Structural Geology
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Lecture 26
Boudinage and Pinch and Swell Structure 2

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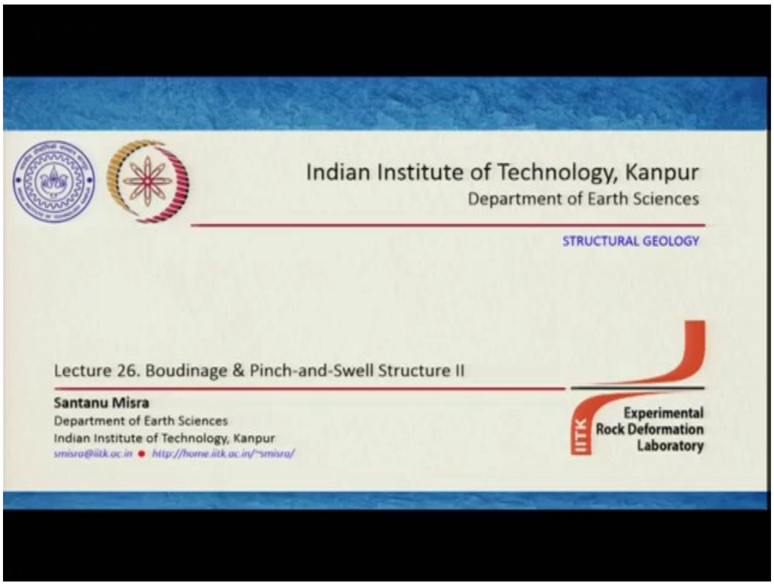

Hello everyone, welcome back again to this online NPTEL course on Structural Geology. We are today in our lecture number 26 and we are learning (this) in this lecture Boudinage and Pinch and Swell Structures and this is the last lecture of this week.

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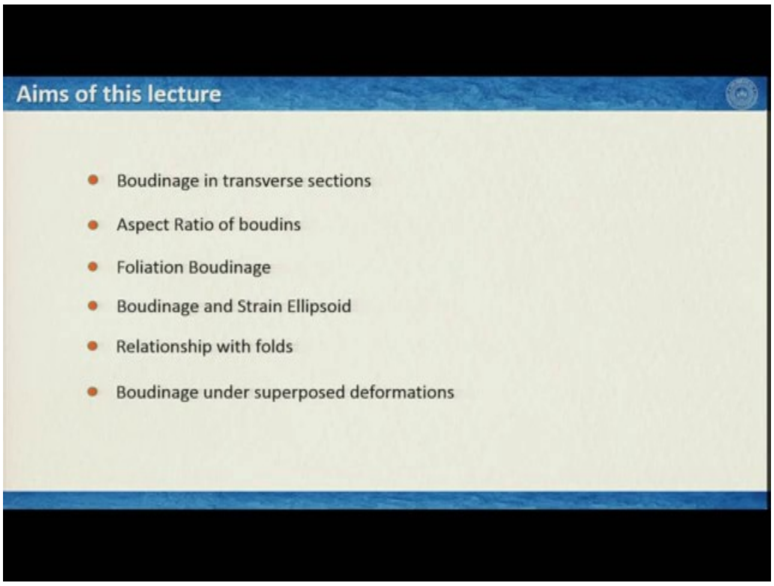

So this week we will cover a few topics very-very briefly, the first we look at Boudinage in transverse sections. We have learned a few terminologies in this previous lecture but in this lecture we will mostly look at their processes that how we actually do generate different types of cross-sections in the transverse sections and then we will look at a very special topic which is Aspect Ratio of boudins.

Then we will see the Foliation Boudinage we learned about it while we were classifying this. We will talk a little bit more on this because it demands special attention. Then we will see that how Strain Ellipsoid, the bulk strain ellipsoid is related with the boudinage processes. So which direction, what kind of structures or boudinage we can form.

Then we will see the relationship with folds with respect to the boudinage and then finally we will conclude this lecture with boudinage under superposed deformations. So a lot of topics but they are very small and we will cover it one after another.

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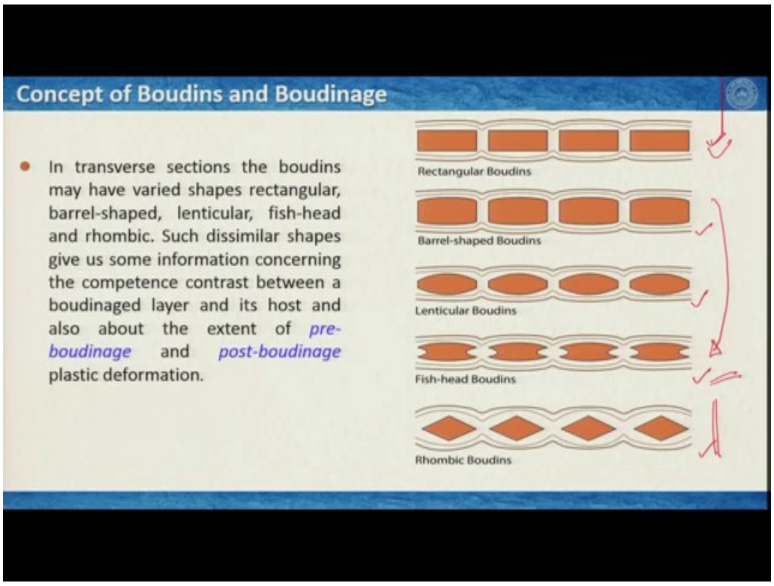

So here, we have learned about it in a transverse section. We figure out that the boudins they may have varied shapes and this could be rectangular, barrel shaped, lenticular, fish head and rhombic shapes. Now these dissimilar shapes give us some information concerning the competence contrast between a boudinaged layer and its host rock and at the same time it tells us the pre-boudinage and post-boudinage plastic deformation in particular. So what I see here a series of illustrations are here you see this, this is rectangular boudins, then barrel shaped boudins then lenticular boudins and then fish- head boudins and rhombic boudins.

Now these are not necessarily the products during the boudinage. So rectangular boudins yes when you just initiate the boudinaged processes then it is possible that you form the geometry of structure like this but with continued deformation we actually arrive somewhere here. The rhombic boudins are somehow different and will not look at it in detail but if you are interested you may have a look of a paper by Professor Mandal in 2001. So that describes but we mostly restrict ourselves towards the up to the fish- head boudins.

Now the presence of rectangular boudins with edges at right angle to the general layering this is what we see here it simply indicates the fact that throughout the course of development of boudinage the layer, this layer which is undergoing boudinage processes behaved in a brittle manner. Now at the corners of these boudins there is relatively high shear stress which tends to deform the boudins.

