Structural Geology
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Lecture 30
Faults and Faulting -II

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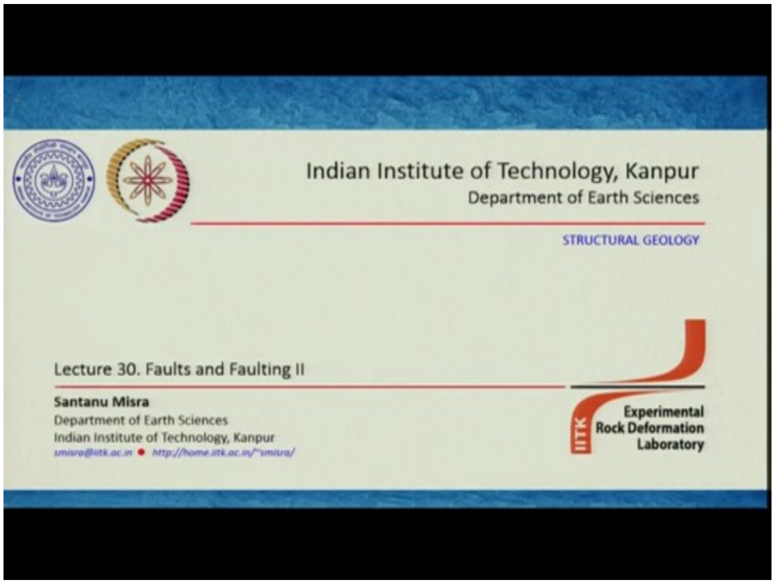

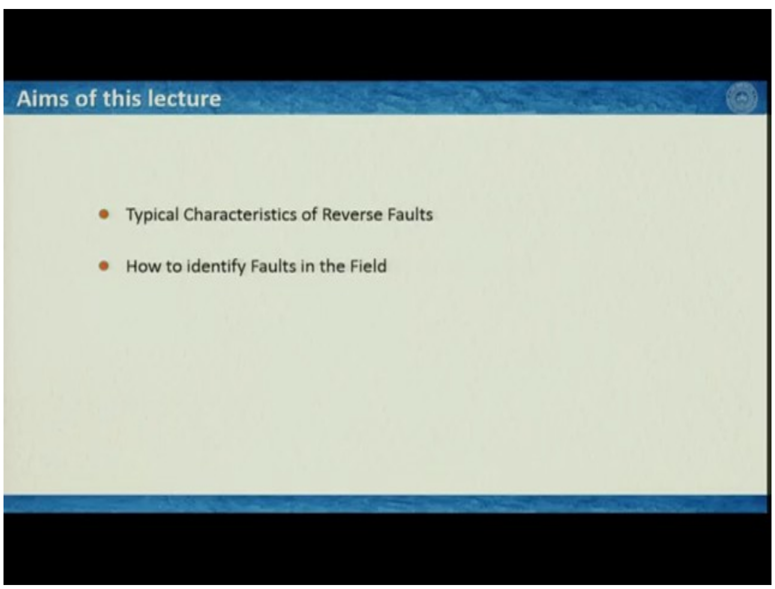

Hello everyone welcome back again to this online NPTEL structural geology course. We are going to start a new week, week 11 and the topic of this week as decided was ductile shear zones but as I said in the last lecture will spill few of our materials of the faults to this week and in order to do that we will start this lecture which is a lecture number 30 and we will learn a little bit more on faults and faulting particularly we will focus on reverse faults.

So in this lecture we mostly cover a typical characteristics of reverse faults as I was talking about and then will look with a particular slide that how to identify faults in the field because it is you not necessarily you see the fault scarp or fault plane exposed but there are few other criteria from very small scale to very large scale by which you can identify the faults in the field. We will very briefly discuss this part as well.

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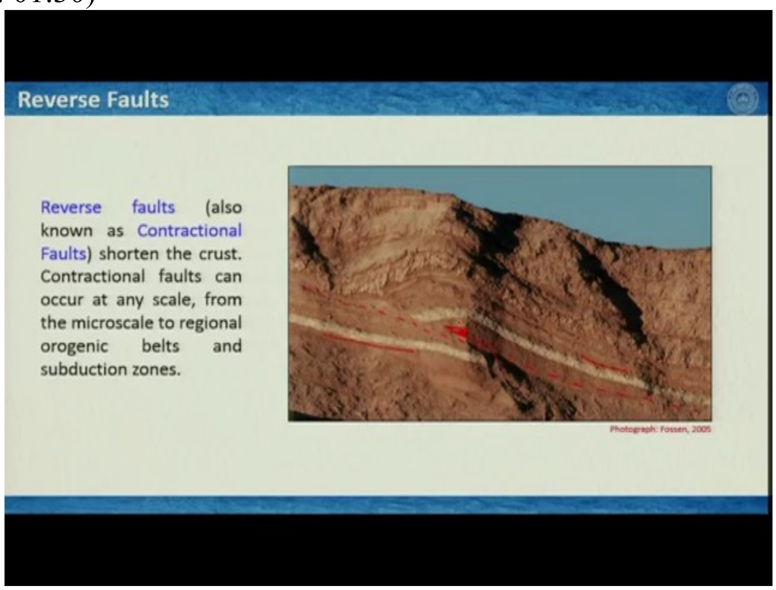

So we learnt about reverse faults in the in the last lecture and we know that reverse faults also known as contractional faults it shortens the crust and reverse faults are generally those which have dominant deep sleep components with a relative upward movement of the hanging wall and reverse faults which has a relatively low deep angle less than 30 degrees are known as thrust faults.

So as you can see in this fantastic image by foison that this is the trace of the fault this one and we can see that this particular white layer this one and this one they were once upon a time together but due to the faulting thrust faulting or reverse faulting this has moved and therefore the entire crust got shortened and this you see in every scale from very micro scale to regional organic belts and also in subduction zones as we have understood from our previous lectures that most of the rocks in the earth are generally under compression so reverse faults are extremely common particularly in subduction zones and contractional orogenic belts.

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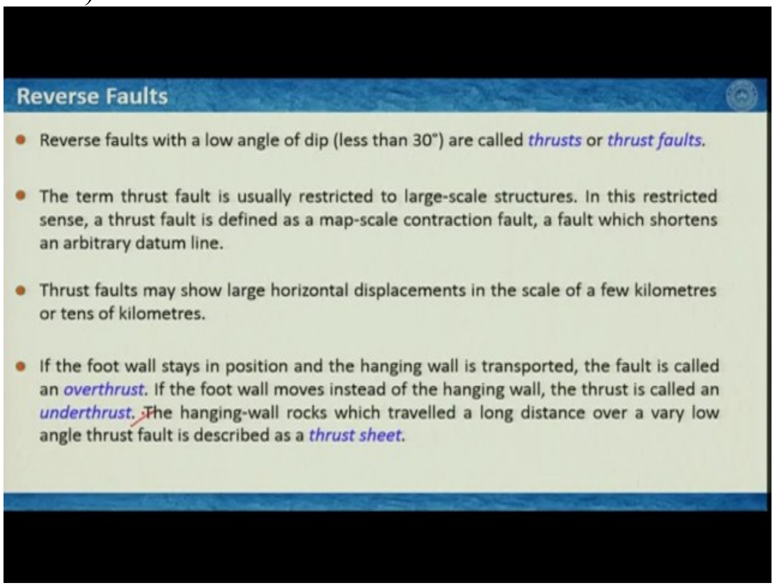

So here are a few characteristics of the reverse faults as I was talking about reverse faults with a low angle deep less than 30 degrees are generally called thrusts or thrust faults and the term thrust fault is usually restricted to large-scale structures and in this restricted sense a thrust fault is generally defined as a map scale contractional fault or a fault which shortens an arbitrary datum line or lithology in general.

Now thrust faults may show large horizontal displacements in the scale of a few kilometers of tens of kilometers if the foot wall stays in the position and the hanging wall is transported that means the hanging wall is moving over the foot wall then the thrust is called and over thrust and if the opposite happens that means the footwall moves instead of the hanging wall so hanging wall stays in a fixed position but the foot wall below is moving then this is called under thrust trust now the hanging wall rocks which traveled long distance over a very low angle thrust fault is generally called thrust sheet.

