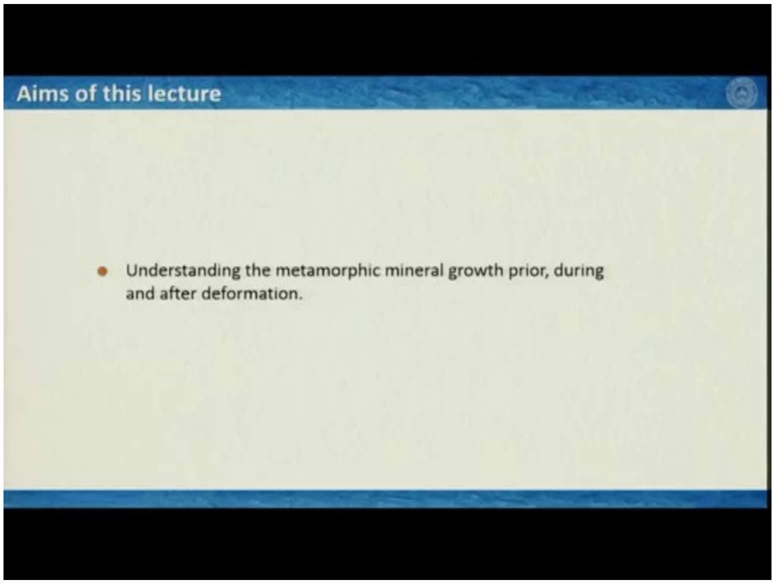
Structural Geology
Professor Santanu Misra
Department of Earth Sciences
Indian Institute of Technology Kanpur
Lecture No. 24
Porphyroblasts

Hello everyone, welcome back again to this online Structural Geology NPTEL course, we are going to start a new week and we are in our lecture number 24.

(Refer Slide Time: 0:27)

As I said in the last lecture that we will continue with the superposed not folding, but superposed deformation. So in structural geology there are some typical micro structures that help us to figure out the different stages of deformation, so I thought that before we go to the actual topic of this week which is boudinage, we talk a little bit about this particular micro structural features which we will cover in this lecture today and this is on porphyroblasts.

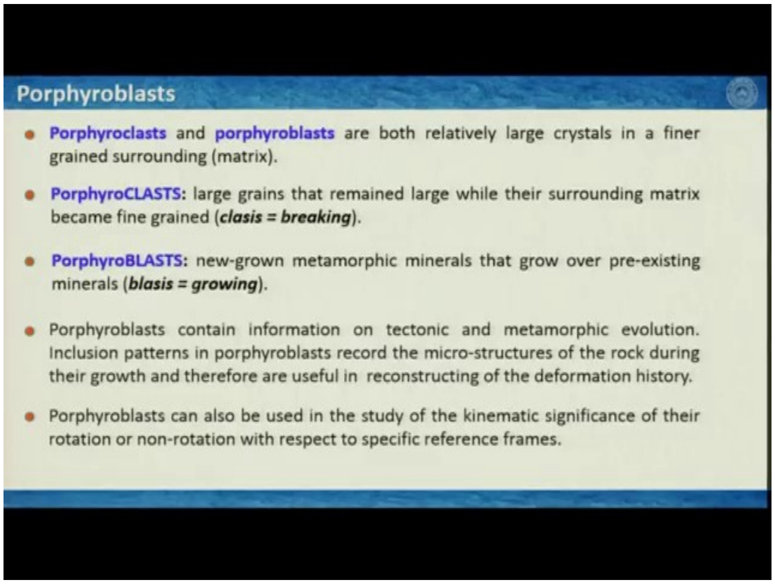
(Refer Slide Time: 0:59)



So the aim of this lecture is basically to understand the metamorphic mineral growth prior, during and after deformation. Now, this is something very important for us to understand at this time that structural geology, it is not a standalone subject in the sense that deformation most of the cases particularly in the ductile domain do happen with the metamorphism of rocks. So rocks experience high pressure and temperature, they undergo a lot of phase transformations, they develop different fabrics due to deformation and these fabrics also do control some sort of metamorphic reactions as well.

So, if we try to study structural geology separately without considering the processes of metamorphism it would be a good idea. So this lecture in a way would give you a visualization or an impression that how metamorphism or metamorphic petrology is closely related to structural geology, so this is why we learn the metamorphic mineral growths that do develop before, during and after deformation.

(Refer Slide Time: 2:12)



So there are two common terminologies that we use, one is porphyroclasts and another is porphyroblasts. Now in general both porphyroclasts and porphyroblasts, they are both relatively larger crystals within a finer-grained matrix or the host rocks. So Porphyroclasts, when it starts with C that means clasts are generally large grains that remained large while their surrounding matrix became fine-grained. Clasis or this word clasts came from this word particularly clasis and clasis means breaking, we will see some examples soon.