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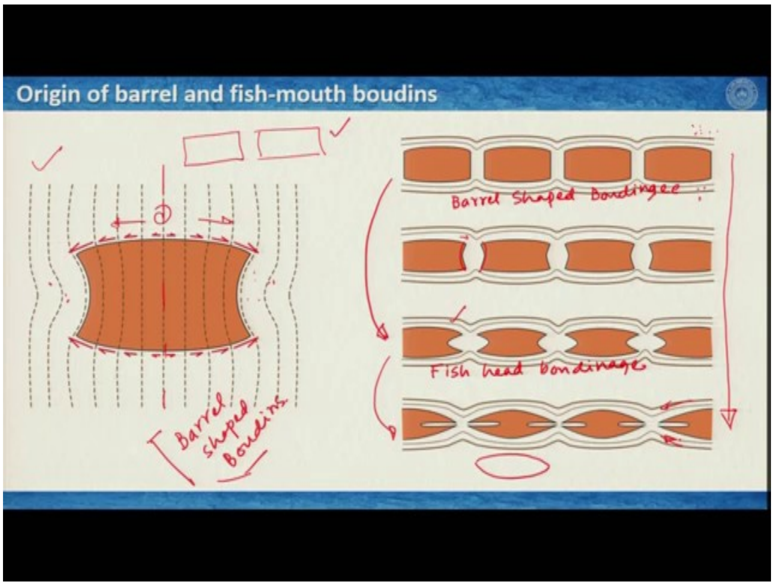

Now this is exactly what happens at the post boudinage processes. What we see here that this was initially probably in this illustration this was initially rectangular boudinage but with continued deformation it is possible. This is the way the boudins deformed or shear stress at the extensional faces or exterior faces. So the preservation of the sharp right angles corners of rectangular boudins therefore indicates that competence contrasts within boudins and the host rock is very large. So if the competence contrast is extremely large then you would see this kind of rectangular boudinage but if not then you will see features like this which will be discussing soon.

So barrels shaped boudins which is this one. This is a very typical process and this evolves with the boudinage processes. So the barrel shaped boudins with straight edges are produced with some amount of making which is followed by extensional fracture at the neck joints mostly at these places. So this shaped that which we see here this barrel shaped boudins these actually can be further modified by post boudinage plastic deformation. Now this is illustrated here we will see one after another, that how these do happen.

Now the boudins are more competent than the host rock this is what we have learned so they deform more slowly than the surroundings. So the matrix outside deforms faster than this okay and if that happens then you develop a shear strength at the longer edges of the boudins as it is represented here. So you see that you have a shear strength not only that the gradient of the shear strengths are there as well.

So at the middle the shear strength is the magnitude of the shear strength is less and while we are travelling towards the edge of the boudinage the corner of the boudins. The magnitude of the shear strength continuously increased and you also see that the sense of shear is opposite if you make this boudin asymmetric line which is this one.

So, since the sense of the shear is opposite in the two halves of the boudins the sheared is associated with an effective lengthening of that part of the boudin with or which is close to the contact. So these materials actually tried to drag it and you always remember that in this case the competence contrast is not as hard as you can expect for the rectangular boudinage.

So the shear strength and the associated lengthening decreases towards the mid-level as it is here of the boudinage layer. Now we can see that as a result the lateral walls of the boudins curved inward, this is exactly what is happening here. So they try to curve inward and also this one. So the zone of curving also undergoes a larger layer normal compression so that the barrel like shapes is exaggerated this is exactly what we see here.

Now when a very large amount of such post-boudinage plastic deformation leads to the formation of fish- head boudinage this is exactly what we see here. So here we had a barrel shaped and with progressive deformation during the post boudinage plastic deformation we arrive at the fish boudinage process.

Now this can actually further continue to develop something which is exactly the shape of lenticular boudinage which we have learned in the last lecture and this is also evident from experimental deformation and these experiments generally show that with soft models the decreasing competence contrast between a layer and its embedding medium extensional fracture is produced. As you have learned by a greater layer parallel homogeneous elongation as well as a greater localised deformation by necking.

Now if the competence contrast is small the necking continuous as we see here. Till the pinched zone stepper of lenticular boudins are separated without the formation of a clearly defined layer normal extension feature.

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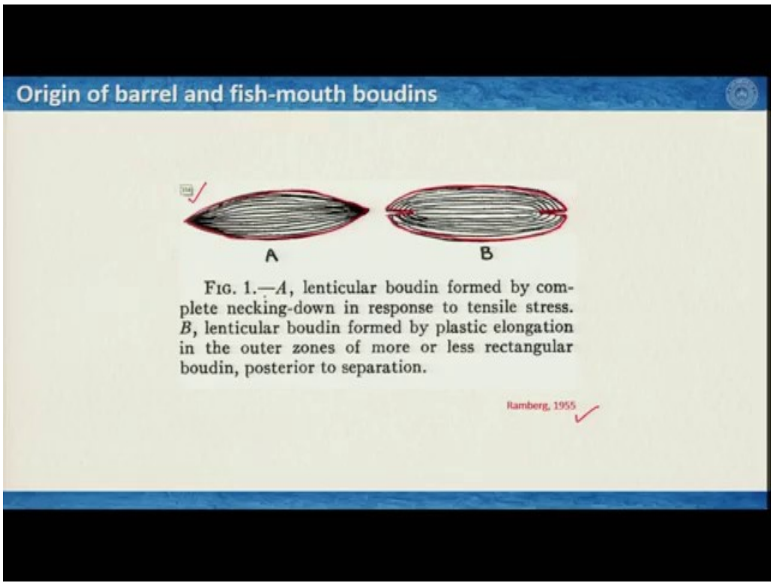

So this has been noted by Hans Ramberg and this is the classic paper of 1995. As we can see the first one, this one is a classic lenticular boudin. So there it was like this, this is the shape of this boudin. Okay, this is some sort of a pinched swell structure but the pinch are got teared of but here if you look clearly that the shape of the boudin is something like that.

So it was initially a barrel shaped boudinage then it turned into fish mouth boudinage and now its morphology is very similar to that of a lenticular boudinage. So it is a continued process where you actually can figure out that initially you form a barrel then slowly it tapers inwards and then it forms fish mouth with further progressive deformation you can arrive at a shape of lenticular boudinage or lenticular boudins.

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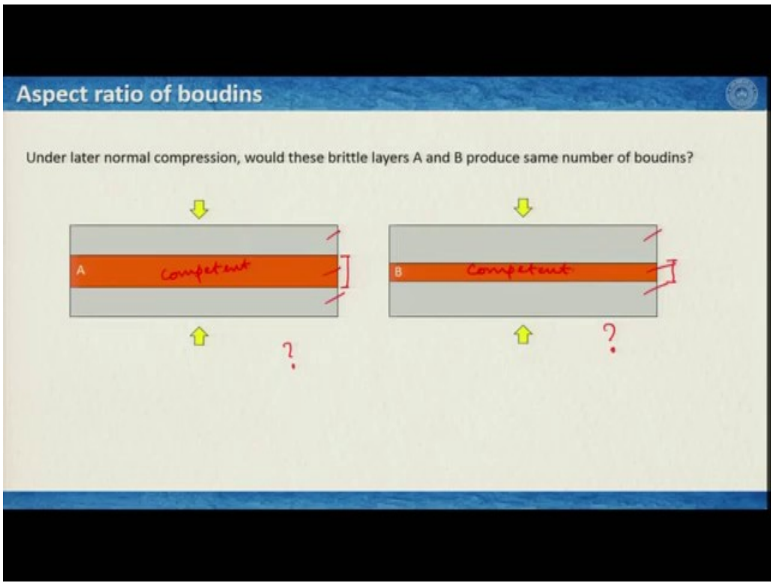

Now let's talk about the aspect ratio of the boudins which is the next topic we will cover. So here I have given two drawings for you. What I see here is that if you imagine that this layer, this layer, this layer, this layer they have very similar properties and also this to orange layers.

