Evolution of the Earth and Life
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How does Earth Science work?

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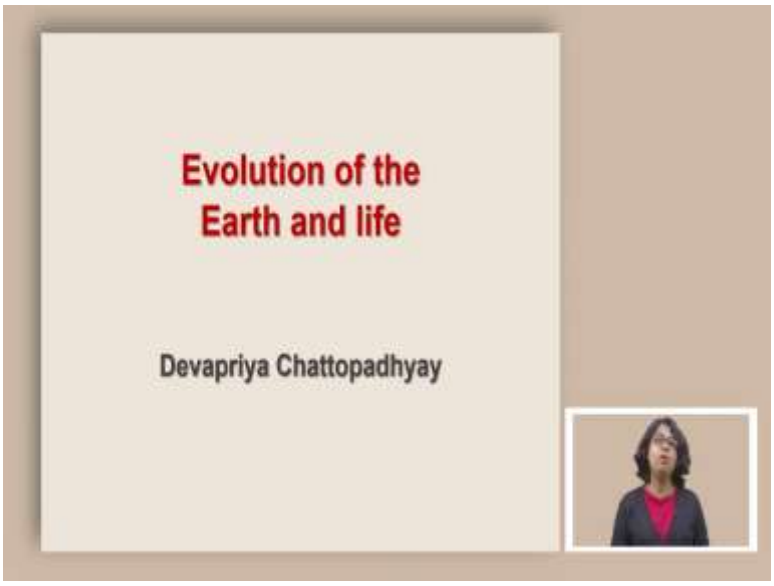

Welcome to the course Evolution of the Earth and Life. Today, we are going to talk about how the earth science works as a scientific discipline, we will also try to talk about some of the history of Earth Science.

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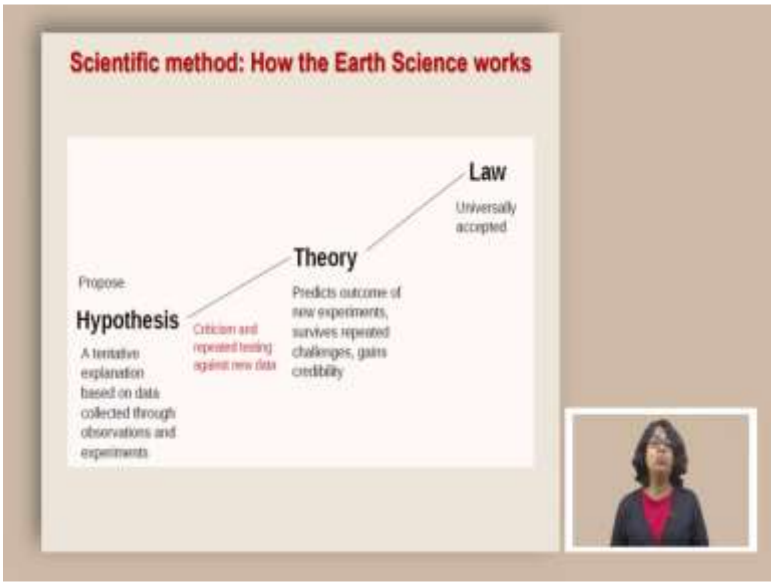

Like any other scientific method, Earth Science also works on these following steps. So, first we propose a hypothesis, it is a tentative explanation based on data collected through various tools and observations and experiments. And then this hypothesis actually gets tested. And it goes through multiple phases of criticism, repeated testing against new ideas, new data, new observation, once it reliably predicts the outcome of a new observations and survives repeated challenges, then it can be called a theory.

And theories are still out there to be tested to be re-implemented and verified with newer observations. And if everything works out, and it is universally accepted, then it is called a law. Now, Earth Sciences not a different. Earth Science does not practice anything different than that, the only difference is how we do it. And there are certain aspects of it, which are different from any other Science. So Earth Science is a natural science, and it has certain unique features.

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The interesting points about Earth Science is its nature of the discipline. And we are going to talk about 3 major important features, which makes it unique. The first one is something called an inverse problem. The second one is scale of time and space. And the third one is the interdisciplinarity.