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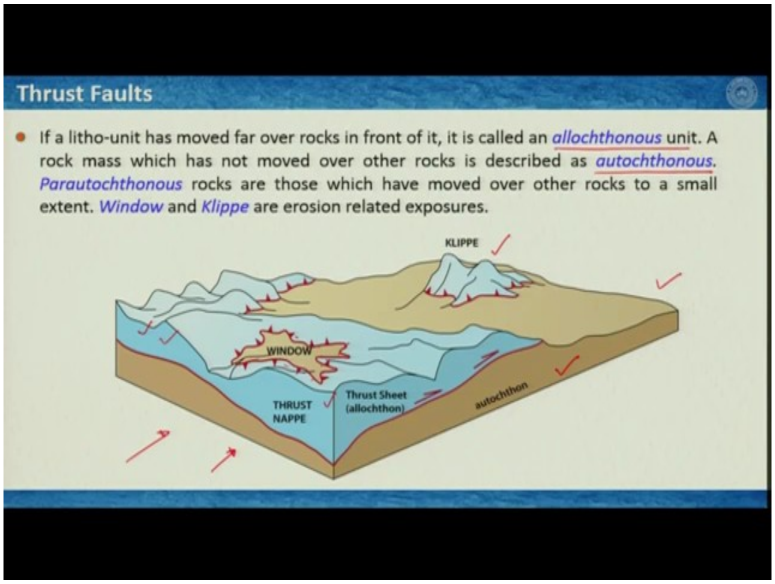

Now this over thrust under thrust these are some tectonic terms that people generally use so we will not go into that part in detail but we mostly look at some other features of that we have already learned now if a tectonic unit has moved for example far over the rocks in front of it that means it does not stay in its original position so it is mostly due over thrust then we will have learnt it previously you have also seen this illustration then this is known as allocthonous unit.

Now a rock mass which has not moved over other rocks described as autochthonous so for example here this is an autochthon because it stays it is original position in its deposition site but this blue rock that is your blue unit that is see here it has moved far from this side and it is now staying here.

Now there are also some erosional features and there is also another term that we would like to introduce here that we did not learn before that is Parautochthonous so Parautochthonous rocks are those which have moved over the rocks with a small extent so it did not move a large extent but a small extent and this large and small these are generally relative terms with respect to the autogenic setting.

Now we also have learnt 2 terms windows and klippe these are erosion related exposures so a closed outcrop of a thrust shape isolated from the main mass by erosion is called klippe which you see here and in contrary you can you can say that I mean if you have an allocthonous material which is the blue one and if that gets eroded like here and it exposes within it the autochthonous rock then this is known as window or sometimes people call it also tectonic window.

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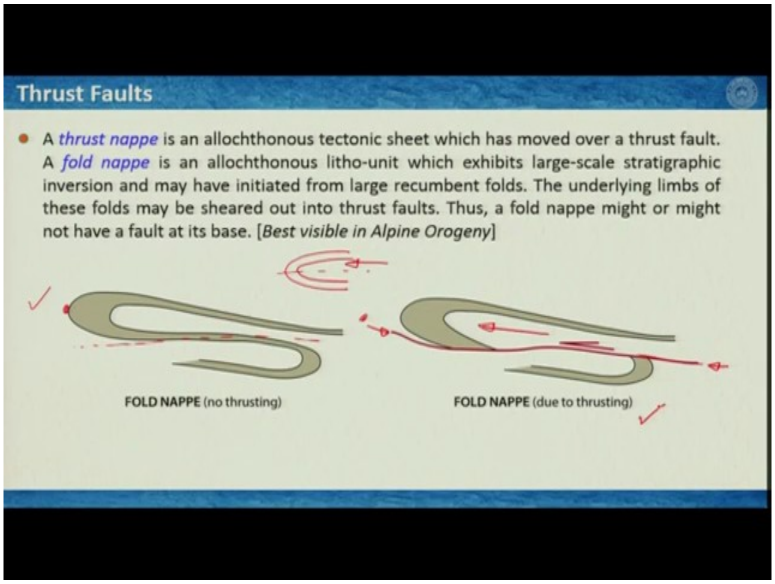

Now in this context there is also one more term that I would like to introduce here to you this is called is nappe so generally it is called nappe or thrust nappe, trusts nappe is an allocthonous tectonic sheet which has moved over a thrust fault now this can happen in 2 different ways what I mean by this that it can involve a thrusting or it may not involve a thrusting but generally it is associated with folding.

So a fold nappe is an allocthonous litho-unit which exhibits large scale stratigraphic inversion and may have initiated from a large recumbent folds so for example you see here if you remember recumbent fold or something like a fold which has its axial plane horizontal and now if this side it gets a significant movement then you end up with a structure what we see here and it does not involve any thrust.

So this part was initially probably somewhere here and it moved a long distance and in that case this is known as fold nappe without thrusting so the underlying limbs of this fold sometimes may be sheared out into the thrust faults as you can see here so this is a sheared unit so along this the thrust has happened so if I can consider that while this is happening this got thin enough and then it just broke and then the travel becomes much easier in that case this is also known as fold nappe or thrust nappe due to thrusting.

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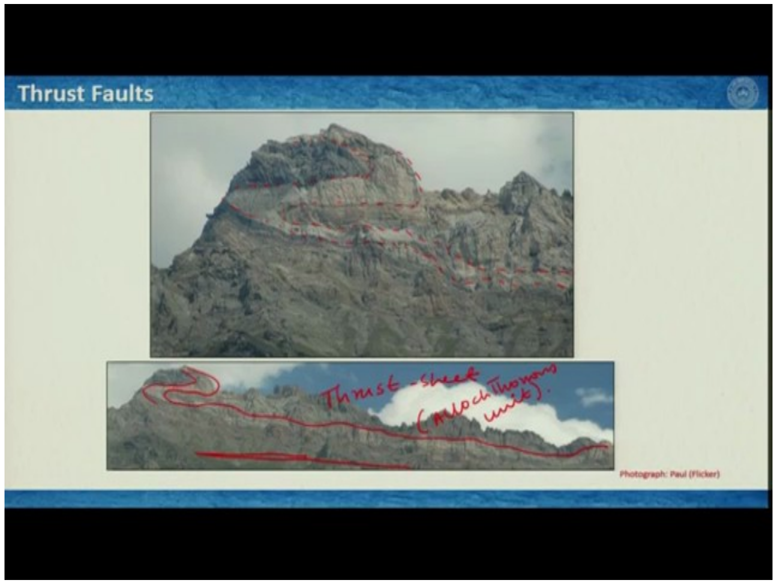

Now these kind of structures you see in Alpine orogeny fantastic so here I show you two examples rather one example one photograph taken from panoramic view but let us let us look at the first one so we have seen this, this is a moracle nappe in one of our first lectures so you see that the trace of the fold here is going like this and this got folded and it coming here and like this and the other layer is something like that and if we see it here in this panoramic view the fold is something going something like that.

So you see it has moved a long distance and this can only happen if you have a thrust somewhere below and this sheet here is actually going above, this is thrust sheet and this is moving due to tectonic movements above the thrust fault it is in a different position and therefore this is also allocthonous.