Now what I also see here in this illustration is that this layer is thicker than this layer. So this is the competent layer, this is as well compared to the surrounding grey layers. Now if there is layer normal compression of very similar magnitudes, similar deformation rate and so on. Then you can ask yourself a question or I would like to ask you the question what is the expectation after a finite time of the deformation and the boudinaging is going on?

Then where I would form the maximum number of boudins in this case or in this case? We can think of this and you can likely back your answers but this is a very interesting problem and we will see with time that how we can go ahead with that and we can figure out that what would be the aspect ratio of the boudins. But before we jump into this topic let us have a very common understanding of this.

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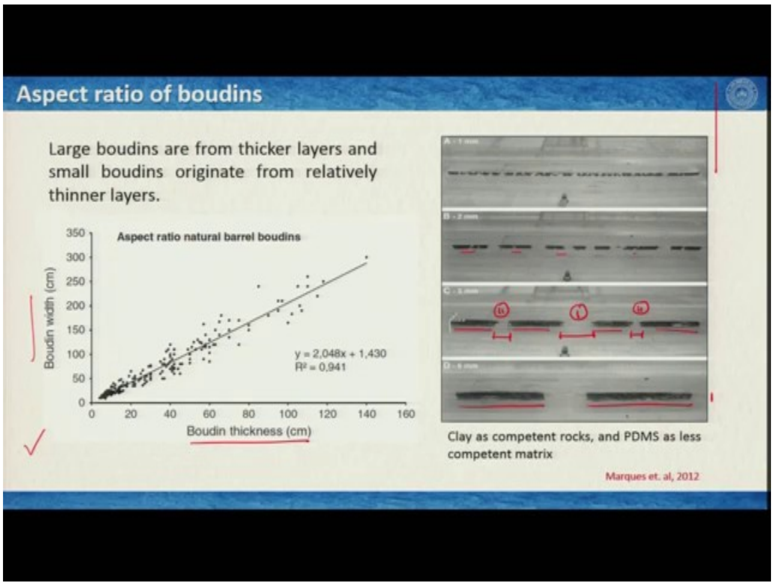

So general observation as we can see here from this illustration, its from Marques et.al, 2012 that large boudins are generally form thicker layers and small boudins, they do originate from relatively thinner layers. So this is the plot boudin's thickness versus boudin width they more or less follow a linear relationship as we can see here from a lot of data that is found and collected and he also conducted analogue experiments we have seen this image in the last lecture.

But what we see here that this is thicker layer and this is much thinner layer and with this thicker layer we have large boudins and with the thinner layer slowly we are increasing the number of boudins. Now you can also see one more very important thing we will see this also in the illustration that the gap between these two is smaller than these gap this indicates that we had the first fracture here then this one and so on and this is how it proceeds.

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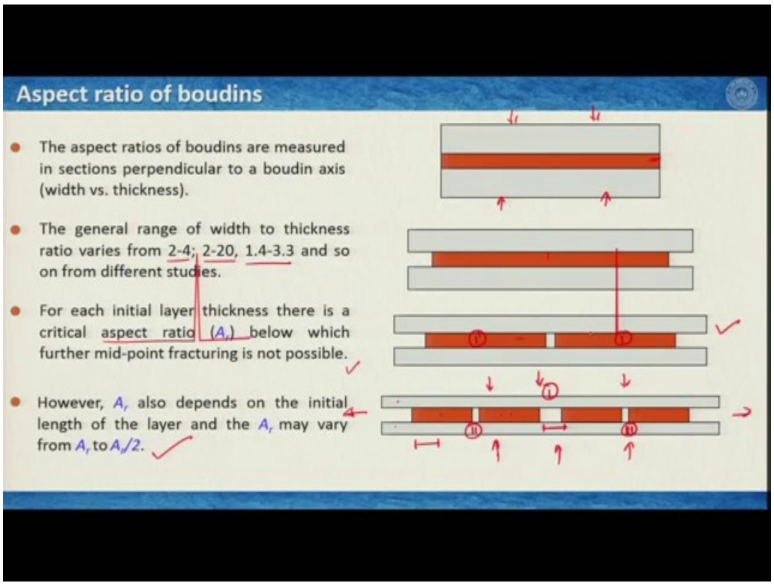

So generally what we can figure out is that the aspect ratios of boudins are generally measured in sections perpendicular to a boudin axis. For unidirectional boudinage the aspect ratio is the ratio of width versus the thickness of the boudins. And you can consider the two-dimensional boudinage then we have also to measure the length to thickness ratio.

The width to thickness ratio of boudins interestingly may vary within a wide range. However in most areas there is a general tendency of thicker beds to form boudins of larger widths. Now what do we see here that the general range of width of thicknesses which are being reported from different field studies that field studies reported that it is generally from 2 to 4 if you made it really large 2 to 20 and then some made it really narrow 1.4 to 3.3 and so on and these are from different studies.

So the theory of boudinage if we can consider predicts that in any one of the competent bed boudins with a restricted range of aspect ratios should be more frequent than others. Now you can consider a simple situation, assume that a brittle layer is sandwiched between two ductile layers and is subjected to a layer normal compression. This is the case we can consider we have seen in this illustration before okay.

Now we have understood this before that when stress exceeds the strength of this piece rock it flows and then it forms a fracture in the middle and then the boudinaging process starts so in a way we can say that when the stress exceeds the strength and extension fracture develops perpendicular to the layering and the layer is thus broken into two segments which is this case, so this is one segment and this is the second half of that segment.

Now if you continue the deformation that means if you continue the layer normal compression and it continues flowing laterally in the separation between two cases increases so this is exactly what is increasing and very interestingly that the you have the fresh midpoint fractures from each of these pieces. So you are having these new fractures whether this is the first one and then you arise at the new fractures.

Now the stress within a competent fragment increases with increasing widths that means that is the length at a right angle to the boudin axis and decreases with increased thickness. This means very interestingly that it becomes increasingly difficult for a bed or for a layer competent layer to fracture when boudin width become shorter right and this is very easy because if we have a shorter boudin the length of the boudin is less than instead of fracturing it will try to produce if the ductility of the layer is pretty high but still more than these two layers then it can form the barrel shape, fish mouth shape and so on.

So this is the reason why it is expected that the boudins of a bed would show a small range of width to thickness ratios. Now then the question comes what would be the final aspect ratio? The final aspect ratio which is obtained after this processes this midpoint fracturing is a function on its initial length and this becomes clear if we consider you can think of an example and you can imagine that the critical aspect ratio for example you can think of that will be the two.

