Evolution of the Earth and Life
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Lecture 30
Attempts to Estimate Absolute Age

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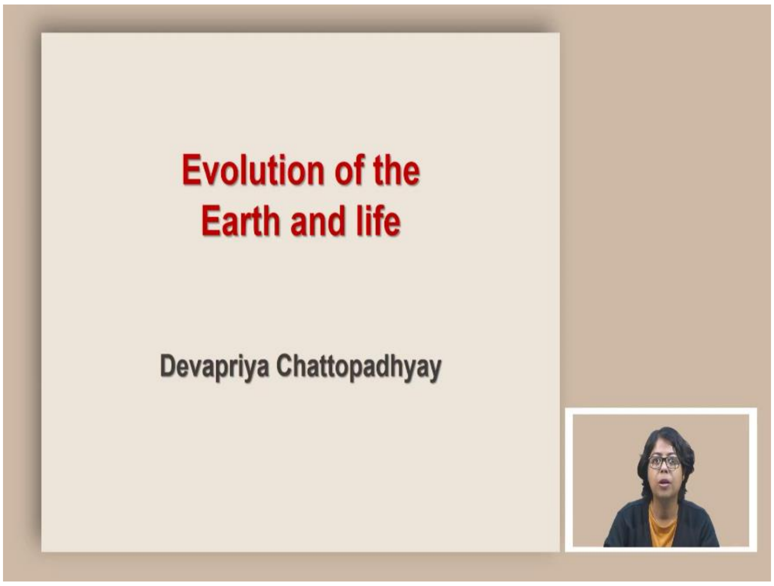

Welcome to the course Evolution of the Earth and Life. Today we are going to learn about how to calculate the age of the Earth.

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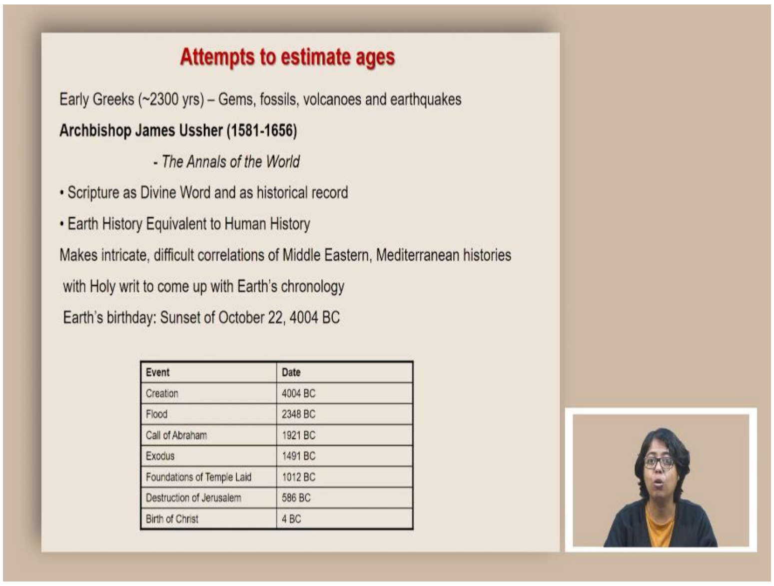

For quite some time, people try to estimate the age of the Earth through various ways. Very early on around 2300 years ago, early Greeks started to look at gems, fossils, volcanoes, earthquakes, and that that tried to understand how far were these records going, in order to estimate the age of the earth. And in many places, they have written that they are things quite old. But it was difficult for them to come up with a number.

The first person to come up with a number was Archbishop James Ussher. But instead of using the natural record, he used a very different record. And that is the written record. And in the annals of the world, he wrote the scriptures as a record keeping rock. So, scriptures as divine ward and their historical records were used to calculate the age of the earth. So, the idea of James Asher was that earth history is equivalent to the human history.

So, whenever the humans came into the planet, that must have been the starting point of the earth. And therefore, what he did, he looked at the scriptures, which are written by human beings, and which talks about different generations of people that came before them. And what he does, is an interesting pattern, he looks at the scripture, and he calculates how many generations have been mentioned. And if we know the number of generations, he also attaches the timeline for each generation.

