Structural Geology
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Lecture 07 - Strain Measurement

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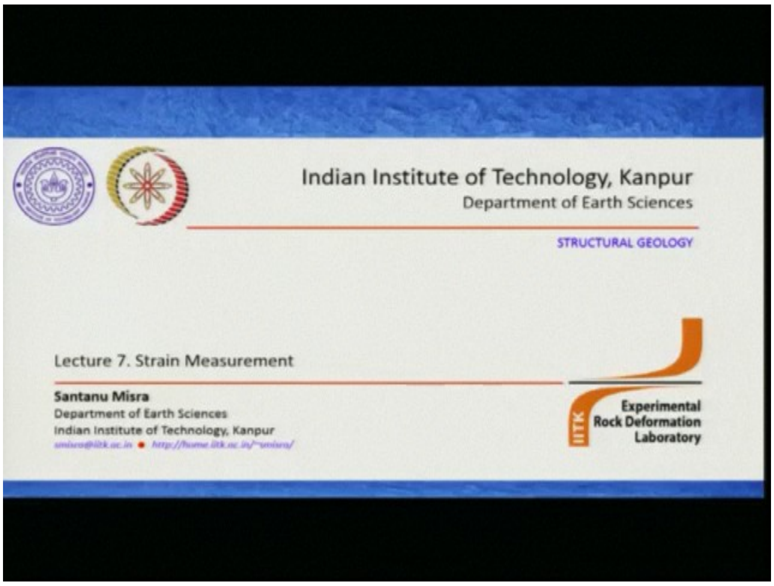

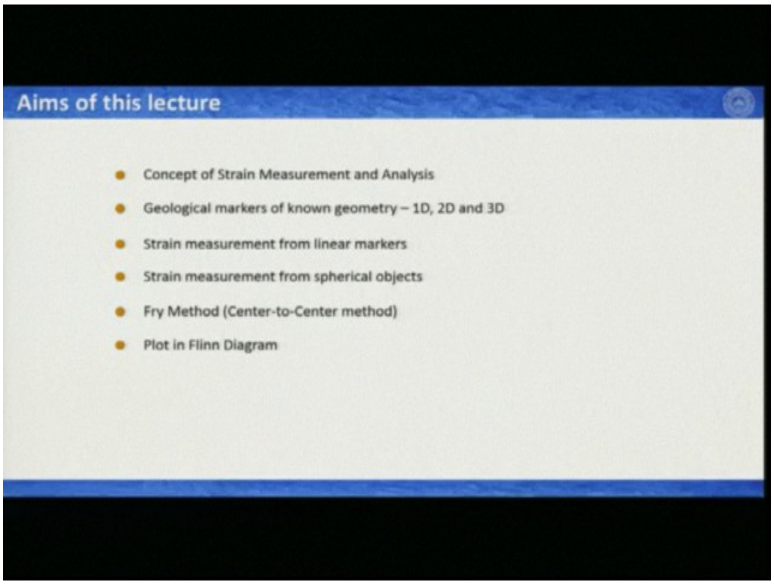

Hello and welcome everyone to this online Structural Geology course and today we are in our lecture number 7 and the topic of this lecture is strain measurement. So the topics or the areas we will cover in this lecture are mostly concept of strain measurement and analysis, now we will learn about different geological markers that we use for strain measurements. They are in one dimension, two dimensions and three dimensions and then we will present some examples of strain measurements from linear markers, spherical objects and then we will go to measurements of strain in three dimensions.

So we will employ a method called Fry Method or Centre-to-Centre method, and then we will see how using these other techniques we can also go and plot in Flinn diagrams and use Flinn diagram to analyse the strain of deformed rocks.

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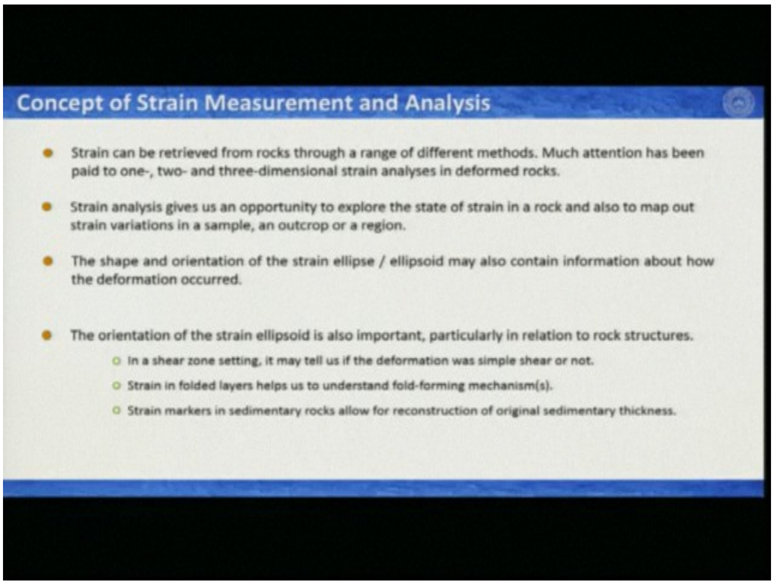

We have already have learned from the last two lectures of deformation and strain, there are some sort of theories, there are some sort of backgrounds and it is possible that one can retrieve the strain from rocks through a range of different methods and mostly you can determine strain in one dimension, two dimensions and three dimensions based on the outcrops you have, based on the features you look or you get in your deformed rocks.