Now what is the crystal aspect ratio here? That there is always a critical aspect ratio below which further midpoint fracturing is not possible that means the boudinage processes for that particular layer is finished for this particular deformation. Now you can think of that if we start from a layer segment of aspect ratio 20 where you can consider that the critical aspect ratio for that particular layer is 2 then by successive midpoint fracturing you can arrive at a value of 2.5 this is simple arithmetic.

Now since this is larger than your critical aspect ratio or Ar, the segment will suffer further extension fracture to yield stable boudins with aspect ratio in that case it would be 1.25. Now if instead you can consider that instead of 20 if the starting layer segment has an aspect ratio 30 we get the final aspect ratio to 1.875 of a stable boudins. So depending upon the initial length of the layer segments in a transverse section the final boudin aspect ratio may range between the original critical aspect ratio which is Ar to Ar/2 as it is written here.

Now in the nature because this is some sort of geometric aspects that we are considering here but in nature the range is likely to be modified by lot of other factors such as you can consider the occurrence of flows in the competent bed, variation of strength and micro structuring in different parts of this bed, some defects or some initial fractures within all these layers and so on. So these also control the aspect ratio of the boudins but in general if everything is homogeneous then you expect the aspect ratio of the boudin between the critical aspect ratio and half of it.

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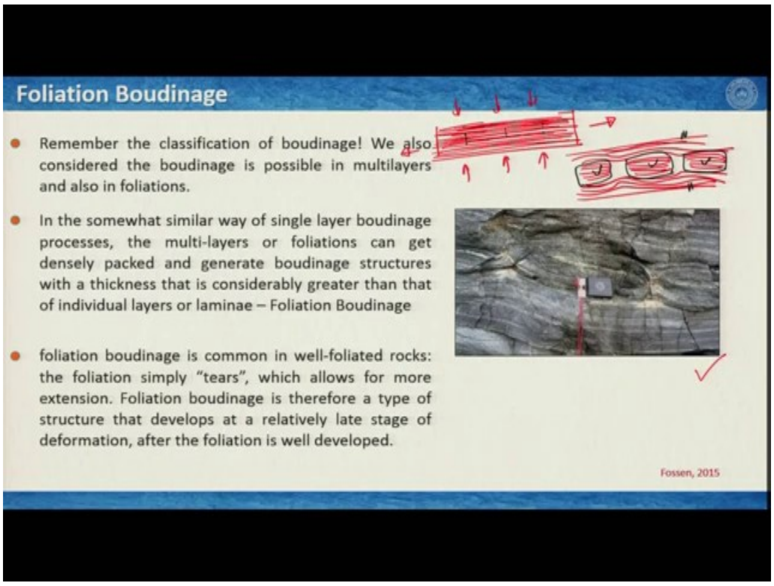

Let us move to the next topic which is the foliation boudinage (I know) we have learned about it this foliation boudinage. If you remember the classification we also consider that the boudinage is possible in multilayers and also in foliations. Now in somewhat, in the somewhat similar way of single layer boudinage processes, the multilayers or foliations can get densely packed and generate boudinage structures with a thickness that is considerably greater than that of individual layers or lamina and these are known as foliation boudinage.

Now what do you mean by this? So for simple single layer boudinage processes we understood that requires a competence contrasts between the boudinage layer and the layers outside. But when we have a foliation like this or multilayers like this there is apparently no competence contrasts, it is almost a continuous layer with very high and strong an isotropic. But what is interesting in this kind of situation is that you are still applying a flow along the layers and therefore you can also imagine that there is a layer normal compression.

Because an isotropic is very-very high and layers are very thin you can expect the fact that a group of layers can fracture at one point of time or one after another. When that happens then you arrive at a situation where everything flows like this outside and these layers are fractured and they appear like this. The layers on the other side are like this and so on. Now you see that this actually is representing your like a shape of boudins. But apparently these segments, this segment, this segment or this segment they do not have any competence contrast with respect to the surrounding layers.

So this is a very interesting process and we see this in nature people do research on it and here is an example of the foliation boudinage. Now foliation boudinage is common in well-foliated rocks, the foliation simply tears as I have explained here they just break in little pieces which allows for more extension and foliation boudinage is therefore a type of structure that develops at a relatively late stage of deformation because we need this strong anisotropy and it generally forms after the foliation is extremely strong and is well developed.

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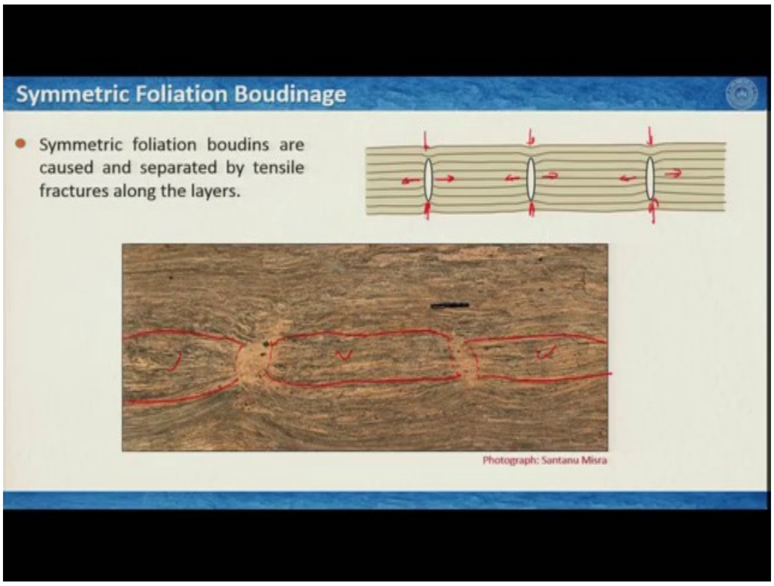

Now foliation boudinage as we have classified can be symmetric or asymmetric, so symmetric foliation boudinage is where we do not have any, you have only separation by tensile fractures the separated zones or the makes zones as we can see here they do not undergo any shear deformation, so it is only separation by tensile fractures and if that happens then this is a symmetric foliation boudinage as we can see here so you see that these layers, this packet of layers here they got boudinage and this is the tensile fracture that it has developed right.

So there is no apparent sleep along this or no feasible sleep between this segment and this segment and this segment and therefore this is a symmetric type of foliation boudinage.

