Structural Geology
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Introduction (Part I)

Hello everyone. Welcome to this NPTEL Structural Geology course. This course is being offered for the undergraduate students and designed accordingly. In the first two lectures, we will cover the introduction and then slowly we will jump into the other topics of the subject.

Before going into the actual course, we will have some administrative parameters that we will follow in this lecture and then we will proceed. So, before we start, I am your instructor. My name is Santanu Misra. I am a faculty member in the Department of Earth Sciences of IIT Kanpur.

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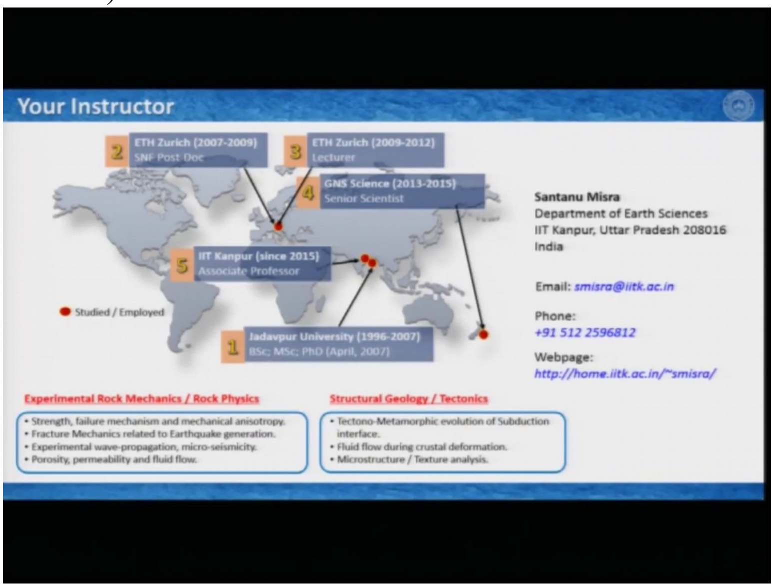

About my academic background: I studied Geology in Jadavpur University. I had my Bachelor degree, Master degree and also PhD degree from Jadavpur University. Then I moved to ETH Zurich in Switzerland for a post doc, later I became a lecturer in the same institute. I learnt mostly Experimental Rock Deformation and worked on high pressure temperature deformation behavior of rocks. Then I moved to another beautiful country, called New Zealand. The institute was GNS Science. I worked there on earthquakes and landslides phenomena.

In 2015 I decided to come back to India and joined IIT Kanpur as a faculty member. My research interest mostly includes primarily experimental rock deformation, rock physics, structural geology and tectonics. Throughout this course or even later you can contact me via this email. You also can call me during the office time and to know more about my research, my research group and other activities, you can follow me via my webpage.

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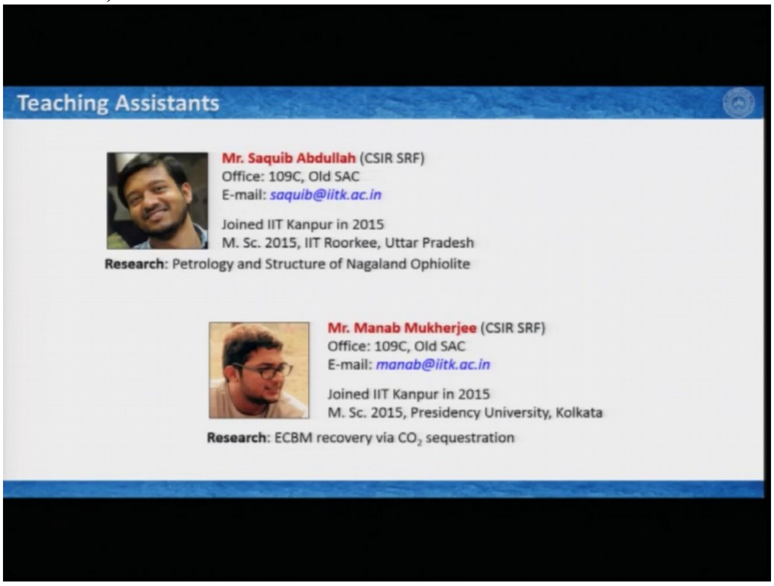

Saquib and Manab, are the two TAs of this course. They are teaching assistants. Both of them are my PD students. They are CSIR Senior Research Fellows in IIT Kanpur. Saquib joined in 2015 and Manab as well. Saqib works on petrology of structure of Nagaland Ophiolite sequences, and Manab works in the direction of rock physics and he works on enhanced coal bed methane recovery via CO2 sequestration.

About the study materials for this course there are *n* number of books, there are *n* number of online resources that you can explore.

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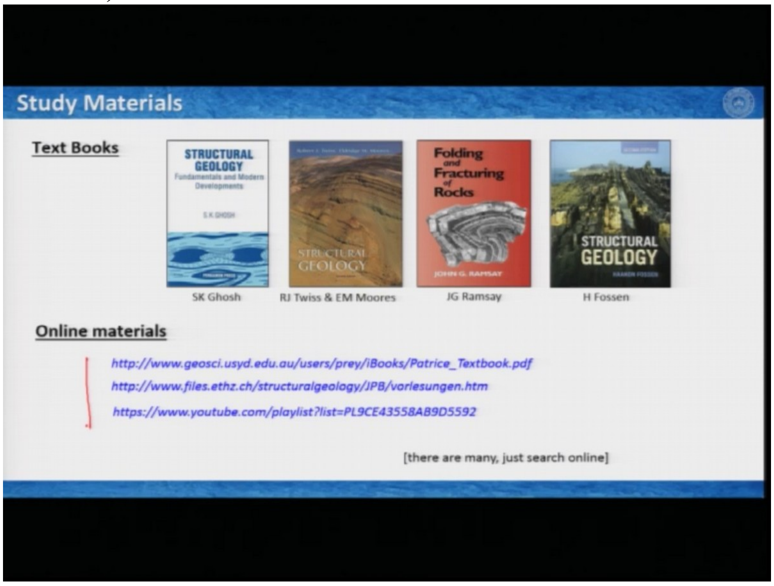