We know that on an average and human being lives, probably now around 80 years. But if we go back in time, probably the number fluctuates anywhere between 40 years to 60 years. And he calculated based on those numbers to come up with the age of the first time, the generation started. And he basically came up with a chronology of different events, starting from the very first event that was happening during his time and going back. And when he did that, he came up with this idea that 4004 BC was the time when the earth was born. And that is why even now, Earth’s birthday celebrated on the October 22nd, as a reminder of the attempt to understand the age of the earth.

Now, this approach has couple of problems. The first problem is that his assumption is Earth's history is equivalent to human history. It is not and we know it, because if you look at the rocks, there are Rock Records, which are much older than human history. In fact, there are rocks which are completely devoid of any sign of life, which means those rocks formed before even the first life came about.

And, but that knowledge was not available at that point of time. And therefore, it was one of the first attempt to come up with a very specific number, but what it did, it gave this number 4004 BC, when the earth came about, and then subsequently people started checking this number, whether they can prove or disprove that Earth is younger than this number or older this number. And for doing that, they started using different naturally found materials, which can work as a clock.

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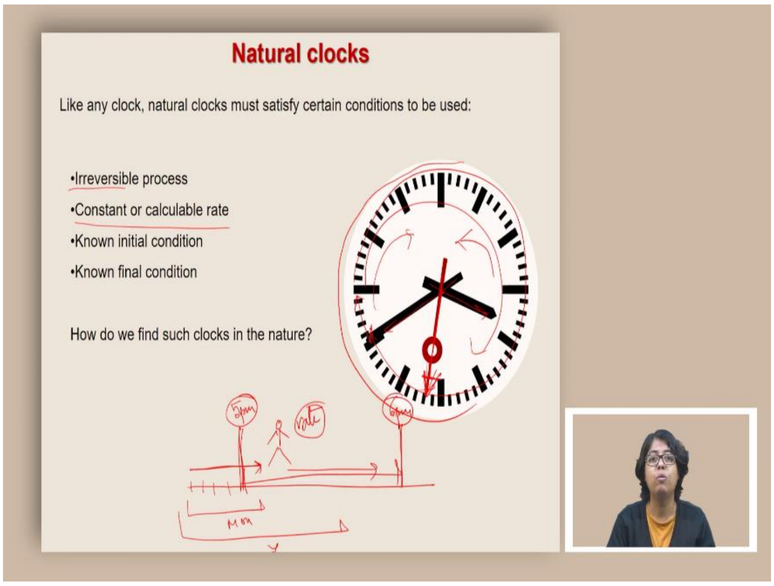

The whole idea of natural clocks are some way to capture the passing of time using natural material. So, the natural clocks must satisfy certain conditions. The first one is, it should have an irreversible process. Because if the process comes back and forth, and it operates, it goes up or down or with time without following a monotonic change, then we cannot really use it as a clock. Now, use a clock analogy, let us imagine that this is a clock, it can only work only if this dial and that these arms of the clock only moves in one direction.

Now, if it keeps on moving in one direction, after some time, it moves back in other direction, it really cannot be used to tell anything about the time, because then it is not going to be reversible process. And for a clock to work, it has to be an irreversible process. So, once it passed in this fashion, it is not going to come back unless it completes the full loop.

So, a better way of looking at it is if we are basically stretching it onto a straight line, and every time has a mark, and then we are also capturing the month, and then we are also capturing the year, then we will see that once the process has gone, or once the dial has moved past this part, it is never going to come back, it may come back to the same time, it may come back to the same month.

But the years are constantly changing. So, you cannot really go back in time. When we think about a natural clock in the natural system, we also think about a process, which will ensure that it will never come back to an earlier state. The second part is constant, or calculable read what it means again, that let us take this analogy of this clock every time with every second, this particular dial moves. Once it moves, it has a very specific movement. Now, we know that in one minute, it basically makes a full circle.

But let us imagine a scenario where this dial, this arm basically moves sometimes very slowly, sometimes very fast, then you cannot really have any estimate of what one minute is because one minute might be longer at times and might be shorter at times, if this one is taking unpredictable times as it goes about. So, therefore, having a constant or calculable rate is very important. Final thing is the initial condition and final condition these have to be known. So, this is also an idea about not really a clock but more of a stopwatch.

So, if we are using a stopwatch, we need to know what was the initial reading? What was the initial time? And what is the final time and then only we can talk about how long would it take for that event to happen. So, let us again take an example of someone running. So, if someone is running and you are trying to basically measure how long he has been running, we need to know how fast he is running. So, that is the rate. And we also wanted to know when did he start maybe he started at 5pm. And then he also started, he finished at 6pm.

