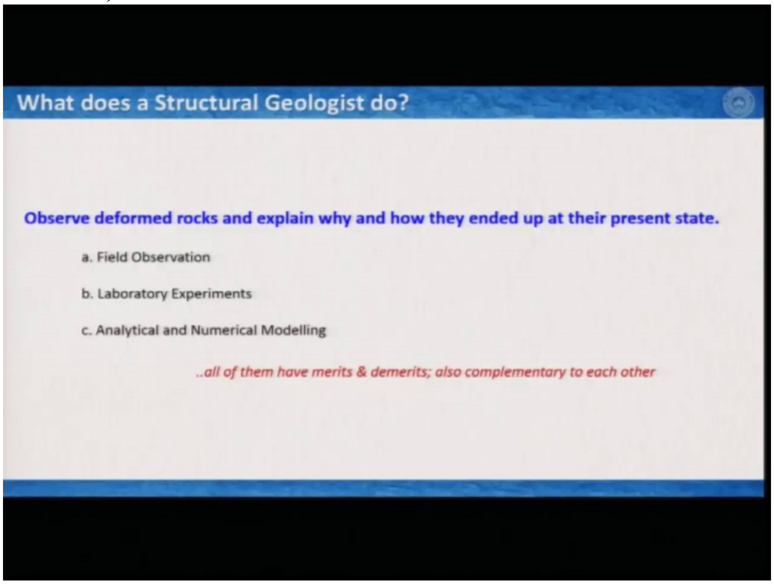
Structural Geology
Professor Santanu Misra
Department of Earth Sciences
Indian Institute of Technology Kanpur
Introduction (Part II)

Hello everyone. Welcome to this NPTEL Structural Geology course. We are at our lecture number 2 and we will continue today with this introduction.

(Refer Slide Time: 00:26)



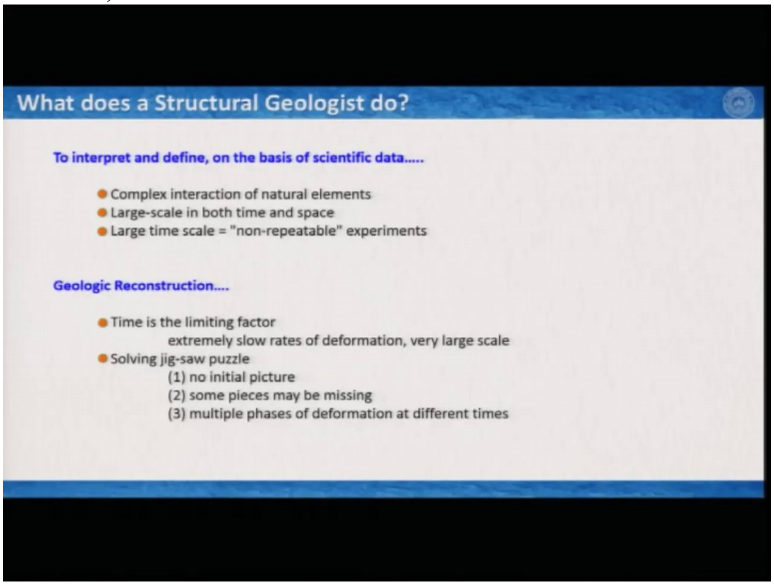
So where we stopped at our last lecture that what are the different ways to look at the rocks, particularly, when you see a piece of rock or a photograph the questions you should ask were, whether you are looking at a deformed rock, whether it is homogeneous, heterogeneous, isotropic, anisotropic, whether the structure is continuous or discontinuous and most importantly what is the scale?

Now in this lecture we will mostly cover what are the different ways to observe and interpret a rock structure? The question we would ask mostly today is what does a structural geologist do or what are the different processes that a structural geologist follows to interpret a rock structure? To answer this question what does the structural geologist do, is essentially to observe deformed rocks in very, very intelligent way and explain with some scientific observations and evidences why and how they ended up at their present state.

And to do so, a structural geologist has many approaches. And one can categorize it in three different sections. The first one is field observation, second one laboratory experiments, it can be real rock deformation experiment or analogue experiment and of course analog, and the third one is the analytical and numerical modelling.

Now these three basic tools have their own limitations. We will learn it later but at the same time these three tools are also complimentary to each other, that what you cannot observe or understand from the field, you can understand if you perform an experiment in the laboratory. So to continue this question again that the main job of the structural geologist is to interpret and define on the basis of scientific data and at the same time a structural geologist also does geologic reconstruction.

(Refer Slide Time: 02:46)



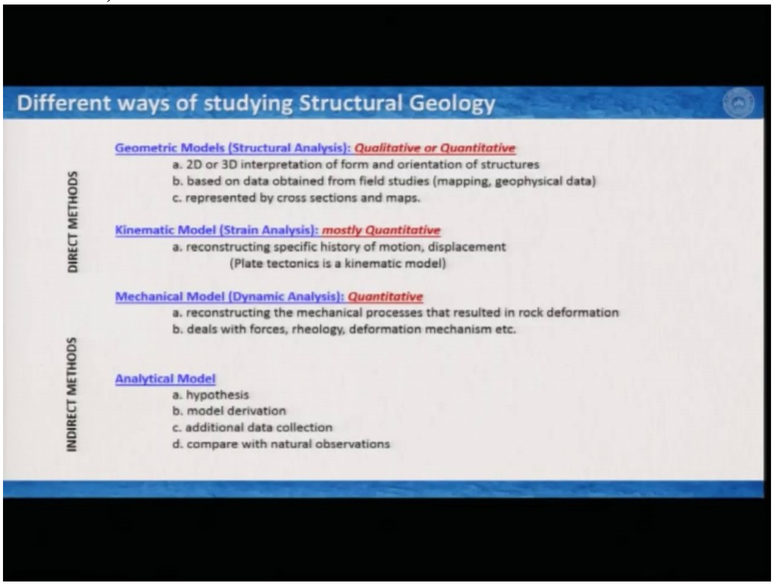
So, in the first part. to interpret and define structures, a structural geologist has to deal with very complex interaction of natural elements. We will look at it, all these processes soon. Then most of the geologic structures as you can imagine, these are extremely large in their extent. For example, you can think of Himalaya or the complexity of South India and so on. And these structures have formed with time scales that ranges from million to billion years. And few processes are still happening.

