Conservation Geography
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Module - 2
The Earth
Lecture – 4
Origin and evolution of the Earth

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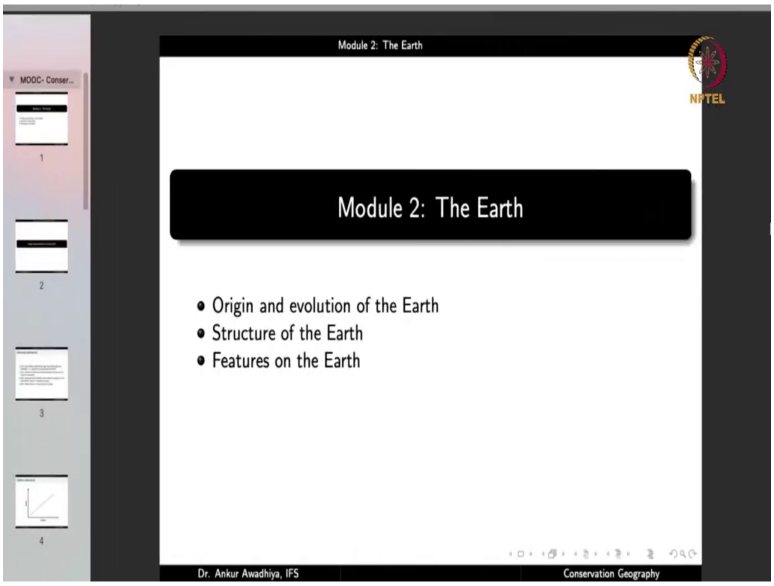

Namaste, today we begin a new module, which is The Earth. This module will have three lectures, origin and evolution of the Earth in which we will study how the Earth came into existence, how the Earth changed with time and vented different life forms come into existence.

In the second lecture, we will look at the structure of the Earth. How is the Earth on the inside? How do we come to know about what is inside the Earth? Now, this is very important because a number of processes such as earthquakes, volcanic eruptions, are dependent on the structure of the Earth.

In the third lecture, we will have a look at the features on the Earth, things like mountains, things like oceans, how did they come into existence? How do they change with time? So, this is the module in which we are going to discuss about the Earth, its structure and the features.

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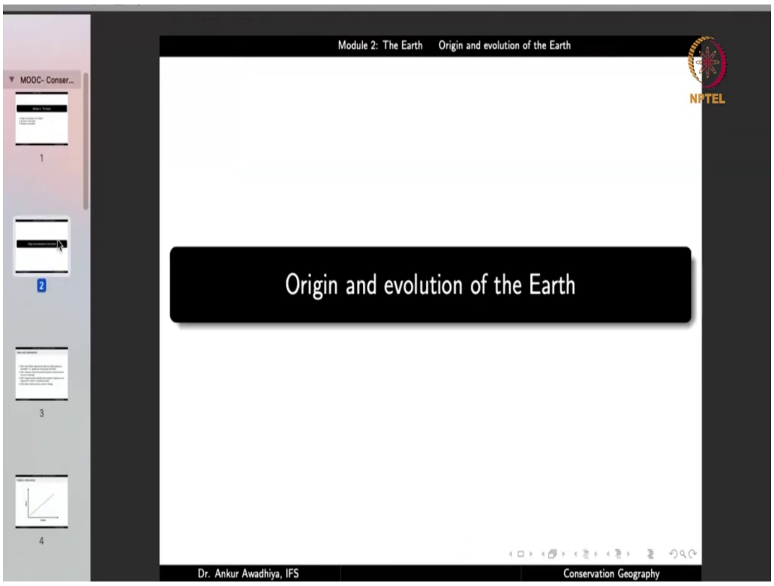

So, let us now begin with the origin and evolution of the Earth. So, what do we know about the formation of Earth? When did Earth come into existence? How did it come into existence?

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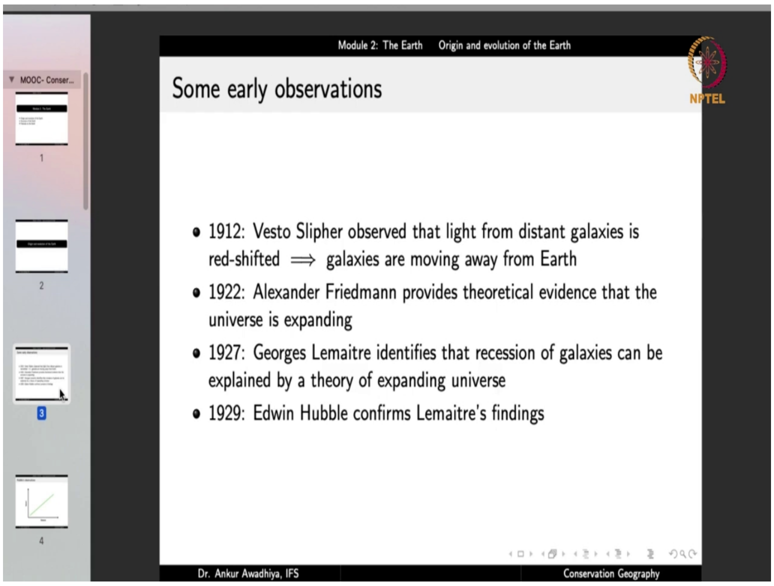

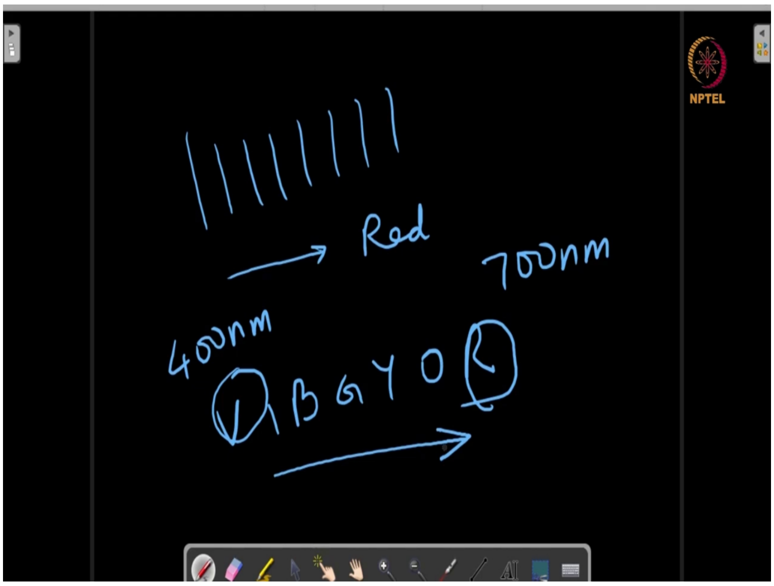

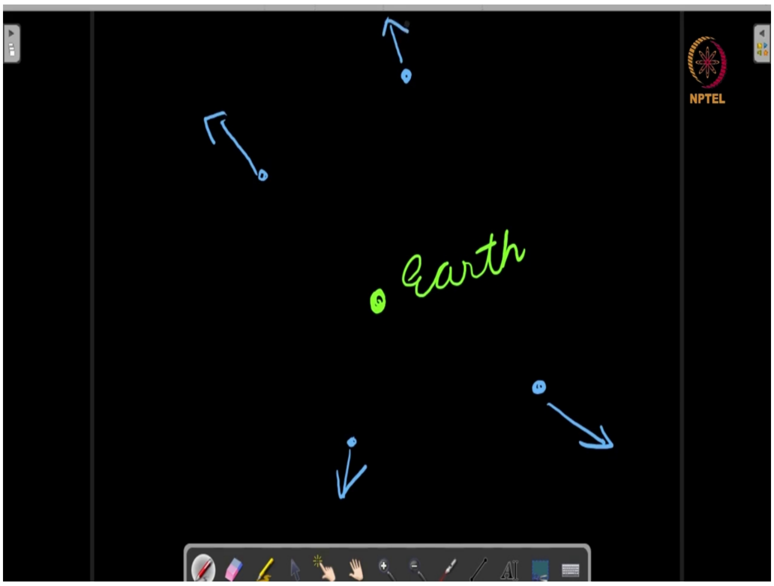

So, the current knowledge about the origin and evolution of the Earth begins with the origin and evolution of the universe. So, in the year 1912, Vesto Slipher, observed that light from distant galaxies is red shifted, meaning that the galaxies are moving away from the Earth. So, you observe that the light from the distant galaxies is red shifted. Now, what does that mean?