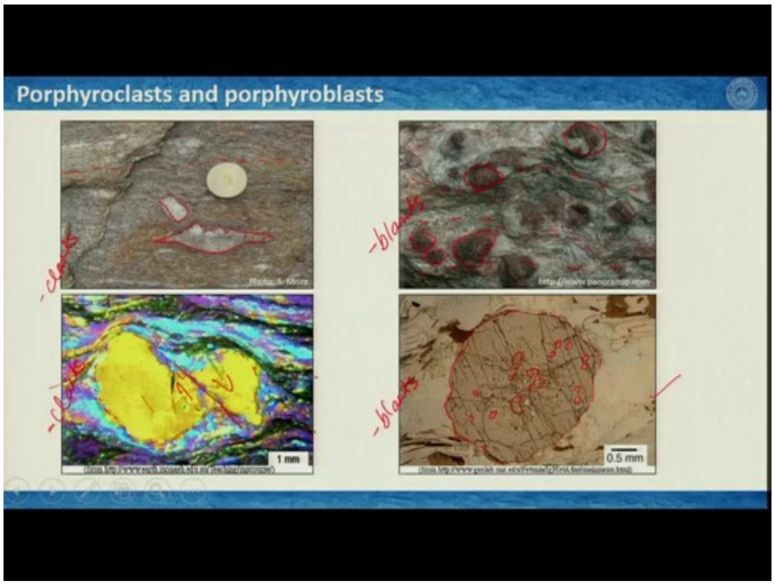
On the other hand, porphyroblasts, so the new grown metamorphic minerals that grow over pre-existing minerals, so this is the new minerals, these are the reaction products during metamorphism, so blasis means growing. So porphyroclasts are old larger grains and porphyroblasts are new larger grains. Now, why this is important to study porphyroblasts? This is actually the topic we are going to learn today so Porphyroblasts mostly contain information on tectonic and metamorphic evolution.

Now there are series of inclusion patterns within the porphyroblasts that record the micro structures of the rock during their growth and therefore they are very very useful in reconstructing the deformation history and to some extent the history of the metamorphism as well. Porphyroblasts you can also use to study the different kinematic behaviors or kinematic significance of their rotation and non rotation with respect to a specific reference frames, this we will learn in a sheared zone lecture and there we will see that how you can use the rotation of

Porphyroblasts in figuring out the kinematics, so whether we which sense the shear zone moved with respect to a fixed reference frame, we will learn it in the shear zone lecture.

But in this lecture will mostly focus on this point 2 and we will see that how porphyroblasts are useful the information that is that it contains within itself to figure out the when they have grown and therefore we can figure out the deformation history.

(Refer Slide Time: 4:42)



So here are a few examples of Porphyroclasts and Porphyroblasts as you can see in the right panel we have examples of porphyroclasts, so these are clasts and these are we will see it soon blasts, of course they have to add the prefix porphyro. Now, what do you see in the first image? We see this matrix is as you can see it is fine-grained, you can also figure out that there is a foliation going on, almost east, west in this image.

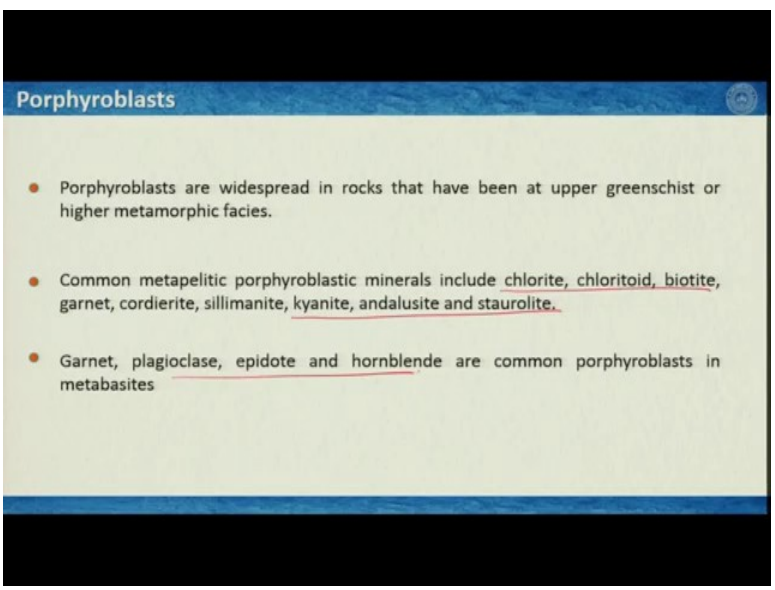
But there are few larger grains, for example, this one or this one. Now these are not new grains, these are some old grains which did not participate in the deformation process, but it may participate or it could participate if the deformation would continued, but it did not happen, so it stayed like this probably because this is the stronger minerals or did not have enough reaction kinetics to develop new grains or to fragment for not having enough stress.