And with our human life span, we cannot see it happening, right? So, we see the end product and almost fossilized. A structural geologist has a challenge to interpret this large scale in space and time. And one more important thing that structural geology has, which is somehow advantageous to us is that most of the processes that happen in nature are non-repeatable or non-reversible in nature. If something has happened then you cannot go back with time, in most of the cases.

Geological reconstruction is another type of challenges because it has several limitations and structural geologists have to solve a series of jig-saw puzzles. For example, as I was talking about the, that it takes a lot of time to produce a structure. The rate of deformation in earth is extremely slow in almost every case. There are of course few deviations of this. For example, if you have an earthquake, or if you have an impact crater formation so that, these, there are few things that happen very quickly but most of the other cases, the rate of deformation in earth is extremely slow and it is almost impossible to track through a human life. And then you do not have any initial picture. That how it was, how it looked before? You don't have the entire picture as well, because some pieces are missing. You also cannot access all the areas, even if you can access, maybe there is no exposure.

And on the top of that, the deformation that we look at on the surface, it is not a single deformation. That means one deformation has happened sometime ago and then later some other deformation which is occurring from other directions or in a completely different nature, it is either demolishing or overprinting the previous deformation. So this is a challenge of a structural geologist to reconstruct and interpret, separate out these deformations and what has happened at the first deformation, what has happened in the second deformation and so on. So at one point, at one time this is really challenging, sometimes frustrating for a structural geologist, but at the same time it is extremely fun. And this is why structural geologist, most of the structural geologists like their job very much.

(Refer Slide Time: 06:11)



So there are three basic ways a structural geologist looks at the structures in earth, or in nature. So these are geometric models, kinematic models and mechanical models and you can classify them together as direct methods of observations. To understand that geometric models, these are mostly qualitative and sometimes quantitative. It does not involve any other detailed scientific, what it does, it simply tries to interpret from what we are observing, its 2D or 3D representation, its orientation, how it is, in a more comprehensive way. We will look at some examples later and these are mostly done using some data obtained from field studies or some experiments.

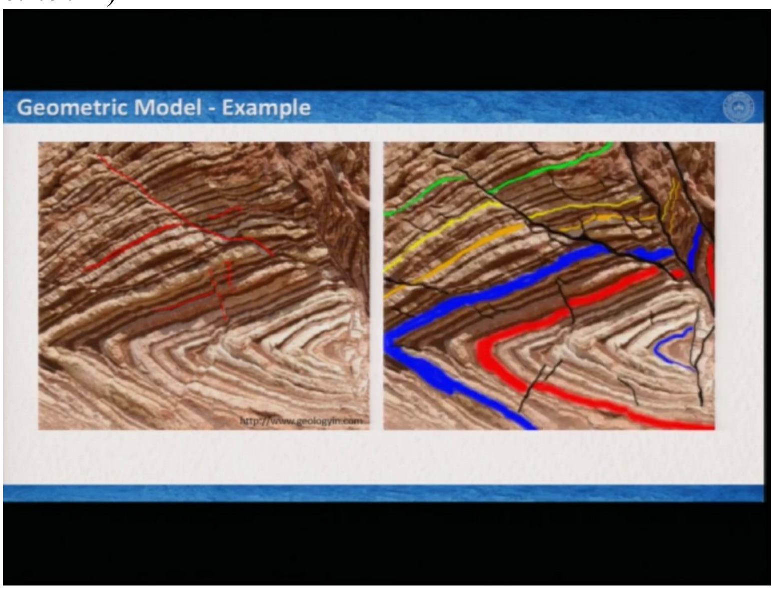
Kinematic model on the other hand is the next stage of the geometrical model where a structural geologist after constructing the geometric models try to understand what are the different motions at different parts of the structure? That which part has moved which way relative to the other parts. That helps you in the next stage to understand the deformation, displacement, motion of things. You can imagine plate tectonics which actually deals with the motion of the plates, is a kind of kinematic model.

The mechanical model which is the most developed or the most advanced model among these three, or we call it dynamic analysis which is highly quantitative; this model involves interaction of material properties and forces and so on. So, these are mostly done by performing some experiments, reconstructing the features in the laboratory and so on. These three geometric models, kinematic models and mechanical models are very important direct methods of structural geology study.

Then there is another method. We call it indirect method. In indirect method a structural geologist may hypothesize a feature that Himalaya has formed by this, this and this and then he or she tries to understand it by performing some models, experiments or numerical models. The structural geologist collects data from the field and then either prove this hypothesis or disapprove this hypothesis. So, this is some sort of models or ideas that most of the structural geologists nowadays do and these are done mostly for the processes that we do not see.

For example, we do not see the plumes, we do not see the mantle convections, so there are many hypothesis and models by which a structural geologist or tectonics expert or a geo-dynamic expert, they try to work on some indirect methods and these are known as analytical models. In the following slides we will mostly focus on these geometric, kinematic and mechanical models and I will try to give you a very basic idea that what are these, how these are done and most importantly how these are being applied to the real field. Okay so let us start with the geometric model.