So, he ran for one hour that we can find if we also know at what rate he was moving. So, these are ways to use the initial condition final condition the rate to figure out the duration of time. So, if we are talking about the age of the Earth, we also have to find something of the sort where we know what is the final configuration, we also have to know what is the initial configuration and then at which rate, things are changing. If you know all of these things, then it can work as a good natural clock. We are going to see some of the examples of such clocks.

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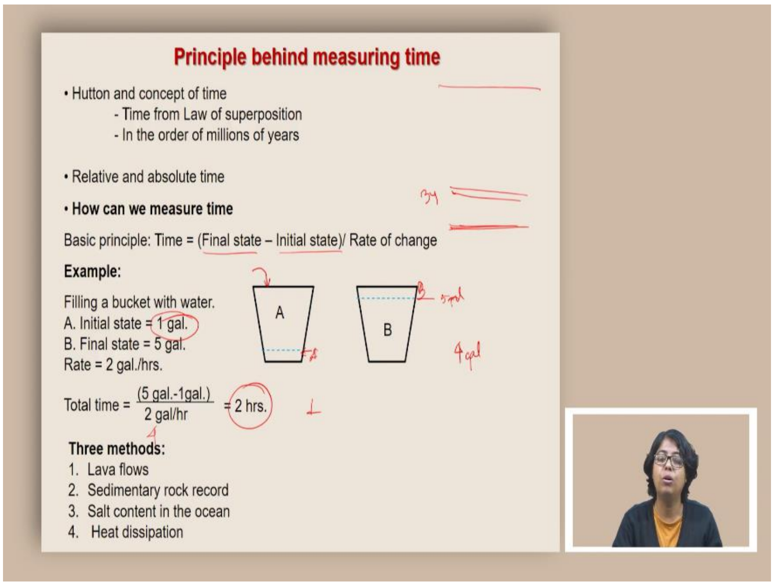

So, again, to recapitulate. The principle behind measuring time is to have a very good understanding of the initial rate and the final rate. So, James Hutton came up with this idea of or the concept of time. And we learned about it in the laws of superposition in the different laws of stratigraphy. And he also understood that the order or order of magnitude of time must be ranging in millions of years. Because he observed that if you look at sedimentary layers and how long it takes to accumulate sediments by river flow, it takes a couple of years to even deposit a very tiny layer of sediments.

And he postulated that if it takes, let us say, 3 years to even develop such a tiny layer of sediment, then when we look at sedimentary rocks of very thick pile, then it represents millions of years, which will only be required to accumulate that much of sediment, considering the rate has been the same. Now, a related idea can be used to calculate time. So, as I mentioned before, that the basic principle would be that we have to know the final state, we have to know the initial state, and then we have to divide it by the rate of change.

An example, let us try to understand filling up of a bucket with water. So, if we look at the bucket at state A, it has only this much of water. And after some time, we see this much of water. Now, if our question is, how long did it take, to fill it up to this point, what we need to know is, how much water was there initially. So, let us say at this point, we are talking about 1 gallon of water where we started from, and then the final state at this point is 5 gallon and again that we can measure and therefore the final state is 5 gallon. And then the difference between the two is 4 gallon.

Now, how long did it take to fill it up till 5 gallon? That will depend on how fast you are filling it up. So, let us say we are talking about a situation where you know, the rate of water input is 2 gallons per hour. So, every hour, you are adding 2 gallons, and It is a constant rate. In that case, we can say that this process from let us say A to B, it must have taken 2 hours, we basically subtracted the initial state from the final state and divided it by the rate of 2 gallons per hour.

Now, what happens if we are filling it up faster, let us say 4 gallons per hour. In that case, the time that it must have taken to fill it up must be just 1 hour because you are dividing it by 4. So, depending on these combination of the initial state final state and the rate of change, you can calculate the time. And people have tried different ways of utilizing the same principle using the record from the rocks.