It means that if we look at a spectrum, for say an element and if this whole spectrum shifts towards red, which means that this whole spectrum shifts towards higher wavelengths. Now, why would a spectrum shift towards a higher wavelength? Well, this happens because of the Doppler effect.

So, if things are going away from us, then the frequencies that we get from them, they reduce, so reduction of frequency is an increase in the wavelength. Now, if we consider light, we have the seven colours given by VIBGYOR, V I B G Y O R. Now, R is towards a higher wavelength of around 700 nanometers, violet on the other hand, is having a lower wavelength, which means a higher energy. So, this is around 400 nanometers.

So, when we say that the spectrum is getting the rate shifted, it means that the spectrum is shifting from a lower wavelength to a higher wavelength and higher wavelength means a reduction in the amount of energy that we have. So, we find that there is a red shift when we observe different distant galaxies and redshift tells us that these galaxies are moving away from the Earth.

Now, in the year 1922, Alexander Friedman provided the theoretical evidence that the universe is expanding. So, we now not only have a practical data in the form of redshift of galaxies, we also have a theoretical foundation about the expansion of the universe. Then in the year 1927, Georges Lemaitre identified that the recession of the galaxies can be explained by a theory of expanding universe. So, what does this theory say?

It says that if you look at different galaxies and suppose this is our planet Earth and we are observing different galaxies and all these galaxies are moving away from the Earth. Now, with time, different things are moving away from us, it means that if we could go back into time, then there should be a point at which all of these matter, all of these different galaxies should come together.

So, this is the theory of expanding universe that the universe currently is expanding, which has very great ramifications because it can lead us to a point where all this matter was together and in the year 1929, Edwin Hubble confirmed Lemaitre’s findings that the universe actually is expanding.

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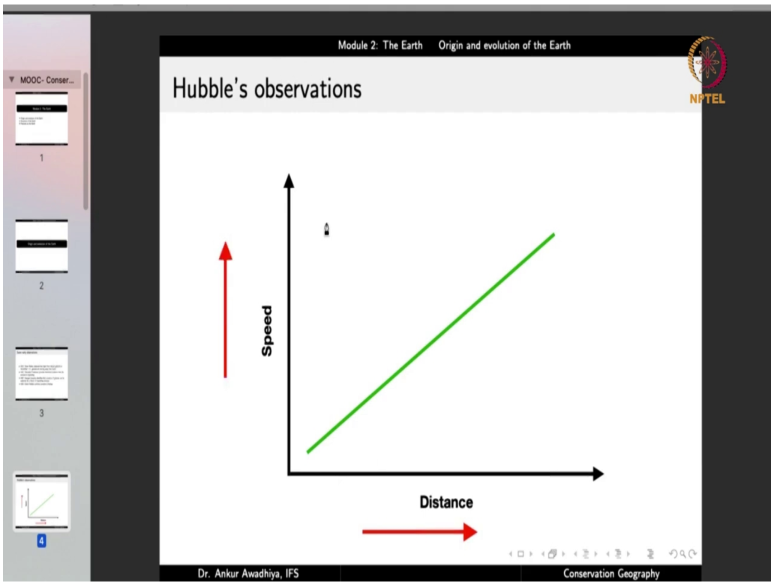

And what Edwin Hubble observed was that if we plotted the distance of various galaxies from us, versus the speed at which they are going away. So, this is the kind of curve that we get, that is with an increase in distance, the speed also increases, meaning that if a galaxy is close to us, then it is going away from us, but at a lower speed, whereas a galaxy that is far from us, is going away from us at a much greater speed.

It means that, as the universe expands, the rate of expansion should also be increasing. Now, this can help us calculate the time point at which all this matter should have been together. So, this is actually what was done.

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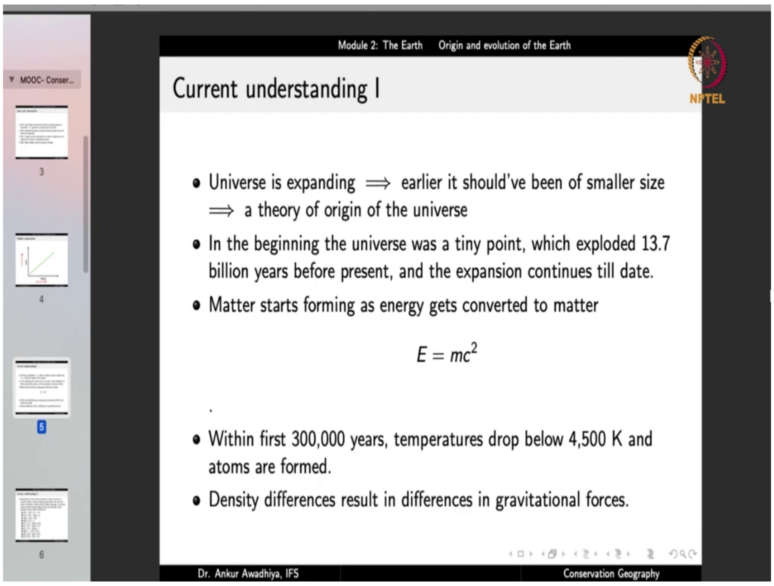

And so the current understanding is that the universe is expanding. So, earlier it should have been of a smaller size, which points to a theory of the origin of the universe. In the beginning, the universe was a tiny point and it exploded 13.7 billion years before present and the expansion is continuing till date.

So, what the scientists did was, they did a projection, looking at the locations and the speeds of various galaxies, you can make a projection about what would have happened way back in the past and, if you run the model, we will get to the figure that around 13.7 billion years ago, all this matter was together.

In a point that was infinitesimally dense and that was having an infinitesimally high amount of energy and something happened 13.7 billion years back, because of which it exploded. Now, this explosion is known as the Big Bang. Now, because of this explosion, things started to move away from that particular point and this expansion of the universe is continuing even to date.

Now, when this point exploded, a huge amount of energy was released. Now, this energy with time converted into matter, because energy and matter are related to each other by this equation is E to mc square. So, with time this energy gets converted into matter, but still there is so high amount of energy that the temperatures are very high and so the, even the atoms cannot be formed.

So, all the matter that was formed in that small period of time, that was there in a very hot surroundings and so electrons and protons and neutrons, it just could not come together and so, atoms could not be formed and after around *three lakhs* of years, the temperatures dropped below 4500 Kelvin and atoms are formed and when these atoms get formed, then there are density differences in different locations, which result in differences in the gravitational forces.

So essentially, what happened was that around 13.7 billion years back, there was the big bang, a huge amount of energy was released, this energy got converted into matter and when temperatures reduced, then this matter was able to come together form the atoms and once you have the matter, you have the force of gravity that starts to act and because different locations will have different densities of matter, so different locations will have different amounts of gravitational forces.

So, if there is a location where the matter is close together, then the gravitational forces will be larger and it will start to clump together. Whereas in locations where the matter is having a very less density, then the gravitational forces will probably not be that strong.

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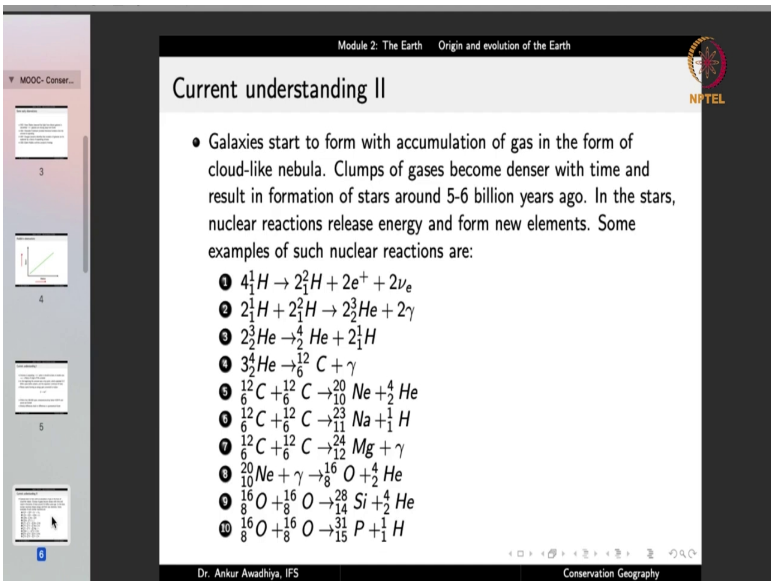