I particularly recommend these four books and a few online materials which will be helpful for this course. And, I also derived most of the study materials from these four books and these online materials. The first book is the book of Structural Geology, Fundamentals and Modern Developments written by Professor S K Ghosh, who was a Professor in Jadavpur University, Kolkata. This book is little bit of advanced level for an undergraduate student but initial sections are written in a very general way, in a very scientific way so that one can understand.

What I like about this book, particularly for the students of India, that the examples of geological structures are cited from Indian continent, or different Indian fields. So, if you go to the field you can see those structures and relate yourself. The second and third book are the two classic ones.

The second book is Structural Geology which is the second edition of Twiss and Moores. It covers entire span of structural geology. And the third one of Professor John Ramsay, Folding and Fracturing of Rocks is a classic textbook of structural geology ever considered. It is very important to have this book in your library and it is worth reading book.

Fourth book is relatively new in the structural geology field written by Professor Fossen. What I like about this book is it is written with examples with lot of applications; the language is very easy to comprehend and understand. And most importantly this book has fantastic field photographs, colored field photographs and in addition to this, a complimentary CD of illustrations which are essentially helpful to understand different structural features.

About online materials, I recommend these three. So, the first one is a textbook in pdf by Professor Ray Patrice, the second one is lecture note from Professor Jean-Pierre Burg. And the third one is one YouTube lecture series given by Professor Janos Urai of Aachen in Germany.

In all these three materials you will get excellent illustrations, very nice texts and particularly for Professor Urai's lecture he has given lots of analog models and numerical exercises which will be helpful for you. Needless to mention, there are n number of, there are series of online materials which are available.

You just have to type online that what you are looking for, you just type the keywords or the phrase or the sentences and you will get series of suggestions from Google or whatever search engine you use and you can figure out what you are looking for. I am sure you will get it. If not, you are always welcome to contact me or the two teaching assistants of this course.

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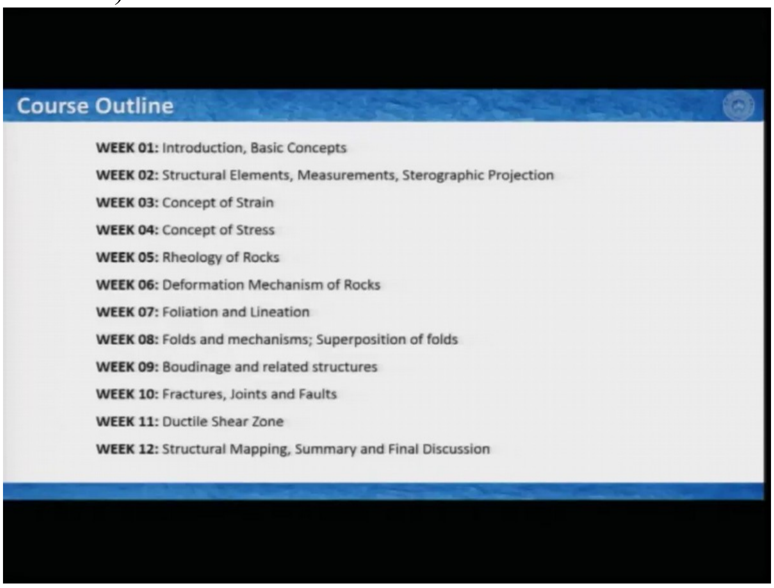

This is the course template of this course outline of this Structural Geology course. The course is designed mostly following the general undergraduate courses that is being followed in India and globally. So it is a twelve weeks course. Initially we learn at least in this lecture and in the next lecture, introduction and basic concepts of structural geology. Then we will follow the certain different aspects sequentially one after another to cover different structural elements, their measurements, stereographic projection. We learn about strain and stress. We learn about rheology and deformation mechanism of rocks, then slowly we will go to the actual real rock structures that we see in the field like foliation and lineation, different types of folds, their formation mechanisms, superposition of folds, then boudinage and related structures, fractures, joints everything. Then we move to the ductile domain that is the ductile shear zone which is very important in structural geology and in general. And finally, we will end up with some notes on structural mapping, summarize this course and do some discussions for the future developments and studies.

The question that one should ask at the very beginning that, why I should study structural geology? Personally, I like this subject very much. We will see in course that this subject makes you like a detective. Like you have something in your hand, this is a puzzle. You have no clue what happened in the past. So, your challenge or your task is to, whatever you have in your hand, just looking at it, observing it, analyzing it, you have to go and understand what has happened in the past. So, in a way, this is a very challenging work and I like it very much. Apart from this, you of course would like to ask what are the job opportunities, what are the different aspects like, what is the use of studying structural geology in the context of present-day society? The answer is: it is significant.

