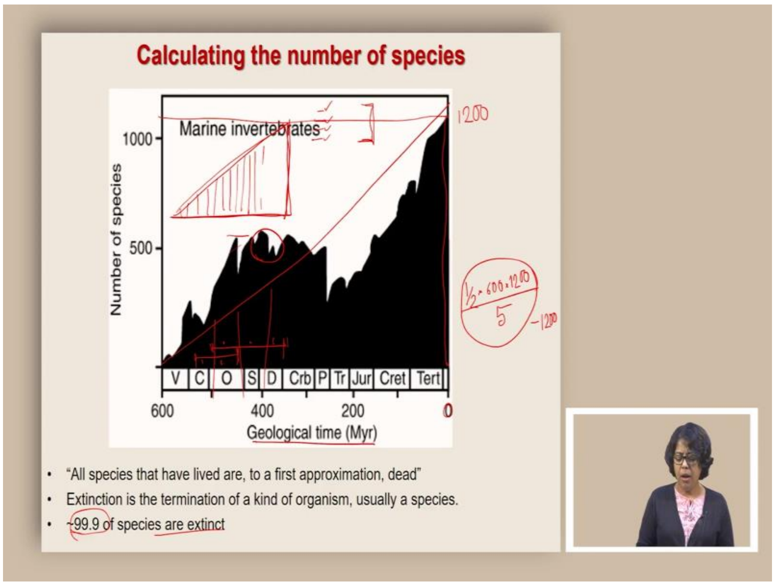

So, let us try to do that. So, what I am going to do is I am going to use the same technique. So, if you look at the diversity curve, we have the geologic time in this axis, we also have the number of species on the other axis. Now, does it look like a triangle? Well, in a crude approximation, it looks like a triangle. Why am I saying that? Because if you actually try to make a triangle, there are some gaps which are not filled up, but then there is an excess here. And again, on a very, very crude approximation, it will, if you adjust this, it will look like a triangle.

And can we have a very rough estimate of how many species ever lived on the earth? So, what do we need? We need this base, and we also need this height. Now, if I look at it, this is the modern time. And if I extend this line, it will come around, let us say 1200 roughly. And please remember, we are not talking about all species. At this point, we are just trying to estimate the width the graph where it is only marine invertebrates. And the reason we choose the species of marine invertebrates is because they get preserved very well in the fossil.

But you can also do that for other groups separately, because each one of them will have slightly different preservation. But even if I look at marine invertebrates, let us try to take a look at the number that what percentage of the total number of species that have ever lived on the earth actually survives today. So, we are going to use the same mechanism that we are going to take half of the base, and the bass becomes in this case 600 million years. And we are also going to look at the height. In this case, the height we are taking as 1200.

But if you look at the unit is half is an unit less number, 600 is actually billion years, and this does not have any unit. So, the total number of species is sort of coming up in a million-year unit, which is not the ideal thing. And now we also have to adjust the fact that there are multiple species which we have counted over different time bins, and the same species was counted. Let us say in this case, twice, in this case, three times and so on and so forth. So, we have to adjust for that.

One way of adjusting is to get a sense of what is their average duration. So, you look at this one, let us say this survived for 15 million years, this one survived for, let us say, 10 million years. And you add those up and divided by the number of species, that gives you the average duration of our species that lived. And if you do that, for marine invertebrates, this number can vary. But it would be somewhere near 5 billion years, let us say. And that means we are dividing it with 5 million years. And so basically, this has a million on top and this has a million at the bottom. So, unit wise, it is also balanced.

So, now the product of this entire calculation will come as an unitless number, which is going to tell you what is the total number of species. Now, if you look at this number, this number will give you some number, but I am not going to calculate it right now. But what I am going to do is to ask you, what do you think is the percentage of the present-day number of species, and what you are going to find is, it is actually very tiny, it is only this much.