So strain analyses generally, essentially the primary aim is to measure the strain of the rock, so this gives you an opportunity to explode the state of the strain in a rock and also to map out the strain variations within a sample or in an outcrop or a region. So if you are analysing the sample, by means of strain analysis you can actually figure out whether the strain is homogeneous, heterogeneous, isotropic, anisotropic etc, etc.

As a result the primary aim is of course the shape and orientation of the strain ellipse and ellipsoid, this is what you need to figure out. In most of the cases we try to do that and then this when you figure out that what is the shape and the orientation of the strain ellipse or ellipsoids, this also give you a lot of information about the overall deformation of this region.

So for example, you can think of that in a sheared zone setting, we learn about sheared zones later that you can figure out that whether the deformation was actually the simple shear or not. Then in a folded layer you can also do the strain analyses and it can give you some ideas of fold mechanisms, how did fold happen in past and then some sedimentary rocks also you have some markers we learn about it soon. These also give you some information of the deformation processes.

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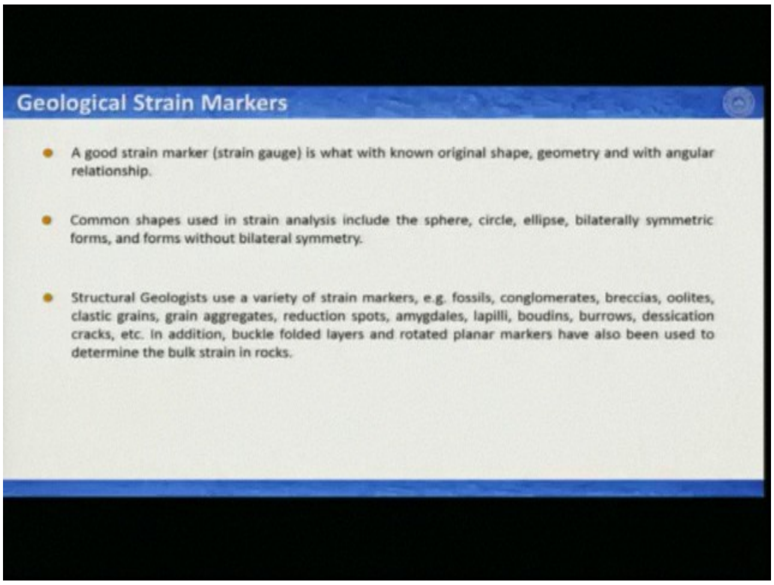

You have probably figured out so far that you need a strain marker, if your rock or the scale you are looking at is homogeneous, and then it is not a good idea to measure the strain from this rock. So, you need some sort of markers or strain gauge that actually gives you the idea that was the original shape and now what we see in the field, this is your deformed shape. So you need to know the geometry and some sort of angular relationships of the object you are looking at which was initially in a different shape and therefore you actually figured out that your rock is deformed.

So the common geometries that you use for strain analyses mostly include sphere, circle, ellipse, then some symmetric forms mostly fossils we will look at them soon and some forms without symmetries, but which has some other special geometric relationships. And to do that, to figure out that these shapes like say sphere, circle, ellipse etc etc. structural geologist generally use as strain markers mostly some geological features like we use fossils, we use some conglomerates, breccias, then oolites. Again these are kind of fossils, some individual grains, if we have to study the grains, the strain in very microscale, then reduction spots and so on.

In addition to that some deformed features also are helpful for analysing the strain, for example if you have a fault or if you have a fold then you know what was the initial disposition of this formed surfaces of the fault and the fold and by bringing it back or unfolding the fold or making the fault to its initial position by some sort of analysis, you can figure out that how much strain was involved in these processes.

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And so let us have a look that what are the different markers that structural geologists do use for analysing the strain and we will look at from linear objects to the spherical objects one after another. The first image or first slide discusses the objects which were initially linear and there we generally consider some sort of fossils, for example what we see here, this is a belemnite an artist’s impression which is an extinct animal and if it gets fossilized, then it takes a shape of this.

So this is a fossil of belemnite, of course, in this image this is undeformed but now imagine that you know the orientation of the belemnite, you know the shape of the belemnite and now this is deformed, this piece then you can figure out the strain using some methods that you have learned. Then also the bedding planes are linear, the traces of the bedding planes are linear, so I have this bedding planes and now, for example if I consider this black layer and this got folded, so I can unfold this black layer which is now folded and can figure out that what was the magnitude of the strain involved in making this fold.

Then we know that he have a sedimentary feature which is cross bedding, so this angular relationships not always, but if you can get the same rock in a different place with known angles, that can be also useful or helpful to measure the strain.

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Now let us have a look some spherical or cylindrical objects and here we mostly use some fossils and some typical geological features. What we see in the first image is a microstructure, this is ooids this you mostly find in limestones and then also in limestones you find a very typical geologic feature which is in this case, this circular thing that is known as reduction spot. So these are very much circular and these are excellent strain markers, also you know that there are many creatures that do burrows in beach sands or in riverbanks, so these burrows are later filled by sediments and therefore it remained cylindrical if it is undeformed, for example here, these are undeformed burrows.

So deformation of which can give you an estimate of the strain of the rock and similarly, if you have the burrow holes preserved and they can also deform, so a cross-section of these burrow holes if undeformed would be circular approximately and if they are deformed the cross-sections would be elliptical, so these are essentially very good strain markers.