(Refer Slide Time: 09:44)



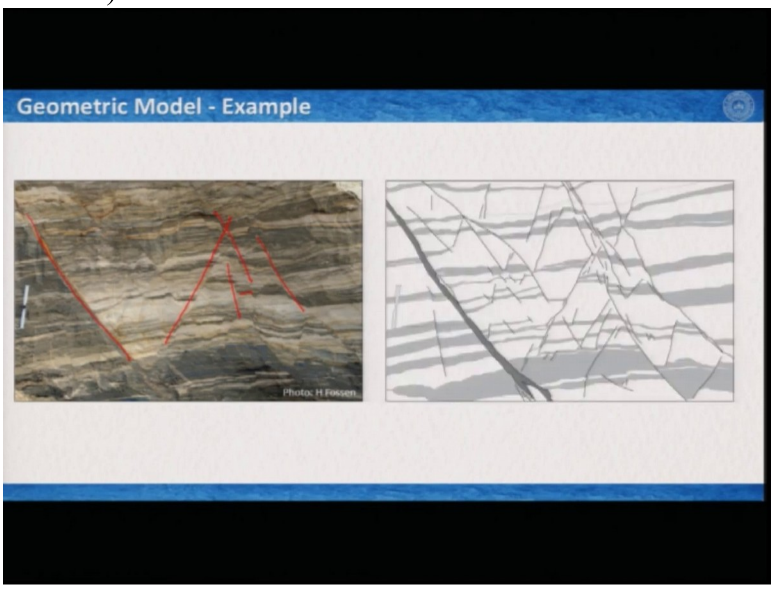
If you remember in the last lecture, I talked about fold and this is a fold. So what we see here? These light yellow and dark brown alternate layers, these are folded, and the thickness of these layers did vary during the deposition and it remained intact while it got folded. Now if it was a simple fold then no problem, we can simply trace one layer and figure out how did this fold happen, which layer is what.

But this structure is somehow discontinued with some slips, for example this is one. We can see from this relative displacements that it moved from one to another. But this is part of the kinematic model which we are not looking at. But the challenge is to trace, that if I look at this layer, this brown layer here then where it is in the other side. In this case, it is simple, it comes here.

Now similarly if I look at this brown layer and again, I have a discontinuity here then my challenge is to find out whether it is this one or the other one. Now whatever interpretation you make out of this, that whether this is this layer or the other layer, you have to come up with some sort of logics and this logic is the fundamentals of geometric model.

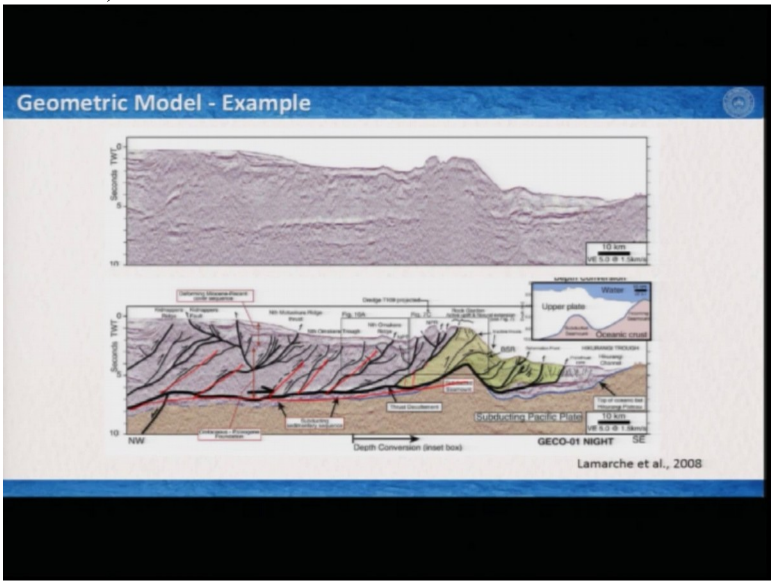
For example, with this model, with this photograph I prepared this geometric model. I did not cover all these layers but few of the layers are color-coded and they are represented in this way. So this is a very simple example how geometric models in structural geology are constructed. Can we apply it to a little large scale? The answer is yes.

(Refer Slide Time: 11:49)



Here we have one syn-sedimentary deformation and you can see that this alternate black, white and few light brown layers got disturbed by a series of faults. To understand it better what I try to do? I tried; I made a geometric model of it which looks like this. And here you can better understand what are the different geometries of the layers, which layer moved where, which layer is continued to where and so on.

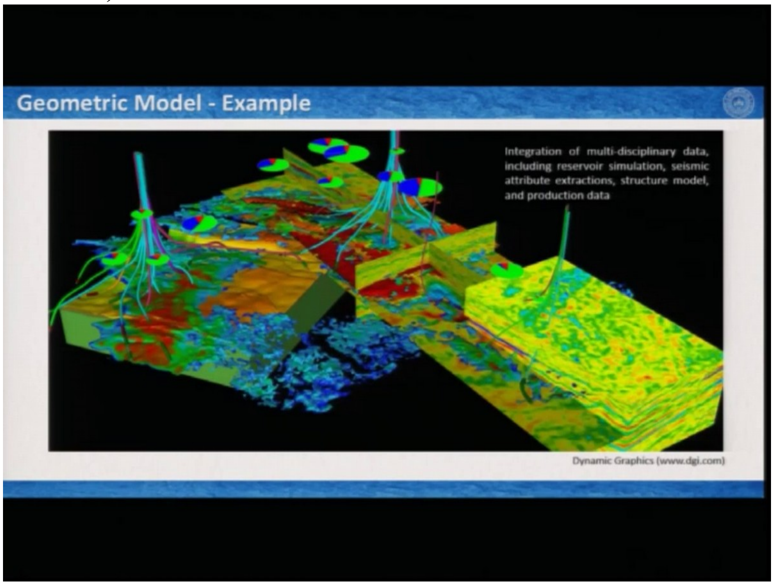
(Refer Slide Time: 12:31)



Now talking about the large scale, this is a seismic reflection image of a subduction plate, a plate which is subducting under the sea floor. Now looking at it, apparently it looks very homogeneous with some sort of topography and some other little features. Now creating a geometric model of this reflection seismic data is a daily routine of a seismologist and a structural geologist helps in this process significantly. So if someone who is an expert of constructing geometric models apparently which is look extremely homogeneous and most likely there is nothing but this person would interpret this structure in this way.

