Evolution of the Earth and Life
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Proterozoic events and life

Welcome to the course Evolution of the Earth and Life. Today we are going to talk about some events that took place during Proterozoic.

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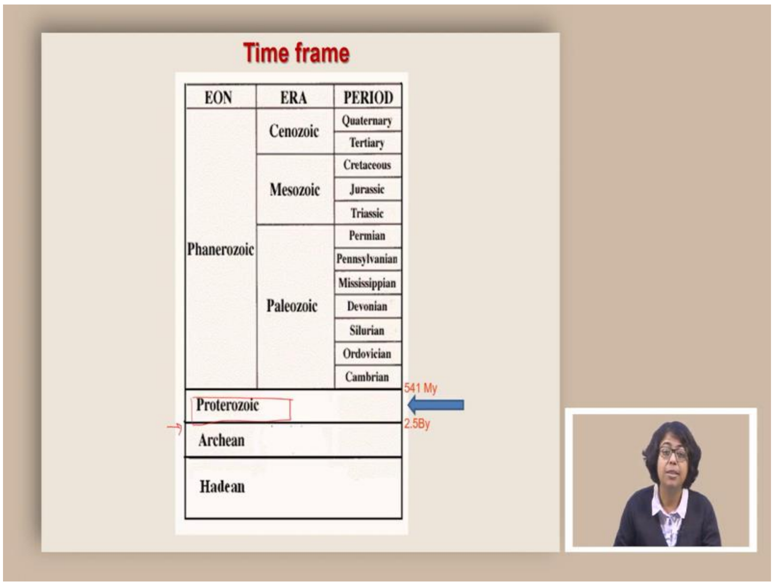

So, the timeframe that we will be looking at would be primarily concentrated around Proterozoic. This is an Aeon, and it spans between 2.5 billion years to 541 million years. And one of the major events that makes it different from Archean is the appearance of unmetamorphosed pristine sedimentary rocks.

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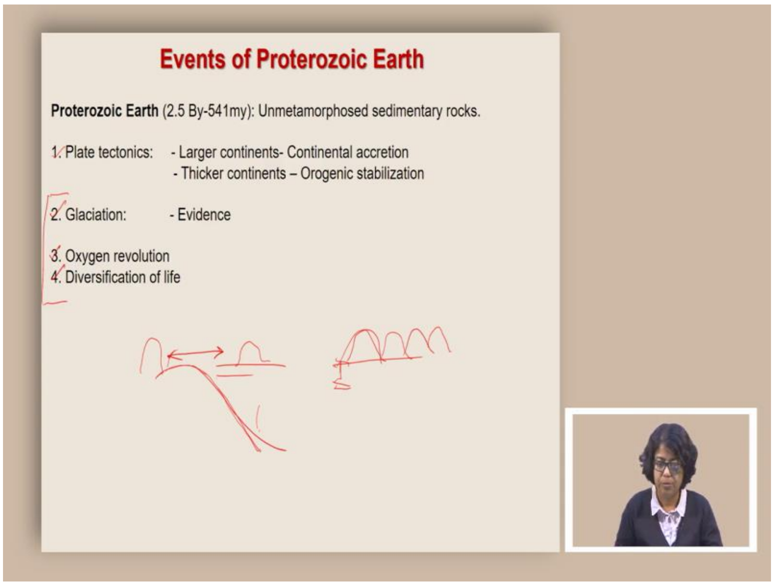

So, the events that took place during the Proterozoic Earth includes a variety of changes. And we are going to talk about a few of them, including the oxygen revolution, diversification of life, glaciation, and a bit of plate tectonics. So, unlike the Archean time, during Proterozoic, we started finding relatively larger continents, which were formed due to continental accretion. This is a process by which the continents grow.

So, if you think about a subduction zone, and part of it is basically going down and melting, and then creating an island arc somewhere here, this island arc will have a continental composition. But imagine a scenario where the entire plate is abducted, and there is another continent already in the side, this space when it gets reduced, eventually, these two spots are going to be next to each other.

And this is one of the ways that continents grow in size in their surface area. And if you continue to do this, you can actually end up having a large continent, the different strips, which formed at different times, and this has been happening for quite some time, we started finding real good evidence of large continents during Proterozoic.

The second point is during Proterozoic, we also started to see really thick continents. And this happens through continental collision where two continental plates are colliding with each other and making the overall thickness of the plates much larger. Now, the other things that were happening requires a much more detailed look in the Proterozoic rock record.