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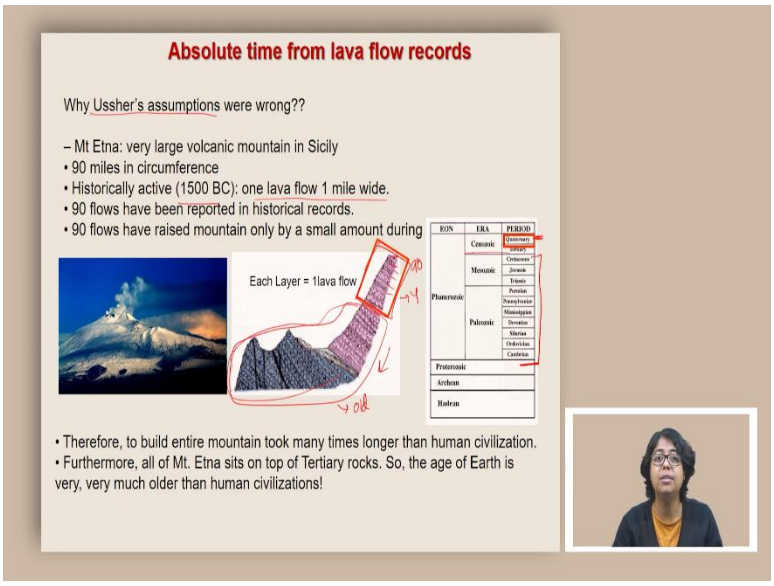

The first approach was the lava flow. And this is also a way to understand why Ussher's assumptions were wrong. So, people looked at Mount Etna, it is a very large volcanic mountain in Sicily, it is in Italy and the circumference is more than 90 miles it has been historically active and therefore, it was possible to have written records about the eruption and the flows from 1500 BC there has been records of lava flow. Now, if you look at the historical record or written record, it looks like that there has been one lava flow which is created 1 mile wide. And that basically means 90 flows have been reported in historical records.

So, the entire historical record accounts for 90 flows. And 90 flows have raised the mountain only by a small amount during the Quaternary. So, now we know that It is called quaternary. But if we look at the mountain, and if we try to trace which are the 90 lava flows, you will start from the very top and what you will find that 90 if you count 90, it only accounts for only a little height of the mountain. But then there is a vast area, which accounts for multiple lava flows much more than 90.

Now, the question is, when did they happen? From the law of superposition, we know that these must be younger. And these must have been older. And if this is younger, and if he can count 90 here, it also relates to this written record that in the written record, as it was talked about that 90 such events took place. But then, if you look at the records below, they must have happened before that, and which does not have any written record.

This shows that this to build an entire mountain took many times longer than human civilization. And that is why you do not really get the written record of the events, which happened before that probably it happened much before then the human existence. Furthermore, all of Mount Etna sits on top of tertiary rocks, so the age of the Earth must have been much older than the human civilization. So, not only does that 90 is a small number, compared to the entire part of the volcanic flow, this entire section is sitting on only the top part of the Cenozoic.

So, it is not even it does not really have the entire rock section, the entire rock section is actually below this. This shows that there is a really vast passage of time before the human civilization. And this observation definitely challenges our Ussher’s assumption, which says that human civilization can be used as an indicator to estimate the age of the Earth, because you can calculate when did the first human arrive, and that must have been the time when the earth form. Clearly, Earth has a much deeper history or older history before the appearance of the humans and therefore, these records are critically challenges Ussher’s assumption.

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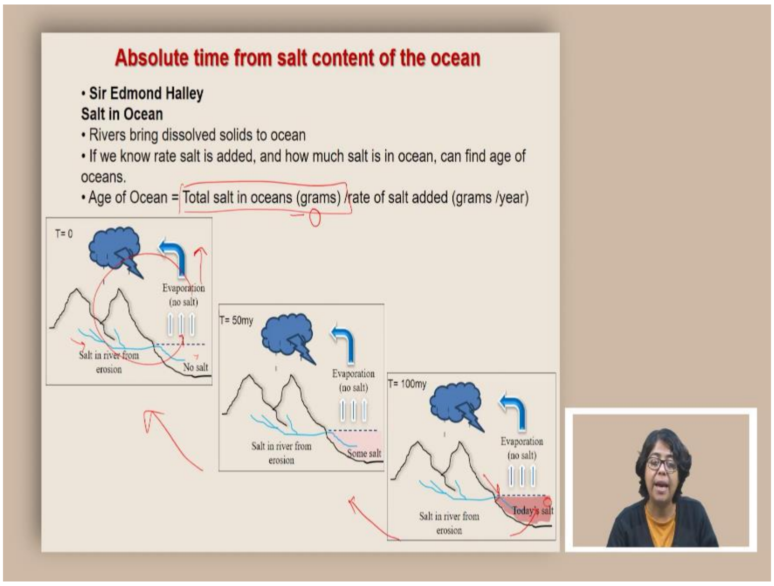