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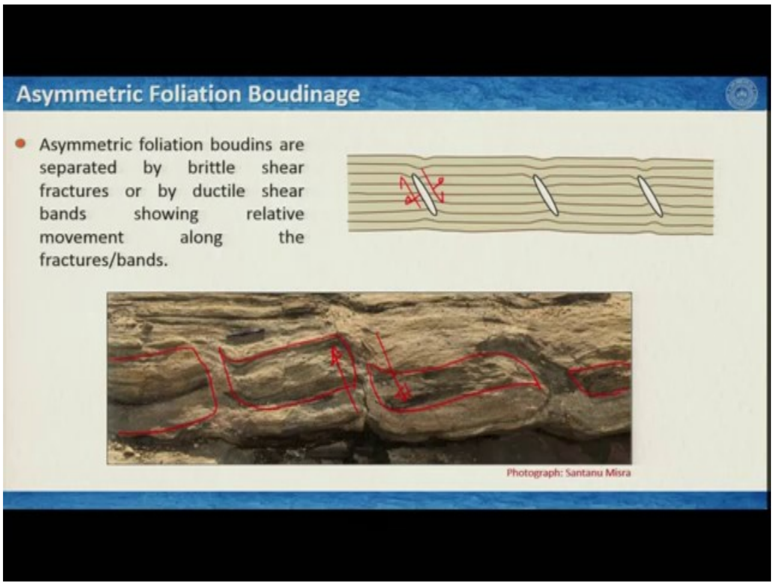

However asymmetric foliation boudins are separated by brittle shear fractures or by ductile shear bands showing a relative displacement along the fracture or bands as you can see here that it had a tensile fracture at one point of time but after that it has a sense of displacement along the fracture zone and this is an excellent example as we can see here.

So we can imagine that this is a packet and then is another packet defining the boudin, this is another packet which is defined in the boudin and this is another packet which is defined in the boudin. And you can clearly see that it got relative displacement along the make zone or fracture zone of the boudins and therefore this is asymmetric foliation boudinage.

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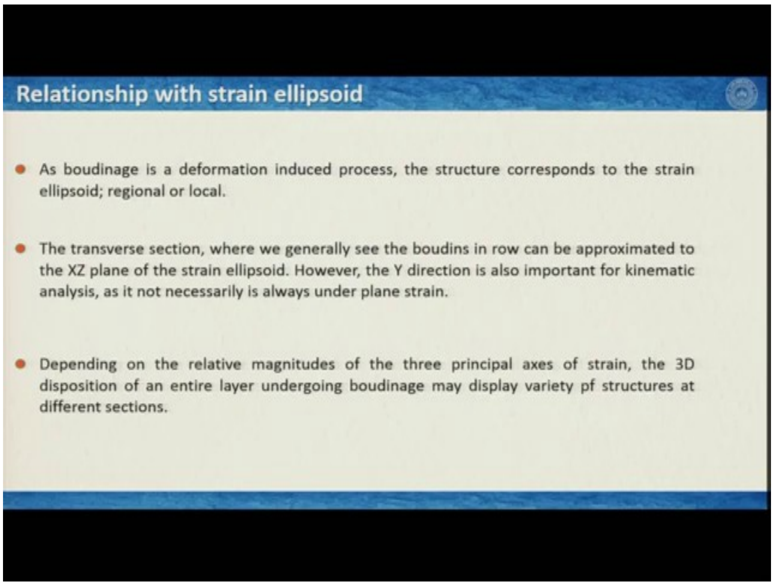

Now we will switch to the next topic that how this boudinage are related or budins are related with the strain ellipsoid? Now the boudinage is a deformation induced process this is quite obvious we have learned it, so the structure must correspond to the stain ellipsoid either regionally or locally. The transverse section, where we generally see the boudins in a row can be approximated to the XZ plane of the strain ellipsoid. However, the Y direction is also important for kinematic analysis, as it is not necessarily is always under plain strain and we will see this very soon.

Now depending on the relative magnitudes of the 3 principal axis of strains, the 3D disposition of an entire layer undergoing boudinage may display variety of structures and this is exactly what we are going to see into next slide and I request you to recall the strain lecture or go back to the strain lecture because we will be seeing now plain strain, constrictional strain, flattening type of strain and so on and then we will see how we form the boudinage or some other related structures along with this kind of various strain ellipsoid.

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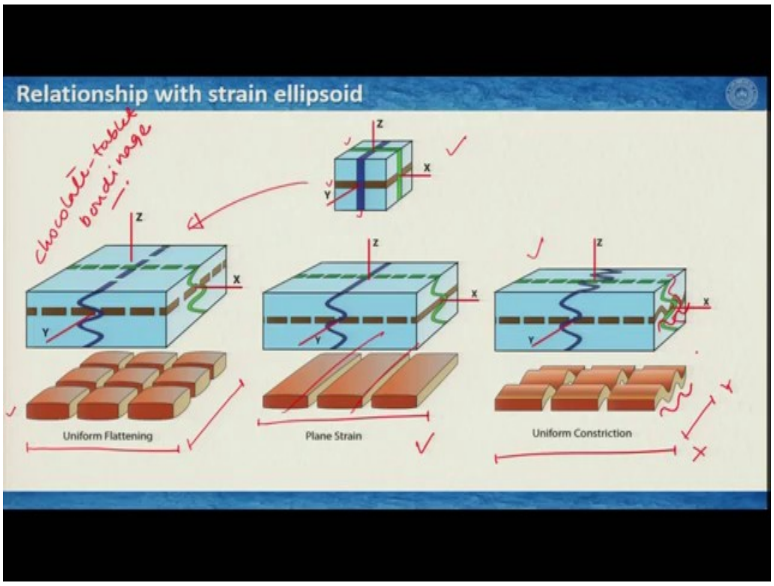

Let us have a look, so what do we see here in this slide? This dispersed image looks like a gift box but it is not. So this is you can consider a unit cube and this brown then blue and this green layers are competent layers which are aligned perpendicular to X, Y and Z axis. So for example this blue layer is aligned perpendicular to the x-axis, the brown layer is perpendicular to the z-axis and the green layer is perpendicular to the y-axis.

Like one can also ask this question, do you see this kind of features in geology in structures where you have three layers cross cutting each other? The answer is yes, you can consider one is your primary bedding plane and then the other two could be two different types that have intruded at different stages of time and then the entire packet is undergoing deformation so this is not a problem therefore we will see that yes this is a possibility.

Now first we will take over this problem of uniform flattening, uniform flattening if you remember that your z-axis has to be shortened and y and x-axis should move or should flow equally. So the condition is x equal to y which is greater than 1 and z is less than 1 this is the condition. Now if that happens then this brown layer because it is flowing in perpendicular to the z section therefore the brown layer would get boudinage along the X direction also along the Y direction and therefore this layer if I consider this brown layer here this one exactly then it would produce two sets of boudinage and this is known as we have learned it chocolate tablet boudinage okay.

If that does not happen if the strain is like a plain strain that means your y-axis is constant there is no deformation along the y-axis then this brown layer which is the horizontal layer perpendicular to the Z then the flow is only along the X direction and shortening along the Z direction so this brown layer of would actually experience a layer normal compression and layer parallel extension therefore we would have a boudinage of shape like this.

And if we have a uniform constriction which is shown here that means this brown layer is very interestingly would flow in X direction so no problem that it is forming boudinage along the X direction but because it is uniform constriction so it is getting compressed along Y direction. So along Y direction because it is getting compressed it will produce some compressional structures like fold.