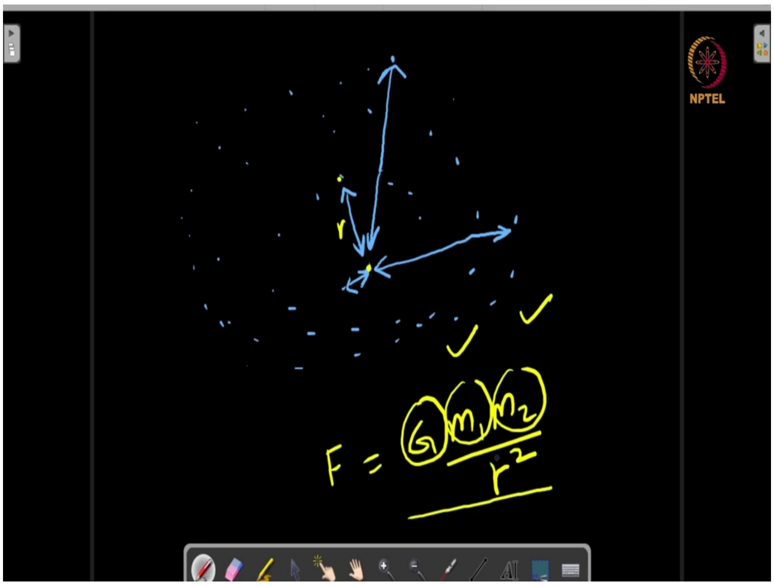

When you have the matter and when gravity starts to form, we have the formation of the galaxies. Now, galaxies start to form with the accumulation of gas in the form of a cloud like nebula. So, nebula is a cloud of gases. Clumps of gases becoming denser with time and result in the formation of stars around 5 to 6 billion years ago.

So, what is happening now is that you have a cloud of gas. Now, in this cloud, every particle is attracted to every other particle, because of the force of gravity. So, this particle here is attracted to this particle and this particle is also attracted to this particle. Similarly, this particle is attracted to this particle and this particle in turn is attracted to this particle, you have a force of attraction here as well, you have a force of attraction here as well.

Now, the force of attraction or the gravity is given by this equation force is equal to G m 1 m 2 by r square:

$$\frac{Gm_1 m_2}{R^2}$$

, where G is a constant, m 1 and m 2 are the masses of any of these two particles between which we are trying to calculate the gravitational force and r is the distance between both of them.

Now, one thing that is clear with this equation is that, if m 1 or m 2 or both of them are large, meaning that you have larger sized particles or you have lumps of particles or you have stones that are getting formed, then if the mass increases, the force of attraction also increases and the second thing is that the distance, if distance increases the force reduces or in other words, when the distance reduces, the force increases, which means that if you have a cloud of gas, then because of the force of gravity, this cloud is coming together and when it is coming together, then the force of gravity increases even further.

And so, there will be an even greater compaction and when this compaction continues again and again for a period of time, you will have that this cloud coalesces into a more and more denser material or a more and more denser cloud and after a while, you can have the formation of a star because a lot of matter has come together.

So, clumps of gases, they become denser with time and they result in the formation of stars around 5 to 6 billion years ago. Now, how do stars form you have a nebula now, this Nebula it has started to contract and now, it has become a very dense clump of matter. Now, in most of the cases, the matter is comprised primarily of hydrogen because those were the atoms that were formed in the very beginning, they are the most plentiful element on the universe and so, you have a situation where a lot of hydrogen has come together.

Now, as it comes together, the force of gravity increases even further. So, you have the force of gravity that is trying to compress it even more. Now, when this compression happens, this gas or this cloud of gas, it also starts to heat up. So, you have a situation where you have a lot of hydrogen that is packed together and the temperatures are going up.

So, after a while, it will happen that these hydrogen atoms they will start to now, their nuclei will now start to fuse together in a fusion reaction to form helium. Now, once that happens, you have the beginning of a star, because now you have a nuclear fusion reaction that is going on inside, this very tightly packed gas of hydrogen, so this is a star and once you have a star that has been formed nuclear reactions, they keep on releasing energy and they keep on forming the newer and newer elements.

And some of these nuclear reactions are hydrogen that is coming together to form deuterium giving out positron and neutrinos, then you have a normal hydrogen that is reacting with deuterium to form helium 3, then helium 3 combines together to form helium 4, which is the normal isotope of helium, then helium reacts with one another to form carbon and for a small amount of matter, you will, you can even have the formation of the higher elements, such as neon or sodium or magnesium or oxygen, silicon, phosphorus and so on.

Now, remember that in a number of cases, these higher elements or the more massive elements, they will be a very small fraction of the new elements that are getting formed, most of the reaction will be the conversion of hydrogen into helium with the release of energy. But the more massive elements, they also get formed, albeit in a smaller quantity.

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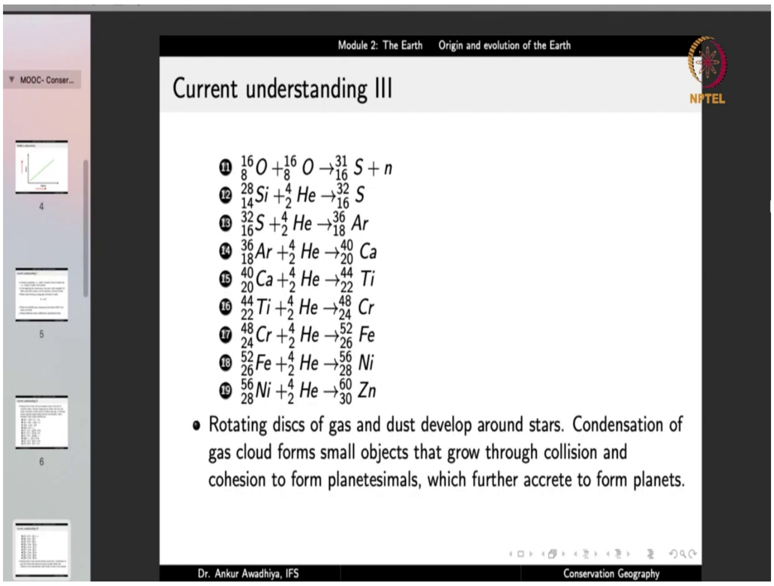

If we look at the reactions further, you can even observe the formation of sulphur or argon or calcium or titanium or chromium, iron, nickel, zinc, and so on. So, what we are observing here is that, through the process of nuclear fusion, hydrogen came together to form helium and then these elements are coming together and forming more and more heavier elements.

Now, this is how we get to all these different matters that we see around us today. All of these started from the Big Bang. So at the, at the time of Big Bang, there was only energy, then matter got formed and most of this matter, it came together in the form of hydrogen atoms and these hydrogen atoms, when they came together in the form of a nebula, they started to contract the nebula because of the forces of gravity and after a while, a star got formed and because we have stars in which nuclear fusion reactions are going on, so in that case, newer and newer elements get formed.

Now, when these stars were formed, rotating disk of gas and dust develop around the stars, because even in the case of a star, you have a star, but then you also have other matter. That was earlier the part of this nebula so the central portion, it has formed the stars, but even removing the star, there is also a lot of other matters that was there in the nebula.

Now, this matter it forms, it is in the form of a cloud of gas and particles and this cloud, it remains with the star and at times, it starts to rotate around or revolve around the star. So, you now have a rotating disk of gas and dust that is around the stars, condensation of the gas cloud forms this, forms smaller objects that grow through collision and cohesion to form planetesimals, which further accrete to form planets.

So, what we are seeing here is that in the centre, you have the star, but in other locations as well, you can have smaller clouds and so here you have a much massive cloud that was coming together. But at other locations as well, you have the forces of gravity that are acting and it is leading to the formation of small objects, small lumps of matter.

Once you have the lumps of matter, you have an increased mass and increased mass results in more amount of force and so now these lumps also come together, they come together, they stick together and they form small bodies that are known as planetesimals. Later on with the accretion of more and more mass, ultimately you have a planet that gets formed and this is how the Earth also formed.