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The elliptical objects you see on this slide may not be considered as ellipses or ellipsoids, but statistically you can consider them that they are of similar shape and geometry. For example, pebbles or conglomerates as you can see in these two photographs, so these two photographs you know what is conglomerate; it is some pebbles embedded or hosted in a fine grain matrix. So these are pebbles, at least in this image these are not necessarily of equal shape and geometry, but statistically if you consider say 10, 15, 20, 30, 50, of such pebbles then you actually if they are deformed you actually can get an estimate of the strain of these deformed rocks.

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And the next one is of course if you have some objects of known shape and their angular relationships and here we mostly use fossils, the first one you see is a fossil, image of a fossil, the creature is bivalve and is known as brachiopod, this is an extinct one and the brachiopods were available or they were prolific in the earth in the Paleozoic time. So you can see that it has a sort of a bilateral symmetry, so this line and this line if you consider, so this is 90 degrees if it is undeformed. So if it is deformed or if you do not see that these angular relationships are not maintained in some sort of exposures then your rock is deformed and using this you can analyse the strain.

The second photograph this one is also a photograph of an extinct animal, so this is a fossil and this is a trilobite you know probably from your palaeontology lectures and trilobites were also prolific more or less at the same time when brachiopods were there in the Paleozoic time. Now what do we see here that if I draw the axis in an undeformed trilobite, these ribs like features that come out from this creature, they are essentially perpendicular, so if that relationships are not there, then you can figure out that what is the strain of this rock where this brachiopod got fossilized.

Now the last two images, the first one is, again an extinct fossil but this was prolific and this have, this animals have seen dinosaurs because these were prolific in the Mesozoic time because these and also this image, these two have a very typical geometric feature on their coilings. So I as you can see here, this actually follow, this coiling actually do follow a geometric formula which is known as Golden ratio, so if this Golden ratio is not maintained in your deformed rock then you can figure out what is the strain in by analysing this geometry.

So based on these ideas we will now have some very basic understandings or very, we will learn some very basic methods where we analyse the strain from a deformed rock using all these markers. One very important thing to remember before doing all this strain analysis from deformed markers, the first consideration we do while we measure strain out of these geological markers is that these materials more or less had same physical properties in terms there, in terms of their geology with respect to the overall country rock and you can be sure that this is not the case because this material is different, your host rock is different, so they cannot be deformed in a very similar way.

Then also these individual creatures or individual line elements they can also deform within themselves differently to that of the country rock which is also suffering the strain. So all these things you must remember while you do the strain analysis, so this type of strain analysis mostly gives you very first-hand ideas of the strain, but to do a detailed strain analysis, there are some other methods and we may learn this in a course which is Advanced Structural Geology or so on.

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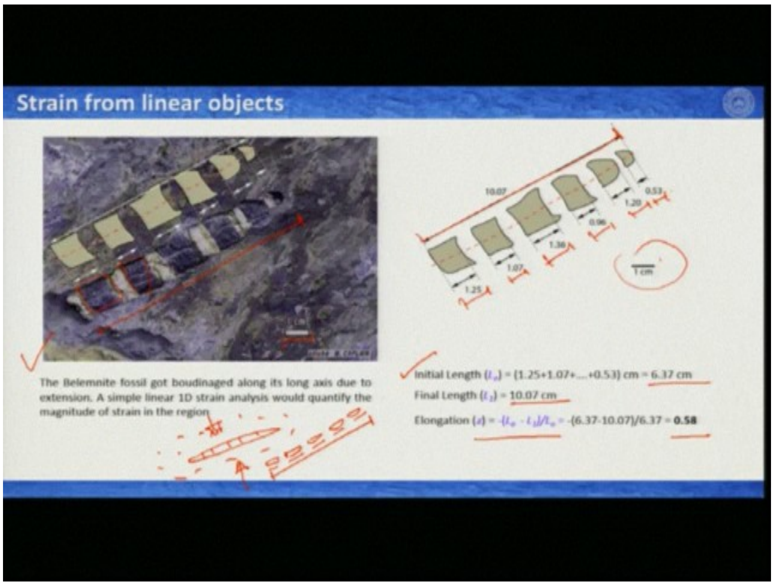

So to moving on let us start with a strain measurement from linear object. What do we see here in this image, this creature as you see that some broken square like features like here, here and fill some materials, so this is a belemnite fossil that got boudinaged, so how did it happen? That you had a belemnite fossil like this, which is embedded in a rock and now if you compress this rock this way, then this belemnite fossil initially got fractured this way and with time it get some, it makes some pieces and this feature in geological context is known as boudinaging.

Accordingly now you can imagine that if again come back to this, if I join or add all these lengths that would give me the L0 or the initial length of this belemnite and if I add from here to here or from here to here that would give me the final length or deformed length, so this is exactly I tried to do here. I sketched this and plotted it here, so these are the individual lengths, you also need a scale or you can do some relative measurements as well. So in this scale the photographer has given a scale and if I see here, this individual out of this scale, I can actually figure out what is the length of this individual boudins or individual segments of this belemnite.

So if I add them together, then I get the initial length and also the way they are disposed, including the gaps between is my final length. In this image the initial length is 6.37 cm and the final length is 10.07 cm, using the formula of elongation which is this one we can actually calculate the elongation of this belemnite and also the surrounding rocks which is 0.58, so this is how you figure out the deformation of or you get the strain, linear strain of an area if you have an object like this.