The second way, Sir Edmond Halley, he tried to estimate the age of the Earth and the ocean was through calculating the salt content of the ocean. Now, what he observed is, if you look at the salts, the salts are primarily carried from the reverse, and it finally goes to the ocean. And we know that the ocean has a very large concentration of the salt. If you taste the ocean water, you will see that It is a very salty taste, but we do not see it in the river water. And one of the reason is that when the evaporation happens, this evaporation does not take any salt, it simply takes the water, and therefore the salt is left behind. And over time as it goes through multiple cycles, the salt concentration increases.

Using this principle, Edmond Halley try to understand how we can use this principle to calculate the age of the ocean. In his mind, he started thinking from this point that let us imagine today's world where we know that there is a high concentration of salt in the ocean. But if you go back in time, this salt is increasing over time. So, if we go back in time, they must have been lower. And the way it was lower is because it had not got enough time to accumulate the salt. If we go back in time further, there would be a time when there was no salt in the ocean, and that was the time when the ocean was forming.

Following this logic, he decided that if we know what is the concentration of salt in today's world, and if he also assume that the initial concentration of the salt in the beginning of the oceans was 0, then if you also know at what rate salt is being deposited in the ocean, then it will give us some idea about the age of the ocean. So, according to him, the age of the ocean would be the total salt in the ocean, because if you subtract the initial condition, but because initially It is saying 0. Therefore, subtracting 0 is not changing this total salt in the ocean, which is the present-day configuration, divided by the rate of the salt added as grams per year.

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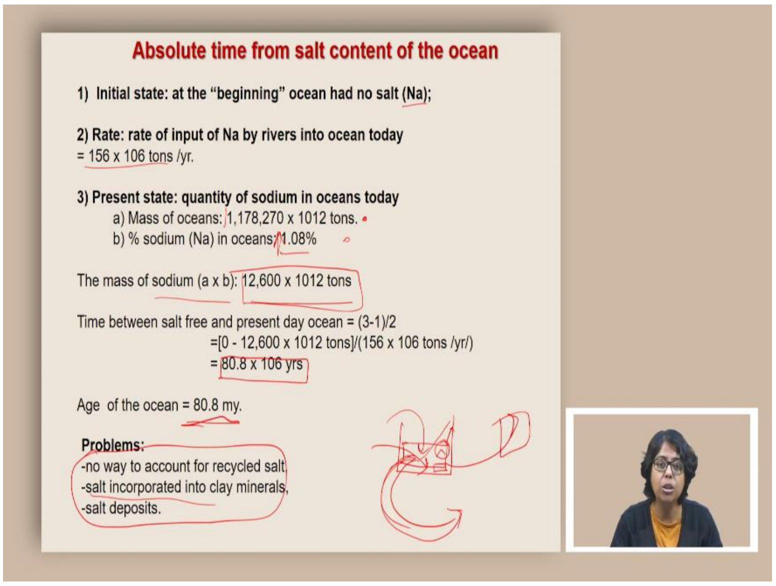

And what happens if we do this? Now, if we do this, we can actually come up with certain numbers. So, the initial state would be at the beginning, the ocean had no salt, so, therefore, 0, and by salt we primarily mean sodium chloride, the rate at which the sodium is being carried to the ocean can be calculated it can be observed today and calculated some rough estimation gives us these numbers 156 times 106 tonnes per year.

And now we have to calculate the present state, so the quantity of sodium in ocean today, so, we know the mass of the ocean, that can be calculated, again, a rough calculation looking at the volume of the ocean, and then concentration of sodium in the ocean, and that we know It is something in the tune of 1.08 percent. And that helps us to calculate what would be the mass of the sodium at this point. So, when you are multiplying this number with this number, you get the total number of sodium or total volume of mass of sodium at this point in the ocean.

Now, we know that this is the final configuration, and we know that the initial configuration has to be 0. And if we use that, we can basically calculate, and it comes up with something like this. So, age of the ocean is 80.8 million years that was according to Halley's calculation. But then there are some problems, one of the major problem is that there is no way to account for recycled salt. Our basic assumption is that when the salt is coming, it is not really leaving the ocean and it is getting recorded in the ocean, and it is constantly adding to the increasing salinity with time, but it is not.