So this is a field photograph as you can see from this scale and this is a optical microscope image so a thin section and here again you see that we have this yellow grain here and this is a porphyroclasts and you see the grain also got fractured and developed asleep along this. So these are examples of Porphyroclasts, you also see that grain was before this is why the foliation got wrapped around this porphyroclasts.

Now, on the other side we have examples of porphyroblasts, what do we see here? This is again a foliated rock, you can see the foliation is overall going like this little bit undulated foliation, but it is a continuous foliation and what do you see here there are again some large grains these grains are garnet and these garnets they grew during the deformation, during the metamorphism. So the host rock is mostly mica schists and then at high pressure temperature due to reactions the garnet grains grow and these garnet grains contain a lot of information or they inherit a lot of information during their growth.

So again this is a field photograph, the second one is an optical image and there you see that this garnet grain again this is a garnet grain, is a plane polarized light and you see that this garnet has many many inclusions in it. So these inclusions are studied for series of petrochemical and geochemical information, but at the same time you can also study this to figure out the deformation histories and so on and this is the aim of this lecture, we will learn this soon.

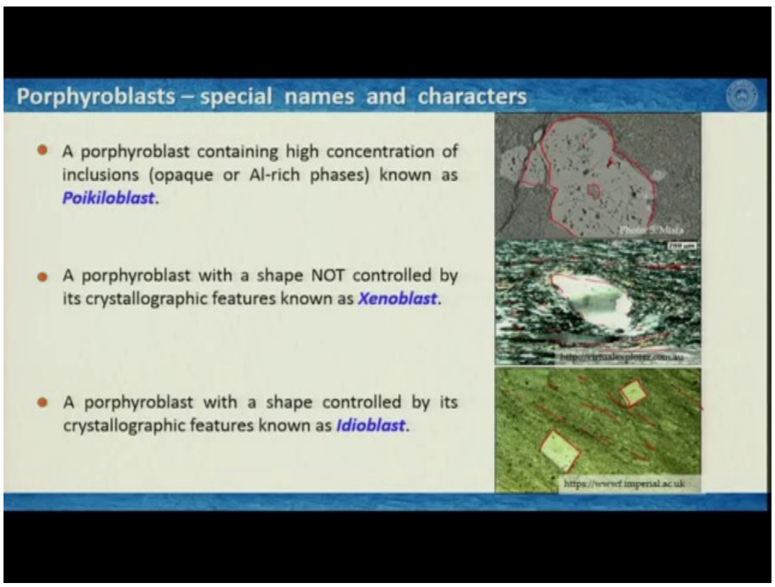
(Refer Slide Time: 8:00)



Porphyroblasts, these are mostly (wise) widespread in rocks that have been at upper greenschist or higher metamorphic facies that means you have to have enough pressure and temperature to make these minerals react and produce new grains. Now in common metapelitic rocks you find the porphyroblasts like chlorite, chloritoid, biotite, garnet, cordierite, sillimanite, kyanite andalusite and staurolite, so these are all metamorphic minerals and they are considered as Porphyroblasts if the source rock is metapelitic by composition. If they are metabasites that means the source rock is a basic rock, then the Porphyroblasts or typical Porphyroblasts minerals one can form are garnet, plagioclase, epidote and hornblende and there are few other minerals.

So, if you see this kind of minerals in your thin sections, you can actually figure out that these are porphyroblasts they have grown during deformation and then you can look for if they are containing some information within it and most of the cases I repeat we study them under a microscope.

(Refer Slide Time: 9:16)