So, only if you have to calculate how much of this is gone, you basically have to take this number and subtract the present-day number. And that gives you what is the total number of species that lived on the face of the earth, but now are no longer there. And if you actually do this calculation, what you will come up is an astonishing number. And what you are going to find is 99 percent of all species that have ever lived on the earth actually are no longer there. The number 1200 for marine invertebrates is really a small number.

Now, obviously this is you can do that for other groups, but even if you do for it for other groups, and consider the groups where at least there is some fossil record, this number, this percentage number tends to be quite robust. So, it does not change much, which tells us extinction or disappearance of species is more of a rule than an exception.

And therefore, a general statement that is made by famous paleontologists is all species that have lived are to a first approximation then and therefore, it also tells us something about the importance of studying diversity, patterns of change over time, because they are important in order to understand how species will behave in long term.

So, now, we are going to define the extinction. So, extinction is the termination of a kind of organism, particularly species. Now, what do we mean by that, it means, if you take a species, when all the individuals of that species disappear, then we are going to call the species extinct. And based on that, we can have different types of extinction which we are going to see soon. Now, it also tells us that the present day diversity is only a fraction of the number total number of species that have ever lived on the earth.

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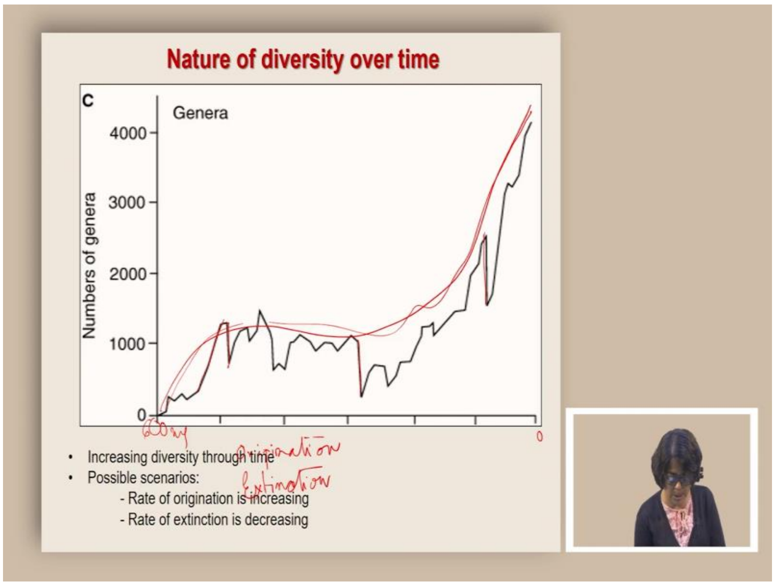

Now, we are going to look at the pattern of diversity over time and this is we are looking at general because sometimes it is difficult to identify species. Genera is relatively easier to identify, but there are other reasons too. So, again, we are looking at the overall pattern. If you are considering other groups, what you are going to find is there are different kinds of patterns in terms of how species are changing, how Genera changing over time.

So, let us take a look at how it changes. So, we are going to see that there are increases for example, this increased in number so, that means the total number of different types has increased, but then there are sharp drops. Here also there is a drop, here also there is a drop. These drops basically mean for some reason the total number of species or Genera are disappearing, because that is the only way you can have these kinds of drops and they can indicate things like extinction.

So, now, we are going to try to understand what creates this kind of pattern? So, first thing that we have to understand is, we are overall seeing an increase. So, if we start from time 0 and sorry time 600 million years and if we come to the present day, here, we are basically seeing the total number is fluctuating, but at the end, it is increasing.

Now, the question is, why is it increasing? So, there can be two possibilities, because this diversity at the end is controlled by two factors, one is origination. The other one, as I said is extinction. Now, what is origination? Let us compare it with a population that we see every day, let us say human population, so, origination is similar to the birth. So, origination of a species is similar to birth of an individual. So, more is the birth rate, it can increase the size of the population.