Also the green layers would produce a compressional structure if you view perpendicular to the X section and the blue layers also produce on both sections because this is something that we are looking at the layer is undergoing compression in all directions. So this is how you have the chocolate tablet boudinage, a simple one layer single boudinage or single boudinage as we see here and then boudinage with folding you can form this in a single deformation we will see soon that boudinage in superposed deformation.

But the message I would like to give you with this slide is that if you see a chocolate tablet boudinage or if you see a boudinage in one section in another section the same layer is folded that not necessarily indicate that it is a result of superposed deformation so when you conclude your observations it is very important you look at some other sections or you observe things in a better way to arrive at a conclusion that whether these are the products of superposed deformation or from a single phase deformation.

And speaking of which we will come to the boudinage which are related to the folds because in folds it is very interesting because a layer at one point of time undergoes compression and then it can go extension at one point of time. So at one stage then it can again come to the compressional field and so on because it is very complex with respect to the local orientations of the strain ellipsoid we have understood it in the fold lectures.

So generally in most cases the majority observations that people have seen that boudin axis are roughly parallel or perpendicular to the fold axis but that is not the thumb rule.

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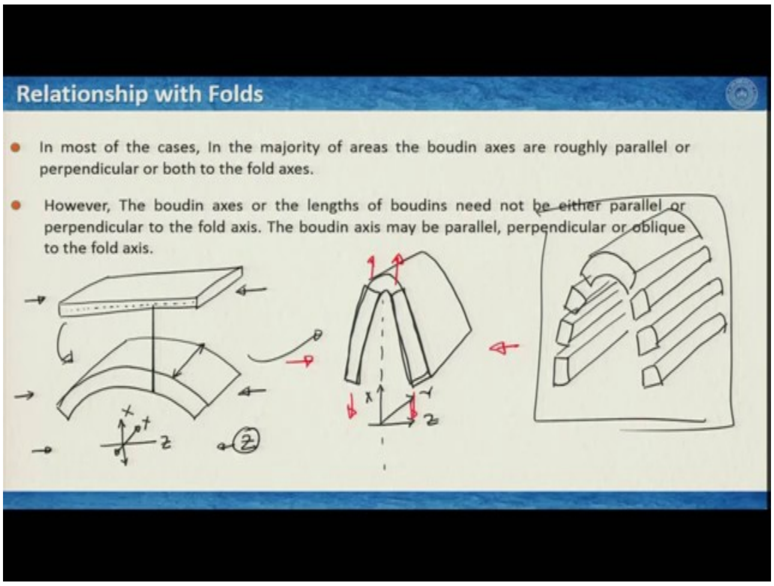

The boudin axis or the length of boudins need not to be either parallel or perpendicular to the fold axis, the boudin axis maybe parallel, perpendicular or oblique to the fold axis. Now how to conceive this idea? Let us have a look on this with some simple drawings. Will see this in the form of illustration but let us imagine the fact that we have a layer then we are applying layer parallel compression, so when we do that then this is undergoing the interlayer is undergoing at least in this section compression, so the layer would produce a gentle fold.

Isn't it? What is the orientation of the principal axis of the strength in this case? Now this must be your Z direction isn't it? Because this is the shortening direction, so this is your Z okay if that happens then it is extending in this direction okay because this could be a long axis so we can consider for the time being this is X that the principle extension direction and we can assume that along the side there is no strain or plain strain condition so this can be your Y.

Now with further deformation if we assume it to the next stage then the fold would get would produce a tighter fold and then we will see very nicely if the orientations are same, this is your Z, this is your Y and this is your X. That these limbs of these folds are slowly orienting themselves along the principle extension direction. So therefore this layer if I consider this particular segment here or this segment here is actually suffering or slowly undergoing a deformation which is an extension along the layers.

However the bulk strain ellipsoid is still the same direction the way we started. If that happens then essentially these layers with further rotation they would form boudinage like this and so on. So you see that under compression the global strain ellipsoid is under compression but in this particular case as we see here with the continued deformation we are forming a boudinage structure which is associated with the fold in a single deformation.

So if we try to get it that we have just learned that not necessarily it has to be in this case actually, in this case we have seen that this is the fold axis, this is parallel to the fold axis however if the compression is oblique to the layers then you can actually form.

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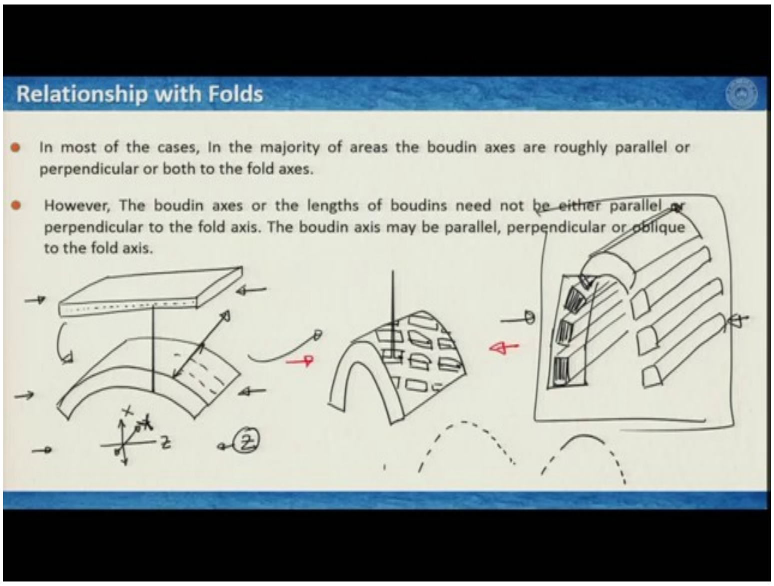

Let me wipe this one out because I do not have any more space. You can actually form boudinage which can be oriented oblique to the fold axis, I am just giving you the rough idea.

Now we will learn about this processes soon in a different way but the boudin axis or the length of the boudins need not to be either parallel or perpendicular to the fold axis, so this is what is important and the lengths of the boudins can be also oblique to the axis of the folds and such oblique boudins as we see here that these are oblique, boudin axis are oblique to the fold and these oblique boudins may develop if the bed is oriented oblique to the principal axis of stresses.

Now the geometrical relation of boudinage structures with folds should never be taken for granted, especially in rocks which are known to have undergone repeated deformations. This is something as I told also (with) when you look at the boudinage and try to correlate with the strain ellipsoid the same warning or same measures must be considered when you try to correlate the boudinage processes with the fold.

So this is because the occurrence of the boudinage structure in a transverse section of a fold does not necessarily imply that the boudin axis is parallel to the fold axis. The reason for emphasising this obvious point that I am trying to convey you repeatedly that the parallelism of the boudin axis and the fold axis has so often being emphasized that you or the student tend to make this assumption when they observed boudinage structures on a fold profile and they consider that this is either parallel or perpendicular to the fold axis and this may not be always true.