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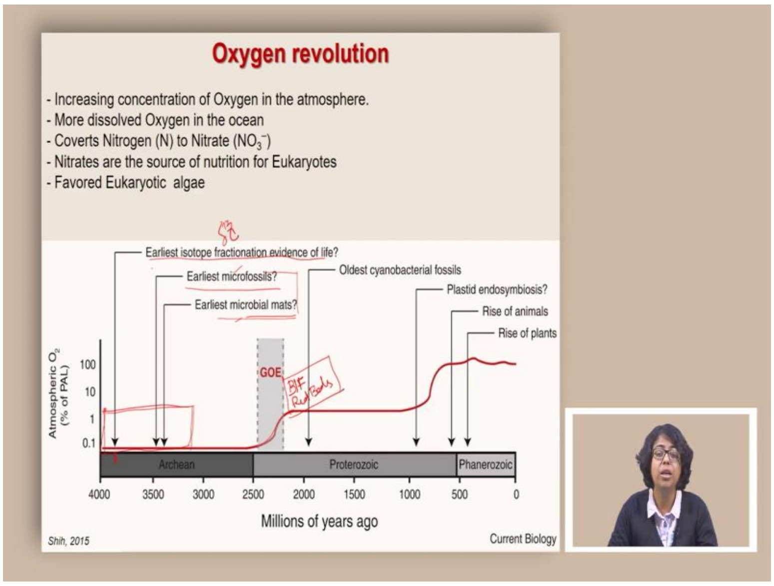

One major change that happened during Proterozoic is the change in oxygen concentration. So, if we look at the Archean oxygen concentration, it was pretty low in comparison to Proterozoic. And this initial increase of oxygen in the atmosphere is called GOE or Global Oxygenation Event. This GOE is a major event and it also had repercussion on other groups. So, again, just to remind ourselves, we have earliest isotope fractionation, which can be taken as an evidence of life, which comes from the carbon isotope right around this time. So, which is well within Archean and we are talking about 3.6 billion years ago.

Then we also have earliest microfossils. These are bacterial fragments. So,me of them have looked like bacteria, some of them looked like segmented parts of bacteria. These come around 3.5. And around the same time, we also started binding stromatolites and bacterial mats. So, all of these were happening right before the increase in oxygen concentration in the atmosphere.

Now we look at the Proterozoic and we see an increase in oxygen concentration. And the proof that the oxygen concentration actually changed after Archean comes in the form of BIF. Because that iron deposition could not have happened if the oxygen concentration did not increase, it comes in the form of red beds. So, which is again a form of rusted material, which has been there in a reducing condition, and many other forms.

So, all of these indicate that there was a sudden increase in oxygen right around the Archean Proterozoic boundary. And it was not only limited in the water, it was also in the atmosphere, and more dissolved oxygen in the ocean. So, once you have increasing the oxygen concentration in the atmosphere, it will also go into the ocean, and it is going to increase the concentration of oxygen in the ocean. Now, if we have that, apart from developing BIF and red beds, it is also going to convert nitrogen to nitrate.

And this nitrate is one of the major source of nutrition for different kinds of cells, and different kinds of organisms. So, so far, the organisms that we are talking about, be it the microfossils, be it microbial mats, these are primarily prokaryotic cell. On the other hand, if we look at the world today, we see that it is primarily that eukaryotic groups which dominate. And this eukaryotic groups are very good in using nitrate as a nutritional source.

And if the oxygen increases in an oxygenated environment, what we see today is a dominance of eukaryotes. So, if there is an increase in oxygen, probably, it is also going to favour the development of eukaryotes or groups, which are eukaryotic in nature.

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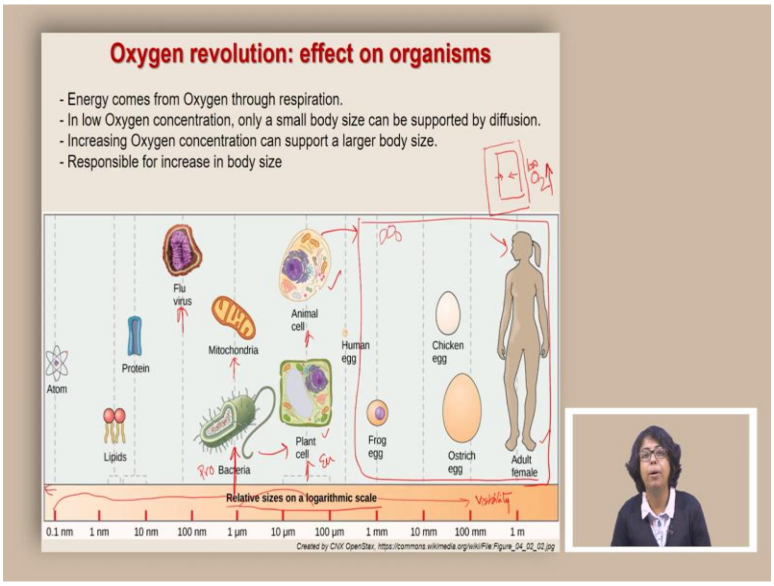

Now, oxygen is an important component of that most sphere today. And in the past, especially in Archean, and it was not there. And therefore, the organisms that were in Archean were not really able to process oxygen, because they were primarily living in a very low oxygen concentration. Now, in low oxygen concentration, only a small body size can be supported, because it basically gets supported through diffusion.