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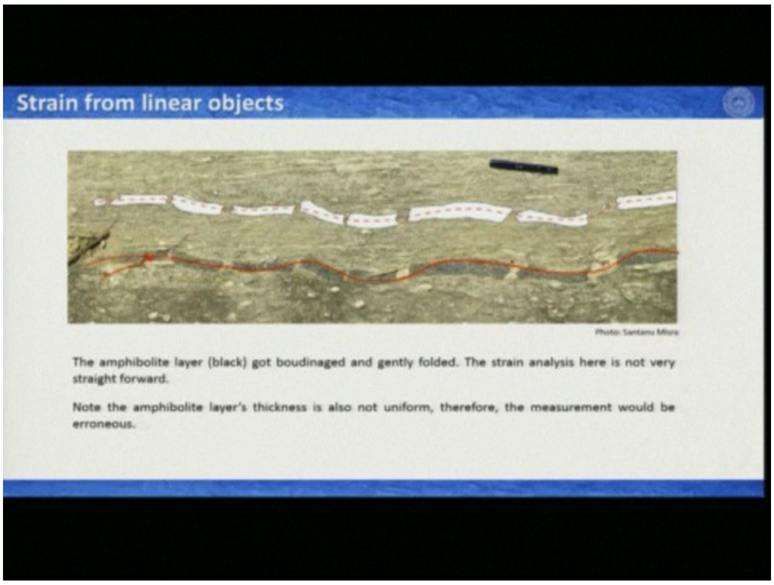

But sometimes life is not that easy, for example what we see in this photograph that we have this black layer here, this one. You see very similarly that we have seen in this belemnite fossil that these amphibolite layer got boudinaged, so you have, I try to make a sketch at the top with the white one, but at the same time while it is boudinaging maybe before or after, you see that it also has a gentle buckling, that means it also got folded. The layer is not straight the way we have seen in the previous slide, so if you try to do measurement out of this it is difficult, first of all, it is not recommended and if you do then you have to be very careful considering other factors.

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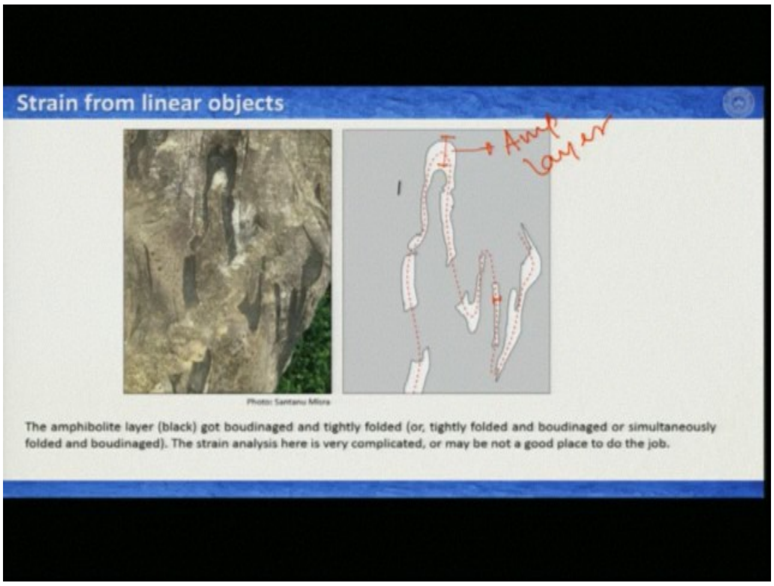

Now it can be even difficult if you have a boudinaged layer which is tightly folded, here in this case again, this is an amphibolite layer. I made a sketch of this amphibolite layer on the other sides, so here the white one is your amphibolite layer which got boudinaged and folded, we are not going to discuss which one happened first or they happened simultaneously or not, but it is, if you would like to do linear strain measurement we can also see that in some parts this layer got thickened, in some part the layer got thinned. So measuring linear strain out of this type of boudinaged and folded objects is not that much recommended unless you have some other clues from somewhere else.

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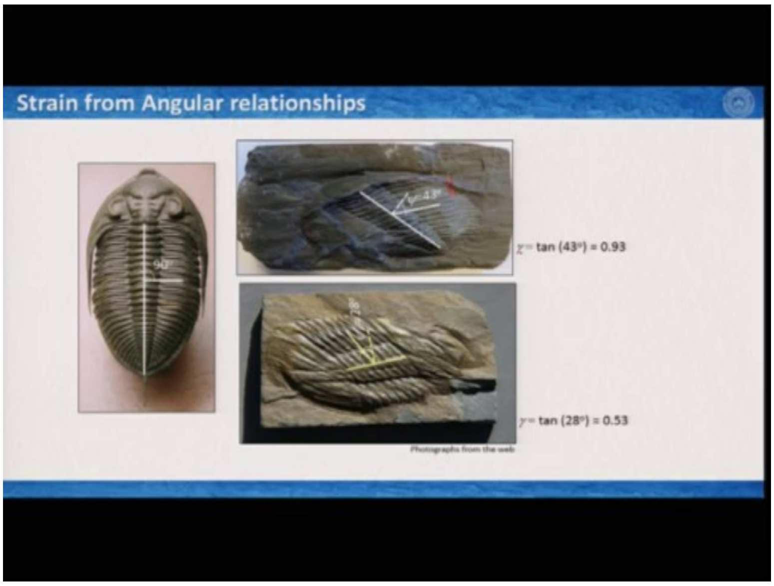

Let us have a look at that how to measure the strain from some sort of regular relationships. As we have learned that again, this is a fossil of trilobite and we know that it has an initial relationship where this angle is 90 degree. Now I have two deformed images which I collected from the web and I can clearly see that at least in this case this angular relationship is not maintained and also in this case this angular relationship is not maintained. Now if I focus only on angular relationships, then certainly I can measure the shear strain, these two fossils and therefore the rock in this case, in these two rocks the host rocks have suffered.