However, it is true that boudin axis and fold axis are often approximately parallel but in making this assumption without actual observation or measurement there is a possibility that we are losing a vital piece of information in the reconstruction of the history of the superposed deformation. So in areas of superposed deformation the earlier boudin axis may be oblique to the later fold axis. So the boudin orientation may get completely modified and since the plan view of the boudinage is very rare to see in the field. So such evidence unless a careful search is made is likely to be overlooked.

Now you can also think of the pinch and swell structures and extension fractures boudinage in which boudin axis parallel to the fold axis, they cannot form at the initial stage of the folding processes. As you can see here that when the fold is pretty open we do not have any possibilities of the boudin.

The bodins may form or they generally form at a later stage of folding when limbs of the folds have entered in the extensional field as we have seen I have worked out the drawing but it you can remember this drawing you can go back with the slider and see the back slides but here you see that this was your compression direction and this is this layer in particular was actually suffering a layer normal compressions.

So this occurrence of small extension fracture boudinage that this is here that these are the extensional fracture boudinage and so on or you can have also pinch and swell structures here in a very similar mechanism. At the broad hinge zone you do not see that, so if you see boudinage in the hinge zone there must be a second stage of deformation. So if you see boudinage like this there must be a second stage of deformation but otherwise in a single stage of deformation your hinge is generally unaffected.

We will see this, that where we have some boudinage where the hinge is affected and in some places where hinge is not affected. Now if there is an extension parallel to the fold axis then the boudinage may develop even at an early-stage when the amplitude of the fold is small and this is something can happen when you have extension along the Y direction in that case you can develop boudinage along this direction. But this is again possible but not very much seen in the field.

So thus among the extension fracture boudinage structures which have grown during fracture or buckle folding those which have their axis parallel to the fold axis must have been initiated when the folds were fairly tight. On the other hand the boudins which are perpendicular to the fold axis could have been initiated either at an early-stage or at a very late stage of the folding. Now we will see some illustrations in the next slide.

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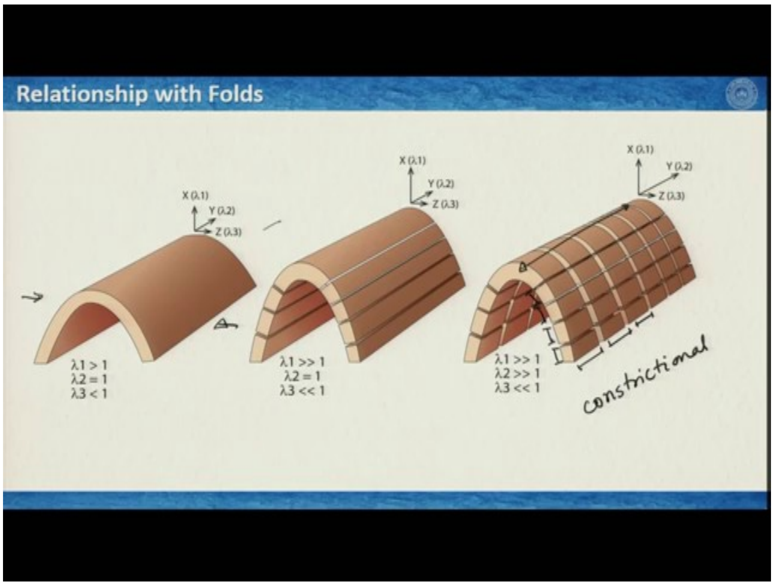

As we can see here we have been drawing this but this is better drawing what we see here that this is open fold nothing has happened then this is your extensional direction X then Y and Z is a compression direction fold is forming in this way. So in such a situation lambda one that is the principal stretch is 1, lambda two there is no movement along the Y direction so this is 1 and lambda three is less than one because this is the compression direction.

Now with progressive deformation as we can see here that this layer along the lambda1 is getting boudinage and if at later stage the lateral extension or it gets extended along the fold axis like this so Y takes over that means lambda 1 is also 1 much-much greater than 1 and at the same time lambda 2, so this is a kind of constrictional deformation okay.

Then you form the boudinage in this direction and also in this direction either simultaneously or one after another and this is again a chocolate tablet boudinage associated with folds.

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And I have a very nice example for you. Now what do we see here this is the formed surface of a fold this, this surface. This is a form surface of fold and you see that this is characterized by one set of fractures and then another set of fractures like this almost orthogonal to that. Therefore it produced the chocolate tablet boudinage and if you are not convinced that this is a fold I would like to request you to see this side you see that this is going like this and coming back like this. The fold axis or hinge zone is actually exposed here, so it is going like this okay.

So this is how it happened, so this could be your X and the or Y and this could be your X or Y and of course the perpendicular direction the way the person is looking at the direction of the person is looking at here is the direction of the Z along which the fold has formed or along which the bulk compression came to generate the fold.

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Now let us talk about the boudinage and superposed deformation. Now what you see in this image that you see this is a fold but it got boudinage here then it rotated it got some pinched then it got some swelling and it has several fractures here and these indicate that these were once a part of boudinage. So what I would like to emphasise here is that you can form boudinage during folding processes then you have a layer undergone boudinage, boudinaging process and then the entire layer can be folded. So these two processes are essentially different and this is one example.

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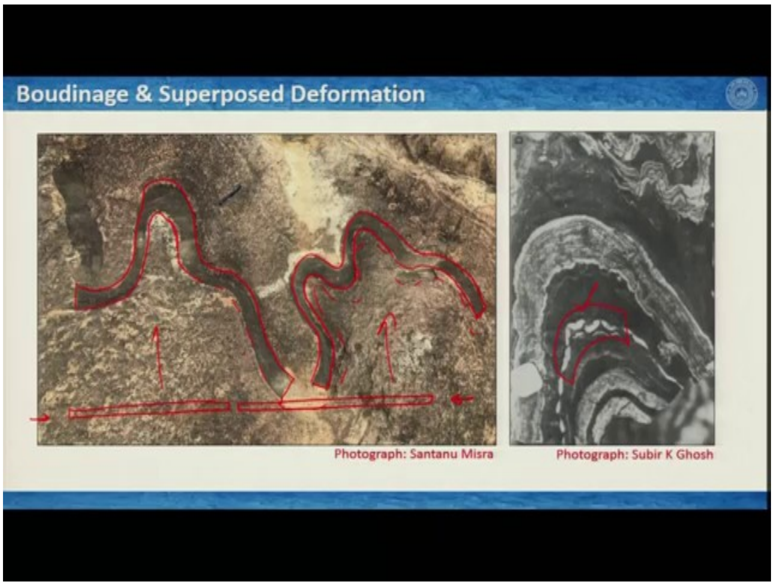

And let us have a look to the other example. What we see here that this is a fold, right? I mean if I draw it thoroughly it is a fold going like this and deforms in form and so on. But we see here that this got a break, so this was one single boudin then this is another boudin and you see it is off here.

So it was once upon a time something like that very much very long aspect ratio boudins and then it got some rare parallel compressions and then eventually produced a shape like this what we see in this other image this is from the book of Prof. Subir Ghosh. You see that the hinge zone of this fold is boudinage so as I have told you that if you see that boudins at the hinge zone that means that this it records essentially the second stage of deformation or this is the product of superposed deformation.