Now, we know that subduction basically takes care of a lot of sediments in the ocean. And many of these ocean sediments also have salt, so some of the salt is actually going through subduction. And we do not have any record of that. The second is the salt also incorporates in the clay minerals. So, basically, whatever salt is coming in, it is not only contributing to the water, and increasing the salinity, it is also being part of the clay minerals. As a result, the salinity what it should increase, it is not really increasing as much, because it is going into the clay minerals, and then there can be isolated salt deposits, which we are not accounting for.

So, all of these basically what it means is all of these numbers should have been increasing the percent of sodium in the water and if the percent of sodium was actually if these were not, the case would have been much higher, then we would have found an age which is much older than that. So, this is an underestimation, a severe underestimation in terms of calculation of the age of the ocean, or the age of the Earth.

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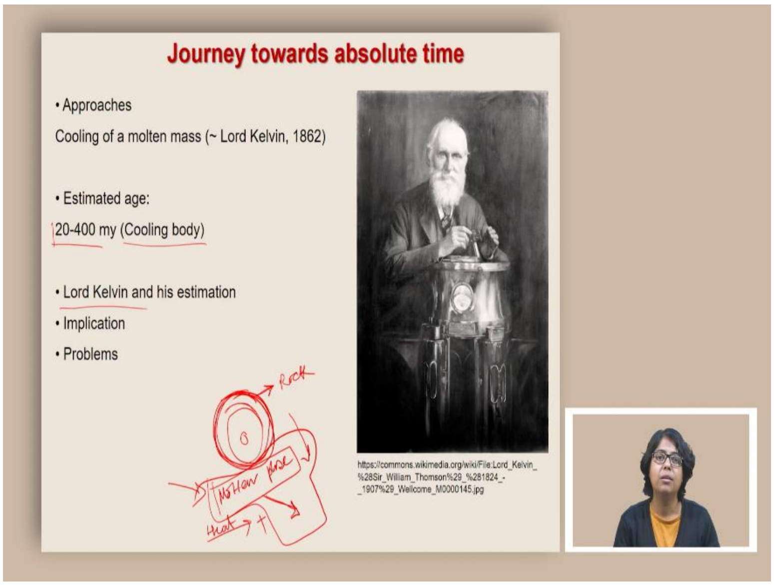

The third, and very important step towards calculating the age of the Earth was done by Lord Kelvin. So, Newton also proposed a similar idea. So, Lord Kelvins idea was that if we think about the Earth, as starting from a molten phase, we know that the surface of the Earth has cooled down enough to form the rocks. And we also know that this earth, if we are talking about a molten phase, it is cooling down in a monotonic fashion, it is not really fluctuating in terms of being heated up again and cooling down.

And therefore, if we know what is the present-day temperature, and what was the initial temperature, and we know the cooling rate, then we can calculate for how long does it take for the Earth to come to the present configuration, where the outside temperature is low enough so that rocks can form. And he calculated this with a detailed calculation of radiation, and eventually, how long would it take. And he came up with a number, which can range between 20 to 400 million years.

And he listed a number of assumptions, which must have been true in order for this number to be true. And that is one of the best ideas or best approaches because he was very clear about that assumption. And now we know that these numbers are still quite young. And it is on the lower side, it is actually an underestimation, just like Edmond Halley's approach. And the primary reason for that is the violation of certain assumptions.

For example, one of the major assumption was that once the earth was starting from this molten phase, as the initial condition, it was only losing heat, there was no extra heat which is being added. But today, we know that that is not the case, Earth's elements that are used to build the mantle and the core, all of them have radioactive material, which decays, and when they decay, they also emit heat. So, basically, this molten heat molten phase, and It is constantly dropping its temperature and cooling down is not completely true, because It is also being added heat is also being added because of the radioactive decay.

And because of which, if you completely ignore this part, the calculation, the results of the calculation will give you a much smaller number in terms of the age of the Earth, it is actually taking much longer time for Earth to cool down, because you are also adding extra heat. And because Kelvin did not consider that he came up with a number, which is much younger than what was actually the age of the Earth. These approaches were at the beginning of the development of estimating absolute age, a more eventful discovery came with the idea of radioactive decay.