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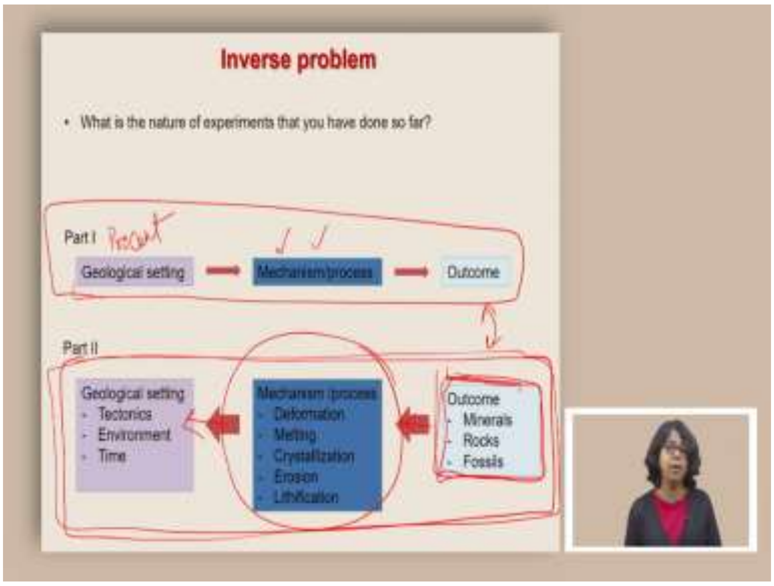

So, when we think about a regular classroom, exercise of other scientific disciplines, such as physics or chemistry, what we generally think of is an experimental setup, where we start with certain conditions, then we change some of these conditions and see what is the effect of these changing conditions on the outcome of the experiment.

That is how the general experiments that we encounter in the laboratories work. And by looking at the relationship between the input variables and the output variables, we try to understand the mechanism that is driving these results. Interestingly, when we think about Earth Science, the questions that we address are often the results of experiments that have already been performed. So let us say the question that I am asking is, is it possible to compress a sedimentary pile and make a mountain like Himalayas.

Now, the thing is, it is not really possible to recreate the same phenomena and change the initial condition to see the final outcome, because that natural experiment has already been performed, the Himalayas is there and it is not always possible to recreate this entire experiment, because of lack of time and space. So, Instead, what we can do is to look at the outcome and then try to understand what was the original condition and what was the mechanism.

So, by definition, these kind of questions fall under the realm of inverse modelling or inverse problems, where we are not really moving forward in terms of changing the initial conditions. and looking at the effect on the final outcome, we are rather starting from the outcome and trying to understand what are the mechanisms and what was the initial condition.

Obviously, this process will involve a lot of uncertainty, but uncertainties are basically giving you more information about the natural systems, because unlike the control setup in natural systems, things are always interacting between different scales, different features. So, the final result is often influenced by more than one factor. So, at the same time, we have to take care of the involvement of multiple factors and multiple stages of the initial condition.

So that is what I captured in part two of this particular diagram, that in majority of the cases, when we ask a question, it actually starts with the outcome. And in this case, the outcome can be in the form of raw materials of the nature, it can be in the form of minerals, in the form of rocks, in the form of fossils.

And from there using clues hidden in minerals, rocks and fossils, we basically try to understand what were the mechanisms that are responsible for creating these particular things. And once we are convinced about the mechanism, and we have a good understanding of how that process operates, that can lead us to reconstruct the original environment, maybe it gives us more important features about how much time it took to develop these things, it can also give us some understanding of what was the configuration of different geography of the earth or tectonics.

So, this is a very important aspect of Earth Science, which involves uncertainty, which involves looking at the outcome and basically reconstructing back the processes and initial condition. Now, how do we do it? Just observation of these features do not really give you the understanding of mechanism if you do not have any other thing supporting this.

So, we do try to study the mechanisms in the natural record. And the way we do it is by looking at the present day geologic setting. And the present day geologic setting, actually gives us more of a forward modelling mode, because there we can actually see the present condition, and we see what is happening and we can also see what is the outcome of it. And this gives us some understanding of the mechanism of process.