So, similarly more the origination rate, the total diversity can increase. Another point, which is similar to the death rate of a population is the extinction. So, if the extinction rate is changing, extinction rate is decreasing, then the population or the number of species or number of Genera can also increase.

Now, the question is, which one is guiding that? So, let us try to understand we have seen an increase in diversity, the overall diversity. So, it can happen either that the origination rate has increased over time and there are more new things that you are adding to the diversity and therefore, the diversity is increasing, when the extinction rate is constant.

The other possibility is that the origination is not changing much, but the extinction rate is dropping down. And therefore, you are keeping more species over time and they are not really going extinct. So, there are some clear predictions that we made. And we are going to check each of these factors. So, the first factor we are going to check is the origination rate.

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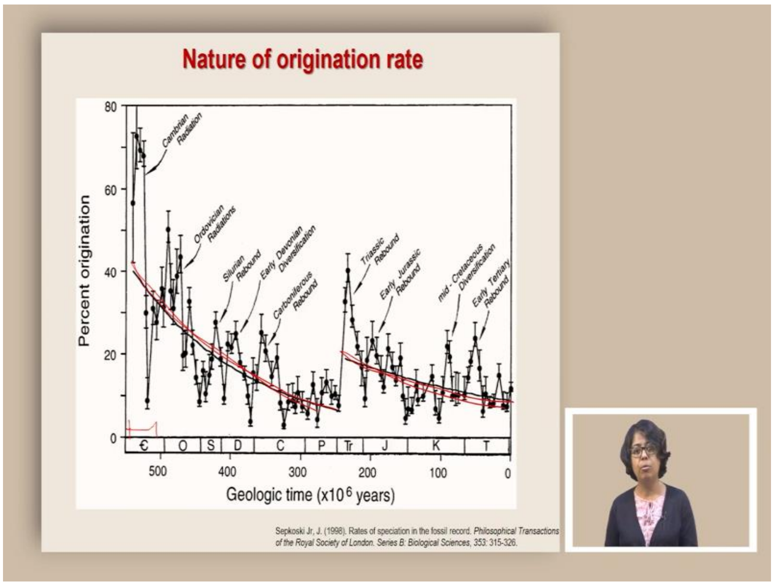

Now, the rate of origination is again calculated based on a specific time period. And in that time period, how many species are originating, and then you can compare it with the percent origination and that will give you some numbers. Now, without going into the detail of this plot, what you can see is if we have to fit these changes, without more of a average pattern, it shows these kinds of lines, which shows in fact, over time, the origination rate the percent origination is decreasing over time.

So, our prediction that the overall diversity increases, maybe because the origination rate increased over time cannot be true, because we can see from the observation that the origination the appearance of new groups, it could be species, it could be family, it could be genus, they are actually decreasing over time.

So, the only remaining possibility is that extinction rate is also decreasing over time, and it is actually decreasing faster or more than the origination rate and therefore, every time you are not adding new things, but you are not removing things from the pool fast enough or not removing it all and therefore the total population actually increases.

To give you an analogy from a population level, it means that the birth rate is not increasing. It is actually decreasing over time, but the population or any individual in that population is living longer, they are not dying and they are on an average they are living longer. As a result, the total number of population, total number of individuals in the population is growing.

Now, let us look at whether this is true because we are predicting that the diversity in order to have this increasing diversity extinction rate must be going down with time. And we are going to see that by plotting the rate of extinction, that means, how many groups are disappearing at a given point of time. And we are going to see whether it is changing.