So, now, if you look at a cell size, and there is a low concentration of oxygen, there is only up to certain depth of that cell, the oxygen can penetrate. Now, if the oxygen amount increases or the concentration increases, this can penetrate even more. And therefore, you can actually increase the size. And therefore, with higher oxygen concentration, you can basically produce larger cells and also larger body.

Now, increasing oxygen concentration can support a larger body size, and therefore, we can expect to see a larger body size. But the question is, do we really see a larger body size in terms of animals or do we see a change in the size of the cell? Let us take a look at what kind of different sizes do we expect to see in the modern biological world. And this is a scale which runs in logarithmic scale.

So, this is a relative size on a logarithmic scale, we cannot really see these bots without a microscope and basically as you go towards this side, your visibility increases, you can really see them without the aid of a microscope. But when we are in this end, it requires very sophisticated microscope to even see it. Let us take a look at what is there in this spectrum. So, very small things include atoms, lipids, protein, and then we come to something which is at the boundary of living and non-living, this is the virus.

But then when we come to look at the cells, we find an interesting pattern, we find the cell of a bacteria is of the similar size in order of magnitude, in comparison to some of the organelles of an eukaryotic cell. And that is interesting, because if you look at a prokaryotic cell, the prokaryotic cells are going to sit somewhere here. And when we look at the eukaryotic cell, they are much, much larger.

In fact, these eukaryotic cells are sitting somewhere here, this is a plant cell, this is an animal cell. And if you see the difference from a prokaryotic cell and an eukaryotic cell, you will see that the size is almost two orders of magnitude different. And this difference in size tells us something about how they formed. So, it is clear that even today, if we look at where we find prokaryotic cells, we will find, often they appear in places where the oxygen concentration is very low.

On the other hand, places where there is enough oxygen concentration, we primarily find eukaryotic cells, either single cell or a multi celled organisms such as ourselves. But the difference is from going from a single cell to this one actually requires assembly of different cells. And these cells need to be differentiated. So, they will serve different purpose, and so on and so forth. So, this is quite complex, going from a single cell to create this kind of a pattern. But we will come back to it a little bit later.

For now, our question is, we understand that at the beginning, the cells must have been very primitive, and by primitive we mean prokaryotic cell, then when did the eukaryotic cells appear? And how do we know about it?

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So, the eukaryotes are part of domain Eukarya. These are single or multicellular organisms with membrane bound nuclei and organelles. So, a big difference between prokaryotic cell and eukaryotic cell is they are membranes, and also the presence of organelles, and the nucleus. On an average, eukaryotic cells are much larger. And we find the oldest eukaryotes from somewhere around 2.1 billion years ago, which is well within Proterozoic.

And this has been found from a part of northern United States, a place called Michigan and this closely resemble an algal ribbon. And what algal ribbons are, if you look at the modern-day example, it will looks like a thin green thread of an algae. They are photosynthetic. And they are definitely eukaryotic. And we started to find evidence of these around 2.1 billion years ago.

So, we found the evidence of eukaryotes. Now, are these the first time the eukaryotes appeared? We really do not know. Because we cannot really look into the cell structure and identify it in the fossil record. Our only clue to identify whether something is eukaryote or prokaryote, is by looking at the size, because that is something which is visible in the fossil record. More importantly, when we look at the fossil record, it tells us about the size. And we know that only that eukaryotes can make large sized organisms.

So, when we find start finding large sized organisms and especially multicellular organism, that is a very solid proof that it is definitely eukaryotes. So, even though we cannot see the cellular structure, the body size itself is a good indicator of the eukaryotes. But this means even if there were eukaryotes before this, which were single celled, we may have missed it. But we are sure that by 2.1 billion years ago, eukaryotes were definitely there.

Now the question is, how did they appear? How the eukaryotes form? It is a very different complex cellular structure. How did they came about when we know that the initial form cells were prokaryotic in nature?

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So, one theory of how did the eukaryotes appear is endosymbiotic theory. It is one of the widely accepted ideas, which argues that the origin of eukaryotes are from the union or engulfing of two prokaryotes. And this was proposed by Lynn Margulies. And why would this idea appear? Because she put together a lot of evidences, which can only be explained if the endosymbiotic theory is true.

So, what endosymbiotic theory proposes, is, there was an initial prokaryotic and this prokaryotes started taking other prokaryotes, which were slightly more specialised through a process called engulfing. And eventually, these things became part of this new cell, which was an original prokaryotic cell. And it also grew in size, and these ones became the organelles. Remember that the organelles of any eukaryotic cell is pretty comparable in size with the prokaryotic cells themselves.