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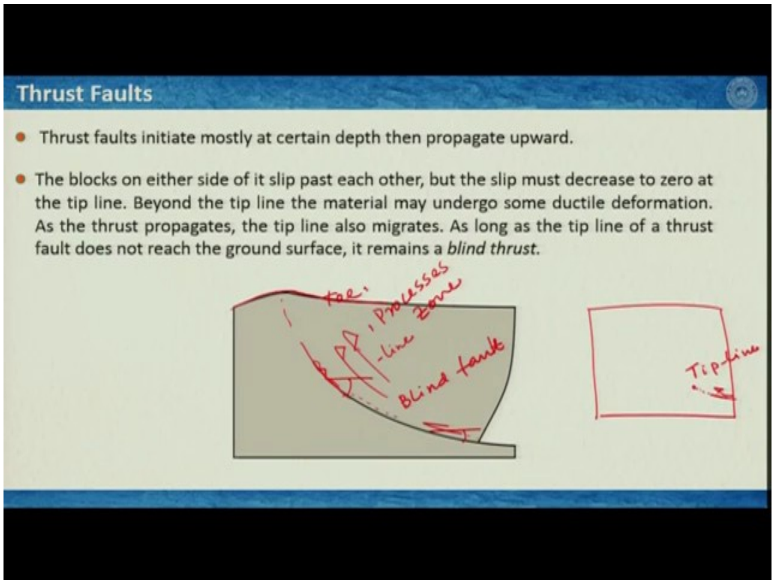

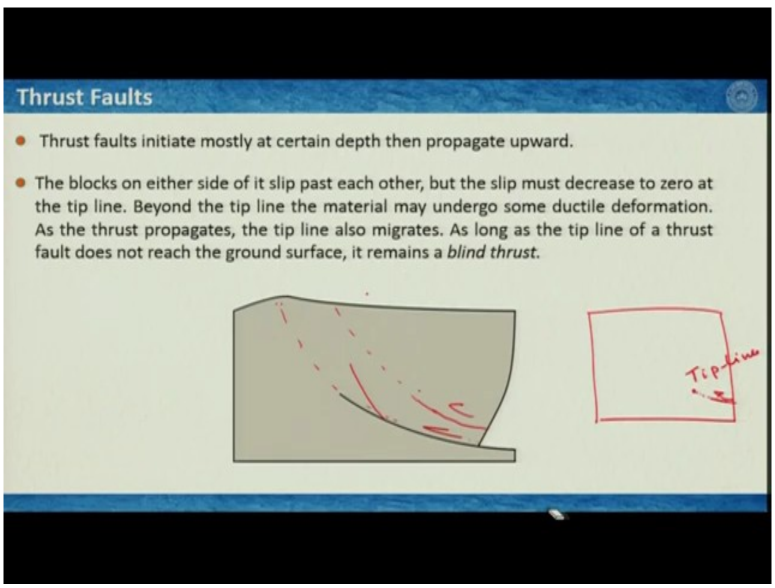

Now when we learnt this allocthonous, autochthonous, klippe, window these are mostly related to a thrust fault it is also important to understand right now that how does a thrust fault initiate. Now when the fault is nucleated with the volume of rocks it initially forms if I can draw it here so a very very little penny Shaped a crack and this crack has a closed boundary and the top part of this boundary when it starts propagating if it propagates in this direction then this is known as tipped line or you can say this one in this illustration that this is tip line.

Now one point is very important to remember here that displacement at the tip line is 0 so therefore this is also a definition of tip line so here the displacement is maximum and slowly along this the displacement slowly terminates to 0 so the blocks on either side of this fault line slips past each other like this way relatively and this sleep has to decrease to 0 at the tip line now beyond the tip line the material here.

So what is happening here now you form a zone here which is known as a process zone and sometimes it also involves a little bit of ductile deformation as well now as the trust propagates the tip line this tip line here let me clean this place.

The tip line here also starts migrating now as long as the tip line of the thrust fault does not reach the ground surface so it stays below the surface then this is known as blind fault and blind faults are extremely dangerous in terms of producing earthquake because you do not see sometimes any surface expressions of the fault and it just stays blindly inside and if there is any movement then it just appears on the surface and make some devastating earthquakes there are many examples for example the Christchurch earthquake in 2011 and 2012 these are examples of earthquakes from the blind faults people had no clue that there are some faults below the surface.

Now many thrusts sometimes because of this migration upwards sometimes have their upward carving shape as you can see here and this can happen only well there are many reasons it can happen but in this case it can happen because this thrust is propagating so the material here it is getting pushed upward and therefore you see this kind of topography and these are sometimes are known as also this kind of faults also known as list rick thrust faults so that at the base the deep is extremely low or sub horizontal let me again clean this space so here you see the deep is very low but here the deep slowly increases towards tip line or at the higher level.

Now a thrust sheet emerging on the surface may have traveled on the erosion surface so for example this one or on the surface itself sometimes riding over on its own debris is in the front and this is then called erosion thrust or relief thrust so sometimes you do not see them on the surface but this elevation tells you that there could be a fault and this not necessarily can happen due to thrusting it can also happen due to folding therefore a detailed geological survey is essential to understand whether this surface elevation is just topography, duty erosion or you have some sort of folds down there or a propagating thrust fault which is blind.

Now sometimes this is also the wage that makes up the frontal portion and the thrust sheet is also known as toe so this side is known as toe now many thrusts as blind thrust and propagate to reach the surface and they are not necessarily let me clean again here propagate as a single fault what I mean by this that may be another thrust fault has initiated here and this thrust fault can also propagate separately or in the course of their journey they can meet each other. They can this fault also can split to another fault and so on.

So we always have a master thrust and then out of this master thrust we have the subsidiary thrusts so which can emerge from this master thrust or some other subsidiary thrusts that can come and join this master thrust and these all are known as splay faults or simply splay.

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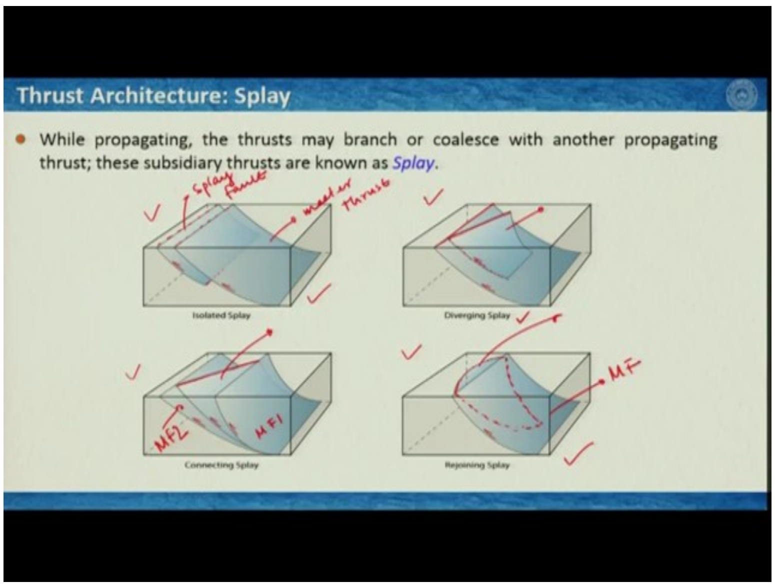

So while propagating the thrusts may branch or coalesce with another propagating thrust and these subsidiary thrusts are known as splay, so here are 4 possibilities I have given here and these are somehow important so 2 faults meet along a branch line so where they meet I will show you later in this illustration that what is branch line in this case and a tip line and a branch line meet at the ground surface at the tip point at a branch point for ancient faults of the ground surface that we see at present has formed by erosion after the fault movements and has seized in contrast the ground surface at the time of development of the fault is the see orogenic ground surface.

So, there is always an interaction between the previous fault and the latest fault. Now a subsidiary thrust as I use talking about may branch out of as splay from the main thrust now this is an example of an isolated splay so isolated splay is characterized by the 2 tip points of the splay are exposed while the trace of the fault is isolated from the main fault stress, so this is you can consider as master thrust and this is isolated so this has nucleated from here but it did not touch the master fault it propagated independently and both of them reached the surface.

So this is splay fault and this is an isolated splay fault to be very specific now sometimes while this is propagating so this is again the master fault then you can have a diverging splay so this fault is touching the master fault here and it branches to generate another splay fault and therefore this is diverged or this got diverged from the master fault so this is known as diverging splay as it is written here sometimes you may have 2 faults so maybe 2 Master faults one this one so MF one and this one MF 2 and then you may have a splay fault which is connecting the 2 faults and this is known as connecting splay.

And then there is rejoining splay fault which is this one in this case again you have a master fault and then it diverges from here say it was like this and then while it is propagating it finds it better to meet again the master fault so it rejoins the master fault and therefore maybe it can look like this so these are the branch lines from the master fault to the subsidiary fault inside this fault and this is known as rejoining splay faults.