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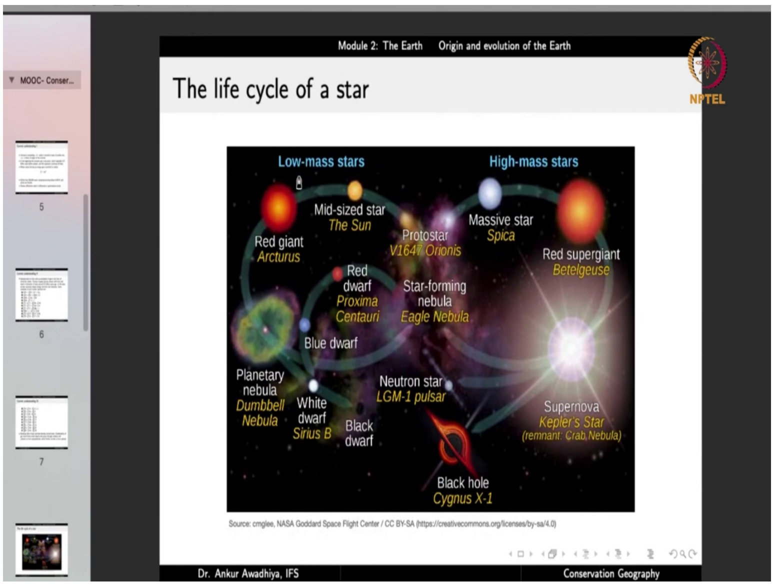

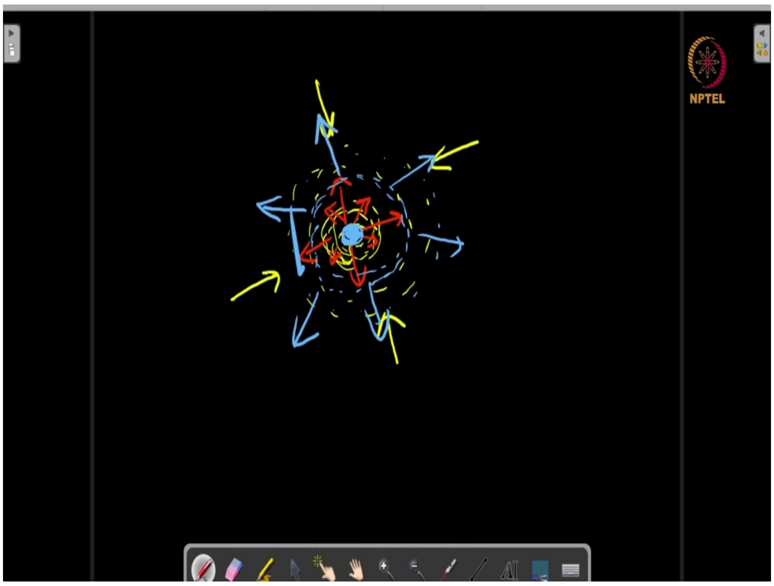

So, if you look at the life cycle of a star, we will find that it begins with a nebula, which is a cloud of gases. Then this cloud of gases, it starts to collapse under gravity, when it collapses, it forms the core of a star or a protostar. Now, once the nuclear fusion starts, you have a star that has formed.

Now, the star has hydrogen that it is using up in the process of nuclear fusion to create helium and in this process, it is giving out energy, but then the storehouse of hydrogen in the star is limited. So, there will be a point at which this hydrogen will get used up. Now, once that happens, then we will observe that the star will come towards the end of its life stage. So, how will that work?

So, you have a star and the star has a very dense core in which you have the nuclear fusion that is going on. But surrounding it, there will be the envelop which is not as dense. Now, at all times, there are two kinds of forces that are acting. There is the force of gravity. That is trying to push this star even more together, so it is trying to make the star more and more dense, but at the same time you have the nuclear fusion reactions that are going on inside and that is also releasing energy.

Now, this energy is trying to make this star explored outwards. Now, for the most of its lifecycle both of these forces they balance each other. So, the star exists without collapsing further or without expanding. Now, later on what happens is that, when the, when in the inside the hydrogen has been extinguished or it is nearing its completion. So, at that time the amount of energy that the star is creating it reduces.

So, now it is giving out a very small amount of energy and so there is a small force that is pushing the atoms outwards. Whereas, the gravitation force it is as good as before and so now, the gravitational force becomes the more dominating force and because of that, the core gets crushed.

So, it becomes from this size, it becomes a smaller core, a smaller but a more denser core and for the other material that was on the outside that was in the envelope or which was surrounding the core, now because it is being pushed because of gravity. So, now it has also come to like this level and now, this has become dense enough that now, you have a nuclear fusion that starts in this shell.

Once that happens, the shell starts to expand, because now you have energy that is, that can be used to push the matter outside. So, you have a dense core that is forming, but at the same time the envelope is expanding and this expanded envelope leads to the formation of a red giant.

So, in the case of a red giant, it is a stage in the life cycle that is therefore medium sized stars, in which case the size of the star has increased a lot, because the shell has expanded, the core probably has condensed even further, but this last size shell is having the nuclear fusion reactions and it is having, it is giving out light and so it still is a star, but it is expanded in size. So, that is a red giant.

Now, in the case of a red giant, you can have after sometime when this hydrogen also gets extinguished, you will have a situation where this red giant has expanded a lot and so with expansion it has cooled and now you do not have nuclear fusion that is going on around it, but all the, but all the matter that was there in the shell that has now expanded out and so now is available for the formation of another star or another planet or plane decimal or whatever.

So, now from this red giant stage, you have a stage of planetary nebula, in which case you have this small core that was earlier the energy given portion of this mid-sized star, but it has now collapsed and the outer shell it has expanded and it has now cooled up and so now you have a planetary nebula.

Now, with time, this core can convert into a white dwarf, in which case there is no more nuclear fusion that is going on, but the energy that is inside the core because it is a very hot body. So, the energy is slowly given out and in that case, till you how energy that is coming out you will say that it is a white dwarf, afterwards when the score has cooled down even further, then you will call it a black dwarf. So, later on it will become a black dwarf.

Now, this is for the mid-sized stars such as the Sun. In the case of smaller stars, you have a situation in which this nebula it converts into the red dwarf, in which case you do not have the core and the shell, but you have this nuclear fusion reaction that is going on everywhere.

So, this happens in the case of smaller size stars. So, in the case of smaller sized stars, you do not have a core, you do not have a shell, you have a condition in which there is nuclear fusion everywhere and this material is called is continuously contracting and once the hydrogen is used up, it will become a blue dwarf for a small period of time and afterwards it will also convert into a white dwarf and later on a black dwarf.

In the case of larger stars, more massive stars, you have the situation where the star forming nebula it forms the protostar followed by a massive star and in the case of massive star, you will have the formation of a red supergiant. So, here you, we say that there is a red giant in the case of mid-size star, in the case of a large size or a more massive star, you have a red supergiant and later on this super giant will explode in the form of a supernova.

Now, when there is an explosion, in the case of these big sized stars, then most of the material that was inside the star in the form of different, that had come through different fusion reactions. Now, that through the explosion it is rapidly thrown out and so, it now becomes available for the formation of other bodies such as the planetesimals and the core that remains, it can either form a neutron star or it can form a black hole.

Now, this chart is important because it tells us that, in the case of a mid-sized star, you can have the formation of a planetary nebula in which case you have matter other than hydrogen and helium that is now being made available for the formation of other bodies, such as other planetesimals or planets and this is the material through which our Earth also formed. Similarly, in the case of high mass stars, when you have the supernova, the explosion throws out matter and this matter will also now comprise the heavier elements, which will now be available for the formation of other planets are planetesimals.

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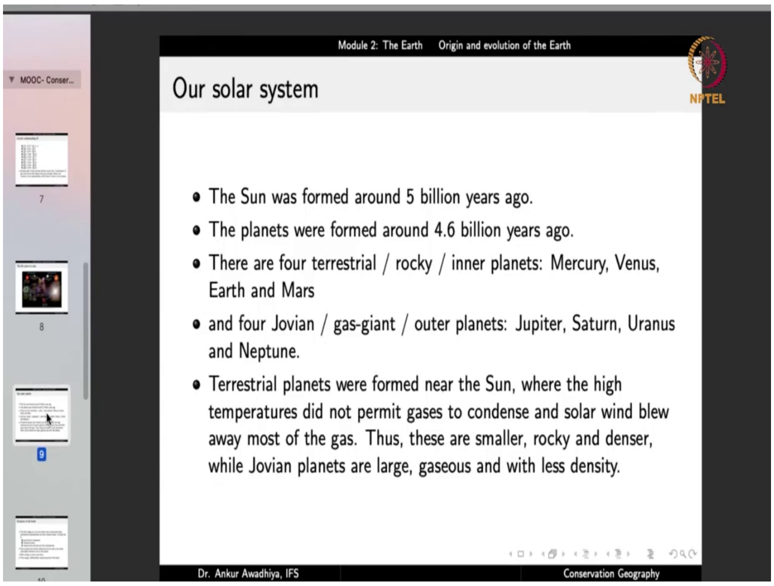

Now, our solar system was also formed in a very similar process. The Sun, which is a mid-sized star, which means that later on it is also going to convert into a red giant. So, this is a mid-sized star that formed around 5 billion years ago. Now remember that the universe formed around 13.7 billion years ago, but our Sun is a relatively very recent edition, it formed only 5 billion years ago and the planets around the Sun, they formed around 4.6 billion years ago, including the Earth.