But again you can figure out probably that these materials also underwent some sort of other deformations like pure shear or combination of pure shear and simple shear, so that may not be possible out of these, but we can certainly measure the magnitude of the shear strain at least from the concept of this angular relationship. So if we try to do that again this is 90 degrees, then what we see here that deviation from the right angle which is the dotted line and what is now is 43 degrees, so simply by putting the formula shear strain equal to tan of this 43 that gives you almost close to 1, 0.93 and in the second case, this is 0.53.

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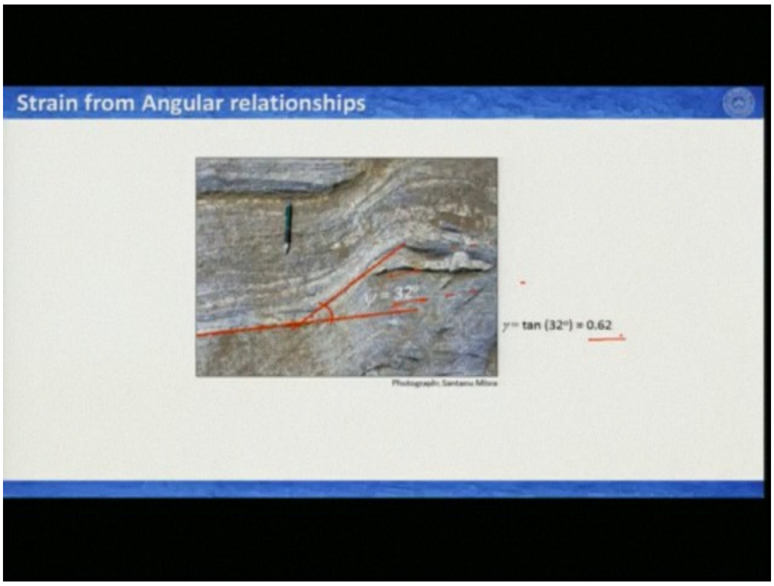

We can do a similar strain analysis from a very simple shear zone, so what do we see here in this photograph that this layer which was supposed to be like this, now it got deflected this way. Okay, so this deflection is essentially due to some this angular deflection is probably some sort of shearing, okay. Now if that shear happened therefore this thing got a deflection and if we can measure this angle we will see how it is done then we can actually calculate the shear strain involved in deforming this particular piece of rocks. So in this case, this angle is

32 degree and again using the same formula shear strain equal to tan of 32 degrees you will get this.

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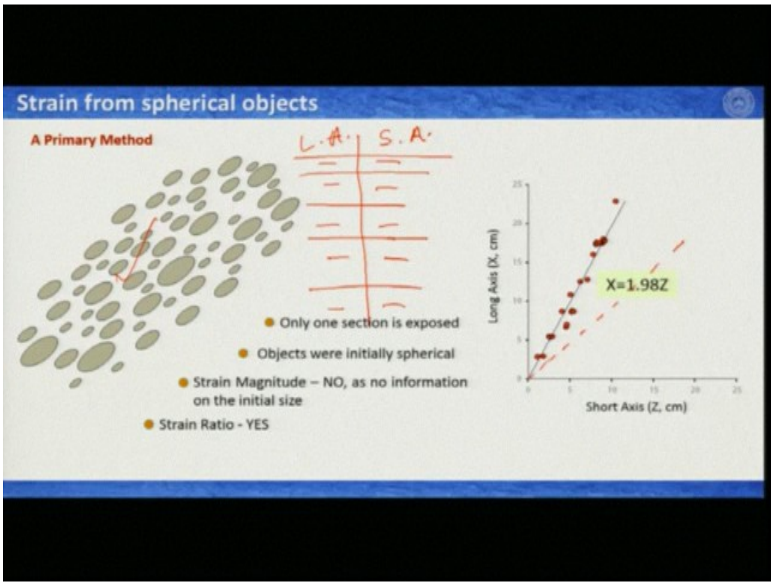

Now if I have some spherical objects which are exposed only in one surface, that means you do not see on the other sides of this rock, then they can deform to form some ellipses. If you have this type of features in your field or in your rock or in your sample then you can get a very basic or primary idea of the strain, it does not give you the strain magnitude, but it gives you the strain ratio. So here is a very simple example that I had some initial circles and these circles got deformed to form these ellipses.

So you can measure the long axis and you can measure the short axis, so what you do in one column you write long axis and in one column you write short axis and then you plot this, you write the values 1, 2, 3, 4 and so on and then if you plot long axis versus short axis then if this rock has any deformation then you should see a deflection of course from the 45 degree. If it is 45 degree then X equal to Y or long axis equal to short axis therefore you have your spherical geometry maintained, but if it is not then you may have some deflections from the 45 degrees and that may give you the very first or basic, first-hand idea of the deformation. Just to remind you that these plots are, these data are from different objects not from the image that you see here, but you can try this one and plot it, it would come in three different clusters because I used three different shapes here.