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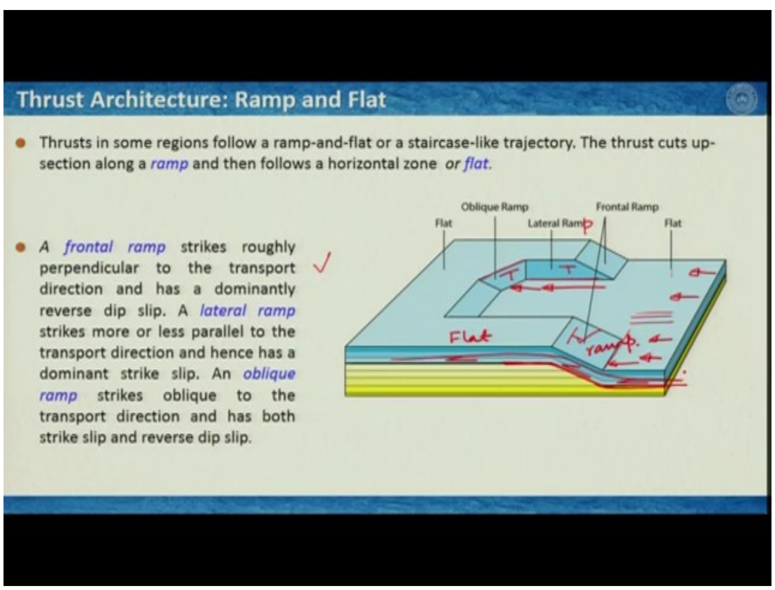

Now this is one kind of architecture that the thrust during its propagation can form but within this propagating part as we have learnt about that these things can move in a different way so from the cross section if we try to look at sometimes these are known as ramp flat model and we learn in this slide what is ramp flat model? So thrust in some regions follow ramp and flat or a staircase like trajectory, the thrusts cut up section along a ramp and then follows a horizontal zone of flat as you can see here that these surfaces are flat so these are flat and then you have some ramp like features which is at an angle to this flat plane and these are known as ramp and then it achieves another flat here, so it can the ramps can happen in different ways and we will learn about it and this is also written here.

So let me explain it in different ways, now when the thrust develops in a previously undeformed sedimentary sequence the flat is parallel to the bedding, so you see it is originating here it is parallel to the bedding so initial we saw it the trust starts the deep angle of this fault is very low or almost sub horizontal.

Now if the staircase trajectory develops in a crystalline basement or in a previously folded sedimentary sequence the flats need not to be bedding parallel and therefore you generate some sort of ramps and then it propagates in this way because it just makes its trajectory changed and then it turns to another ramp and the ramps as I was talking about these are classified according to their orientation with respect to the transport direction.

So this is the transport direction of the thrust and if the ramps are oriented differently with respect to the transport direction then we can classify the ramps in a different way so as I was talking about a frontal ramp which is this one strikes roughly perpendicular to the transport direction and has a dominantly reverse slip.

So this is the transport direction and this is striking almost perpendicular to the propagation direction so this we call frontal ramp then you can have a lateral ramp which is this one I am sorry this would be ramp so there should be a lateral ramp that strikes more or less parallel to the propagation direction so this is the propagation direction and the orientation the strike of this lateral ramp is almost parallel to the propagation direction and this is known as lateral ramp and the movement along the lateral ramp is interestingly not a thrust but it is mostly strikeslip faults.

Then you can have something in between a the frontal ramp and lateral ramp and these are known as oblique ramp so an oblique ramp strikes obliquely to the transport direction and has both strike and reverse nip-slip so for example here so this is this propagation direction again so it the strike is at an angle to the propagation direction and it involves both deep sleep and strike-slip components along its displacement and therefore this is mostly an oblique ramp.

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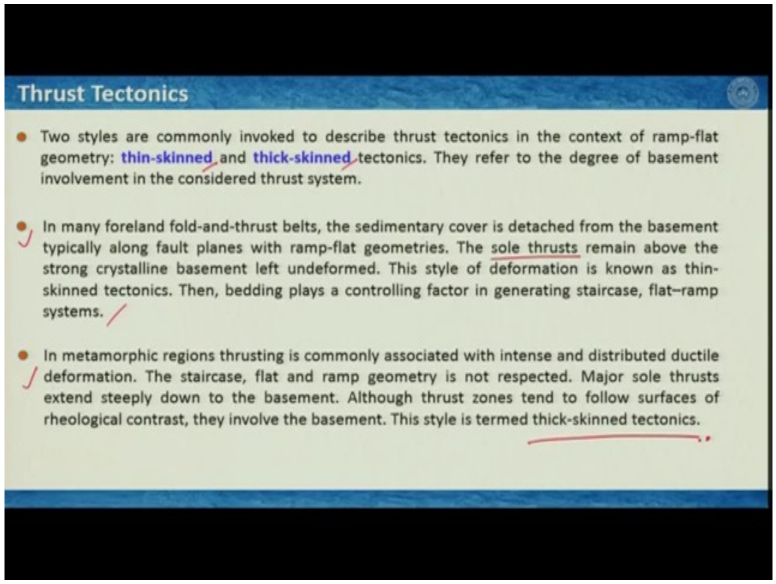

Now the writing of the thrust sheet over a ramp causes the development of reverse faults and these are very very interesting so flat-topped anticlines so you can see that you are actually generating a fold like feature here and these are very very interesting in the sense that while the thrust do propagate they generate an excellent structure which are sometimes very important or tectonic or kinematic analysis and at the same time these are also important for hydrocarbon reservoir mechanics and so on.

So we will learn more about it later but the concept of a staircase trajectory and the consequent development of hanging wall anticline with the kink like geometry were later incorporated in a generalized geometric kinematic model of thrust faulting so therefore these are very very important.

Now according to this model the foot wall of the thrust remains essentially undeformed and if that happens then you have some hanging walls above the foot wall of the thrust fault that can be thick or extremely thin and that gave rise to very important terms what we see here in this slide one is thin-skinned tectonics and another is thick-skinned tectonics.

So two styles are commonly invoked to describe the thrust tectonics in the context of the ramp flat geometry as I was talking about one is thin-skinned and another is thick-skinned tectonics they mostly refer to the degree of basement involvement in the considered thrust system, so the descriptions are given here what is thin-skinned and what is thick-skinned in many fold and thrust belts the sedimentary cover is detached from the basement.

So you have the basement that is and then you have metamorphic or igneous complex and then you have sedimentary layers now if the thrust initiates in between the basement and the sedimentary layers then typically along the fault planes then it shows the ramp flat geometries now the soul thrust will learn about it soon.

Thrust that is generating at the bottom is known as soul thrust they remain above the strong crystalline basement and the crystalline basement is remain virtually undeformed now this style of deformation is known as thin-skinned tectonics then bedding plays a controlling factor so the composition the rheological and so on these are very important parameters in generating the staircase or ramp flat systems.

In contrary the thick skin tectonics in metamorphic regions thrusting is commonly associated with intense and distributed ductile deformations so where the deformation is happening at relatively high pressure and temperature in that case the staircase flat and ramp geometry is generally not expected so major soul thrust extends steeply down the basement so it involves the basement either metamorphic or igneous although the thrust Jones tend to follow staircase of rheological contrast they involve the basement the style is termed as thick-skinned tectonics.

So in these following slides we mostly we will not separate what is thick skin and thin skid in illustrating the diagrams and the processes but you can think of that mostly sedimentary layers are being involved in this processes so in a way you can think that these are mostly thin skins,

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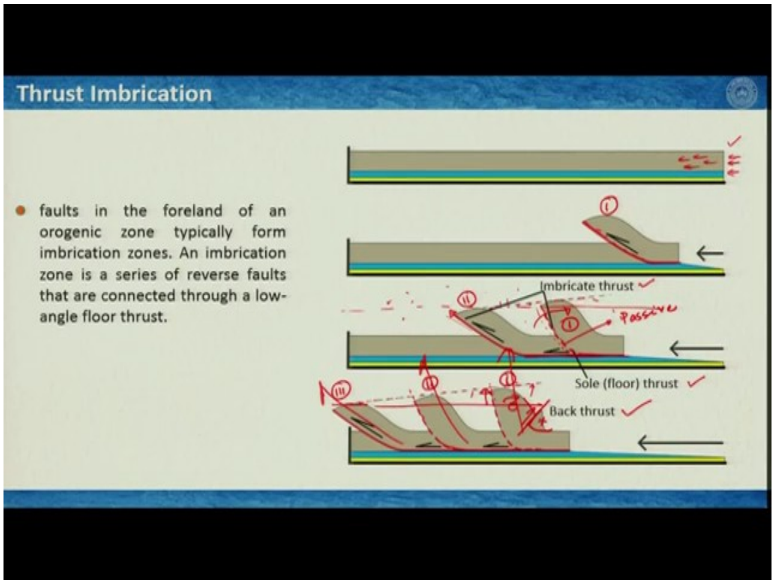

Now let us talk about how do these thrusts propagate they do work in a single fault or there multiple faults we learn that it involves multiple faults which are known as plays but we would look these things now in a different way which is relevant for the large-scale tectonics and we start with the term called thrust implications.