Now, there are four terrestrial planets and for Jovian planets. The terrestrial planets are also known as the rocky planets or the inner planets and they include Mercury, Venus, Earth and Mars. So, Mercury, Venus, Earth and Mars are terrestrial planets. Terrestrial planets means that they have a structure or a composition that is very similar to the Earth.

So, they are the rocky planets and we have four Jovian planets are the gas giants or the outer planets which are Jupiter, Saturn, Uranus, and Neptune. Now, the terrestrial planets were formed near the Sun, where the high temperatures did not permit the gases to condense and the solar wind blew away most of the gases and thus these are smaller, rocky and denser. Whereas Jovian planets are large, gaseous and with less density.

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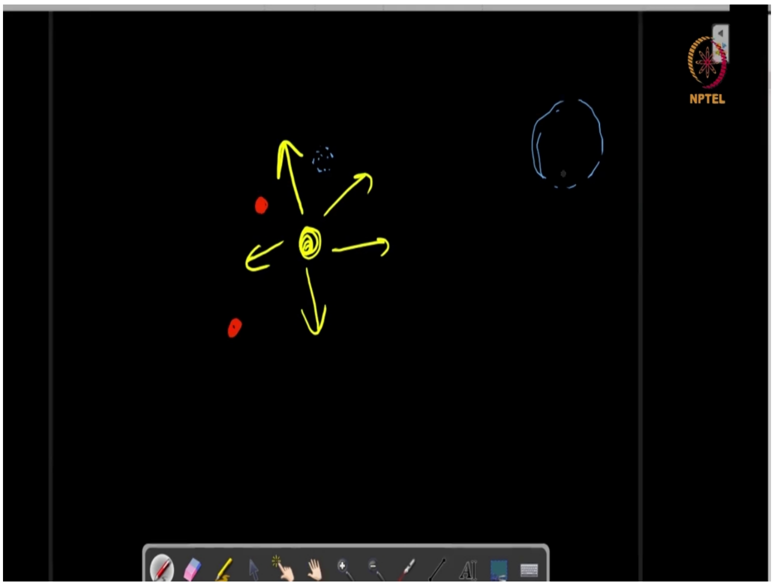

So, what we are saying here is that near the Sun, because you have a large amount of energy and solar winds that are coming out. So, if there was any gaseous planet that formed near the Sun, then it would have been blown off, because of the solar bends and so, near the Sun, you only have terrestrial planets, which are rocky planets and which have a very high density.

But away from the Sun, you can have the gaseous planets, because the solar wind at far off locations it is not as strong and so, it is not able to blow off these large sized gas giants and so you have planets like Jupiter, Saturn, Uranus and Neptune, which are primarily composed of gases. Now, because they are composed of gases, so they are having lesser density as compared to the Earth and they have a larger size, because they have lesser density.

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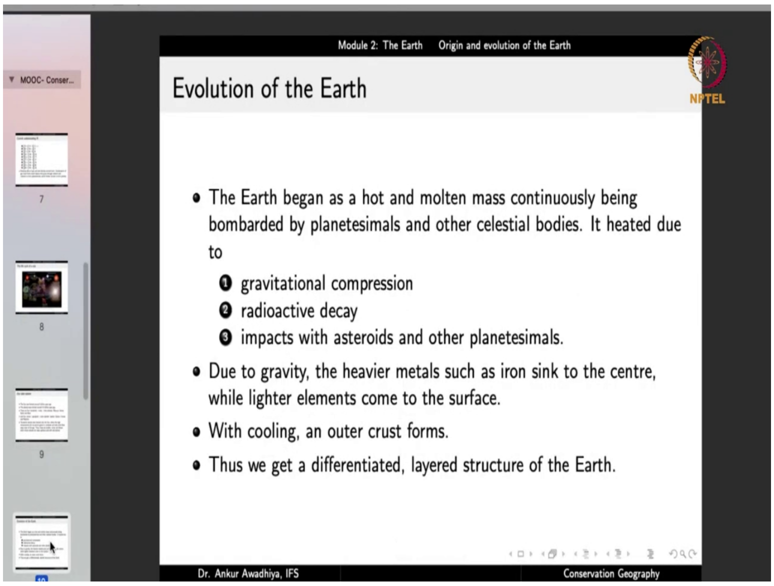

The Earth began as a hot and molten mass that was continuously being bombarded by planetesimals and other celestial bodies. The Earth when it formed around 4.6 billion years ago, it was not the same as the Earth that we see around us today. It was just a mass of molten matter that had just coalesced from other similar particles that were nearby. So like, even today, we have meteorites, that are celestial bodies that enter into our atmosphere, traverse our atmosphere and then reach to the surface of the planet Earth.

So, they bump into the planet Earth. So today we have meteorites, but around 4.6 billion years ago, we had a very large number of meteorites, because through time, most of the matter that could have come to the Earth, that we could have bombarded the Earth that has already bombarded the Earth, because there is a gravitational attraction between Earth and these other bodies and so, they are getting attracted and they are bombarding the Earth, but through time, most of them have already bombarded, so they have already been extinguished.

Also, with time, when we developed an atmosphere around the Earth, then most of these matters, when they entered into the atmosphere, they got burnt up in the atmosphere, like the meteors that we have today. Meteors or the shooting stars are also these small bodies that come towards the Earth, that enter into the Earth's atmosphere, that are attracted by the Earth towards its surface, but through the atmosphere, they get burnt out and so, they do not reach to the planet.

But earlier, when we did not have the atmosphere, nearly each and every of these smaller bodies, they were able to reach and strike the surface of the Earth. Now, whenever you have these bodies that are striking at the surface, you have a condition in which the potential energy is getting converted into thermal energy.

So, all the potential energy that was there, because of gravitational attraction between Earth and these smaller bodies, all of that energy, that potential energy, when these objects, they strike at the Earth, all of that energy got converted into thermal energy, which is heat. Now, more and more number of material that are bombarding each other, the higher the temperature goes and ultimately the Earth turned out to be a molten body. So, it started as a molten body.

There are also other sources of heat. So, you have gravitational compression to the Earth, when it was formed, it was not as dense, gravity was coalescing it more and more towards the centre and so, because of this gravitational compression also, there was a release of energy.

So, in this case, as well, you have the conversion of a gravitational potential energy into a thermal energy and you also had radioactive decay, because quite a lot of the material that had come together to form the Earth that also comprised the radioactive materials, now through radioactive decay as well heat is released and you also had the impacts with asteroids and other planetesimals. So, the Earth started as a molten body.

Now, when you have a molten body, you can have a separation of materials through gravity, depending on their density. So, due to gravity, the heavier materials such as Ireland, they sank towards the centre, whereas the lighter elements remained on the surface. So, with time you have that, the although the denser materials they move towards the centre towards the core and the lighter materials they remain on the surface.

And so, there you have a differentiation of material, a differentiation of density throughout the Earth. Now, this is important, because it led to the structure of Earth that we have today and with cooling and outer crust formed out of this molten mass. So, earlier the Earth was completely a molten blob and as it cooled, you had a situation in which a small crust formed on the top and we get a differentiated layered structure of the Earth.