So, as evidence, she argued that if you compare the organelles, the organelles have double walled membranes. Cell membrane is only single walled and membranes are double during engulfing. So, that sort of supports the engulfing process. And that is why you have organic cells, which have one wall or one membrane, which was their original membrane, the other one, which is due to engulfing.

The second one is the argument from science that the prokaryotes are of the same size, comparable to the organelles. The third line of argument comes from the fact that organelles have similar metabolism to some of the prokaryotes. Especially if we look at mitochondria, which is an organelle, it has similar type of metabolism to some of the prokaryotes. The fourth point is from the fact that organelles have distinct non-nuclear DNA.

Mitochondria has its own DNA. And these organelles have similar genes for some of the prokaryotes. So, it is possible to actually link some of these organelles, or the DNA of some of these organelles to an existing prokaryotes, which is an completely different cell, and different organisms altogether. So, all of these support the idea of this endosymbiosis, which means that there was a prokaryotic cell at the beginning.

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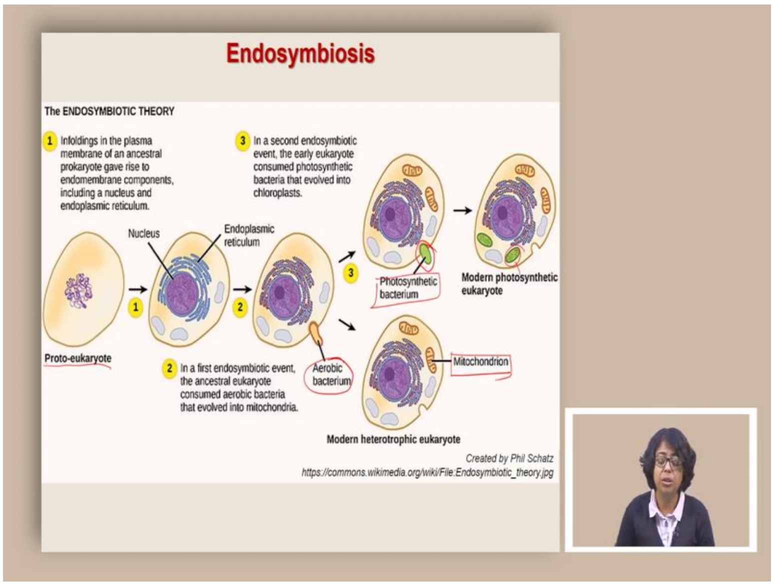

And we are going to call it a proto eukaryote because this is the one which eventually engulfed other existing prokaryotes. So, these existing prokaryotes could be in the form of an aerobic bacterium, which eventually got engulfed and became a mitochondria. It could be things like photosynthetic bacterium, which eventually got engulfed and became chloroplast. And these are some of the ways of looking at the specimens that we have today, which are living cells and connecting it to their evolutionary history.

So, clearly, chloroplasts and mitochondria, both of these organelles support the idea of this endosymbiosis. And probably this is the way the prokaryotes also contributed to the development of eukaryotes. Once the eukaryotes were formed, then they will have a major selective advantage because they can process oxygen much better.

And once they start to have photosynthesis through this engulfing, they will also produce their food, and that keeps them free to spread their range in different environments, because they are no longer restricted to only a specific environment, such as methanogens, or other chemosymbiots, which were only living in specific environmental condition.

So, the advantage of having a very strong metabolic pathway, as well as development of their own food, and increasing size, all helped that eukaryotes to get selected more and dominate the ecosystem. So, we see a switch from prokaryotes dominated ecosystem to a eukaryote dominated ecosystem, right around the time when the oxygen started to increase.

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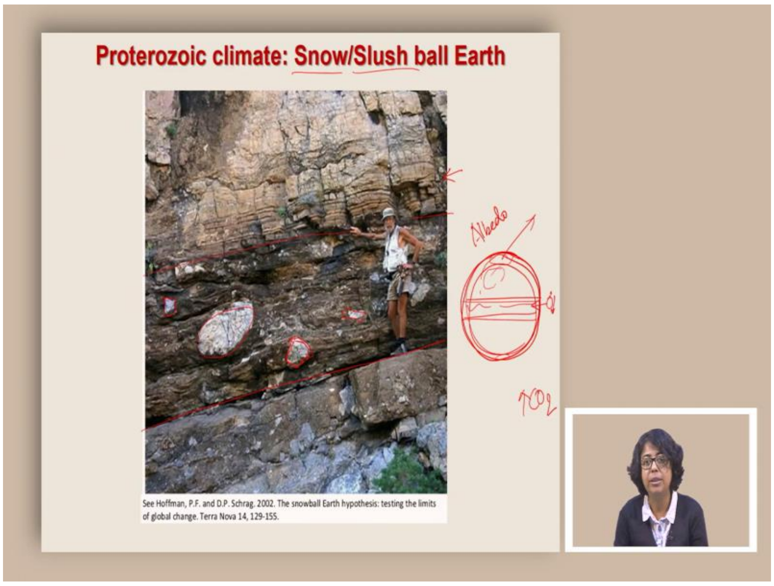