For example, let us say, one of the geologic setting that we can study today is the rivers. And we can ask this question, how much sediment is being carried by the river to the ocean? This we can quantify by observing how much sediment is being carried by the river, we can actually take measurements of how much sediments are there in river water, and keep on doing it during multiple seasons, multiple years, just to understand the variability of the sediment transport over time.

Once we have a reasonable number, then it also tells us that if this continues over millions of years, what would be the outcome in terms of how much sediment can accumulate in the ocean? Let us say yours very specific question is that can it build something like a delta or does it require longer time than 1 million years? So then you have a very good study, a setup where you can comment on what kind of flow, what kind of sediment transport is generally there in a particular river.

If the river is let us say, flowing from high altitude to low altitude and if the length of the river is such and such, then you can have a good estimate of the mineral, of the sediments that are being carried. And then you can comment, how long would it take to form something like a delta.

Now, you can do that for many rivers, because you will see that the numbers change sometimes substantially when you go from one place to the other place. And that gives you more clues that what are there other factors that can contribute in terms of how much sediment volume will be carried by a river, you may find that if the rivers are going from, if the river length is very long, it is travelling over a vast region, the amount of sediment that it is carrying is higher.

So, that tells you that the length of the river plays a role. And this, you can again, bring back to your reconstruction of the processes, if you find a record of a delta in the rock. So, there are certain things from today's world we can use to reconstruct that it was a Delta formation. Using these rates, you can probably talk a little bit about how long it may have taken for that delta to form.

But then, it is also a question that did the Delta stay there for the entire time, how long would it take for it to be eroded to be broken down into small sediment grains, that again, you can calculate some things using the modern geologic setting. So, we often go back and forth between the modern day and to the past to understand some of these mechanisms.

But the important thing to remember is present day is important to understand the mechanisms of the past, but past actually gives us how these mechanisms lead to formation of things over long term, because we cannot really study processes over long term beyond human timescales.

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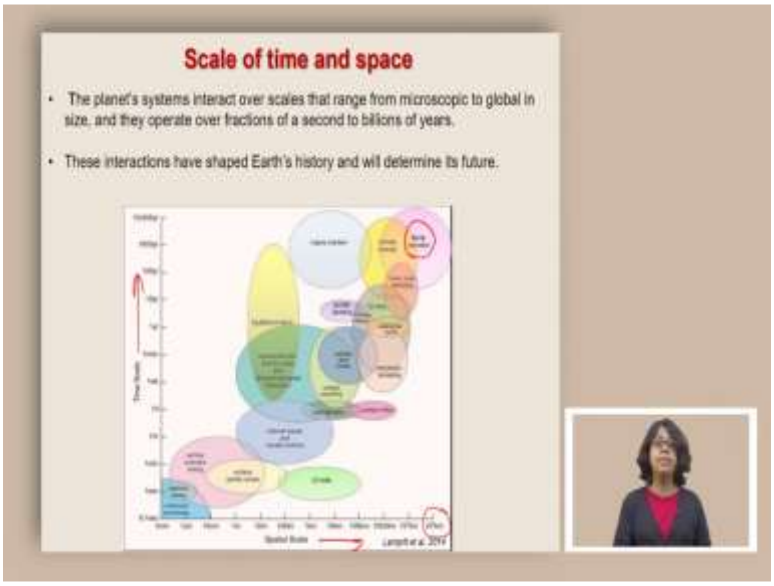

And that brings us to the next unique aspect of natural scientists, especially Earth Science is the scale of time and space. So, the planet system interacts over scales that range from microscopic to global size, and they operate over fractions of a second to billions of years. If we look at this plot, it basically tries to capture different processes that operate on the earth, deeper part of the Earth, shallow surficial processes as well as with other spheres of the earth.

And what you will see is this is a timescale and this is a spatial scale, there are things that are happening deeper inside the Earth, something like mantle convection, which operates at the scale of 10,000 years, and in a spatial scale of 10 to the power 5 kilometres, which is really large. On the other hand, there are things which are, you know, happening in a relatively smaller scale, such as let us say an earthquake happening, and it is waves travelling that can take really small time. Now, these interactions have shaped the earth's history and it will also determine the future. So, it is important to understand how these time and space actually operates, how the processes operate in time and space.