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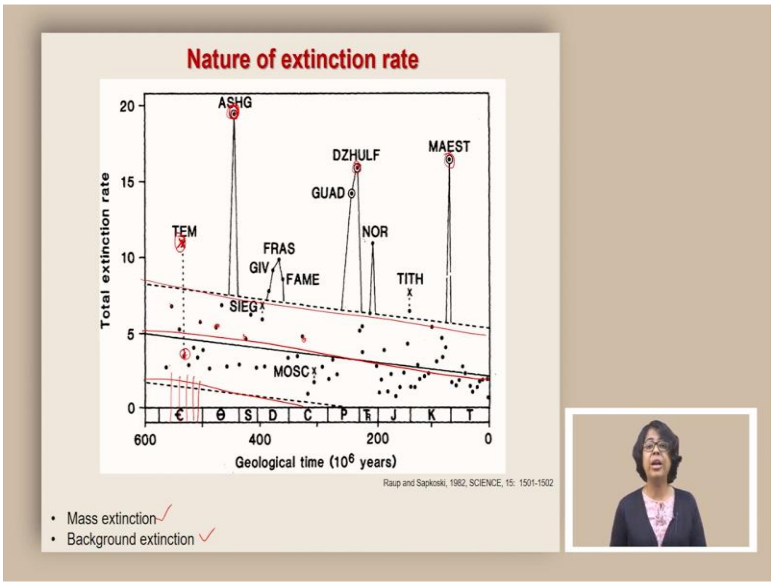

So, when we do that, we find these kinds of patterns. So, let us first explain what these patterns means. The dots that you see all these dots, and these dots, and these dots, all these black dots basically mean, it is an calculated rate for any disappearance at a particular time. So, you can have these kind of time and you smaller bins, and within those bins, within those time periods, you can calculate what is the rate of extinction. Then there are some points which are shown as cross, which basically means, it can be either this rate or this high rate. And this difference is because of the preservation.

So, there are some areas where the preservation is extremely good, but it does not cover the global area. So, if you consider those local very well-preserved things, then you can get a very high rate. However, if you do not take them as because they are not globally spread, you are only taking the global record, then you are going to find things which are showing loaded, then there is some points which are marked with a double circle. And these double circles basically mean that they are somehow very, very different from all these dots that are shown.

And now, if we look at the rate without the rate of extinction is changing, we find a very interesting pattern, what we find is, if you look at these dots are the bottom, so low rates at the bottom, it is kind of showing a trend which is declining over time. This is the black line, it is an average rate based on these points.

But then there are events, which are very, very high rate. So, we are talking about something like around 15 to 20 groups disappearing. These groups can be at the family level, then it becomes very difficult to explain because we still see things like this one, which one is showing close to 15 families disappearing over 1 million years, which is very high.

So, then, there are two explanation of this plot. One explanation is if you only concentrate on the low rate, then yes, the extinction rate is declining. And probably it can explain some of these increase in diversity. But then there are events which are extremely high rates, and those rates are not declining over time. However, they are not very regular. They appear once in a while. But they wipe out a very large number of groups at the same point of time. And this is one of the ways of differentiating two different types of extinction.

The extinctions which are happening very regularly with a lower rate, and you can have an envelope around it, showing that this is the part where all the low rate falls and it is showing a declining trend. These are called background extinction. It keeps on happening on the groups, over time, again and again. But it never reaches a very high level.

Probably we are talking about less than 10 families or less than 5 families even going extinct per million year. But then there are things that are events, which are wiping out large number of groups at a very short time. Those are called mass extinction. And these mass extinctions are not declining over time, their rates are not declining over time, their rates are quite distinct, and there is no trend to it.