The second thing that was very important during Proterozoic was the change in the climate. Now, during Proterozoic, or if you look at the Proterozoic rocks, we find a lot of evidence of major glaciation. So, these are some of the examples of glacial rock or glacial tillites. So, what is important to notice is there are very large rocks and some of these rocks and some of these boulders are quite irregular in shape.

And these are the product of glacial deposit when the glacier melts, the rocks which are inside it, when that they picked up during its transportation start to get released, and the deposit as dropped stones. And that is what explains these kinds of rocks and sometimes even the entire glacier deposit freezes, it also can have very large irregular boulders. So, all of these things are indicating glacial deposit.

The Earth has gone through multiple glacial periods. So, finding a glacial deposit, it is not very unusual. What is unusual about Proterozoic climate is many of these glacial deposits are actually coming from paleo equatorial region. So, when we find a rock, we know its present location, but you can also find its past location by looking at certain characters in terms of magnetism, because every place maintains a specific orientation, depending on where the North Pole is, and it is possible to reconstruct using the paleomagnetism where the paleo location was of that place.

Using that criteria, when people looked at the paleo location of some of these deposits, they found that many of these deposits are actually coming from paleo equator. So, these glaciers were depositing in the equatorial region during Proterozoic. Not only that, many of them are also indicating that they were basically depositing at the same level as the seafloor. Many of them are depositing at the same level as the sea surface. So, that means they are not glaciers which were formed because of the altitude.

And these two factors are very interesting because that means if the equatorial region can also create the glacial deposit, it means that even the equatorial region must have been quite cold, and it must have been colder than 0 degrees centigrade. And if we are talking about the entire equatorial belt to be much less than 0 degrees centigrade to help develop these glacial at the same altitude, not as a high-altitude glacier, that means the polar region must have been even colder.

And what it indicates is the entire Earth must have been frozen. And that is the idea of snowball Earth, where it argues that the entire Earth was completely frozen because of the low temperature or a slush ball Earth where it is partially frozen and some of the parts were not completely frozen probably it had a consistency of ice mixed with water.

But nonetheless, all of these are pointing towards the fact where the temperature overall temperature was pretty low. Now the question is if the temperature was so low, how did the earth came to become again warm, because if the entire Earth is covered with snow, it reflects back sun's energy and reflects back the sunlight which is called an Albedo effect. And because of this, because the sunlight cannot get reflect.

Mostly, this will become even colder. So, it will go into this loop where a cold climate will bring more cold climate and therefore, how do you break this cycle. One argument of breaking the cycle is the moment you have such a cold climate, the erosion rate also goes down. Because, one of the ways of eroding things is by taking up carbon dioxide, which mixes with water makes carbonic acid and that gets absorbed by the erosion and weathering.

And if the weathering stops because of the cold climate, the carbon dioxide starts to build up. If it starts to build up, it is going to create a greenhouse gas. And it is going to create a greenhouse effect, which will eventually break the cycle making the Earth warm again. And using this principle, we can now talk about how this snowball Earth may have existed at some point of time.

And because of the increase in carbon dioxide eventually, because of the stopping of weathering due to cold climate, it would again eventually come back to an greenhouse effect which will make the Earth warm and because of this high level of greenhouse gas, we can also start to find starting of the weathering again and deposition of carbonates around after this. This idea has been debated a lot, it is not completely well resolved, but one thing is for certain that all kinds of observations are arguing for a very cold climate during Proterozoic.

And this also means that once these carbon dioxide drawdown starts afterwards, it will also lead to a dominance or a relative proportional increase to oxygen concentration and this oxygen concentration will also be related to some of the photosynthetic activity, because we have already seen that photosynthetic bacteria were already there.