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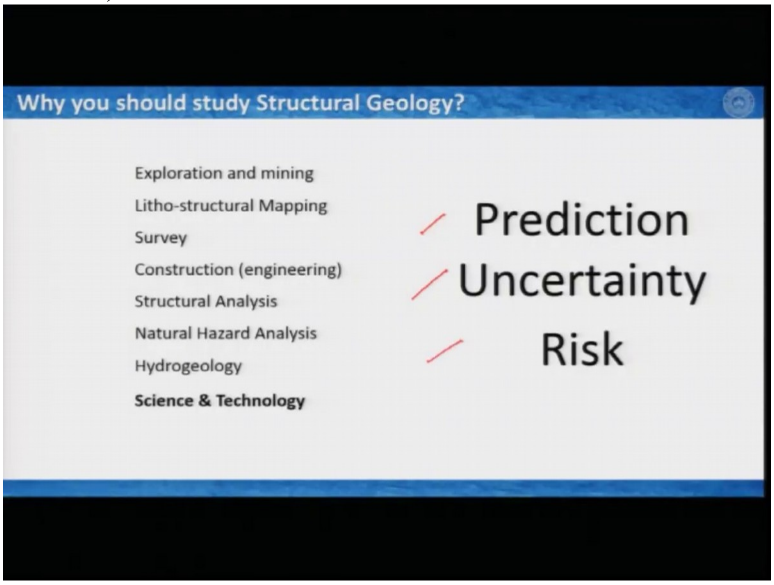

So, if you are structural geologist, your demand is in many industries and also certainly in academia. You can be recruited or you can be hired if you are good enough in exploration and mining industries. You can be also hired in litho-structural mapping and survey companies, construction engineering and structural analysis of different surface and subsurface materials. If you are interested to that, there are many industries who are involved in this type of work and they will certainly be interested to hire you.

For natural hazard analysis, earthquakes, landslides and so on, your job is secured if you are good at it. Hydrogeology is also one of the areas where structural geologists are in high demand. And apart from this, I can certainly join in academia and petroleum industry and other places where you can work on science and technology development.

As I said that structural geology is a subject that unravels the past of the earth, the history of the earth in a certain way and there is no clear picture of that. We have to figure out things what we have today in our hand. So, these three terms, predictions, uncertainties and risks are somehow very much associated with this subject. Whatever you do, you should have some sort of prediction, some sort of risk and some sort of uncertainty in your discussions and in your results. Always keep this in mind.

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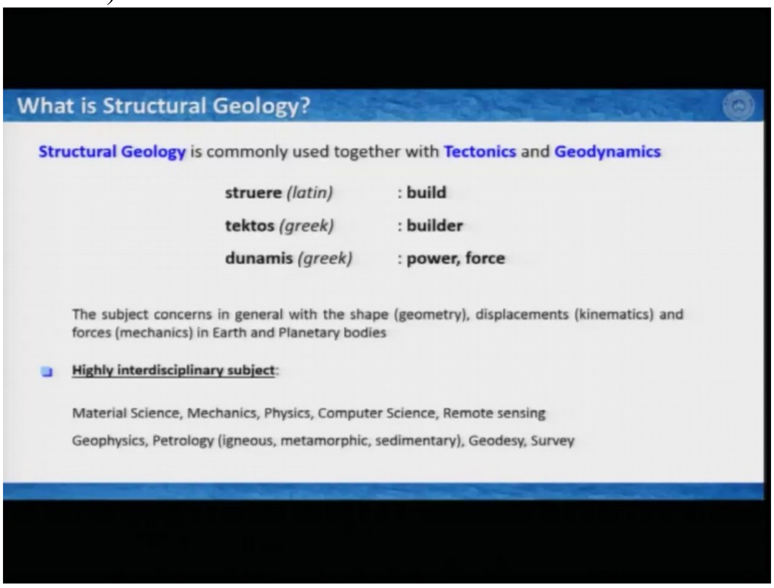

Ok, so what is structural geology? Now if you have heard this term before then you must have heard also these two terms that are being always said or always used together with structural geology. One is tectonics and another is geodynamics. Now these three terms, structural geology, tectonics and geodynamics, their origin comes from Latin and Greek languages. So structure is, comes from the Latin word "struere" that means build, "tektos" is a Greek word from which we have this word tectonics that means builder and then "dunamis" is a Greek word which means power or force. So, you can see that if these three terms, structural geology, tectonics and geodynamics, well geology is “ge” that means the earth. It is also a Greek word.

So, these three terms as I was talking about, structural geology, tectonics and geodynamics, these three, from their origin of these three words can suggest you that with the help of, or with this action of power and force, how you can build something and who is the builder for that? So the structural geology is certainly all about power, forces, building something. And if you apply power and force, you have to deform, you have to move something from one point to another. So scientifically you can finally conclude that the subject structural geology together with tectonics and geodynamics concerns in general with the shape, that is the geometry, the displacements which is kinematics and forces so mechanics in our earth and other planetary bodies.

Now interestingly if you have these terms, geometry, kinematics and mechanics, you can certainly comprehend the fact that the subject is highly interdisciplinary and it is indeed. We take assistance, help and collaborate actively with people from material science, mechanical engineering, physicist, computer science and remote sensing. Within the broader umbrella of earth sciences we also collaborate with geophysicists, petrologists, igneous, metamorphic and sedimentary domains. We also take active help from survey people, and of course nowadays we are also taking people from Geodesy on board. So this interdisciplinary nature of the subject makes it highly broad and in overall geology it makes it a complete science topic together with physics, chemistry, maths and biology.

Now these three subjects or which are commonly used together, structural geology, tectonics and geodynamics, these three form a very coherent and interdependent sub-disciplines of geology. And together with these three topics, we try to understand that how these rocks, different rock formations and earth systems in general, crust, lithosphere, asthenosphere so on deform and how do they deform via which processes? You can understand when you see a rock which is deformed. We will learn in this lecture how to look at a deformed rock. It contains a lot of information. A piece of rock gives you a series of information. Your idea or as a structural geologist or geologist in general, your aim is to unravel this information and use this information to study different processes that happened at the past in the earth, and also what could happen in the future.