So the folding of the boudinage layer in certain instances can be easily distinguished as you can figure out that from the boudinage structure which are initiated during folding. Thus when extension fracture boudinage structure occurs on the transverse profile of a gentle fold wave with the layering in both the hinge and the limbs in the compressional field, we can conclude convincingly that the boudinage layers have been subsequently folded we can arrive at the same conclusion when small boudins are situated at the broad hinge what you see here in this illustration and in addition the shortening of the boudinage layer also produce a variety of characteristic patterns and we will see this in the next slide.

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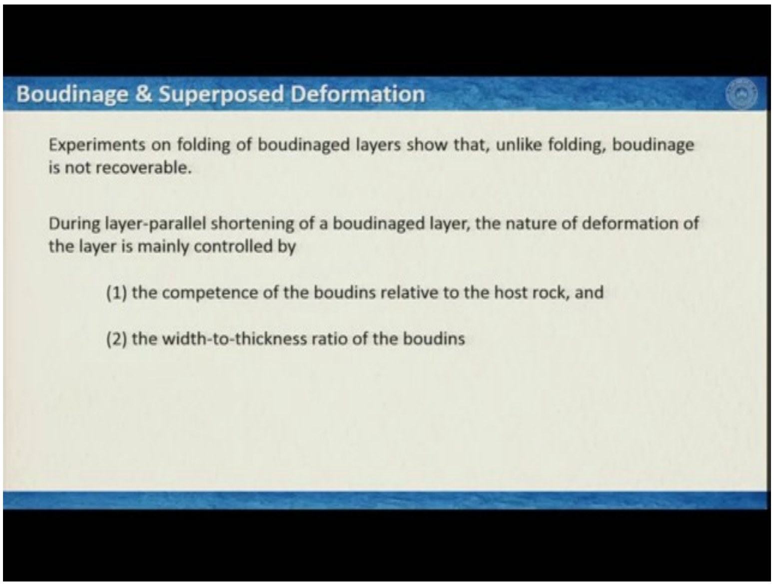

Before that let us have a look that how do we understand that experiments on folding of boudinage layers generally show that unlike folding, boudinage is not recoverable. But you make a fold then you can unfold it so you are compressing something, so you make a fold and then you can unfold it because it is a continuous layer. But if it is a boudinage layer then it is a segment of several blocks. So once you fold it then it is very difficult to unfold it because these individual blocks also deform their own way.

Will see this in the next slide but during layer parallel shortening of a boudinage layer, the nature of the deformation of the layer is mostly controlled by one the competence of the boudins related to the host rock and the width to thickness ratio of the boudins. So these are the main, main ways or these two are the main reasons you can think of and then we have a series of structures that you can produce when you have layer parallel compression in a boudinage layer.

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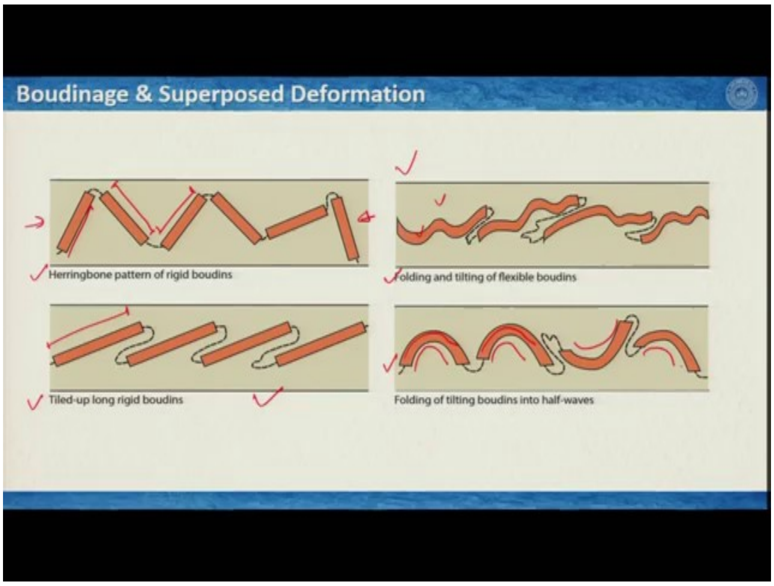

So here are some examples, these are experimentally derived and also observed in the field so one is herringbone pattern of rigid boudins, then tiled up longer rigid boudins then folding and tilting of flexible boudins and folding of tilting boudins into half waves. So how do we form short or medium sized very stiff boudins that can only undergo body rotation. So these are very stiff boudins and it can go only the body rotations so they just rotate with the layer parallel compression and these are known as herringbone patterns and if this stiff boudins have large width to thickness ratio as we see here and they are also very stiff then they may produce a structure like this which is known as tiled like piling of one boudin over another. In the flexible boudins which we see that means the competence contrast between this and this not that significant. They are folded and if the width thickness ratio is not large then the individual boudins are folded into half waves like you see here or here or here and so on and the neighbouring fold often closing in the same sense so you see that this is an anti-form and the second one is also the anti-form. So these are the different structures that the researchers have produced by experiments and they figured out that this is how you can produce different kinds of structures when you apply layer parallel compression in producing folds when you have boudinage layers in it.

So with this I conclude this lecture and also the lecture of this week and we will see some other features in the next class.

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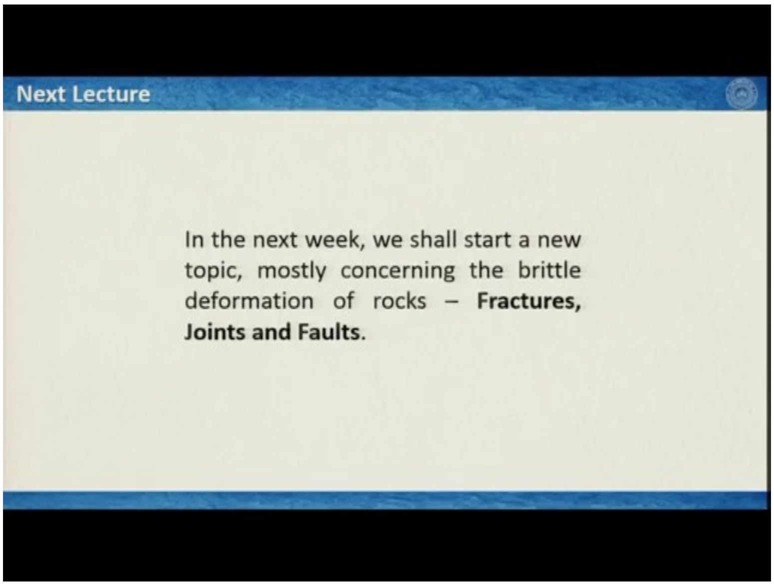

And in the next week we mostly would focus on a new topic and which will be mostly concerned the brittle deformation of rocks and this would be fractures, joints and faults. So thank you very much and I wish you all the best, see you in the next lecture.