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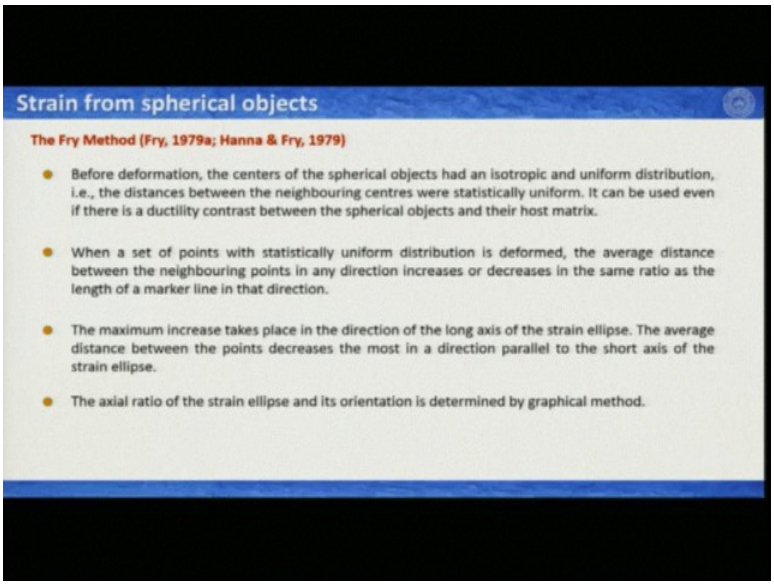

The second one, the one of the most used strain analysis from spherical objects in two dimension is known as Fry Method, so it is given by Professor Fry, it is a paper, two consecutive papers one in 1979 and then another one in the same year with Hanna he wrote this paper. So this Fry method is very interesting and it has some very interesting concepts behind, now the first concept is it is written here, but I would love to read it for you.

Before deformation, the centres of the spherical objects had an isentropic and uniform distribution, that is, the distances between the neighbouring centres were statistically uniform. It can be used even if there is a ductility contrast between the spherical objects and their host matrix. The second point is when a set of points with statistically uniform distribution is deformed, the average distance between the neighbouring points in any direction increases or decreases in the same ratio as the length of the marker line in that direction.

The maximum increase takes place in the direction of the long axis that is obvious of the strain ellipse and the average distance between the points decreases the most in a direction parallel to the short axis of the strain ellipse. The axial ratio of the strain ellipse and its orientation is determined by a graphical method which is the Fry method.

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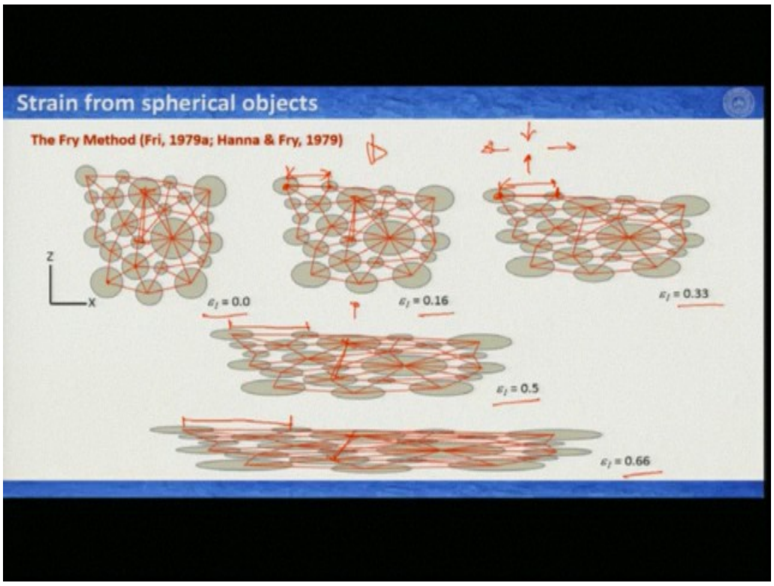

So what is written here, try to understand this in an illustration, what do we see in this image, or in this illustration that I had some spherical objects which are now sphere in two dimensions. This is my X direction; this is my Z direction, these red lines or network of red lines actually defining the distance from one centre to another centre of the neighbouring circle. Now in this setting if I deform it by pure shear manner like this, so here the elongation along X direction is 0, then it is 0.16, 0.33, 0.05 and 0.66, four incremental progressive deformation stages are given.

And so clearly, if I deform this piece this way that means the vertical direction is the compression direction and shortening direction and the horizontal direction is extension direction, we can see that with progressive deformation all distances along the vertical, along the horizontal line are progressively increasing. Here and here it has increased to this amount, if you see the vertical distances for example here if we consider this distance, it is also decreasing with progressive deformation and that is a principal of Fry method that in horizontal direction all the centres would move horizontally and then tend to stretch and so on.