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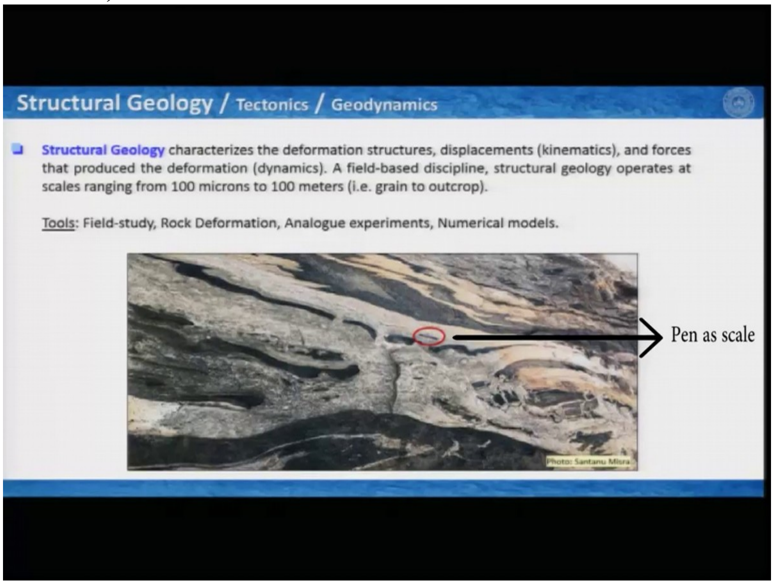

So let us talk about these three topics, structural geology, tectonics and geodynamics, what these are? Whether these are different, whether they are similar or if there is any difference then where is this, where is the difference? Well these individual topics, structural geology, tectonics and geodynamics, from science point of view; from approach point of view they are very similar. Three of these subjects essentially deal with displacement, forces and kinematics, the geometry, shape etc. But the fundamental difference between these three topics are the scales of observation.

So structural geology generally we study in field based, it is a field-based discipline and it operates from very microscale, about 100 microns or less to 100 meters or maximum 1 or 2 kilometers. So, we can say that from a grain to outcrop if you study rocks then you are doing structural geology, of course in the context of deformation. The tools that are used to study structural geology include field study, that is very important, rock deformation experiments; you can do analogue experiments and essentially numerical models.

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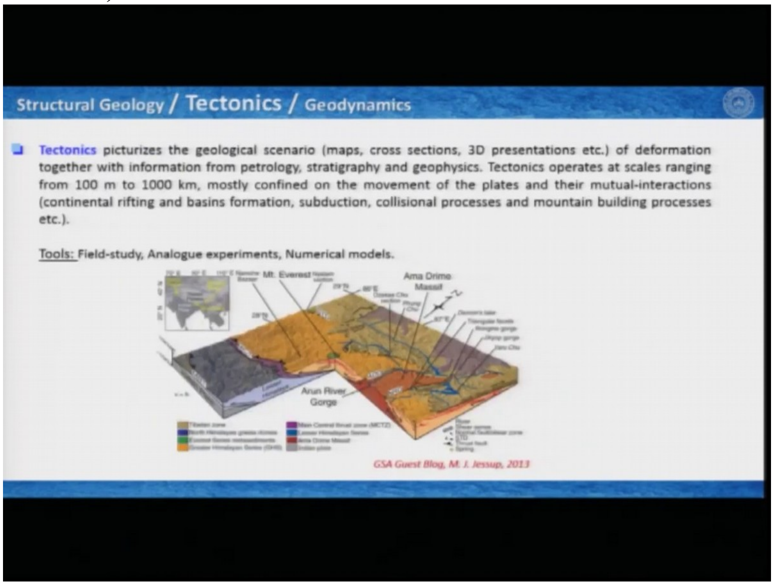

In contrary tectonics is certainly a large scale. As you can see the entire plate tectonics discipline is pretty large. But it does not involve what is happening at the bottom of these plates. It just deals with the movement of the plates, their mutual interactions and so on. So, tectonics in general deals from about 100 meters to 1000 kilometers in scale. In structural geology we learn that it is below 100 meters. So, tectonics is certainly a large-scale study of structural geology, you can consider it this way. The tools we use here are again field study, you can do field work, you can do analogue experiments and you can do numerical models.

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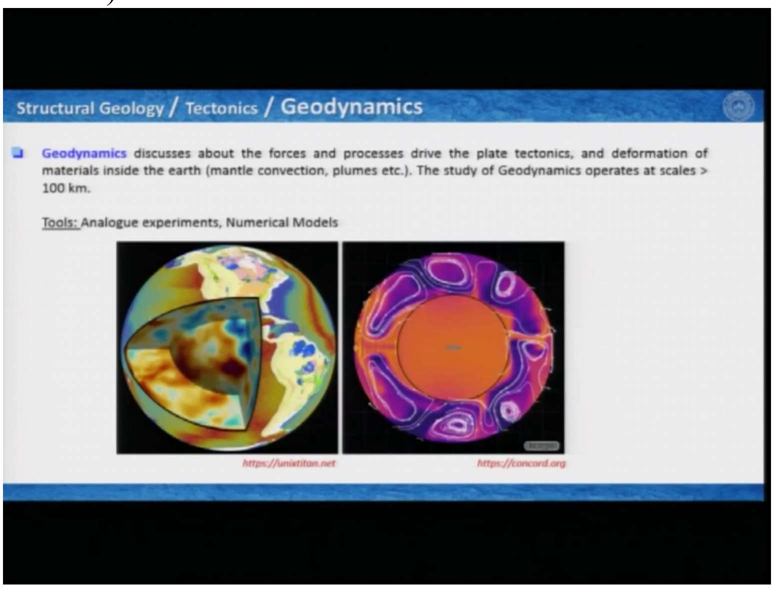

Geodynamics is the subject that discusses about the forces and processes that drive the plate tectonics and the deformation of the materials inside the earth. So you can consider the mantle convection, plumes etc. So as you can imagine the scale from just, from the plate tectonics to where the plates are to the core of the earth or at the core mantle boundary the scale is huge. So it is, it operates at the scale more than 100 kilometers. And there is no way you can do field work at core mantle boundary or even cross mantle boundary. So there is no scope of doing field work. So what tools we are left with are analogue experiments and numerical models.