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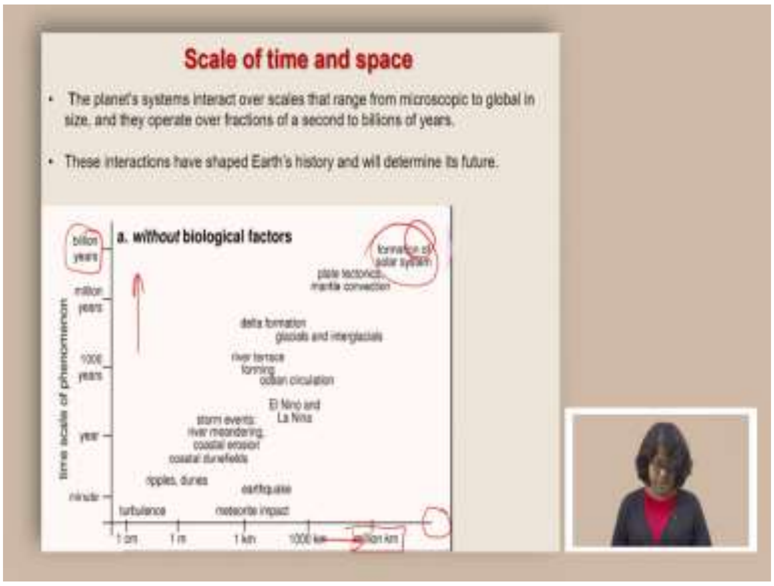

Now, some of these processes are actually happening in much much larger scale because if you recall, the highest timescale in the previous plot was up to 10,000 years, but then there can be timescale of phenomena which goes up to billion years and spatial scale which ranges in million kilometres, such as plate tectonics, mantle convection, there can be things which are formation of solar system, which can take billion years. Now, these are things which is not really possible to produce in a laboratory condition, both because human timescale is very small, and therefore, we cannot really observe all of these things during the entire time.

The second factor is the spatial scale that we cannot really generate a laboratory which is as big as let us say, Himalayas, or the total earth. And that is one of the issues that we face, because it is an assumption and sometimes this assumption actually fails that whatever you see in smaller scale can be scaled up to very large scale or whatever you are basically seeing in large scale both in time scale as well as spatial scale, it can be scaled down, which can fit your experimental setup, it is not always true and therefore, it is a challenge, how to design an experiment, which can be scaled up and down. So, scalability is one of the main challenges of the Earth Science. And therefore, it is also a unique aspect where a lot of people are using creative ideas to encounter this challenge.

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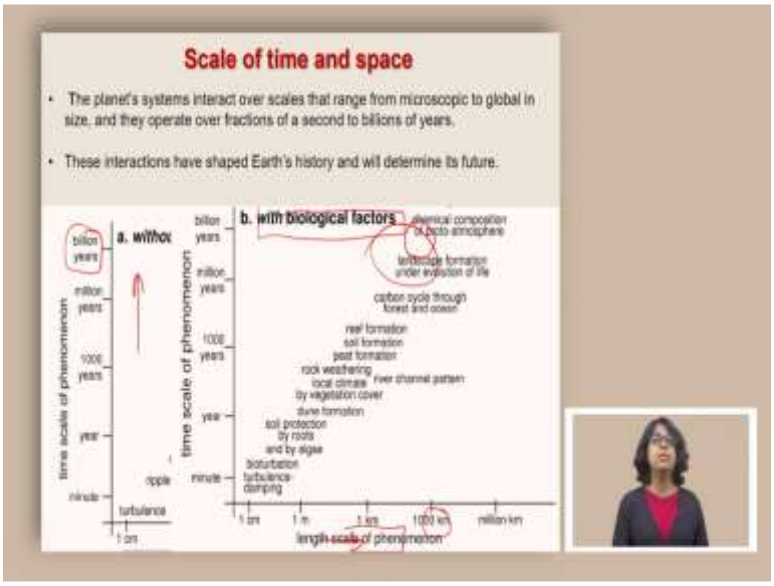

These things get even more complicated when we bring in biological factors. So, the previous plot was only a biological processes that are operating in the scale, but when we bring in the biological factors, then it can operate in these scales and some of the things are even more complex than a biological processes, which are not scalable. So, that is also important to recognise that these interactions need to be studied in a very creative manner that deals with the scale issue.