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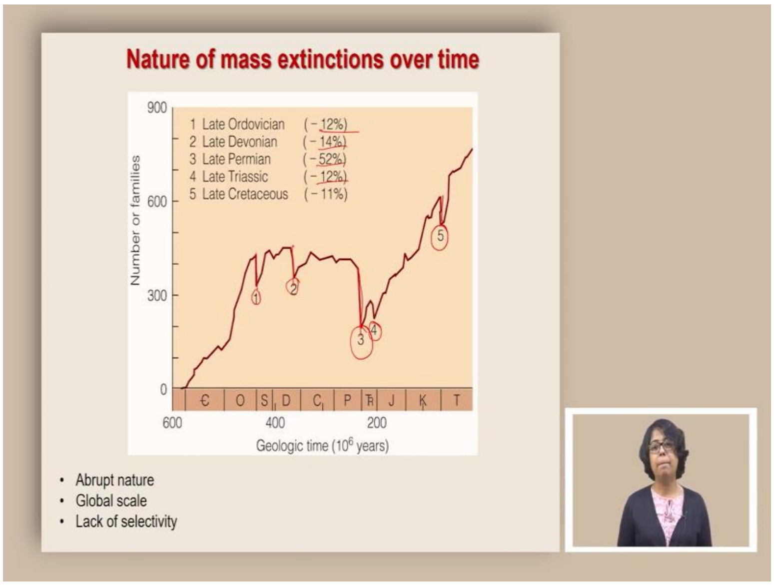

And these mass extinctions are very well documented in the diversity curve. So, there are 5 major mass extinctions over the whole geologic time. The first one is late Ordovician, which killed 12 percent of the number of families and 12 percent of the existing families at that point of time. The second one is Devonian, which killed 14 percent of the existing families. The third one is late Permian, which is this big drop. This is the biggest of the mass extinction, which killed 52 percent of the existing life at that point of time at the family level.

Then we have late Triassic mass extinction, which killed 12 percent of it. And then we have late Cretaceous mass extinction, again, a big drop, which killed 11 percent of the families that were surviving at that point of time. So, overall, mass extinctions tell us that these are events, which is caused by abrupt nature, abrupt change. And therefore, we do not really see any kind of change, gradual change before that.

Even the families, which survived for very long time, or even the families which has multiple species in them, many of them went extinct, right at the mass extinction level. So, they have this tendency, which do not show any selectivity. It is not only the groups, which are, let us say, small or large, which goes extinct, it affects everyone. And finally, what is a very interesting nature of mass extinction, that it is a global event. Globally, all groups get affected by these mass extinctions.

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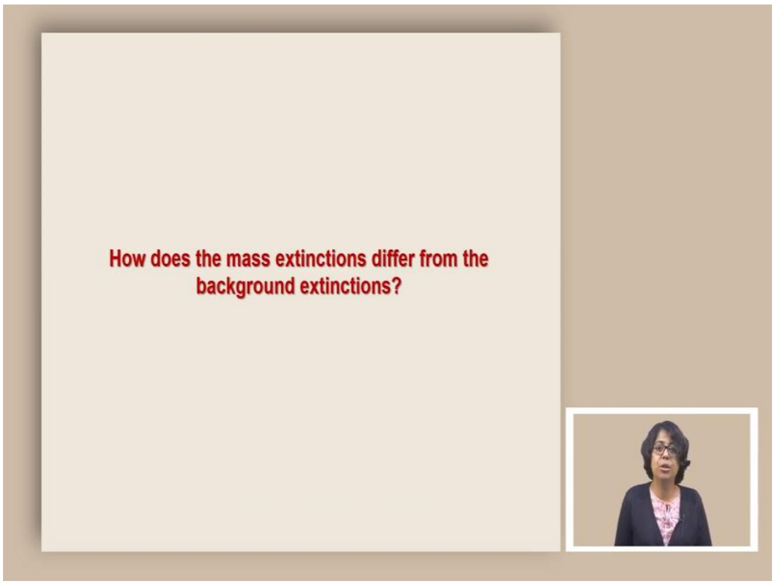

So, in summary, today we learned what is extinction and why extinctions are more then we think in the geologic record. We also learned how to calculate the total number of species that have ever live don the earth and what percentage of it are extinct. We learned that there are differences in the rates of extinction and these rates of extinctions can help us to define completely different extinction mechanisms.

One is a background extinction which goes on at a regular interval with a low rate and then there are mass extinctions and there are five major recorded mass extinctions in the geologic history. Here are some of the resources that I have used for this lecture and here is a question for you to think. Thank you.