Now thrusts in mountain chains generally occur in groups so you do not have a single thrust now you can just quickly think of the thrusts in Himalaya the major thrusts this MBT MCTS TDM and so on so they are in a group not necessarily they occur at the same time and this is exactly what we are going to learn in this slide so the geometrical inter relations among the members of such thrust systems have been intensively studied and this is a topic of research in most of the cases and people do experiments numerical modeling and also intends a field survey to understand the thrust mechanisms and how do this group of thrust do evolves.

A prominent low angle thrust occurs been it some thrust systems this is called floor thrust or soul thrust let us explain this one after another. So this is your initial setting tectonic setting where everything is in peace nothing has happened and then there was a push from this side and this material started moving in this side now when that happens due to contraction it may generate a thrust in this way, this red line is the active thrust here now if this deformation continues then interestingly it generates another thrust in the front of the previous trust so this is my first trust and this is the second trust the second trust interestingly this thrust line here is become passive so there is no displacement along this line so this becomes passive or inactive, but it does rotate backwards and while it rotates it slightly achieves a topographic high while the second thrust is moving with an active thrusting along its boundary.

If the deformation continues further it generates another thrust which is thrust number 3 so this was the 1 this was the 1 then it takes the deformation most of the deformation this was already inactive and this becomes also inactive now everything is happening and they are merging on a horizontal or sub horizontal surface which is also slipping and this is known as sole or floor thrust and the subsidiary thrusts which are emerging from the sole or floor thrusts are known as imbricate thrusts.

Interestingly these previous thrusts previous imbricated thrusts 1 and 2 in this case they again rotate back so these rotates the first one rotates further towards this side and sometimes to accommodate the rotation it produces a fault this is also a thrust fault which is verging oppositely and this is known as back thrust I think I give the sense oppositely the drawing should be something like that so you do not worry about this part yeah the drawing is a little bit wrong it should be something like that as I try to correct it.

So and while doing this this back rotation and also the combination with the back thrusts the topographic elevation is achieved so you see that this is here and this much height we have achieved to this process now this is, this process is known as thrust imprecations the series of thrust that we see here these are known as imbricated thrusts so to describe this process in a different way.

Let me explain in details so the sole thrust is the lowest regional thrust surface in some cases subsidiary faults may splay upward from the floor thrust and may cause a tile like piling of the subsidiary thrust rates this is exactly what we have seen here this arrangement of the subsidiary thrust is known as imbricate structure as we have named it, it is also known as (())(29:32) structure, now this imbricate faults they meet on the floor thrust asymptotically as you can see here they meet the floor thrust and carve upward with increasing dips at higher levels and this is the characteristics of thrust faults we have learnt.

So in a trailing imbricate fan the thrusts so they actually produce something which is called fan also thrust Fanning so they just moved this way like a fan and these trusts fannings or sometimes their rear shows the maximum sleep and imbricate zone or an imbricate stack may be confined between a floor and loop trust we will learn about it, so what I mean by that that here the top part is at least in this drawing is somehow empty but you can have another thrust at the top and then it is known as a roof thrust and it is known as duplex structure we learn about it soon.

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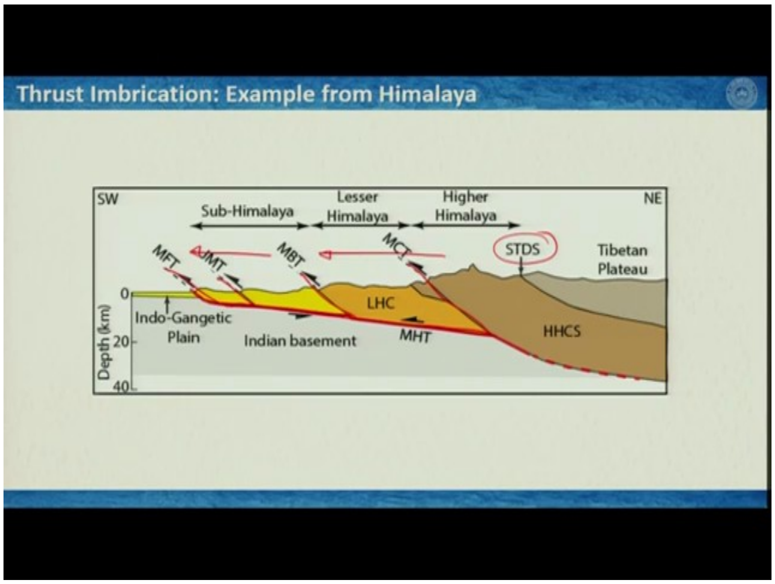

So for an example you can think about the faults in Himalaya that we have series of thrust faults starting from the North we have STD MCT MBT and in this case JMT and MFT now from your stratigraphy or Tectonics lecture you may have learned that MFT is the youngest fault then and STD is the oldest one so this is where things started and then initially first we form these then these then this and now this one so this is exactly what we have seen in the previous illustration that one after another this imbrication thrust is propagating and in this case the floor or soul thrust is MHT the Main Himalayan Thrust.

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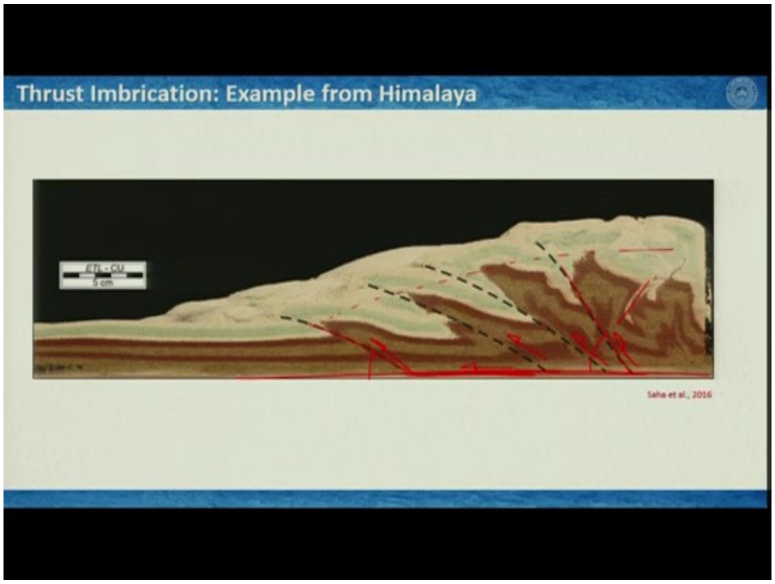

People generally study this kind of things with sandbox models and here I have given an example from one of my juniors Pushpendu he performed these experiments and that got published in a paper, so here you can see that first of all these are the imbrications the floor thrust is somewhere here which is moving this way and in his experiment he has generated a series of thrust faults and you can also see the back thrusts here these are formed and interestingly you see while doing this the topographic elevations are achieved the angle of this frontest imbrications is less compared to the imbrication at the backside the first imbrication that we have formed in this experiment.

So by experiments people also study a lot and these are functions that what will be the spacing of these faults, how much they will rotate and so on is essentially there are many parameters that control this so one is this friction along this sole thrust then the materials you are involving the height you are achieving and so on. So all these things do play an very interesting role and people are still studying this that what causes this implications and the elevation of the mountains because these are one of the most important mountain building processes.