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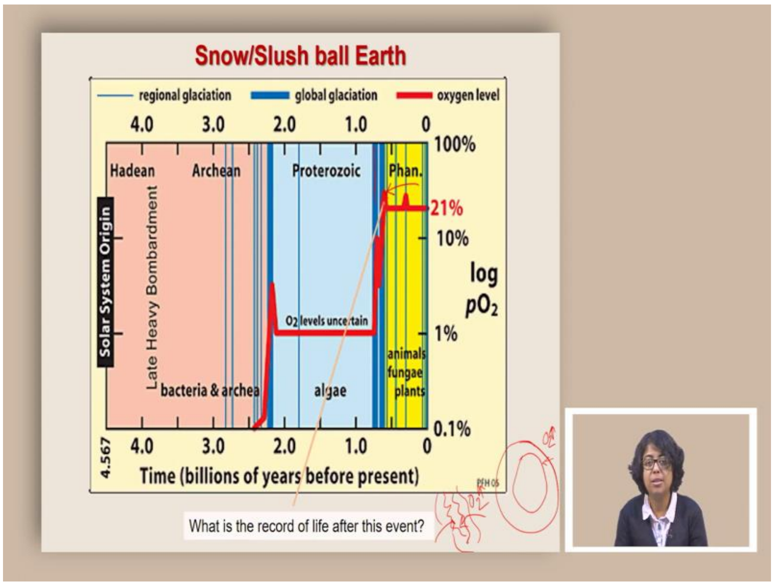

And this is reflected in this plot, where we see that there are major glaciation events are right around the end of Proterozoic. And if we look at the oxygen concentration, the oxygen concentration also increases, sometimes it increases all the way to a very high level even higher than today or at least even higher than many of the parts of the Phanerozoic. Now the question is, if we see this kind of high oxygen level, is there an impact of this high oxygen level on the biota?

As I mentioned, that biota, if you look at the cells, the cells take oxygen through diffusion. And if the oxygen concentration goes up, the cell size become bigger. But it is also true for many of the organisms too many of the organisms they absorb the oxygen through diffusion such as insects, and once you have a higher oxygen concentration outside, they can afford to grow larger, because then the oxygen because of the higher oxygen concentration, it can go to the center of their body. And that is why we generally see a close relationship between oxygen concentration and body size and we are going to see the same thing during this time for Proterozoic.

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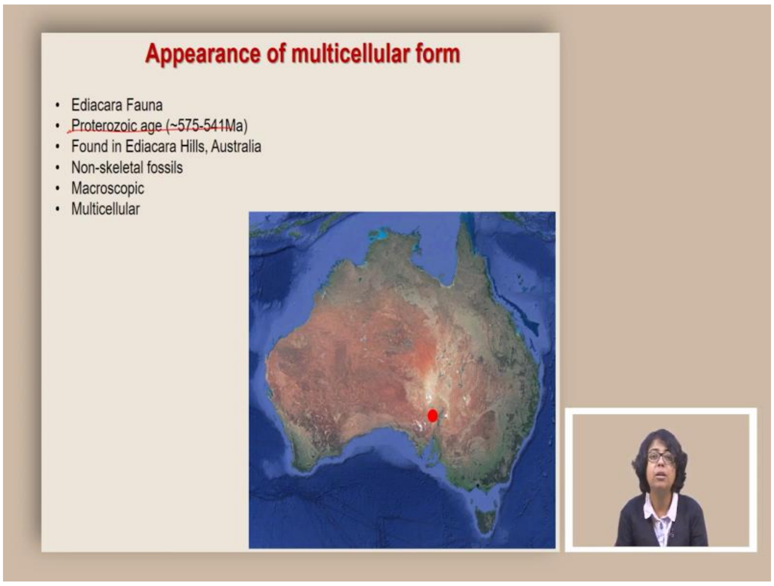

And to look into this, we are going to focus on a specific area in Australia which is called the Ediacaran hills and the fauna the fossil record found around this Ediacaran hills which are corresponding to Proterozoic age of 575 to 541 million years are called Ediacaran fauna. What is important about this fauna? They are non-skeletal fossils, so, they do not have an exoskeleton and therefore, they are soft bodied.

They are macroscopic. So, unlike some of these original Archean groups where we have found either their trace fossils or only fossils of very small size or the algal ribbons that we have seen, which were also very thin, these are animal fossils which are really large, they are macroscopic you do not require a microscope to look into that. And that also means that it is multicellular. So, they indicate multicellularity, macroscopic nature, and non-skeletal pattern.

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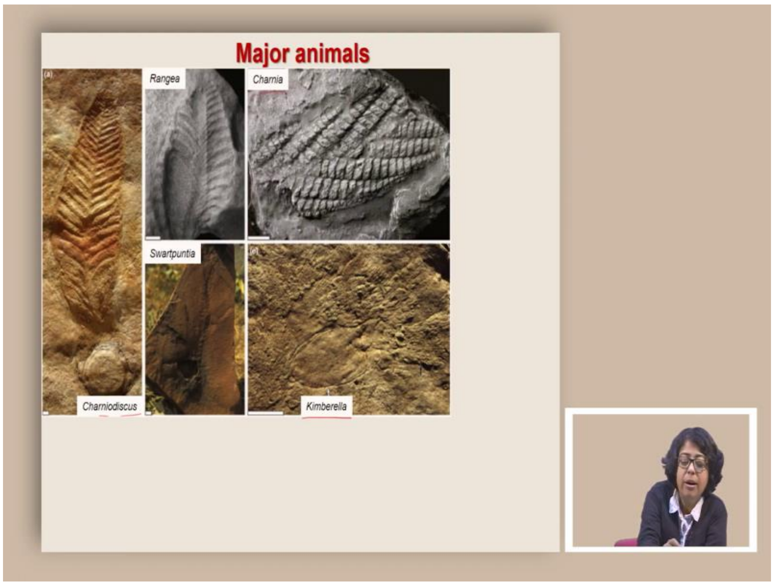