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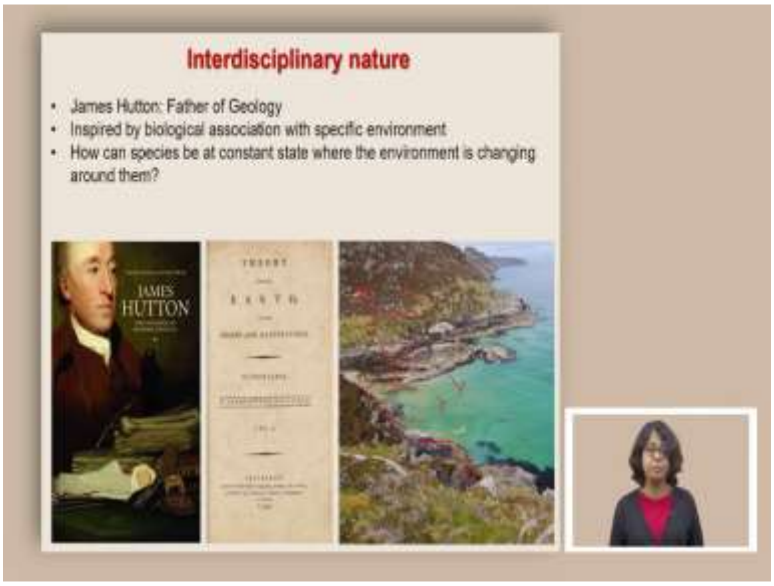

The other important aspect of Earth Science, which is really unique, is its inherent interdisciplinary nature. So, James Hutton is called the father of geology. He was actually inspired by biological association with specific environment, he always realised that wherever he goes, whichever geologic setting he encounters, maybe a small, shallow sea, or the cliffs nearby, the Association of animals, with these are always constant.

Now, his question was very interesting that, he observed that there are certain species that he finds in these shallow seas. And as he moves up the cliff, he is encountering different kinds of species, different types of mosses and ferns all along this cliff. He also observed that the environments are not constant, because he used to observe that part of this hill actually rolls down, and finally ends up being sediments into the sea. And he also calculated that in a year, how much of those sediments end up being in the sea.

And from that, he started thinking that over the years, if this process continues, then the environment is going to change the hill is probably going to be flattened down. If that happens, then how come that the species are at a constant state. So, it was already in his mind that either the species must be changing, or the environment is constant. Now through observation, he was convinced that the environment was not constant. So that only leaves the other possibility that the species are also changing. Now, this question is coming from James Hutton, who is considered the father of geology. And it is a very fundamental biological question.

So at that point of time, the people who were interested in these kinds of Science were called natural scientists or naturalists. So, there are no partitions of geology or biology, or in certain cases astronomy. All of these were natural phenomena and people who were interested in that all were called naturalists. And they were using various techniques, which were shared between them to address different questions, but we will see that often those questions actually helped each other to get a very general view of the nature and how nature works.

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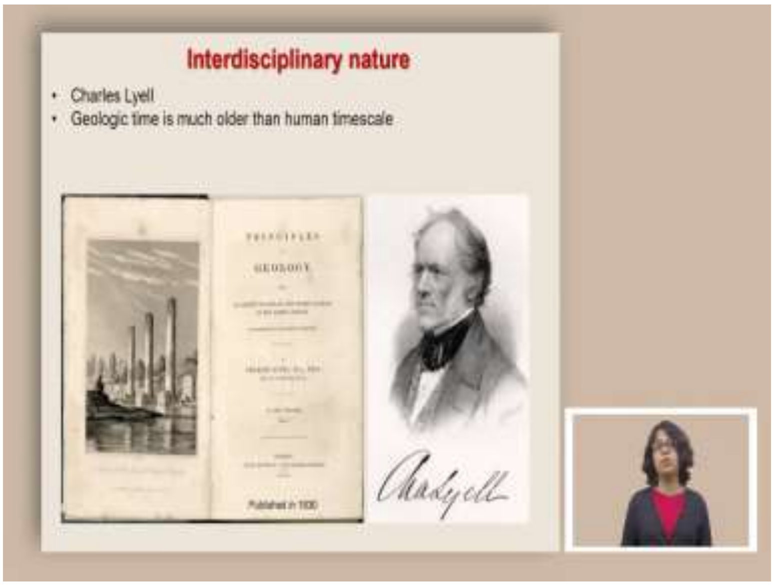