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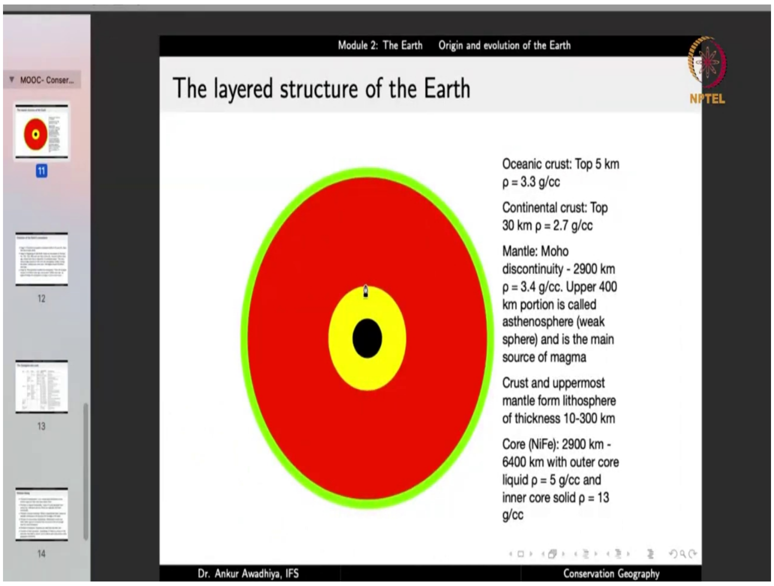

So, this is how the Earth appears today, if you made a cross section of the Earth, you will find that the outer layer, which is known as the crust, that is having the least density. Because early on when the Earth was molten, you had all the denser materials that sank towards the centre and only the lighter materials remained on the top.

Now it is those lighter materials that have formed the crust that we see today and so the density of the crust is less. In the oceans the crust is only five millimetres thick, with a density of 3.3 grams per cubic centimetre, compared this to the core. Now core is the central portion and here the density is from five grams per cubic centimetre to 13 grams per cubic centimetre.

Now, at the centre you have a density of 13 grams per cubic centimetre, but on the crust you have only 3.3. So, the crust is much lighter and it remains on the top. Oceanic crust is 5 kilometres thick, continental crust is 30 kilometres thick and is even lesser dense. So, it is 2.7 grams per cubic centimetre in density.

So, this is the crust what we have represented in the green sheet. Below the crust you have a mantle. Now, the mantle it begins at the mohorovicic discontinuity or the moho discontinuity which is this point or this surface between the crust and the mantle that was discerned because the earthquake waves moved at a very different characteristic in the crust versus the mantle.

So, this is the point at which you have a distinction between the propagation of waves and so we call it the mohorovicic discontinuity or the moho discontinuity. So, the mantle starts from this point, moho discontinuity up till 2900 kilometres. So, this is a very thick portion or a very thick layer of the Earth.

Now, the mantle is comprised of materials that have a medium density in between the crust and the core. It is not as dense as the core, but it is not as light as the crust, it is comprised mostly of solid materials, but these materials are not as much coalesce because of which with time they behave as a viscous liquid.

The upper 400 kilometre portion, which is this portion is known as asthenosphere or the weak fear and is the main source of magma. So, magma is the molten material that comes out during volcanic eruptions and this magma comes from the mantle from the upper portion of the mantle, which is also known as asthenosphere.

The crust and the uppermost mantle form the lithosphere, lithos is rock. So, lithosphere is the rocky sphere which is the solid portion, the solid sphere. So, the crust and the upper mantle form the lithosphere which has a thickness between 10 to 300 kilometres. Now, the innermost layer is the core which is also known as the knife layer for nickel and iron. So, nickel and iron because they are the more heavier elements.

So, when the Earth was molten, they moved towards the centre because of gravity and so, the core is mostly comprised of these heavier elements and so, it is also known as the knife layer for nickel and iron. Now, this core it begins at 2900 kilometres depth and it goes on till the centre of the Earth, which is 6400 kilometres.

The core is differentiated into two portions, the outer core is liquid with a density of 5 grams per cubic centimetre and the inner core is solid with a density of 13 grams per cubic centimetre. So, there are two three things that you can make out. One, as we go deeper, the density increases, two on the very top surface, you have a solid portion, followed by a semi solid viscous portion which is there in the mantle, followed by a liquid portion which is there in the core, followed by again a solid portion in the form of inner core. So, this is the structure of the Earth.

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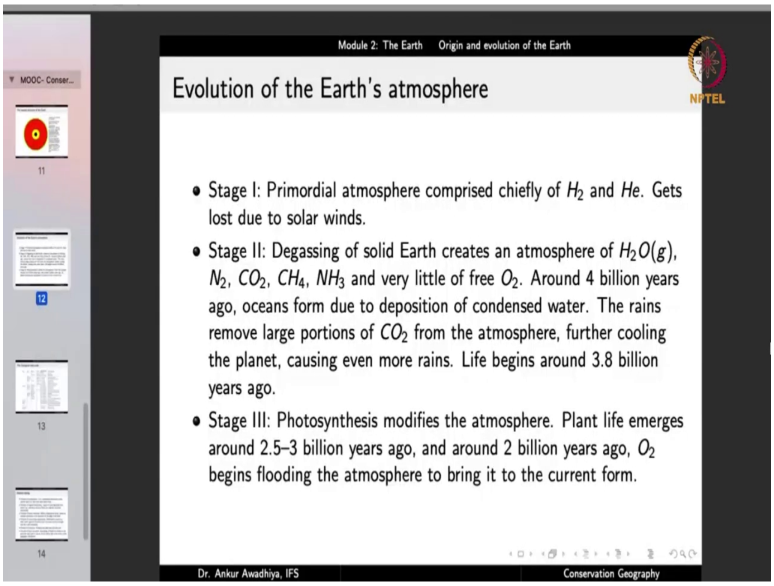

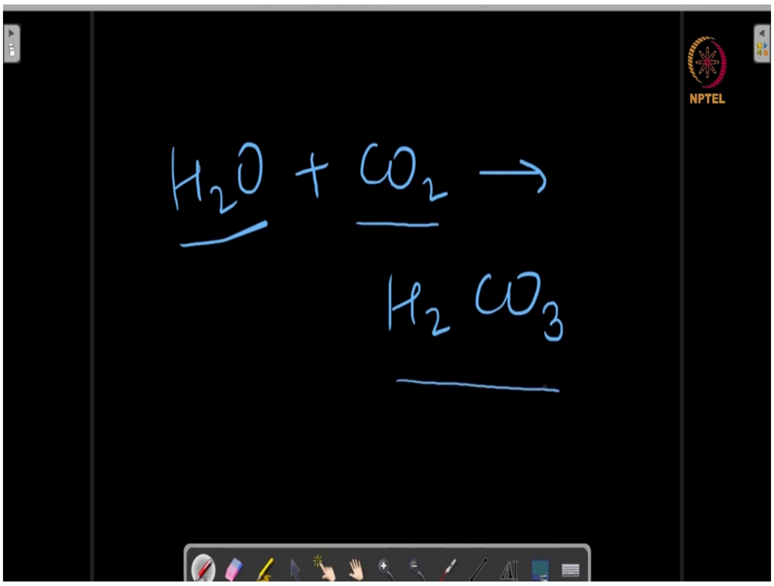

Now, when we talk about Earth, we should also talk about the Earth's atmosphere. Now, the Earth's atmosphere has gone through three stages. The first one is a primordial atmosphere, which comprised chiefly of hydrogen and helium gas and it got lost due to the solar winds. So, when the Earth formed in the very beginning, the gases that were around were hydrogen and helium, because they form the majority of the universe.

Our Sun is also comprised mostly of hydrogen, which is now getting fused into helium. So hydrogen and helium, the lightest elements, they are the most abundant elements. Now, in the beginning, the Earth's atmosphere comprised primarily of hydrogen and helium. But this primordial atmosphere, it got blown off due to the solar winds and so, today we do not find an atmosphere that has a very high amount of hydrogen and helium. We have next to no amount of hydrogen and helium in our current atmosphere.

Now, in the second stage, we had degassing of the solid Earth, which means that the solid matter that had come together it had struck the Earth, it had bombarded the Earth, it had (()) (40:30) together with the Earth and the Earth converted into molten material and this molten Earth it released the gases that were there inside with the rocks.

So, for instance if you, if today if you take a lump of calcium carbonate and if you heat it, then you have a release of carbon dioxide. Now, similarly in the early Earth, if there was a lump of calcium carbonate that came towards the Earth, it bombarded the Earth and it touched the very hard surface of the Earth, then slowly and steadily the carbon dioxide was released.

Now, carbon dioxide being a heavy gas it is much heavier than hydrogen or helium. So, hydrogen and helium could be blown away due to the solar winds, but this heavy gas carbon dioxide it could not be blown away. So, it remained together with the Earth. So, it formed a part of the atmosphere of the early Earth that was not blown away by the solar winds.