Here are some of the major animals that we see in Ediacaran hills and as part of the Ediacaran fauna. So, there are different names, but one of the or some of the major players of these Ediacaran fauna is Charniodiscus, Kimberella, Charnia, Rangea. A few more, Spriggina and Dickinsonia. Now, these are very important, because all of these are actually showing you patterns of large body size and these are organisms, which are definitely not microscopic.

Another question that we have is, if these organisms do not have the skeletal layer around them, how did they get preserved, and we will basically talk about it about the mobility of these organisms. So, certain types of organisms also showed the they are resting in trees. And these tree's fossils are extremely important, because that also tells us something about the movement.

One of the indicators that they show us is there is a lack of movement, we do not really find a lot of movement around them, we simply find their body fossils and very exquisitely preserved body fossils. And when we reconstructed, some of them looked like worm, some of them looked like Aquino domes, but majority of them do not have a very specific link to the modern groups that we can find today.

Some of them do look like some groups of neisseria, which include jellyfish, and coral, and sea pens. But again, many of these groups have unknown affinity to the modern day organism, what it means that if we look at the modern day families, it is very hard to connect these fossils to those organisms.

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Now, this is an artist's reconstruction of the Ediacaran ecosystem. Is it completely correct? Probably not, we really do not know some of the organisms, whether they exactly look like jellyfishes or not, because not everything got preserved. But there are a couple of points, which makes us understand this ecosystem better. One of them is that definitely they lived before the predators.

Predation means movement, a lot of movement, and we do not really see a lot of movement. They are primarily attached to one place. They were suspension feeders, they were taking the water and then absorbing the nutrients from the water. And that is what is meant by suspension feeder. And one important point is because they were not moving, they were not churning the sediments.

And because they were not churning the sediments, the sediments were quietly depositing. And that is one of the major reason for their preservation. So, when things die, they basically go on the sediments. And nowadays, if something dies, it immediately gets eaten up by grazers which are organisms which eat sediments and anything which is within the sediments such as snails and fishes.

Now, if you remove these things from the ecosystem, they are not going to eat anything which is in the sediments, and therefore the things which are on the sediments are going to survive longer after their death. Another point is, often the sediments also have microbial mat and these microbial mats, because they are sticky, they also attract more sediments to it. So, once an organism dies and it falls off the ground, there would be development of microbial mat, which will help it to get covered by sediments.

And if it gets covered quickly by sediments that is going to aid it is preservation and therefore, they are going to get fossilized soon and in a very, very high quality. And that is what we mean by rare taphonomic window. Taphonomy is the process that operates after death and before discovery of fossil. So, it is basically the fossilization process. And today because of this activity, we very difficult situation in terms of fossilization or preservation.

Everything gets eaten up. But during Ediacaran current time, because of the lack of grazers and active animals there were times when things got preserved very well because of the sediment deposition and covering them led to good fossilization. So, the reason they have a very good preservation, even though they do not have skeleton, is the fact that Ediacaran ecosystem did not have grazers or very mobile animals.

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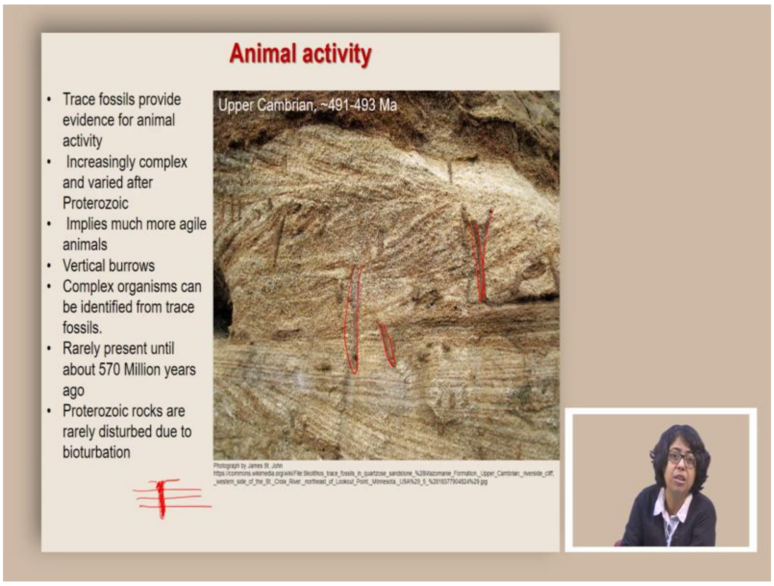

And the animal activity started happening later. So, trace fossils provide us evidence of animal activity. Increasingly complex and varied after protozoic. So, during protozoic, during Archean, even though we see multicellular organism, large organisms, they do not give us any clue about their movement and the lack of trace fossil actually indicates that they were not highly active or mobile.