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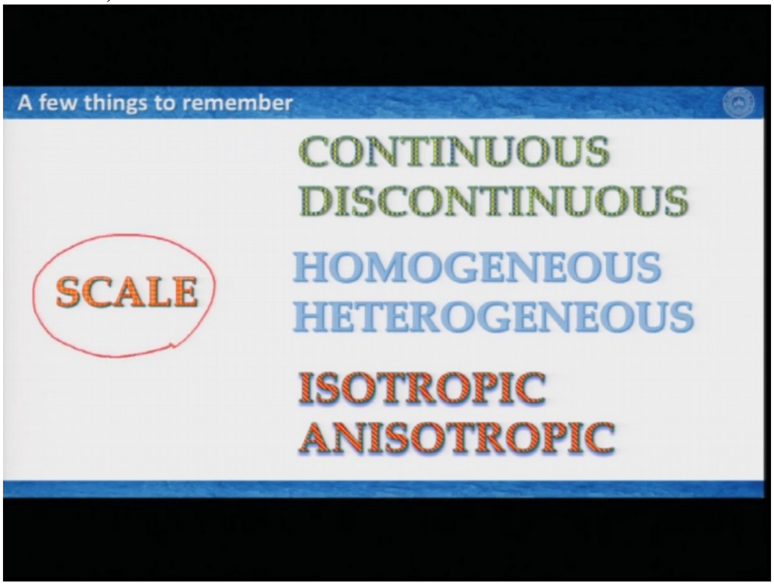

Now to study structural geology as I was talking about, even for, within the subject of structural geology apart from tectonics and geodynamics, scale is something that is very important that you always have to remember. Or always have to take into account what is the scale you are looking at, what is the scale of observation? And structural geologists do it very, very frequently. They jump from one scale to another.

Looking at a single grain, the deformation of the single grain, one structural geologist can immediately interpret an entire mountain building process. So this is a fun, this is a scale as well. Apart from the scale, there are three pairs of terms. One is continuous versus discontinuous. Second one is homogeneous versus heterogeneous, and third one is isotropic versus anisotropic. We are all familiar with these terms but let us have a look at these six terminologies in the context of studying structural geology.

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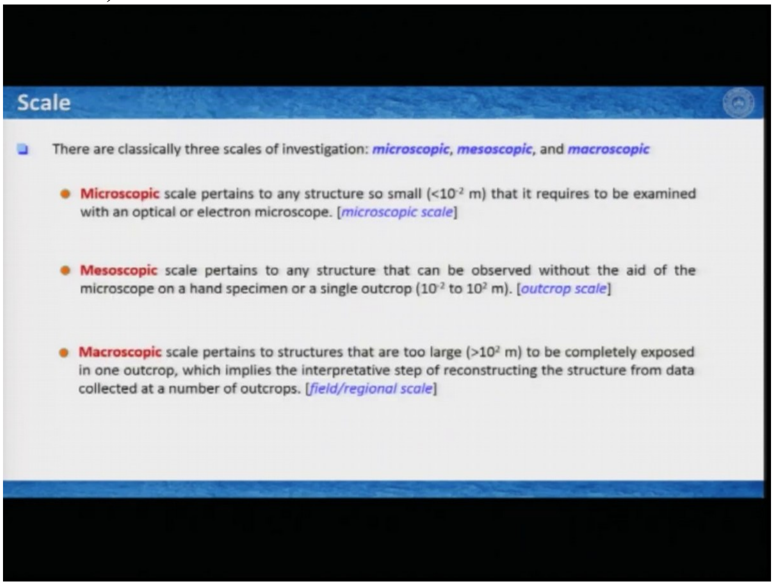

For the scales we generally cover three different terms, microscopic, mesoscopic and megascopic. As the name suggests, microscopic is something that you observe under microscope, be it optical microscope or electron microscope and we call it microscopic scale. Mesoscopic scale is something that you can cover just by a view. So it is scale that to structure that can be observed without the aid of the microscopes on a hand specimen or a single outcrop and so on.

So it is about 1000 meters or 1 kilometers or something like that. And we call it outcrop scale or outcrop study and then macroscopic scale is something that you are doing a large scale field study or regional scale field observations, so this is greater than 1 kilometer and so on. So it is to be completely exposed in the outcrop that you may not get in the field. You may get something here, something there, in-between there is no rock exposure.

So it is your background, it is your intellectual quality of the structural geology background that how you can correlate from this outcrop to that outcrop. And when you do that, you are actually doing a macroscopic field observation or macroscopic study, macroscopic scale study of structural geology.