Now, similarly, other gases such as water vapour or nitrogen or methane or ammonia or and very little amount of free oxygen, they were also released because of the degassing process. So, degassing is the process in which the gas that is there in the form of a chemical it gets released because of the intense heat and pressure.

So, when the material is contracting at times the gas is released, when the material is heated at times the gas gets released. So, in the stage two, you have an atmosphere that is rich in water vapours, nitrogen, carbon dioxide, methane, ammonia and a little amount of free oxygen. Now, around 4 billion years ago, oceans formed due to the deposition of the condensed water.

So, what we are saying here is that, when you had the early atmosphere that was rich in water vapour, with time as the Earth cooled as its atmosphere cooled, this water vapour condensed and when it condensed it became liquid water and it came down to the Earth. When it came down to the Earth, primarily in the form of rain, it got collected in the depressions that were there on the Earth and at that point we had the first oceans that get formed.

Another thing also happens, the rains also remove large portions of carbon dioxide from the atmosphere, further cooling the planet and causing even more rains. Because carbon dioxide can dissolve in water. So, we have this chemical reaction, H2O plus CO2; it gives H2 CO3 that is the rain can interact and it can dissolve and it can react with carbon dioxide that is there in the atmosphere to form carbonic acid.

Now, this carbonic acid when it is dissolved in the rain water, it comes down to the Earth and so it is removed from the atmosphere. Now carbon dioxide as we know is a very prominent greenhouse gas. That is it traps the infrared radiations in the atmosphere, so it keeps the planet warm. So, if you reduce the amount of carbon dioxide, the planet will cool down further, it will cool down faster.

So, once we had the rains, they lead to a removal of carbon dioxide from the atmosphere, cooling the planet and causing even more rains. So, this was a positive feedback. The more the amount of rain, the more amount of carbon dioxide gets, that gets removed from the atmosphere, leading to more cooling leading to even more rains, leading to even more removal of carbon dioxide and so this led to the cooling of the planet.

Life began around 3.8 billion years ago. So, you have around 4 billion years ago you have oceans, around 3.8 billion years ago you have the first forms of life get, that get formed. Now, later on, you have the evolution of plants, plants and those organisms that could do photosynthesis. Now, in the process of photosynthesis carbon oxide is utilised and oxygen is released.

So, once you have the formation, once you have the formation of life and once you have the beginning of photosynthesis you have a situation in which oxygen gas is now being released into the atmosphere and it led to a flooding of the atmosphere with oxygen. So, this happened in a stage three, photosynthesis modified the atmosphere, plant life emerged around 2.5 to 3 billion years ago and around 2 billion years ago oxygen began to flood the atmosphere and bring it to the current form.

So, currently, we have around 21 percent of the atmosphere that is oxygen. In the primordial atmosphere, we did not have or any oxygen or we had a very miniscule trace amount of oxygen, but today, it is a very dominating gas and this is because of life. If we did not have any life, we would not have an oxygen rich atmosphere on our planet.

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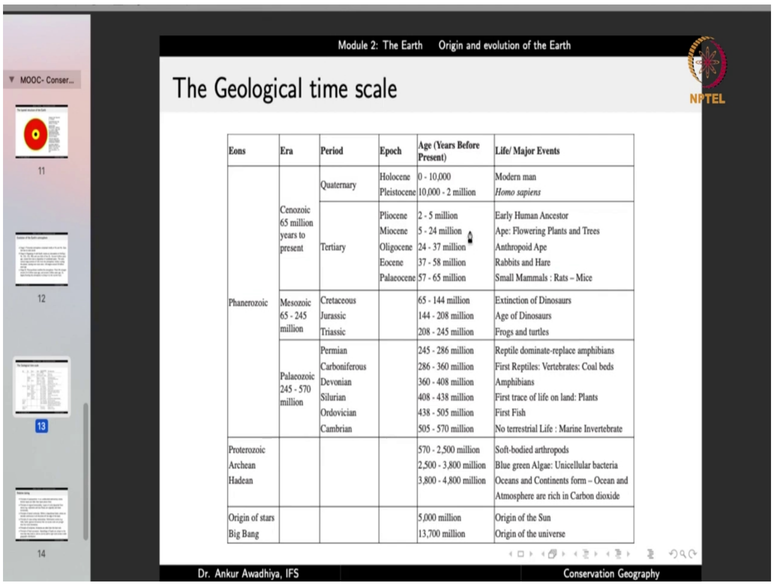

Now, when we make a study of the history of the Earth, we have to look at a time scale that is known as the geological time scale. Because in this case, we are not talking about a few hours or a few days or even a few years, we are talking about things like thousands of years or millions of years or billions of years.

Now, for that we look at a time scale that is known as the geological time scale. So, it is a time scale that is a very large size time scale and in this time scale, we divide times into yawns, which are large chunks of time, which are then subdivided into eras and each era is divided into periods. Each period is divided into a box. So, what are the eons?

We have big bang that occurred 13.7 billion years ago, we had the origin of stars around 5 billion years ago. But when we look at the Earth, we have the first eon, which is the Hadean eon. Now, Hades is the Greek god of the underworld. So, it is a God of hell and we normally believe that hell is a place which is very hot, which is having very adverse conditions for life and those were the conditions that were there in the Hadean period. So, it was a hellish period.

It was a period where temperatures were very high, the Earth was molten, there was no life, whatsoever. So, we have the Hadean period, it begins at around 4.8 billion years ago and it lasts up till 3.8 billion years ago. So, it was a period that lasted for 1 billion years and the major events in this time was the formation of oceans, the formation of continents and the ocean and the atmosphere were rich in carbon dioxide.

Because you have the atmosphere that is rich in carbon dioxide and the oceans are also rich in carbon dioxide because the rains are bringing this carbon dioxide down into the oceans. So, this was a period where you have carbon dioxide everywhere. It is a very hot and molten period. Then you have Archaean period. Archaean means very old. So, it is the word root that comes into archaeology, study of old times. So, the Archaean period began after the Hadean period, so it began at 3.8 billion years ago and it lasted till 2.5 billion years ago.

The major life events were the formation of blue green algae and the unicellular bacteria. So, the Archaean period is a period where life begins to form. Archaean is followed by Proterozoic, proteroz is former, so it is former animals or primitive animals in the form of soft bodied arthropods and the current eon is Phanerozoic which is visible animals.

So, now we have animals that are visible everywhere. Now the current eon is divided into three areas, which is Paleozoic which is old animals, Mesozoic, which is middle animals and Cenozoic, which is new animals. In the beginning of the Paleozoic era, we did not have any terrestrial life. There were only marine invertebrates.

Then with time, we have the evolution of fishes, the first trace of life on land in the form of plants. Then we have evolution of amphibians, reptiles and then we have a period in which the reptiles dominate and they replaced the amphibians. But then we have a Permian Triassic extinction event in which a large number of species on this planet, they became extinct and we again begin with a Triassic period, which was dominated by frogs and turtles.

So again, it is dominated by amphibians and reptiles. Then we had Jurassic period, which was the age of dinosaurs, followed by a Cretaceous period, which saw the extinction of the dinosaurs. Then we have the Cenozoic era, where we have two periods, tertiary and quaternary. In the tertiary period, we had the expansion of the mammals.

So, we begin with small mammals, because at this time point at around 65 million years, we have the extinction of dinosaurs. So again, there is a void that gets created and this void is now filled up by the mammals. So, in the beginning, we have small mammals like rats and mice, rabbits and hare, then slowly and steadily, we have the evolution of apes, followed by the early human ancestor and the current period is the quaternary period, in which we have the man and the modern man. So, this is the geological time scale.

Now, how do we know that these time scales actually existed? How do we know that the extinction of dinosaurs happened around 65 million years ago? Because we did not have humans at that point of time, there was no recorded history. So, how do we know that it happened 65 billion years ago.

So, there are a number of ways to date things. So, if you have, say a fossil of a dinosaur, you can figure out when this fossil was formed. Similarly, when we talk about the formation of mountains or the erosion of landforms, we can figure out when this happened and we do this through dating methods.