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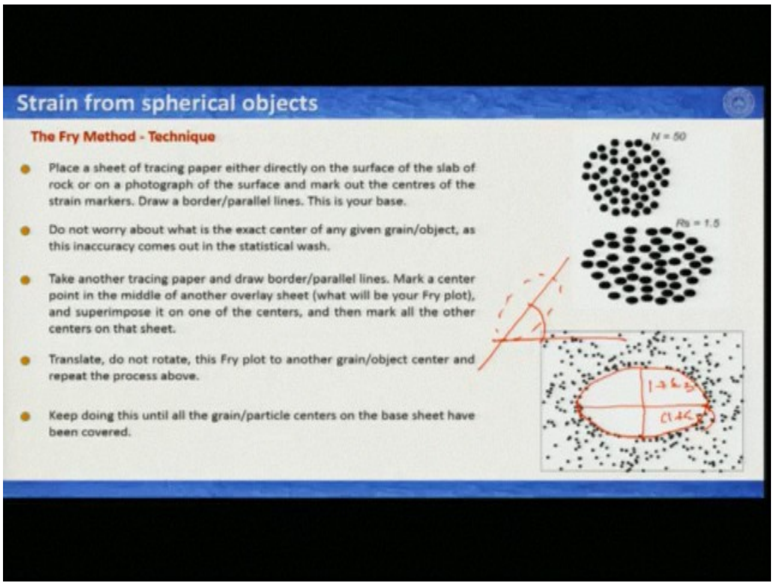

Therefore based on this now we learned how to plot or how to work with the Fry method to get your strain analysis. So here the techniques are described. What you have to do that, so in this case what I have shown that I have some circular objects here and that got deformed to strain of 1.5 and you will give this in your field or in your thin sections when you look at microscope. So it could be stretch grains, it could be some fossils or whatever.

Now the methods are described here you have to first of all trace this, this individual ellipses and then you have to mark their centres in a piece of paper and then with another piece of tracing paper, you have to move one point to another point such a way that once you keep in one centre your points, your single point, then you mark in all tracing papers, in the tracing paper all centres of the visible.

So on the basis of this idea or the basics of this Fry method, now we learnt how to plot this Fry plot in a piece of paper or how to do this analysis of strain using some deformed spheres. But in 2D it would be deformed circles, so what you get is deformed objects, deformed circular objects which are ellipses, you can get conglomerates which are deformed, you can get oolites or ooids in thin sections. You can get many other features like reduction spots and so on, you can also use stretched or deformed grains, so you can take an image and do the Fry analyses or Fry method analysis for measuring the strain.

Therefore you need two sets of tracing papers for that. The best idea is the take a photograph and have a printout and in this printout you overlay a piece of tracing paper and then what you do that first you mark the boundary of this tracing paper or circular or square boundary and then on that tracing paper you mark a dot somewhere and this is the base and you do not have to worry that where you are putting the centre or what you are putting the dots because it would be statistically done, the method is statistical method, so it will be taken care of by itself.

Then if you take another tracing paper and draw the very similar border keeping the borders that you have made on the first tracing paper or your based tracing paper. Okay, now in this tracing paper, you match the centre points that you have marked in the previous tracing paper. Now when you are done then it would superimpose your borders, it would superimpose your centres, then keeping that you hit all the centres of this deformed ellipses and mark them as a dot that is your first dataset.

At the moment you move this tracing paper without rotating, so that means you have to translate and go to the centre of another grain and then you do the same process and you continue doing it, so you have datasets for each and every centre of these ellipses. And while doing this, you will figure out that you are clouding your tracing paper with a lot of dots and while you are plotting the dots when you are at the end you will slowly see that an ellipse would emerge like this and based on your orientation you can figure out once you are done, then this is your long axis, so this is 1 plus E1 and this is your short axis 1 plus E3.

However this orientation it may not remain as horizontal as it is, you may have a strain ellipse like this, so this would also give you the angular relations or angular strain. So this is a very basic method that we always use for measuring strains from deformed ellipses or deformed circles which you get in form of ellipses. There are many softwares you can also use it, so I recommend that you download some images of deformed objects it is available or you just type Fry method, then take a printout and then do it by yourself and you can send it to me or the two TAs for checking.

Now the final one is three-dimensional strain analysis, if you remember the Flinn diagram, then actually you can get three different types of deformed rocks, in three-dimensions, one is L-tectonite, one is S-tectonite and in between, you have LS-tectonites.

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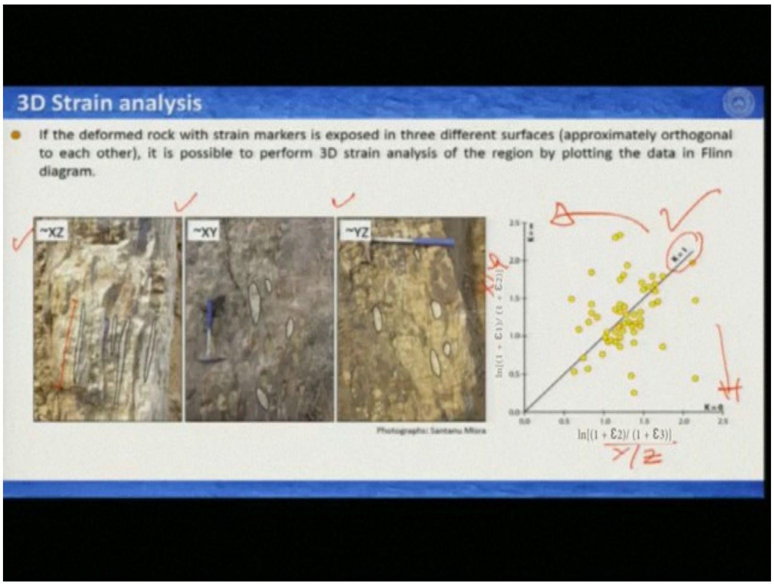

Now also because we have a three-dimensional scenario here, you can also in the field with some techniques or with some typical observations you can figure out what is your X direction, what is your Y direction and what is your Z direction of the principal axis of the strain ellipsoid. Now here I have three photographs that we commonly do for or commonly go this place for, with our students for undergraduate field training, this is near Singhbhum shear zone behind rock mines and there you have a layer or marker layer of deformed conglomerates and this place nicely exposes the three different sections because we have foliations. It is possible to identify the different, the three different principal axes of strains and their orientations.