So what you can see, it has a basal decollement and then series of thrusts are imagined from this basal decollement with the reflection data and some velocity calculations, one can also find if there are some different lithologies and so on. Again I repeat, this model does not include any of the material parameters. I had some data and with this data I had to interpret what has happened there. That is it. This is the geometric model. Can it be applied in other fields? The answer is yes.

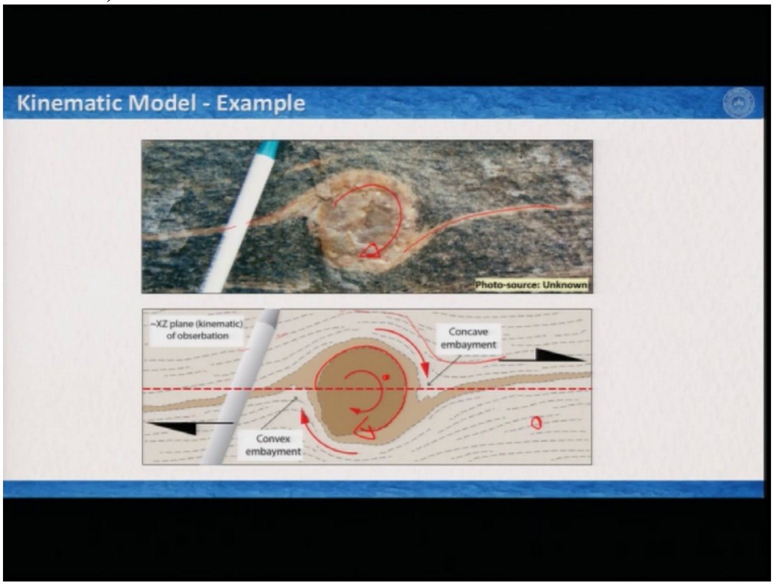
(Refer Slide Time: 14:05)



What we see here, this is integration of different sets of data. This is a computer-generated image. It involves millions and billions of data. This is hydrocarbon reservoir somewhere in the North Sea. I took it from the internet so dynamic graphics is the website, you can go and check. What we see here with this geometric model, these red patches that we see at different areas, these are oil-rich areas.

So once the geometric model comes up properly with the interpretation of different geophysical, structural and other petrological data it is possible for an oil engineer to design the wells and then it can actually intrude different parts of this, hydrocarbon reservoir and extractor. So geometric model is essentially important not only for understanding the structures but at the same time, after understanding the structures one can also explore simply by constructing a perfect geometric model.

(Refer Slide Time: 15:19)

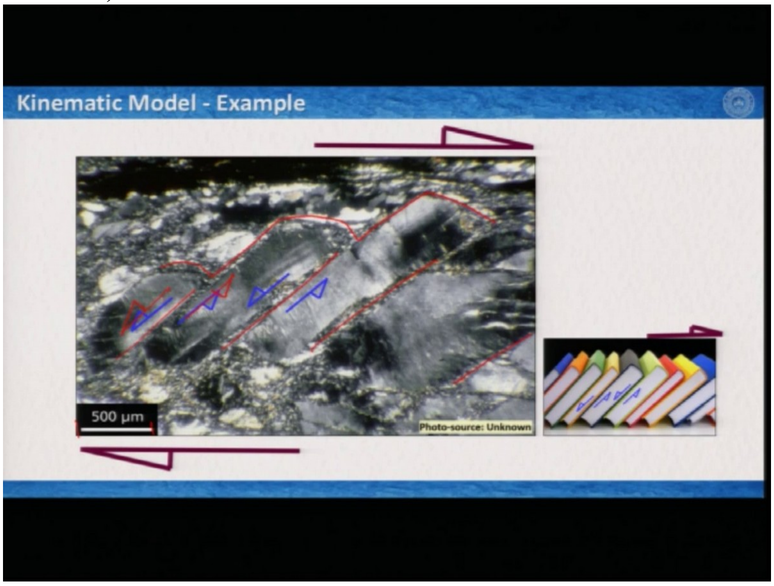


Let's look at the kinematic models. As I said kinematic models are one step advanced from the geometric models because after constructing the geometry, the kinematic model includes the relative displacements, motions of the observation we are making at. Now what we see here at the top photograph is a very classic structure that we commonly observe in ductile shear zone. We will learn about it later. This is known as delta structure.

Now looking at it, if we try to construct this geometric model without all these arrows and so on, this is how it should look like. Now it is possible to look at this structure and with some other observations that this little ball which is inside, maybe it is rotating this way, and therefore you have some sort of tail-like features at the both ends. You can also construct this foliations or little layers outside that concave embayment that also proves that while this little ball is rotating, it was also dragging the other layers.