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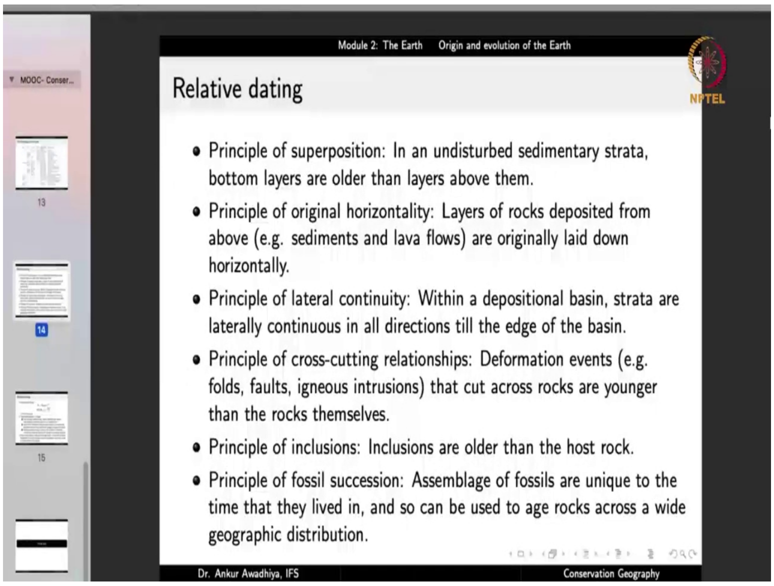

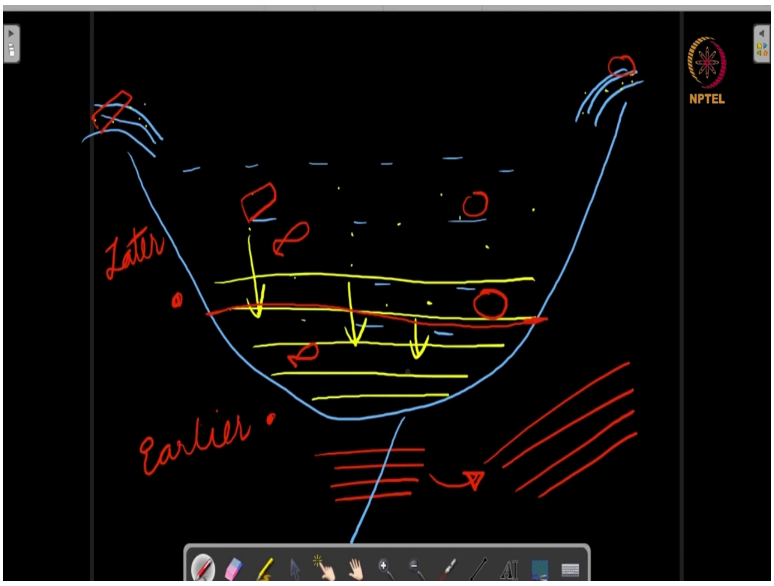

And there are two different dating methods. The first is related dating and the second one is absolute dating. Now, relative dating says or it tries to figure out which came before and which came after. So, it tries to put a time point in terms of before and after. So, how do we do it? There are certain principles of relative dating. So, what are those? In a number of cases, we begin with locations that were a water body.

So, suppose this is a water body and this water body is being drained by rivers or streams. Now, these rivers and streams, they will also be bringing sediments with them. So, there are sediments that are coming with these streams and you have now these sediments that are there in the water body.

You might also be having certain animals that live in the water body, say a fish, there are also some organisms that are coming from the land in the form of say, a dead log or a twig or say, a fruit of a tree that fell into the river and is now brought to this water body and so now you have all of these that are there in the water body.

Now with time, what happens is that these sediments, they settle down and when they settle down, they form different layers. Now, when you have these layers and suppose you have a fossil of a fish that was there in this layer and the fossil of this fruit that was in this layer, so can you tell which came first, the fish came first or this fruit came first?

Well obviously, the lower layers they were formed earlier. So, this portion is earlier and this portion is later. So, in this case, by looking at the fish that is there in the lower layer, we can say that the fish came earlier and this fruit came later. So, this is a way of relative dating.

Now, in a number of cases, we do not find these layers in the water body. Because with time these layers would have gotten compacted, they would have formed into sedimentary rocks, these rocks probably would have moved to some other places because of geological processes.

But still, we can make a number of deductions by looking at the principles of relative dating. So, these are the principles, one principle of superposition. In an undisturbed sedimentary strata, bottom layers are older than the layers above them, which is what we saw here. The bottom layers are earlier the late and the top layers are later.

Principle of original horizontality, layers of rocks deposited from above such as sediments and lava flows are originally laid down horizontally. So, for instance suppose today we find a rock layer that is like this, then too we will say that no it did not get deposited at an angle, it would have gotten deposited horizontally and later on, because of some processes it would have turned.

So, this is the principle of original horizontality, we have the principle of lateral continuity within a depositional basin, the strata are literally continuous in all directions, till the edge of the basin. So, if we consider this layer, this layer would begin at this point and it will be continuous till this point, there is no breakage.

So, if we look at a layer and we can make correlations between things that are formed at one point and things that are founded at another point because both of these, if they are there on the same layer, then they would have been deposited at the same time point. Then we have the principle of cross cutting relationships that is deformation events such as folds, faults and igneous intrusions, that cut across rocks are younger than the rocks themselves.

It means that if you find a layer that has been say, cut like this. So, this event of cutting would have come after the formation of the rock, because of which this rock has been cut, this event of cutting the rock or an event or folding the rock or an event of thrusting the rock it could not have occurred before the formation of the rock itself.

Similarly, if you have a rock within inclusion, then the inclusion is older than the host rock, because it was formed before and later on, it got incorporated into the rock. So, the intrusion is older than the rock itself, then we have the principle of fossils succession, that is assemblage of fossils are unique to the time that they lived in and so can we use to age the rocks across a wide geographic distribution. That is when the fossils are formed in are found in a layer of rocks, then the layer should have been formed at around the time when the fossil was formed.

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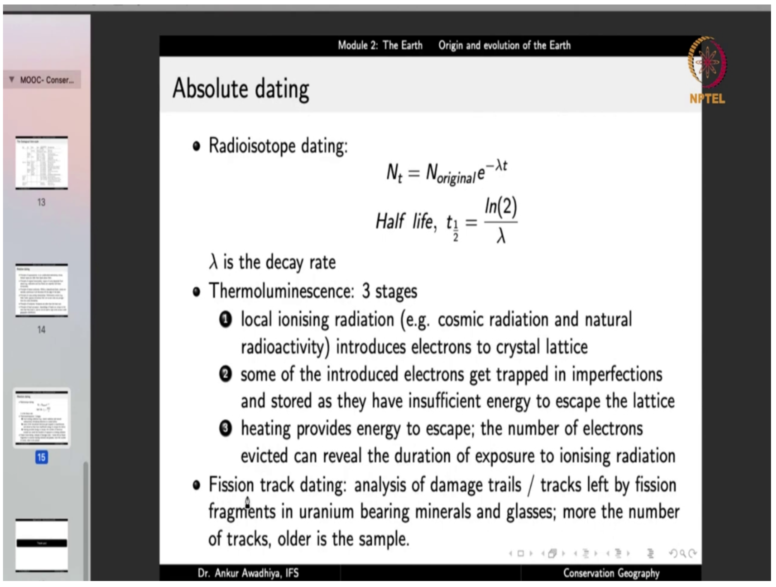

And in the case of fossils, we can also make use of absolute dating methods such as radioisotope dating, so we can make use of carbon dating. Now carbon dating is based on the fact that the radioactive carbon which is carbon 14, it decays with time and so there is a half-life through which we can back calculate when that organism was living.

Similarly, in the case of rocks, we can make use of uranium dating methods. So, these are absolute dating methods, which tell us the exact time point. So, if you have layers of rocks and you know the exact time points of some portions that were there in a layer, then you can make inferences.

Another absolute dating method is thermoluminescence, in which case ionising radiations introduce electrons in crystal lattices and these electrons are stored because they do not have sufficient energy to come out. So, if you look at an old piece of rock, there will be a number of electrons that are inside and if you heat up this piece of rock, typically sedimentary rocks are used for this.

If you heat this up, then these electrons will get released and the more the number of electrons the older is this rock specimen. So, this is thermoluminescence dating. Another is fisson track dating. That is, the analysis of the damaged trails or tracks that are left by fisson fragments in uranium bearing minerals and glasses. More the number of tracks, older is the sample.

Which means that if you have a glassy material with uranium inside and uranium being radioactive it decays and when it decays, it leads to cracks in that glass. The more the number of cracks, the older this glass should be. So, we can make use of relative and absolute dating methods to understand what was formed and when it was formed. So, this is about the origin of Earth and we will continue our discussion in the next lecture. That is all for today. Thank you for your attention. Jai Hind!