So I have three photographs here taken along XZ, along XY and along YZ sections, as you can see here, maybe not very clear from these images but I highlighted some of this stretched or deformed conglomerates on each planes. What you see here in XZ planes these conglomerates are extremely stretched on XY and XZ planes they appear, at least in terms of their ellipticity more or less similar, what the students do in the field? They measure this long axis versus short axis and then out of this on each planes they figure out the stretch and then they plot it in the Flinn diagram which is you see here and when they plotted it, they got an excellent cluster along the K-1, K equal to 1.

So that gives the students idea that the Singhbhum shear zone at least the area, they are looking at the strain was flattening or sorry the strain was plane strain. So if it was in this side, it would be flattening if it was in this side, it would be constriction, we get these features in other places, but in this area as an example, this is a very beautiful example. We can see that the strain here is plane strain, so this is how you do three-dimensional strain analysis using Flinn diagram.

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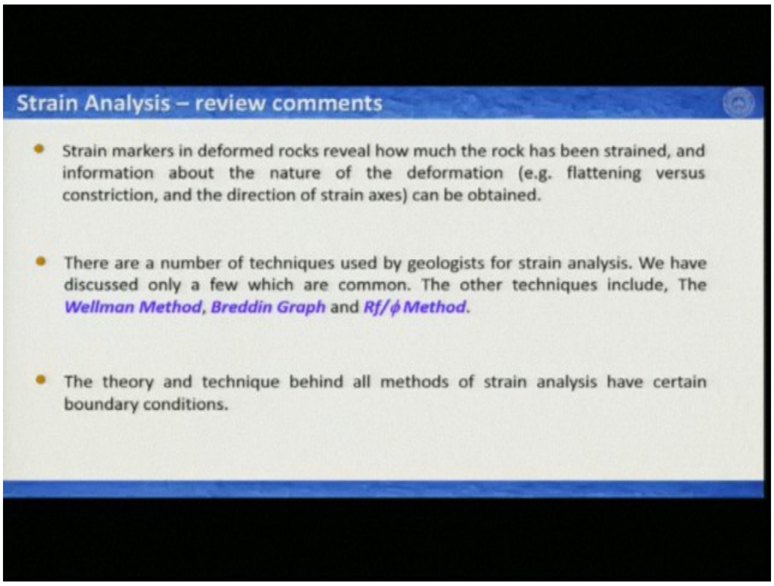

Before I conclude this lecture, I would like to give you some remarks that I have given you in the very beginning as well, so strain markers in deformed rocks reveal how much the rock has been strained and information about the nature of the deformation that is whether it is flattening, constriction and the direction of strain axes etc, you can get it.

There are number of techniques, I have just given you some very commonly used and easily can be operated in the field or with your computer or with a piece of paper, but there are many other techniques for measuring strains. I just mentioned few like Wellman method, Breddin method and RF Phi method, the books I referred all these three techniques are described, so if you interested you can go and have a look.

What is most important the theory and technique behind all these methods, they do have certain limitations and they have some sort of boundary conditions, you cannot do everything using a single and simple method. So based on this I conclude this lecture and I believe with these three lectures on strain, we have now a very good knowledge on this topic.

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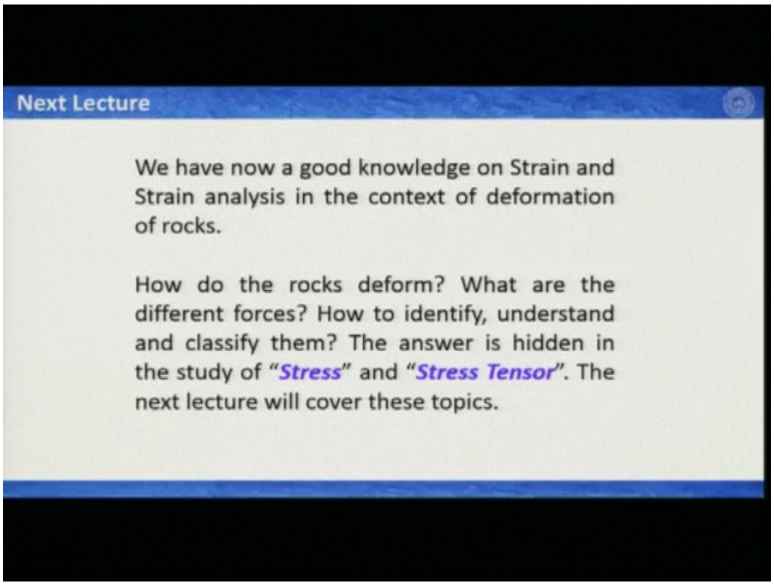

So strain deformation and strain analysis in the context of deformation of rocks, when the question comes next that how do the rocks deform? So what are the different forces that deform the rock? How to identify, understand and classify these different type of forces and their actions? So the answer of all such questions are hidden in the study of stress and stress tensor and their different components. So that would be a topic of the next lecture and we cover this in one or two lectures, so for the time being thank you very much. Enjoy reading strain chapters. Thank you.