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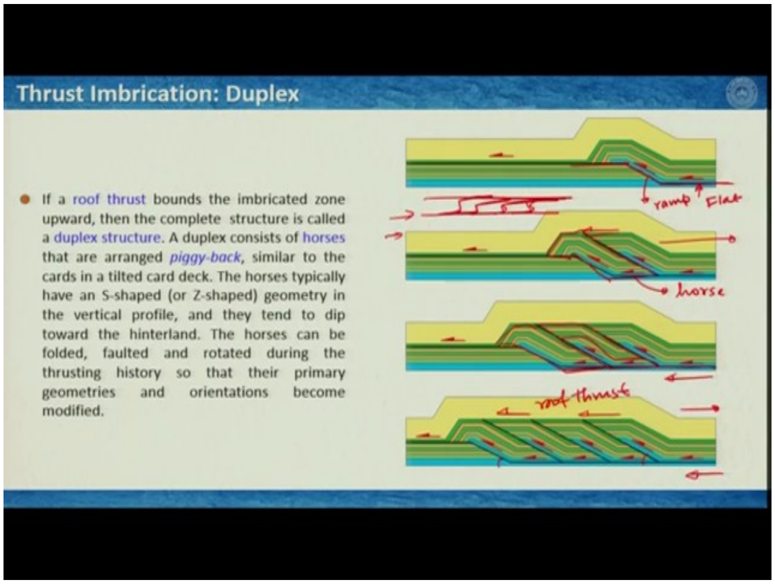

Now we will go to what I was talking about this duplex structure so when imbrications do happen and it has a soul or floor thrust and it also has a roof thrust at the top so if a roof thrust bounce the imbricated zone upward then the complete structure is called a duplex structure in it generally develops in sequence so duplexes consists of horses that are arranged piggy back so let us try to understand this.

So, we have this sequence may be one, one before and then we have developed this ramp flat model this is a flat then we have the ramp and then we have again a flat now this is the sole thrust or the floor thrust and then if we have a significant amount of sedimentary cover at the top it may not involve the entire sequence.

So we can have also a thrust at the roof in the next segment and this is known as roof thrust and these individual segments while doing it, it would also produce imbricate thrusts and these individual segments this one or in this case may not be but in the next sequence we will see that these are known as horses or an or a single imprecation that we see is horse so this is a horse you can see confined here this is another horse so it continues this way we will see an animation in the next slide how do this form so you have your sole thrusts which is marked by this thick black line then you have imbricate thrusts and you also have roof thrust going here.

So if an imprecation zone is restricted between sole or floor thrust and roof thrust then this is known as duplex structure so the horses typically have an S or Z Shaped geometry so here it is like Z but if you see it in other way around if the movement was from this direction then it would form something like that and then so this is your roof thrust is your floor thrust and then these would produce something horses like SS, S Shaped structure and then they tend to deep towards the hinterland.

So in this case this is your hinterland and the horses can be also folded faulted and rotated during the thrusting history and they produce some fantastic structures we learn about it soon so that their primary geometries and the orientations become modified so you may see that at this is the hinterland side, in this hinterland side you may see that the imbrication closest towards the hinterland may have a higher angle compared to the angle which is furthest from the hinterland

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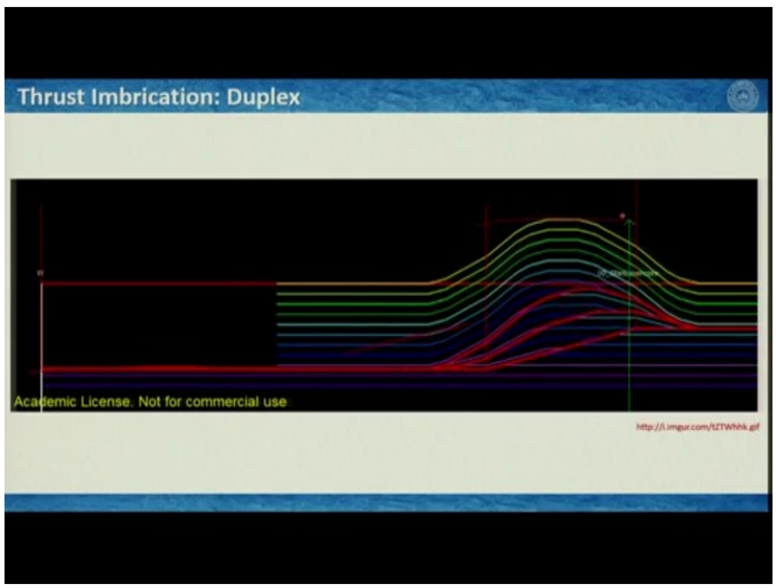

But let us see an animation, how do these forms, so this is an animation I collected from the internet so you see this is how, this duplex structure do form. This is your sole thrust these are your imbrications this red lines here and you have your roof thrust there, now do we say in the field of this kind of structures yes we see them in many different scales so here is an excellent example from the same page from where I took this animation.

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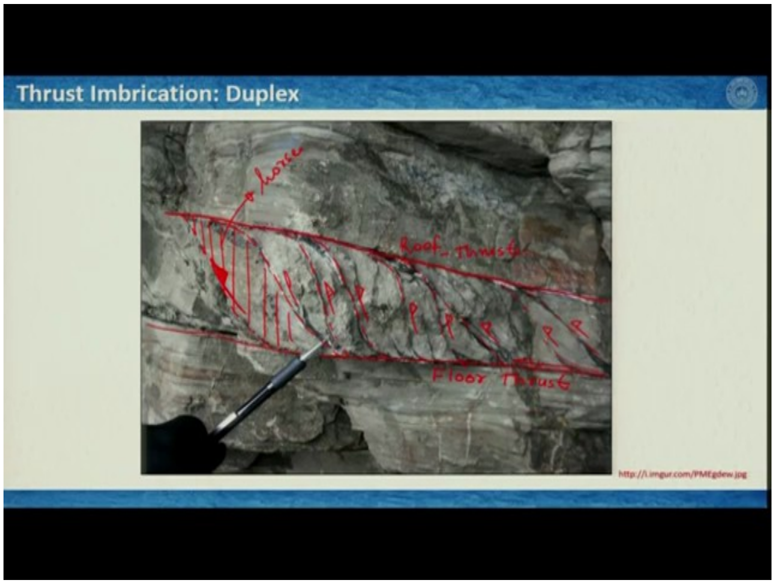

So looking at it you can clearly now identify from this illustration that we have seen that this is certainly a thrust plane and this is your floor thrust and there is also one more here going like this and this is your roof thrust and between the floor and roof thrust you have the imbrications like this do not mix it with cross-bedding this is tectonic process.

So you see this this complex structure here so this individual blocks here this one it has moved this way so this is the orientation of the thrust here and these are known as your that we have just learned horse so individual horses and each of them slipped this way this is an excellent example of this duplex structure so you have roof thrust, you have floor thrust in between you have series of imbrications defining the horses and so on.

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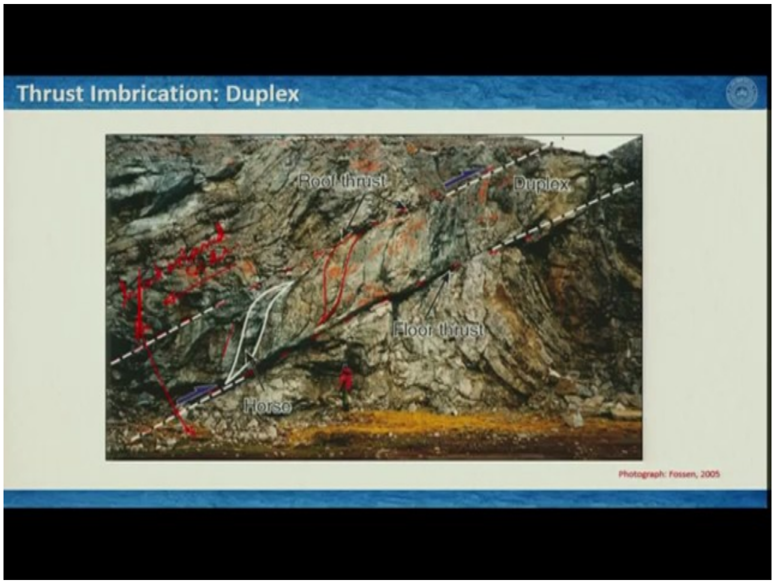

We have one more example from the book of a professor Fossen, so here again you have roof thrust you have this one you have floor thrusts here and in between he already have marked you have the horse individual horse and you see they are dipping this side all these horses so this must be your hinterland side and this entire structure is known as duplex structure so you have now very clear idea what is imbrication what is sole thrust what or floor thrust what is roof thrust what is duplex what is piggyback and so on.