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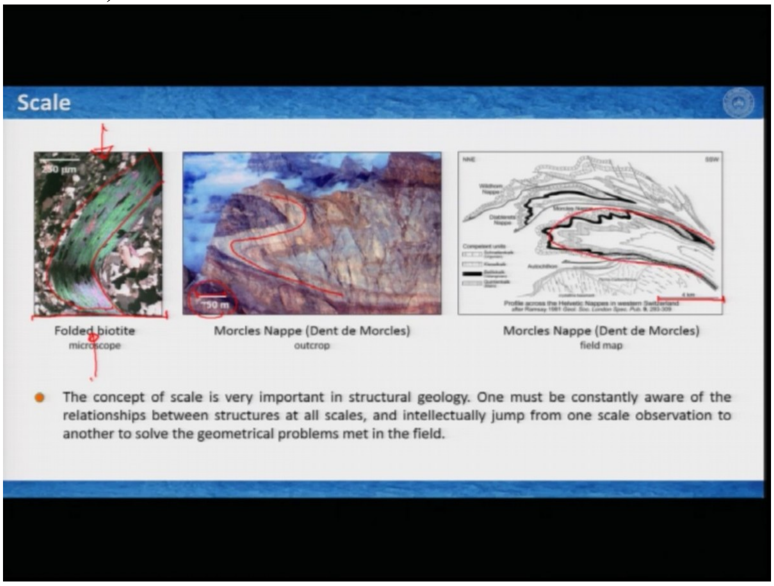

So here is an example of what do we understand by scale. What I try to convey with this slide, you have learnt probably already that if a layer is horizontal or at any orientation and if there is a layer parallel compression this layer is ductile enough then it makes a curved feature which is known as fold.

Now in these three images, in the first one you can see that the width of the image from the scale is given, is about 750 microns. In these 750 microns from here to here, approximately what you see this green material is an aggregate of biotite mineral which is a kind of mica. And you can see this biotite is not straight here, it is folded. So there must be a layer parallel compression here.

Now if I jump to the next image, we see a very similar structure which is fold but here the scale is, or this distance in this entire image is close to 50 meters. And if we look at here, this distance is about 4 kilometer and we almost see a very similar structure. Now if I see fold in the first image and if I see fold in the second or last image, then they characteristically may be same, mechanically they may be developed in a very similar way but their scales are different.

So, therefore I was talking about, the concept of scale is very important in structural geology. And one has to jump from one scale to another scale to solve the geometrical problems that we see in the field and also in the experiments and when you do observations under microscope.

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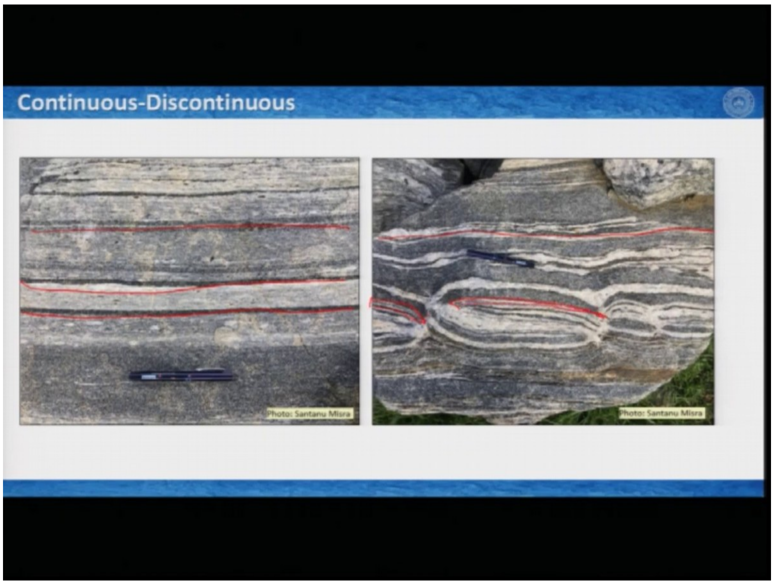

Now about the continuity and discontinuity of structures, this is something that is also scale dependent. So for example this picture here, you can understand that this is a layered rock, we are not going into the fact that how did it form and what it is, but we can figure out certainly that it has alternate dark and white colored bands. Now if I follow any of these bands I see in this scale of observation of this photograph I am looking at, these layers are continuous. That is, there is no discontinuity.

However when this layer got extended and it formed a structure called boudinage we can figure out that few of these layers are continuous here, for example if I try to draw it here but there are few layers. For example if I take this little packet of layers, it comes here then it vanishes and then it starts again from somewhere here. So there is certainly a discontinuity. This is something what we call continuity and discontinuity, or continuous and discontinuous.

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We have few more examples and here we would like to highlight the fact that why this continuity and discontinuity are also scale-dependent? For example here in the first image we see this, this is a shear zone, ductile shear zone and this layer, this black layer is continuous. However if I consider this white layer in the second image it is going like this and then we have some other material inside and then probably it continues somewhere here.

Now looking at it I have a discontinuity from here to here, the layer is not continuous. So this is a discontinuity. Here in this image, you see again a layered rock and we have n number of fractures which made these layers discontinuous. Now at this scale of observation I see them as a discontinuous layer, an individual layer. But if I look it from far, I may not see these fractures and I may consider this as a continuous feature. So therefore continuity and discontinuity in rocks are essentially a function of the scale you are looking at.