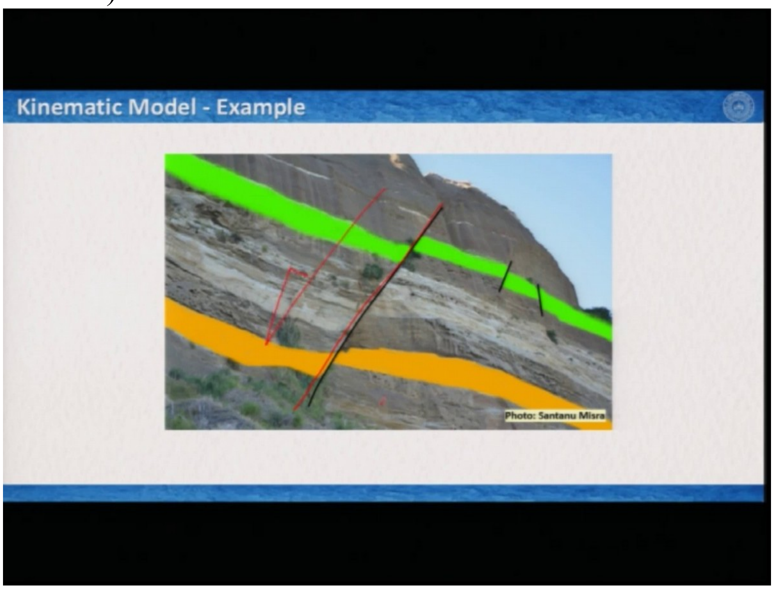
Now again this model doesn't consider what is this material of this ball, what is the material outside, and so on. It simply constructs first the geometric model and then it considers that what was the relative motion and this is very important as shear sense indicators in structural geology. There are many other shear sense indicators but this is one of the most important ones.

(Refer Slide Time: 17:06)



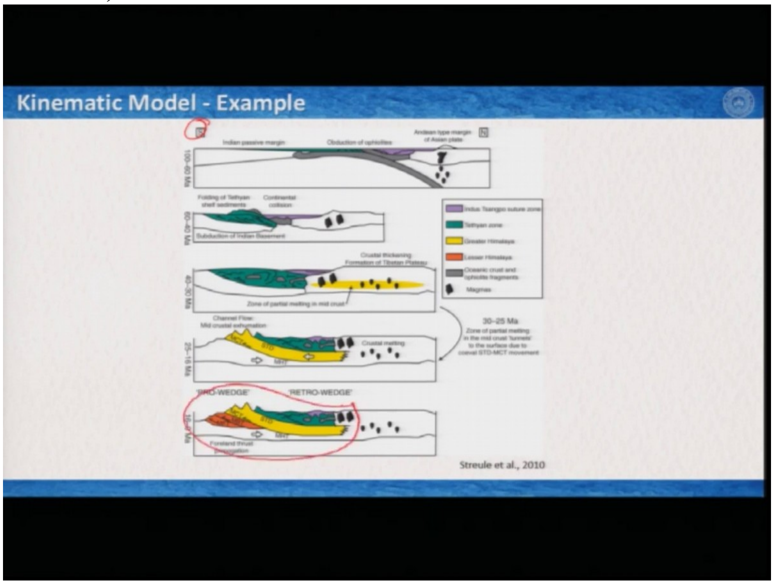
Now here is another one. This is microstructure observed under microscope. You can see the scale here this, this length here is about 500 microns. What we see here, a mineral grain is broken along this lens and then there are some sense of steps. Now these steps indicate that one grain has moved past another grain. And just looking at this we can construct that this grain has moved down relative to this and similarly others. Now this is a classic structure of structural geology in ductile shear zone as well, in brittle ductile shear zone and this is known as bookshelf structure. So this is how it happens. So if you have a series of books you tilt the books then they rotate past each other. And this is how they slip individually. So this is a kinematic model again.

(Refer Slide Time: 18:05)



This is a field photograph and looking at it, I color-coded the two layers with green and orange and this displacement plane that has happened. So you can quickly, just looking at this geometric model you can say that this entire block has moved this direction relative to the other block. So once you interpret this, this you are actually working on a kinematic model.

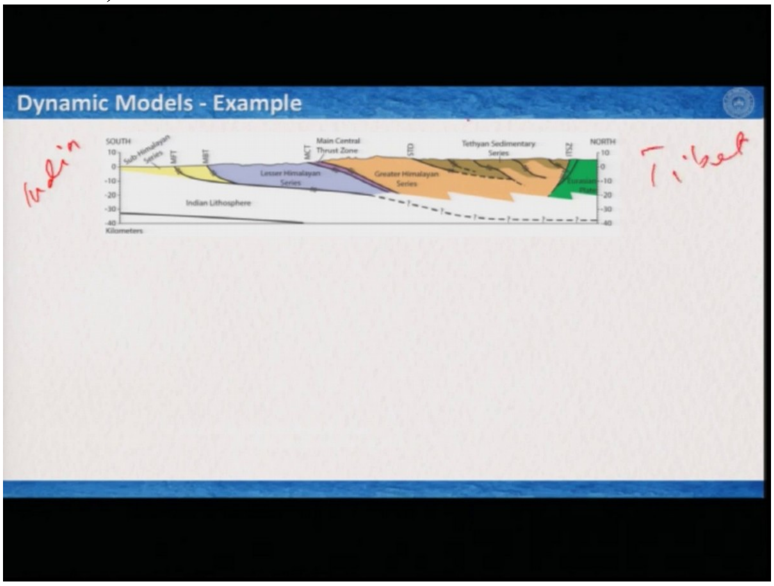
(Refer Slide Time: 18:37)



Now in large scale as I said, you know in the past lectures the tectonic model, the plate tectonics is some kind of a kinematic model. Why? Because it doesn't involve the individual material properties of the plates, what are their different properties and so on. It simply constructs that how one plate moved relative to other, what was the mutual interaction between them and so on. So this is how Himalaya is conceived, the development of Himalaya.