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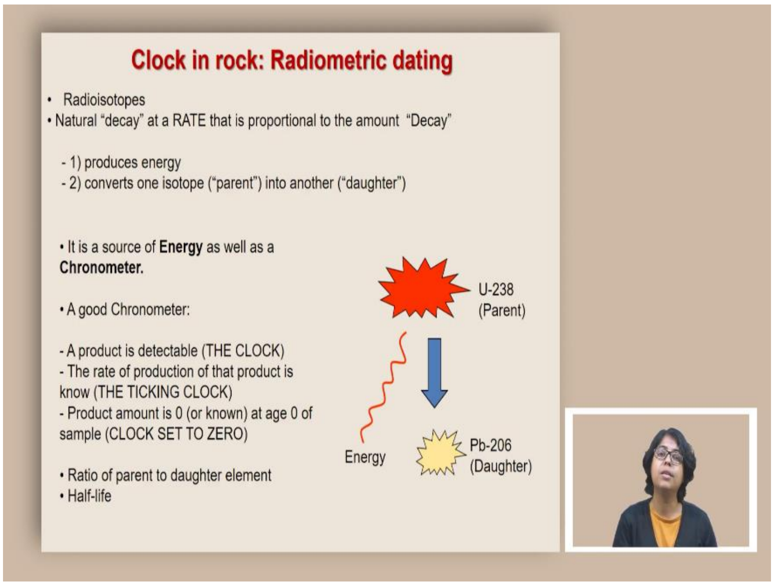

Now, radiometric dating's are one of the most well accepted methods of calculating absolute ages. So, there are radio isotopes, they have a natural decay at a rate that is proportional to the amount of decay, it produces energy, and that is the energy that we were talking about that it also keeps the Earth warm for a longer time. For radioactive dating. The radio isotopes are the ways where they decay naturally, at a rate that is proportional to the amount of decay it produces energy, and it converts to other isotopes.

So, it converts the parent isotope into something else daughter isotope, and it is a source of energy as well as a chronometer. It is a good chronometer because it is detectable, the product is detectable. And that is why it is a clock, the rate of production of the product is known. And that is why you actually know the digging.

So, that means you also know the rate. And you also know that initial condition, because that is when the amount is going to be 0, at age, 0, and after some time, the change of the amount is going to be telling you the final state. And therefore, people have used it in multiple ways to figure out the age of different natural setting using the minerals and rocks.

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So, now, in summary, today, we learned about different ways where people try to estimate the age of the Earth or to come up with some numbers in terms of their age, there were attempts to use the scriptures and to relate human history with the Earth's history and come up with a number. There has been use of natural clocks using the lava flow using the salt content in the ocean and using the cooling rate of the earth.

Finally, the radioactive decay scheme has been used to understand the age have different systems including the whole earth as well as different subsystems to have very precise estimate of absolute age of formation of different natural systems such as rocks, minerals. Here are some of the resources that I used for making the slides.

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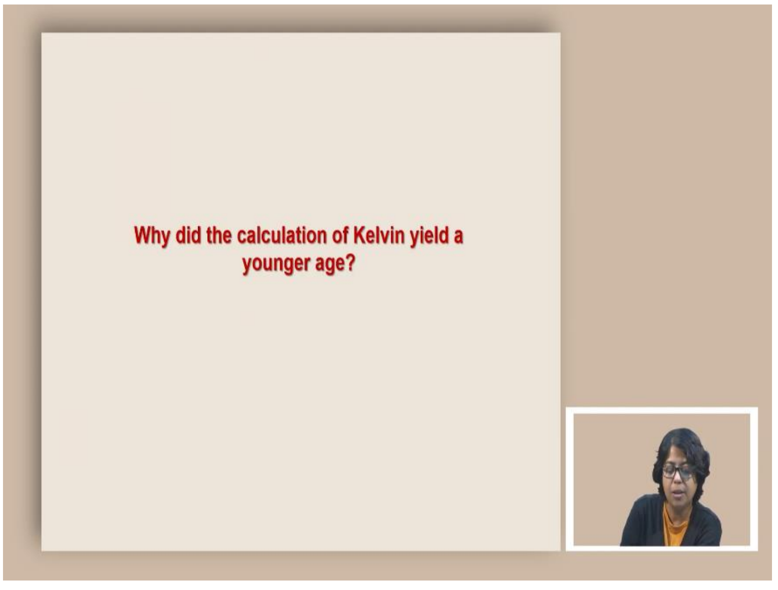

And here is a question for you to think about. Thank you.