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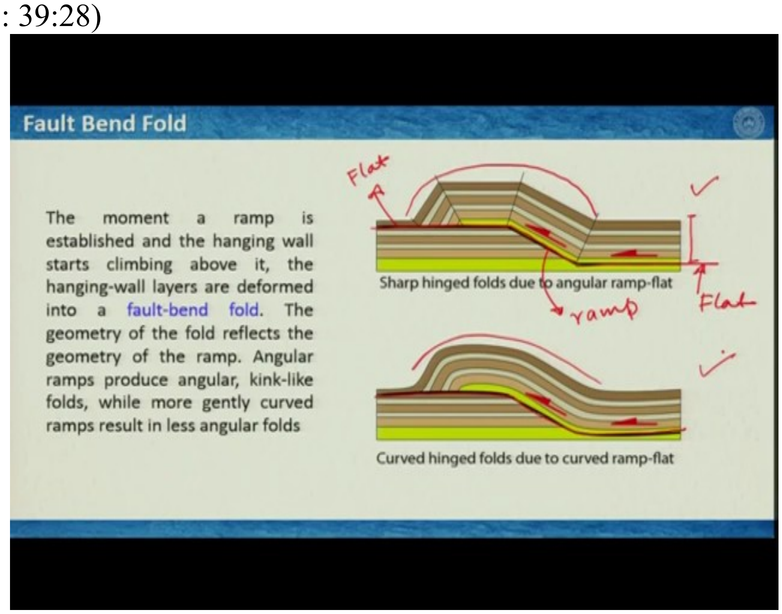

Now this kind of structure so in these imbrication do happen during thrusting they produce 2 very interesting kinds of folds one is known as Fault Bend fold and another one is known as fault propagation fold when I was a student I was extremely confused that which one is what later it got clear to me but I believe with this lecture you will never confuse what is Fault Bend fold and what is fault propagation fold a two very commonly used terms in structural geology sometimes people also ask in the interviews and so on.

Now Fault Bend Fold is essentially a structure that you see in the ramp flat model so the moment a ramp is established and the hanging wall starts climbing above it the hanging wall layers are deformed into a fault Bend fold as you can see here this is your this is the flat this is the ramp and this is getting another flat and the movement along this ramp flat is this way.

Now this hanging wall materials sedimentary layers it has to write over this ramp flat so when it does it because we have a ramp here it has to produce a fold like structure so the layers over the ramp when it rides it has to bend to accommodate the space and therefore this is known as Fault Bend Fold when the layers the hanging wall layers got bended along a fault plane is Fault Bend Fold this term along is very important.

The geometry of the fold reflects the geometry of the ramp angular ramps produce angular folds kink like folds while more gently curve ramps which you see here this is not as sharp as the illustration we have above so also the folds we form these are very gentle and curvy folds. So you can have this you can have this and these are known as Fault Bend Fold.

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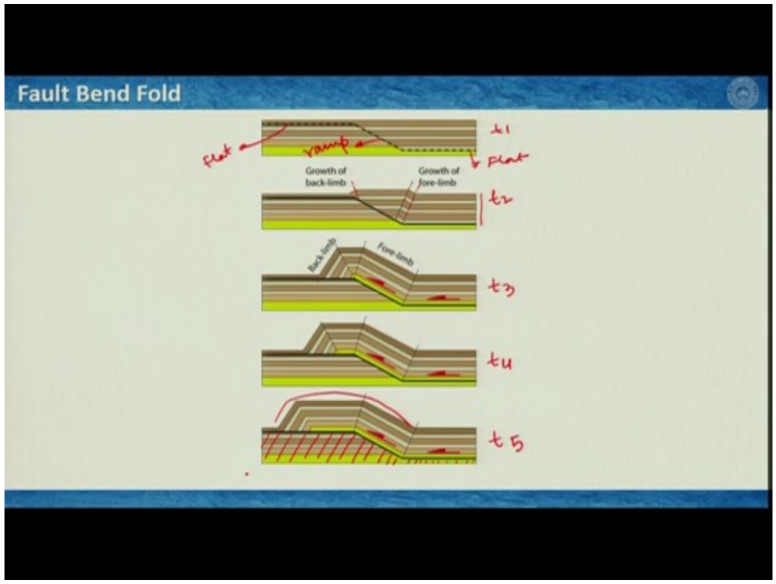

Now this is how do they occur in sequence so this is your first stage so t1, then t2,then t3, then t4 and then t5 so this is the initiation of this ramp flat model so again this is a flat this is the ramp and this is again a flat, now when that happens when this hanging wall materials are trying to ride over this ramp flat then it has to produce a kink like feature at the forelimb and this is known as growth of the forelimb.

And then it also has to adjust at the backside so this is known as back limb and then with time it propagates the forelimb expands back limb also develops it achieves a topographic elevation and so on and finally it appears fold like feature and this is the process we form the fault Bend fold. Now interestingly you see in this entire illustration this the foot well rocks, they are virtually undeformed, so everything is moving on the top side the hanging wall is taking all the deformation.

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Now this is an example of a Fault Bend Fold you see here that this is the thrust propagating like this so this one is your foot wall and this part is the hanging wall and you see due to riding it is producing a structure it has to produce you also have some back thrusts here and it is going like this and this is Fault Bend Fold a classic example of Fault Bend Fold.

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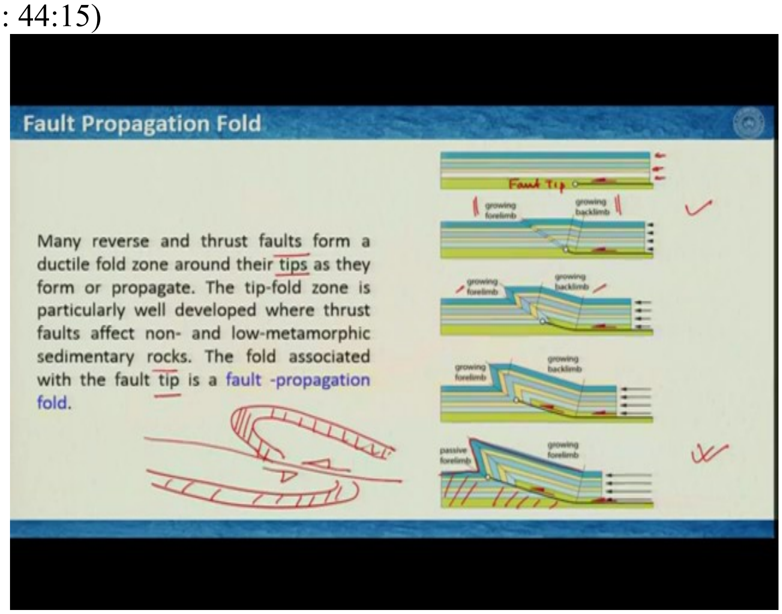

And you can have another thing which is Fault propagation Fold, now many rivers and thrust faults form a ductile fold zone around their tips and they form to propagate, this is very important

Fault Bend Fold is along the fault the geometry of the Fault Bend Fold is defined by the ramp flat of this thrust involved in this process.

But fault propagation fold is essentially controlled and also nucleated from the tip of a propagating fault so these are the basic difference between fault propagation fold and fault Bend fold we will see how do these things occur with this illustration but the tip fold zone is particularly well developed with thrust fault effect non and low metamorphic sedimentary rocks.

The fold associated with the fault tip is Fault Propagation Fold again the tip is very important and for Fault Bend Fold it is along so let us see how does it work in contrast to what we have learned with the Fault Bend Fold, so we have a series of sedimentary layers and say we have initiated due to some compression here or thrust and this is the tip of the fault.