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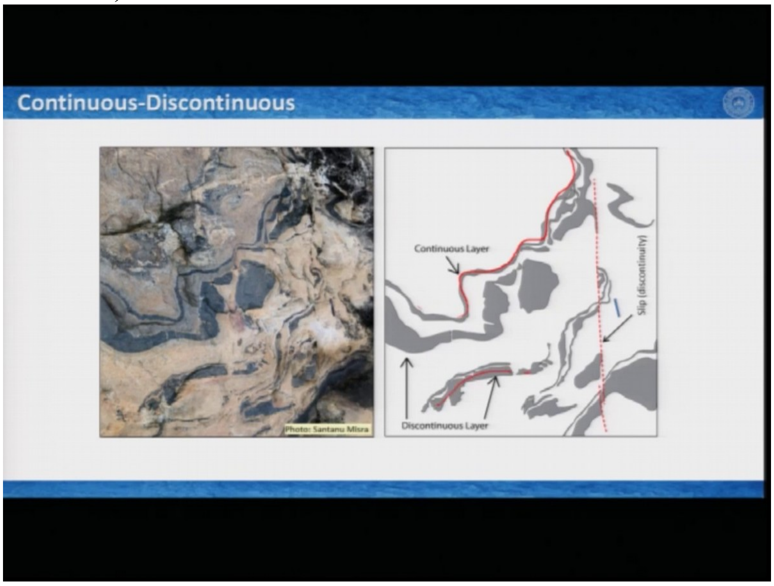

Again you have another example where I try to provide, for example here this is a little complex structure. To understand it better or to highlight its features I made a sketch of this which is on the right side. And you can see few layers which are marked by this arrowhead are continuous, and few layers here, these are getting discontinued. And also the entire outcrop or entire image that we can see, we can see a little discontinuous line here that is separating by a sleeve. So there are many ways you can produce discontinuity. And that is also important to understand that what is the reason for the discontinuity in the structure you are looking at?

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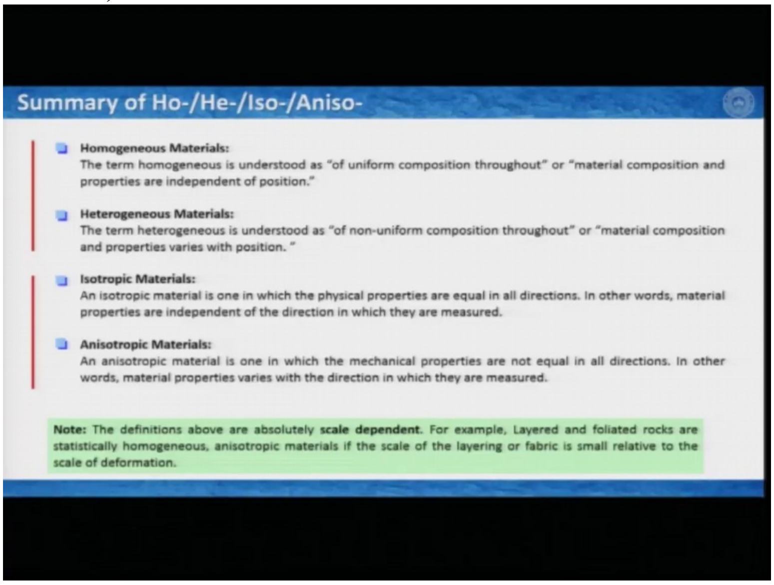

Coming back to two other terms that is homogeneous, heterogeneous, isotropy and anisotropy, now these are very classic terms which are being used in almost all subjects. So in brief, homogeneous materials are of uniform composition throughout, or any properties that you are looking which has uniform properties throughout the material. And if that doesn't hold then this is heterogeneous material.

Isotropic material is on the other hand, is one which the physical properties are equal in all directions. And if that does not happen then it is anisotropic materials. You can also consider it in a way that material properties are independent of the direction in which they are measured. We will learn more about it with time but again I would like to remind you the fact that this concept of homogeneity, heterogeneity, isotropy and anisotropy are again function of the scale.

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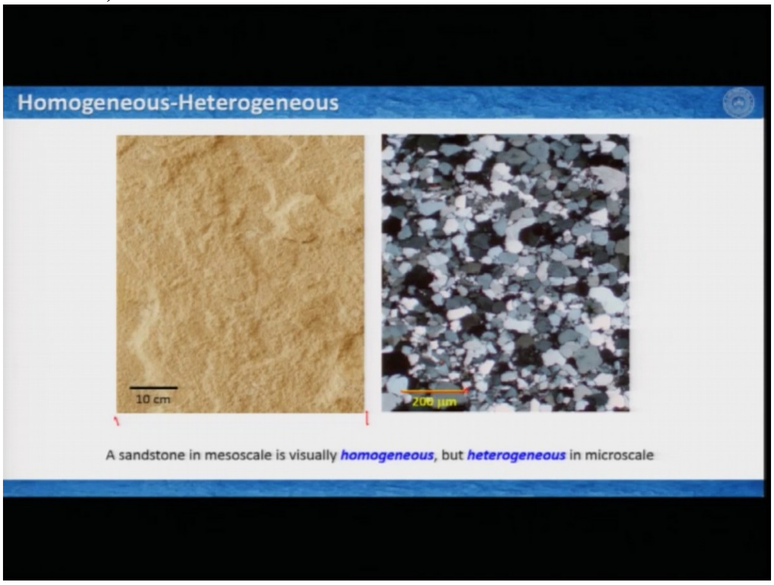

So let us have some, have a look on some examples. On the left side we have a photograph of a sandstone, hand specimen of a sandstone. This is the scale. So if it is 10 centimeters then may be, this would be around 80 or 90 centimeters altogether. And we see here that if we look at the color, that is one of the physical properties then color is mostly homogeneous. It does not vary. The appearance is mostly homogeneous, it does not vary.

And if we have some tools, if we can measure some other properties like electrical conductivity of rocks, hydraulic conductivity and so on, then we might find that this material is very much homogeneous. And if I make a thin section of this little rock and then I observe it in this scale then I figure out that it is not at all a homogeneous material. So same piece of rock I am looking at two different scales, one is homogeneous, another is heterogeneous.