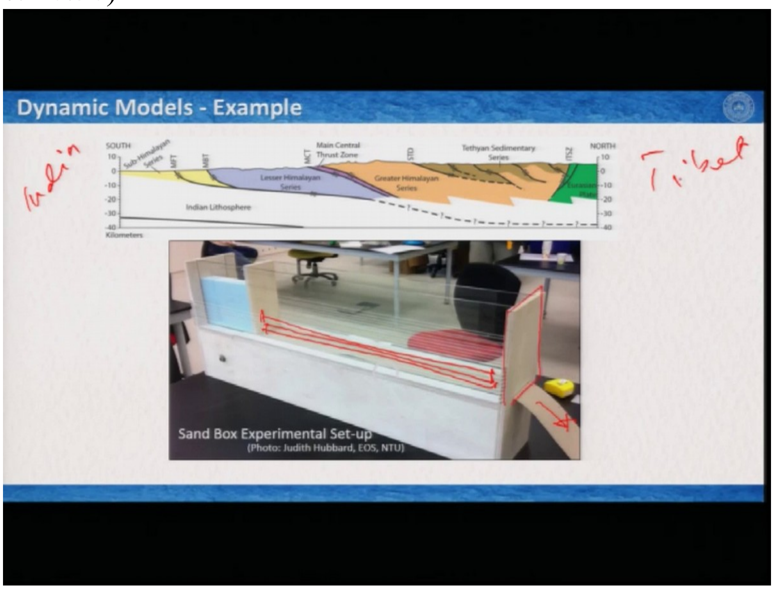
So on the south side you can see, this is south, you have this Indian plate and then here you have Tibetan plate and then Indian plate moved with time and then we have formed series of thrust faults and then this is the present day configuration of Himalaya where we have lot of faults, major faults are known as MCT, MBT, MFT, STD and so on and there is also certainly a basal decollement which is MHT, Main Himalayan Thrust. Now this is a kinematic model. It does not involve any sort of forces. It does not involve any sort of material properties, the dynamics of these plates and so on. But if we have to involve that then actually we are approaching to develop a dynamic model.

(Refer Slide Time: 20:03)



Let us have a look. So this is again the cross-section of Himalaya and what we see here that, in this side you have India, the southern part, so here you have India and here you have Tibet. So in-between you had this Tethyan sediments that got squeezed out from series of crusts, from series of thrusts and we have this present configuration of Himalaya. Now to understand this entire process how did it happen, one can perform a dynamic model by conducting sandbox experiment.

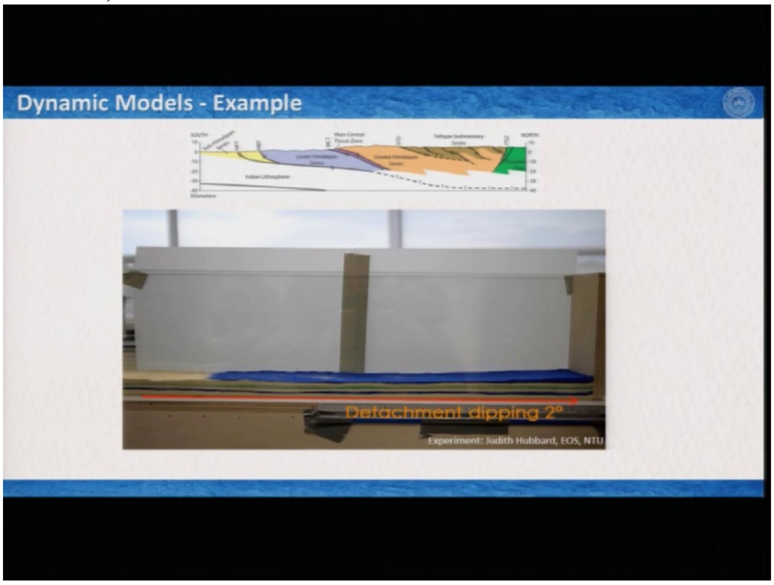
(Refer Slide Time: 20:36)



So a sandbox experiment is a very simple experiment which is scaled down from the nature. So this is a typical sandbox. What it does that, in this space you actually add series of layers of sands. You add different colors to distinguish the different layers which represent or which are analogous to the sedimentary layers and then you drag this belt so that these sand bodies, entire sand bodies move from one side to another side and this is a block which is analogous to the rigid Tibetan plate where the entire Tethyan sediments are hitting and we would like to see what is happening here.

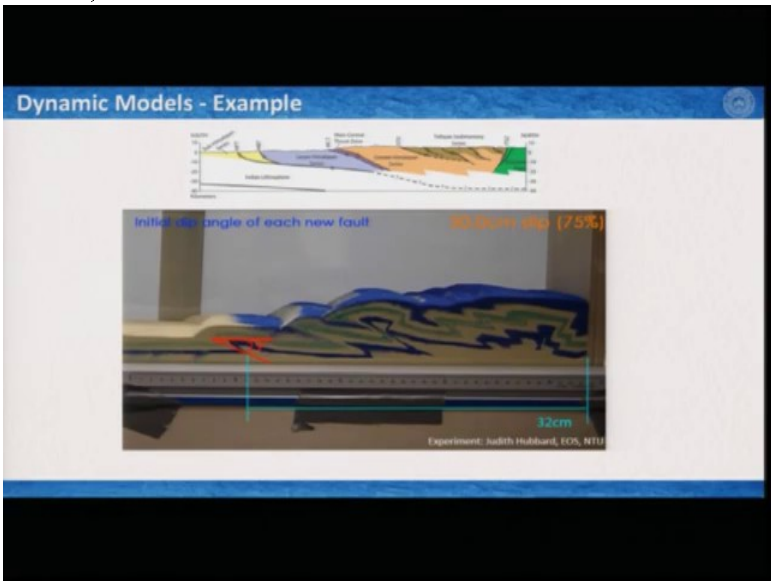
Now what you see here, that we are involving the materials. We would like to see what is happening with them. So this is a dynamic model. We are involving some sort of forces as well. So let us have a look of this movie and see how it works.