Another important figure in documenting the interdisciplinary nature of the earth science is Charles Lyell. Charles Lyell, demonstrated in his book Principles of Geology, that geologic time is much older than human timescales. It is a very simple statement, but it had a profound impact. Charles Lyell's book got published in 1830. And at that point of time, the concept of deep time was not favoured.

People primarily thought that Earth is not really older than a few thousand years. And Charles Lyell started arguing about it, and he said that it is much much older than what is predicted in terms of a few thousand years. His primary argument was that if we look at really large features, such as mountains, and we look at the processes that operate today, these processes take, these processes are slow processes, but we also see changes because of these processes.

So, that changes in the land form, which clearly shows that there was a mountain before and now there is no longer a mountain, that means the slow process must have flattened down the mountain. So, that means those slow process must have operated over a very, very long time. So that it led to this result of flattening of mountain and hence, the time that is required is very long, and hence the history of the Earth is very long. And this concept, that slow process, the processes that we are observing today, even though they are slow, if they are led to operate over a very long time, they can lead to results, which are very distinct and very dramatic, attracted attention from all spheres of science.

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So there was a young naturalist at that point of time, who was interested in biology. And he was inspired by this geological idea of vastness of time. He was so inspired by it, he started asking similar questions, but in a more biological fashion, he started asking this question, how can species be at constant state where the environment is changing around them? So this was again a question which was originally framed sometimes by Hutton.

But then he added this idea of vastness of time. And then he started thinking along these lines, that if the time is so vast, environment is changing, even the slow process of organismal change the changes that we see in every generation, if they are accumulating over this fast time. It can lead to a major shift in biologic composition of species, this young person was Darwin. And he used this idea, like the forces, Lyell talked, the shifting and rising and falling of land.

Darwin held that the forces seen today in the biological world, reproduction, inheritance and competition gradually produced the whole diversity of life on the earth. And he, after a lot of hesitation, he finally wrote down this in his book On the Origin of Species, which was published in 1859, which was primarily a result of observation decade long observation.

Which was one of the primary inspiration point was Charles Lyell’s book, because when Darwin took this voyage to Galapagos Islands, he actually carried this book along with him and read it every day to understand the geologic processes, and he was convinced that the biological processes of development of newer species is not very different. It is all connected to the processes that are operating today. But that has to operate over a very long time. And he was convinced by reading Charles Lyell's book.

That the time that we are talking about the history of the Earth is actually very, very old. And therefore, he can use this concept to explain the whole diversity of life through time on the Earth. So, in some sense, geology, biology, all these approaches to understand the nature are not very distinct. And therefore, the entire discipline of Earth Science is actually very interdisciplinary. To start with. It is not just a word that we use, it is at the core of this discipline.

Where we use different techniques to understand the nature and sometimes disciplines, other disciplines, findings in other disciplines actually corroborate our idea, our data and the sci, the field of Earth Science actually grows, evolves.

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So, there are a few important concepts of earth science that we will be using. The first one is the Earth is made up of recycled and recycling atoms. So, all the atoms that are being used, they were developed at certain point of time long back in history, and they are going through phases, and they are basically remnants of those very old processes in certain ways, we are made up of parts of the stars, which were developed long time ago.

Earth is immensely old when compared to human time frames, this is also a very important concept to keep in mind. The third point is Earth is three dimensional, and most of the action is hidden from view. So, the processes that we see are only processes that are operating on the surface of the earth, and many of them are connected to some of the deeper Earth processes, which we cannot directly see. But they are there. All kinds of natural things such as rocks, minerals, and fossils, all of them actually found in rock, minerals, and fossils.