One of the very clear signature of mobility is the development of boroughs. What it means, if you have a sediment surface and then there are mobile organisms, they often create a borough where they live and these boroughs get preserved and we do not find any such vertical boroughs up until 570 million years ago. So, primarily in Proterozoic, we do not find a lot of vertical boroughs. Only when we go to Cambrian, we started getting these kind of boroughs.

So, if you look at these rocks, this is a Cambrian rock, you will find these vertical structure and these vertical structure basically indicate these borough outlines. It basically shows you that activity of organisms. But this is happening in Cambrian. During Proterozoic, although there is multicellular organisms, there are organisms which were large, there are activity was very limited. They were living in relatively high oxygen level condition, but they were not very mobile, they were not very agile.

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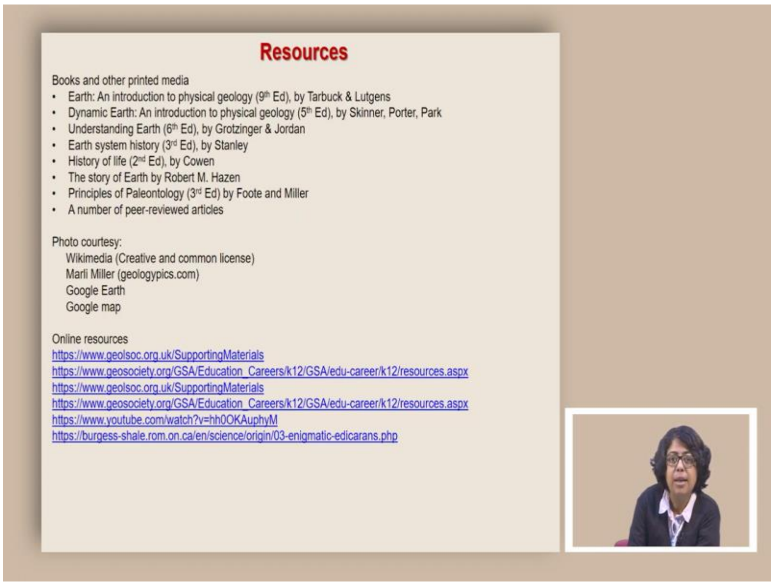

So, in summary, today we learned about some of the Protozoic events, including the continental configuration, the Glaciation, and its impact on life. We also learned the development of eukaryotes and how can we know that they are very eukaryotes. We learned about the idea of endo endosymbiont theory, which explains some of the similarities between organelles and prokaryotes, and which also explains how the development of eukaryotes happened from a prokaryote.

And finally, we learned about the Ediacaran fauna, their ecosystem, and their preservation, how they came into be this good preserved fossil ecosystem? Here are some of the resources that I created. Here are some of the resources that I used for making the slides.

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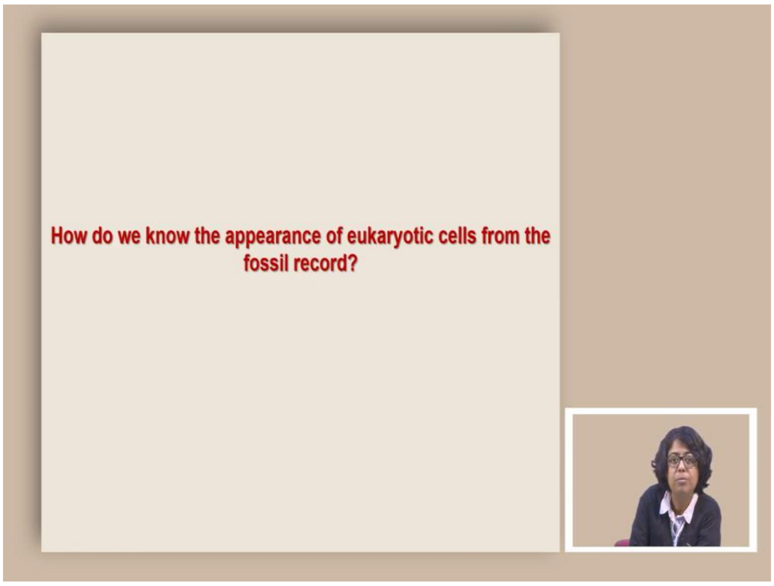

And here is a question for you to think about. Thank you.