(Refer Slide Time: 21:33)



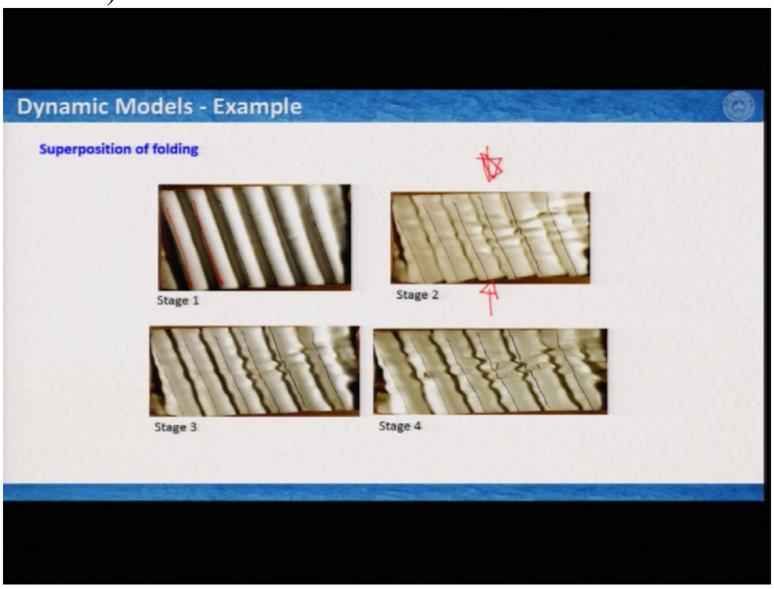
So this alternate yellowish dark blue, then again yellowish green, yellowish and the dark blue, these are different sand layers representing or analogous to the sediments, sedimentary layers and you see deformation has already started. The belt started moving from this side. What we see here with more displacements a series of thrust folds are being formed. So these type of models not only discuss the dynamics of the processes but it also tells you the evolution of the process, that how from one setup, one geologic setup you actually achieved a different geologic setup just by adding some sort of deformation.

(Refer time slide: 23:31)



So this is a quick view of this entire experiment. You can see series of thrusts being formed. They formed at different angles initially and while they rotated they achieved a different angle. It also achieved some sort of elevation and these are the very basic or key ideas of mountain building processes and one can observe all these processes using a dynamic model.

(Refer Slide Time: 24:04)

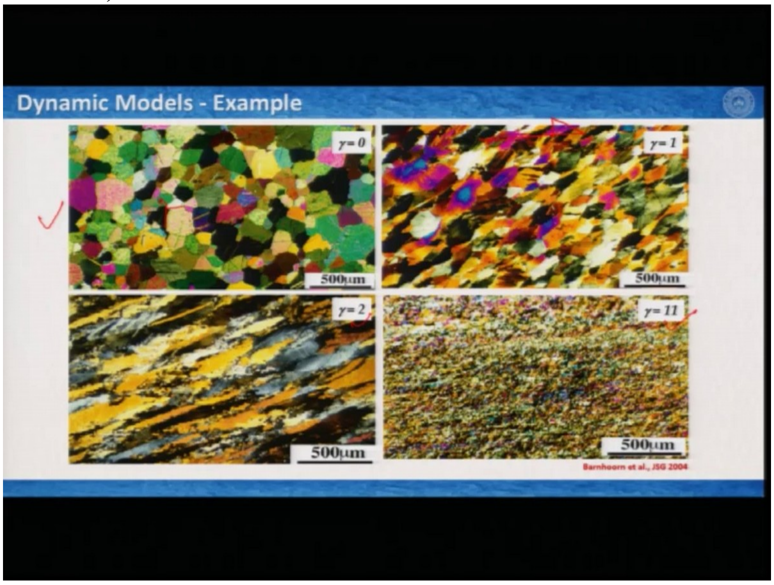


Now if we try to look at to another geological process which is folding and we try to understand how one fold interferes with another fold in nature, then one can perform the analogue experiments. So here is an example that we have performed in the laboratory. What we see in Stage 1, we have prepared one fold, one set of folds here where you can see the folds are here and these are the hinge lines of the fold marked by the black lines.

Now the folds are at an angle and then if I compress it, this is what we have done, then we see some tiny folds are coming up. And these experiments were performed to understand whether the new folds are generating are as big as the previous one or they are small of the previous one or even larger than the previous one and we figured out that no, these are small, at least these are very small in this case.

But this is a dynamic model. We tried to, why? Because we tried to see, we tried to mimic the layers of the geological features like the layers when we form folds. These are ductile so we used some putty or plasticine layers which are ductile in nature. The scales and other things are also maintained with respect to the geological scales. So this is again a dynamic model.