They are the record keepers of Earth's history. And if you know how we can actually read Earth's history using these records, Earth history documents long periods of no change. That is what stasis means punctuated by sudden events. And we are going to encounter many of the examples of this situation. And that makes it complex when we are trying to use some of the modern observations to stretch back in time, because it is not always scalable in time, because sometimes these processes encounter abrupt halt.

Sometimes these processes fasten quite a bit. So, it is not perfectly scalable. And whenever we are designing a research question, that should be kept in mind, Earth systems are complexly interconnected. And that is also another issue of reproducing them in a laboratory setup, because in laboratory setup, when we are designing experiments, we always try to figure out the effect of one factor and try to negate the factors of other things which are influencing, but the Earth system is complex interconnected.

So, the effect that you are going to deduce just by a negating all other factors is not going to be realistic. And therefore, it is important to study those things in nature, when they are interconnected. And finally, one of the most important aspect of Earth Science is to recognise that life has changed, and continue to change the Earth's surface. And as a result, if you remove life, the Earth is not going to look, the way we look at it today.

And the Earth's history has been complexly, influenced by the presence of life at that point of time. And once we know more about life and how it evolved through time, it actually gives us much better understanding of how Earth evolved through time. And hopefully, all of these would give us better understanding to have a policy or to have conservation efforts to save the atmospheric condition of the Earth where we can live.

Otherwise, if you do not understand how this entire system works, which is a complex system, probably we in future we are going to face certain hard situations, the earth is going to survive, but the life on Earth may perish, or at least part of the life on the Earth may perish, and hence, an understanding a deeper understanding of the complex earth system is important.

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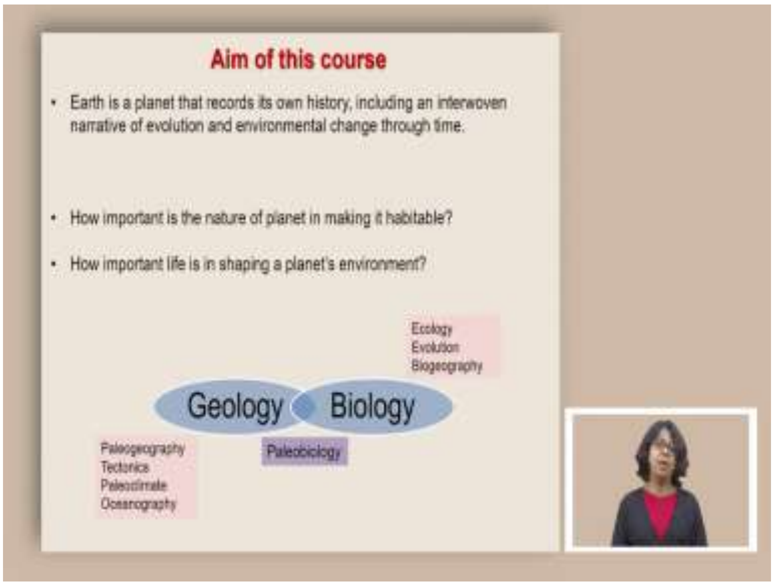

So, the aim of this course is to grow this awareness that Earth is a planet that records its own history, including an interwoven narrative of evolution, and environmental change through time. So, we are going to try to answer these two questions. One is, how important is the nature of the planet in making it habitable? Why Earth is only discovered planet where we find the life? Is there a very specific thing about the Earth, that makes it habitable?

But the second question that we are going to address is how important life is in shaping a planet's environment. So, if there was no life, would Earth look the same the way it looks today, or it is important to have life to actually make changes on the planet’s environment. So, it is a dynamic relationship of life and Earth that we are going to study. So, obviously, this course is in the interface of geology and biology.

And we are going to use different concepts from both biology including Ecology, Evolution biogeography, and concepts from geology, including paleo geography, tectonics, Paleo climate oceanography, and also something which is sitting right at the interface, which is called paleo biology. Using all of these, we will try to address all these questions that why Earth is a habitable planet. And once it is habitable, how did it change with time?

So, the way we see Earth today, what part of it was a contribution of life? And I am hopeful that the history of life through time will show you that how Earth evolved as a planet, in an interaction with life and in terms also changed the life on Earth.

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These are some of the resources that I will be using throughout the course. Thank you.