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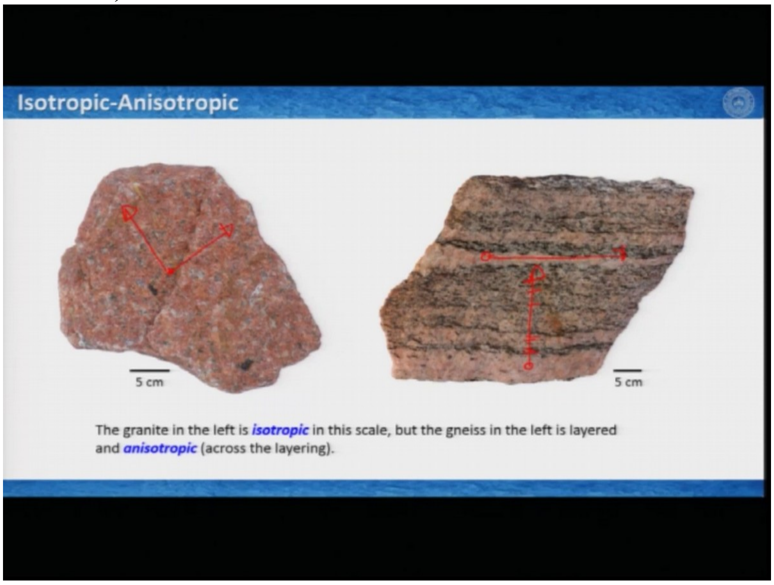

About this isotropy, anisotropy these two are the photographs of two granite hand specimens. The first one is sort of a massive granite. You can see many different scales but statistically if I consider this entire specimen then doesn't matter if I am measuring a property from here to here, that is in two different directions, they would appear more or less same.

However in this sample if I try to measure a property from here to here then I actually encounter different layers. However if I measure from here to here, the properties would remain same because I am following the same material. With time we will know this is known as transverse isotropic material which is a layered material and most of the cases our rocks are so. So again the concept of isotropy and anisotropy could be something that you are considering with respect to the scale.

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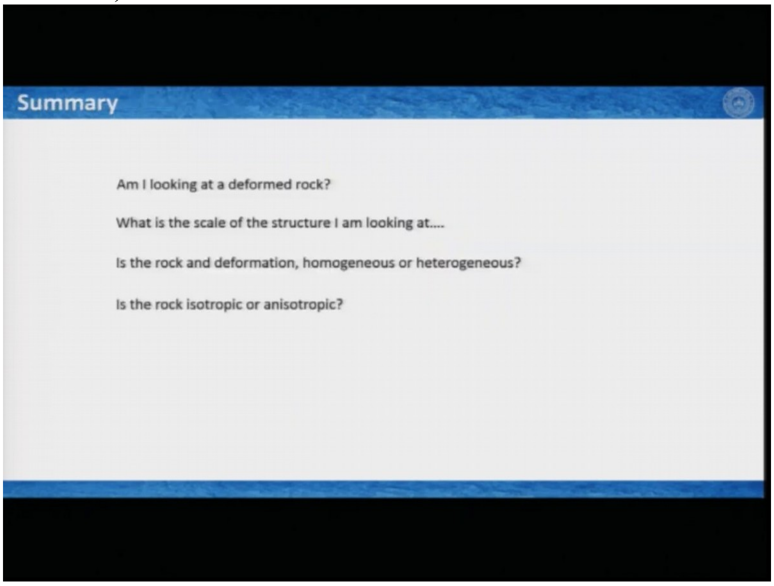

So we are almost at the conclusion of this lecture. And what we learnt from this lecture is very important when you see or when you go to the field or when you see a photograph of a deformed, of a rock sample, the first question you should ask as a structural geologist, am I looking at a deformed rock? And if yes, then what is the scale of the structure I am looking at? If this rock deformation or different layers or different features that I am looking at are homogeneous or heterogeneous, and if this rock is isotropic and/or anisotropic? So with this note I conclude this lecture.

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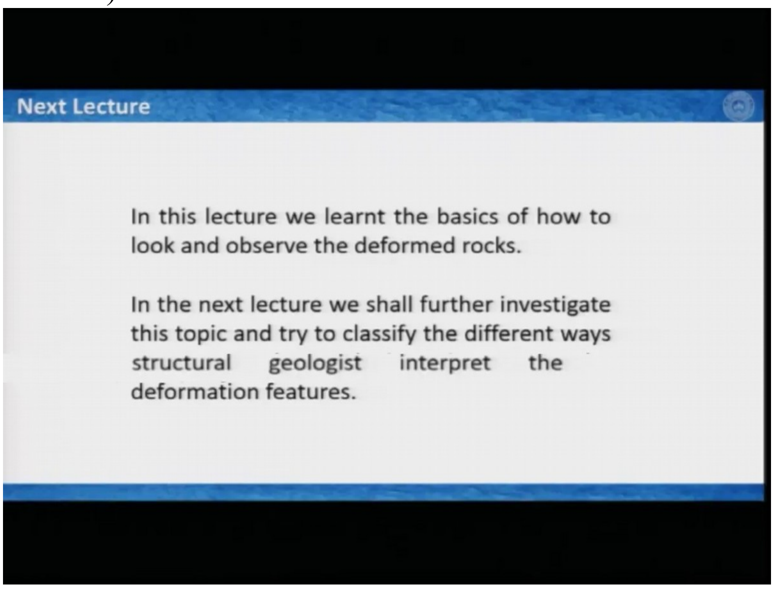

And in the next lecture we will mostly learn what are the different ways structural geologists approach to look at deformed rocks. Thank you very much and stay tuned.