So it is moving straight this part is getting contracted fine now because it is a thrust fault it has a tendency to move upward with a higher deep now when it does when it starts moving upward it first-string it does that at the back side it develops a back limb and the front side it also develops a forelimb and with time when it propagates it is also grows or accentuates the growth of the back limb and the forelimb and this is how it works and finally one stays with a structure a fold like structure like this.

Now geometrically it may appear very very similar to what we have seen with the Fault Bend Fold, but a Fault Propagation Fold it may have a very similar geometrical disposition but the mechanism of development is essentially different sometimes you also develop so in this case if you have a fault where you have movement both on hanging and footwall.

So here we see things are happening only on the hanging wall but the foot wall is virtually undeformed. You can also have a thrust like this where you can have something like that in this side and then something like this in the other side. So both you can have Fault Propagation Fold on the hanging wall side and also on the foot wall side so these are also kind of Fault Propagation Fold that has grown due to the movement of the fault tip line let us see some examples.

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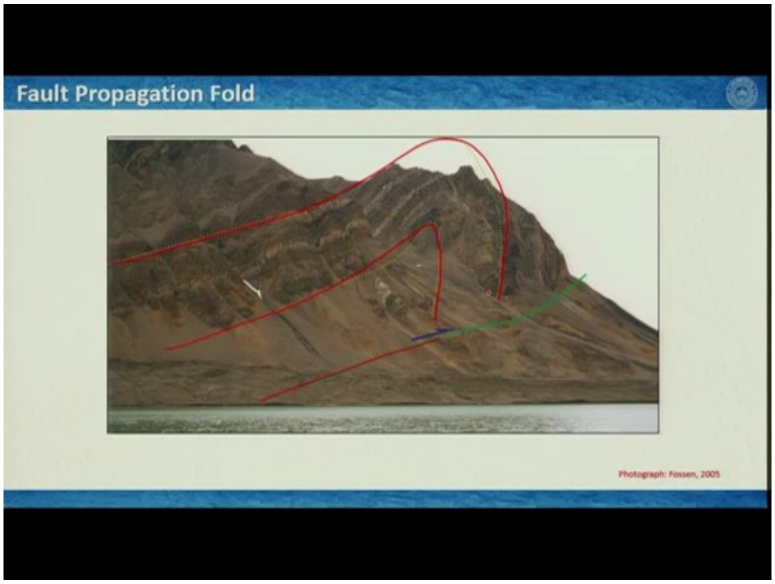

So this is one which I have taken from the book of a professor Fossen so you see this is the fault plane going and you have an excellent Fault Propagation Fold here in this structure.

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We can also see here that that example I gave you, you have this is the thrust claim so it is moving this way and then what we see here that we have Fault Propagation Fold in this side and we also do have Fault Propagation Fold in this side. So this is how you define the Fault Propagation Fold in two three different ways but I am sure with this presentation or with this illustrations it is now very clear to you the difference between Fault Bend Fold and Fault Propagation Fold.

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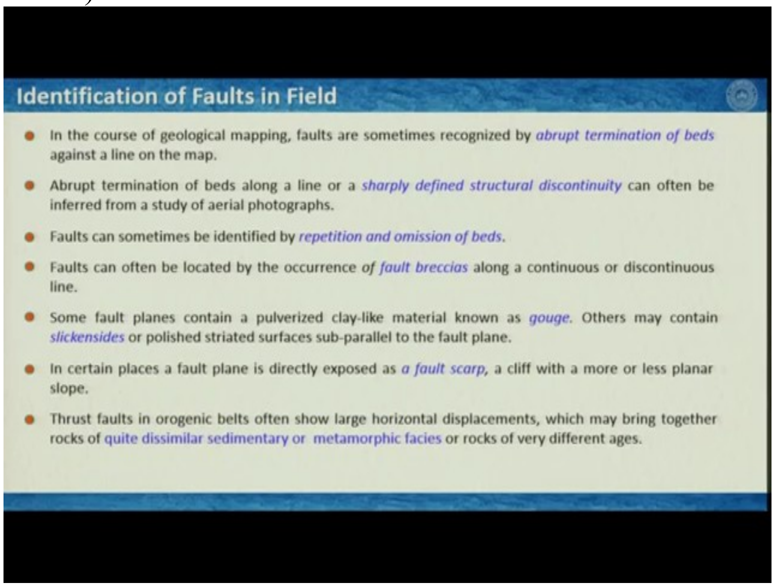

Now what we are going to do that last topic of this lecture that how do you identify faults in the field, now there are several criteria in recognizing the faults particularly in the field or also from a map so even when the fault line is mapped the dip of the fault plane may not be miserable the dip can be measured in certain circumstances for example you can think of an fault trace is exposed in areas of high reliefs that means a fault surface itself is exposed and so on.

I mean if someone does some drilling work and other things so by this you can measure but the challenge is to identify the faults in the field so there are several criterias which I have listed here, the first one is the geological mapping so faults are sometimes recognized by abrupt terminations of beds against a line on the map.

You can also think that abrupt termination of beds along a line of sharply defined structural discontinuity if that you see in your map you also can figure out as a Fault in the field but you have to be very sure that this is not some sort of angular discontinuity so you have to separate or rule out the possibility of angular discontinuity with respect to the sharply-defined structural discontinuity.

Now you can also identify the faults if you have seen repetition or omission of beds now we did not learn what is repetition of omission of beds but we learnt it with respect to the fold so in fault you can have repetitive layers or some layers are missing, now it is also important that repetition of beds you also can find or it can result also due to folding. However in the case of repetition in fold it is symmetrical so repetition of beds caused by fault is essentially asymmetric and that can help you to figure out that you are somewhere near the fault zones.

Now faults can often be located by the occurrence of fault breccias if you see highly crossed rocks we have seen before in the deformation mechanism lectures along a continuous or discontinuous line so that tells you there must be some sort of faults around you, some fault planes also contain a pulverized clay like materials or which we call fault gouge and you can also figure out that if you see some slickensides like features or polished striated surfaces some parallel to the fault plane that also tells you that you are in a fault zone.

Now in certain places a fault plane is directly exposed as a fault scarp a cliff with a more or less planar slope that can also tell you that you are in a fault zone and finally if you think about the thrust faults which are large orogenic scales then because the thrust faults they move they travel a long distance that may bring together rocks of quite dissimilar sedimentary or metamorphic faces or the rocks of very different ages they can stay together that can also happen due to folding but in thrusts it is more common and finally for the subsurface if you do some seismic imaging seismic reflection survey and so on you can also figure out the faults from those images if you know how to interpret that. So these are the different ways that you identify faults in the field and with this I conclude the lectures on Fault.

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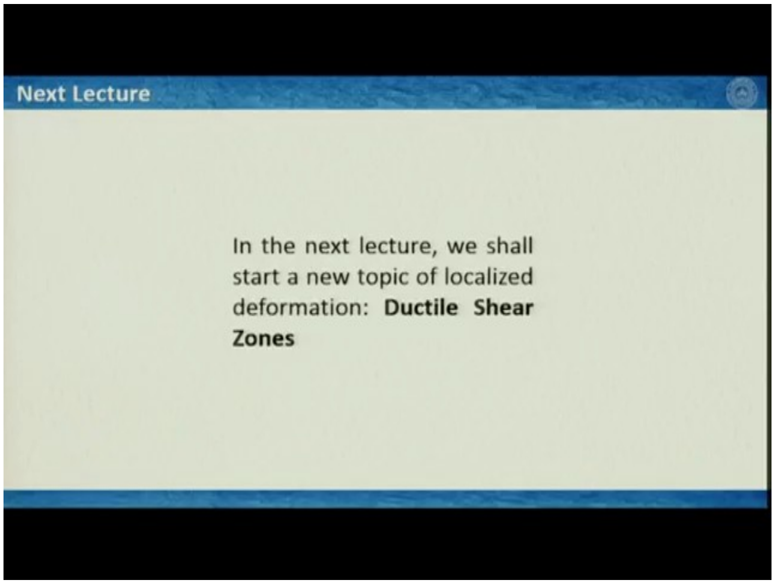

In the next lecture we will start the actual topic of this week which is a ductile shear zone and we will first learn its characteristics and then we will classify and there a series of new things and new terminologies to learn and understand, so stay tuned I will meet you in the next lecture thank you very much.