(Refer Slide Time: 25:32)

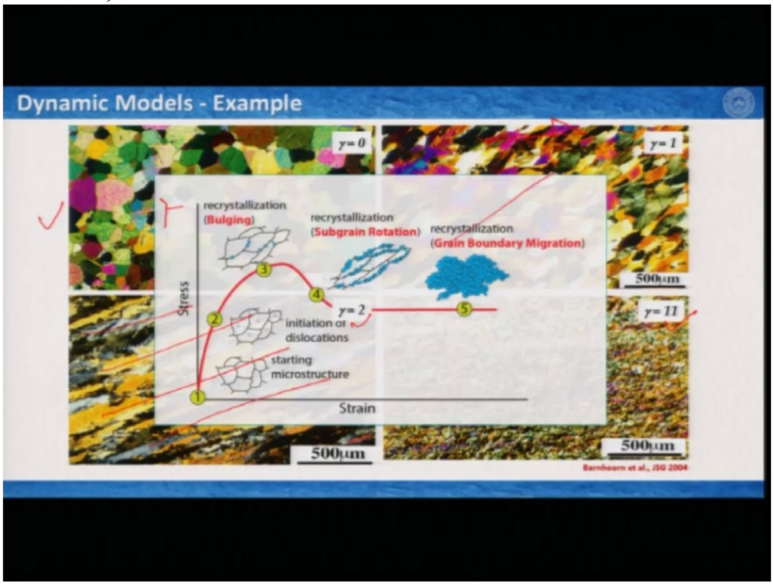


Now, one can also do real rock deformation experiments at high pressure and temperature because most of the deformation processes in nature, that happen at depth and there we have pressure and temperature. So here is an example. A series of experiments performed by one of my colleagues OK, in ETH Zurich with his famous Color marble experiments.

So the first image what we see here is an intact, un-deformed color marble. You can see the grain size is in equilibrium, more or less similar grain size. It has nice triple junctions and so on. And then OK, sheared this at high pressure and temperature and you can see, if this is the shear direction, he applied and with evolution of the strain, this is shear strain 1, this is shear strain 2 and this is shear strain 11, you see first what you observe is that the initial grain size of Color marble has reduced to a very fine grain size rock.

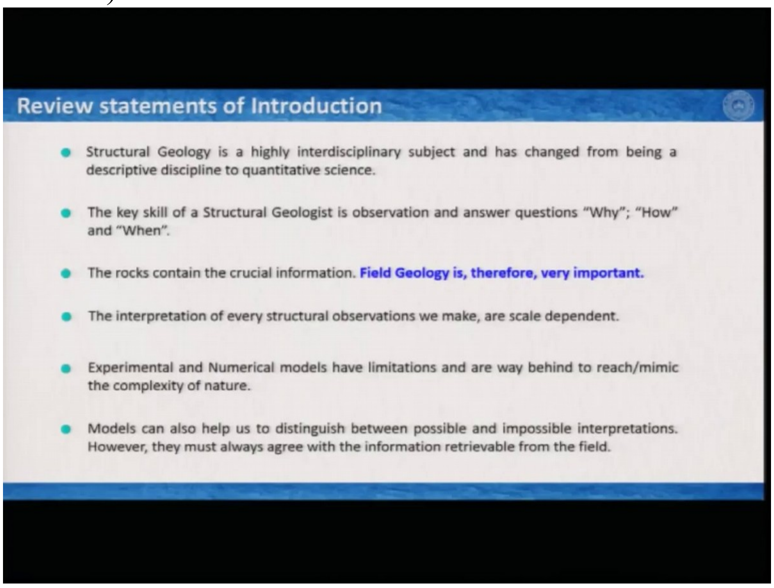
And with time you can also see that here we are trying to develop some sort of directional layers, okay in the rock and this is exactly what happens in nature and in experiments you can produce that with real rocks. So this is a dynamic model.

(Refer Slide Time: 26:59)



And based on that, with the stress-strain curve one can actually understand that at which stage of this deformation what kind of features you see in your microstructure.

(Refer Slide Time: 27:10)

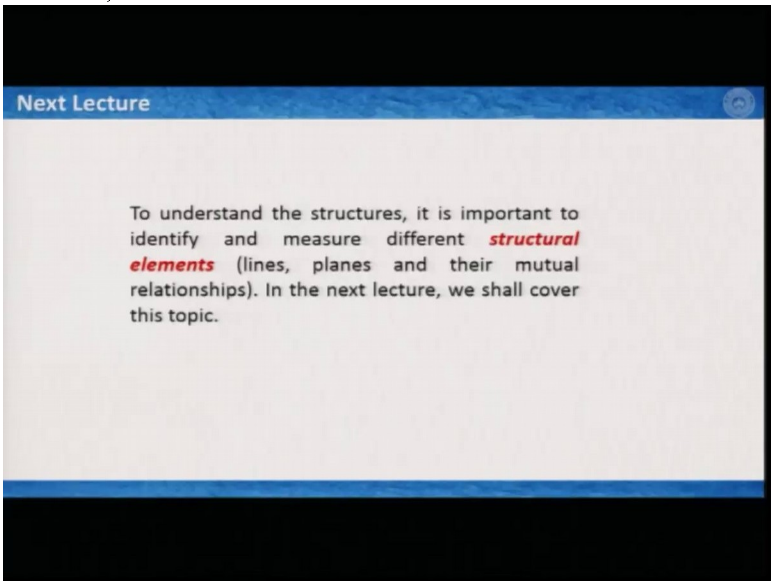


So we are at the end of this lecture so some review comments from this introduction section that we had in this lecture and the previous lecture. So structural geology is highly inter-disciplinary subject as you have understood and it was initially little bit of descriptive subject but now it is very much quantitative science.

The key skill of a structural geologist is essentially how you observe a particular feature in a piece of rock, or in an outcrop and then based on your observation you try to answer these questions why, how and when. One of the most important conclusions that we would like to make from this introductory lecture that it is the rock that contains the information. You have to go and see the rock in the field. So therefore field geology is very important for structural geologists. The scale is one of the very important parameter to study structural geology.

Whatever interpretation you do from a structure, it is important that you remember what is the scale. Experiments, numerical models etc have their own limitations but they are excellent to mimic the complexity of the nature and they also complement each other. Whatever interpretation you do out of your experiments or numerical models, it is important that you validate them with the nature. So I conclude this lecture.

(Refer Slide Time: 28:41)



And in the next lecture we will start a new topic that what are the different structural elements that we measured lines, planes and their mutual relationships. Thank you and stay tuned.