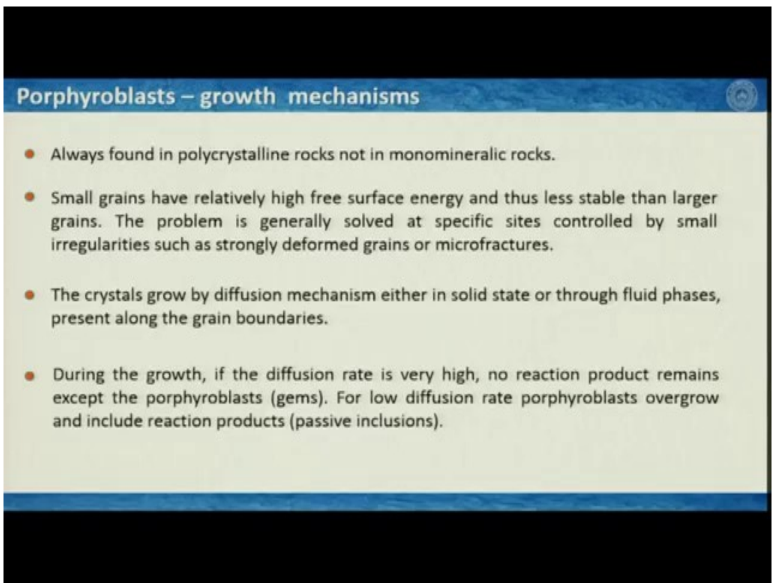


So there are three classifications of Porphyroblasts, one is poikiloblasts and other is xenoblasts and the third one is idioblasts. So a poikiloblast is when porphyroblasts contain high concentrations of inclusions. So for example, this is an SEM image, you see this is again a garnet, the matrix is very fine grain and then you see a few garnet grains here, here and here and these garnet grains have lot of inclusions within it, so these are known as poikiloblast.

Now a Porphyroblast with a shape that is not controlled by its crystallographic features known as xenoblast. For example, again we are looking at a porphyroblast that has grown and you see that it has lot of finer grains outside, you can also figure out a foliation here. But this crystal which you say inside it really does not have any crystallographic features within it. So we will call it xenoblast.

On the other hand, if a porphyroblast that has, that appears to us with some sort of crystallographic features within it then these are known as idioblast. For example, again in this image you can see that you have a fine grain matrix with the foliation and within this foliation you have porphyroblasts which are showing very straight edges. And therefore, they are, their growth or their presence in this thin section some sort of their growth were controlled by their crystallographic features and these are known as idioblasts.

(Refer Slide Time: 11:01)



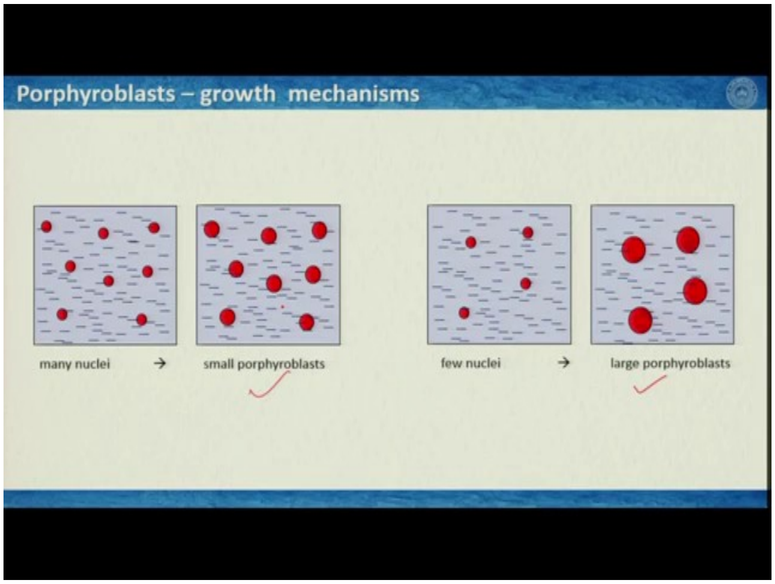
Now Porphyroblasts you do not form in a monomineralic rock you need to have a polycrystalline rock to develop the porphyroblast and this is simply because you need two different minerals so that they can react to each other or two different phases to react each other and produce a new mineral which would be the porphyroblasts.

Now small grains have relatively high free surface energy and therefore less stable than larger grains, so how do they grow porphyroblasts? So this problem is generally solved at specific sites controlled by small irregularities such as strongly deformed grains or micro fractures, so these are the sites where it controls the free surface energy and so on and therefore grains can grow bigger and bigger.

Now the crystals they can grow by solid-state diffusion, so diffusion mechanism in solid-state matter through or it can develop some sort of fluid phases through fluid phases that can present along the grain boundaries and these fluid phases can help in growing this porphyroblast or minerals and these things you may have learned from your metamorphic lectures, so I am not going into the details.

Now during their growth if the diffusion rate is extremely high then you do not have any reaction product remaining in your material. So therefore, the porphyroblasts do not contain any inclusions or any sorts of features of the previous stages of deformation or its own host rock and in that case if it is free of any inclusions and things like that then you get a gemstone. But, if the diffusion rate is extremely low then the porphyroblasts they over grow and include the reaction products and these are known as passive inclusions, we will mostly look for this. So gemstones yes they are useful but for structural interpretations gemstones are not that useful.

(Refer Slide Time: 13:09)



Now, if you have many nuclei then you will form small porphyroblasts, so if the nucleation sites in the rock are many then you do not grow large porphyroblasts so porphyroblasts could be also many numbers but they are of less size. But, if there are few nuclei then you grow large porphyroblasts as it is explained here and for small porphyroblasts we have explained in the diagram on the left side.

(Refer Slide Time: 13:40)

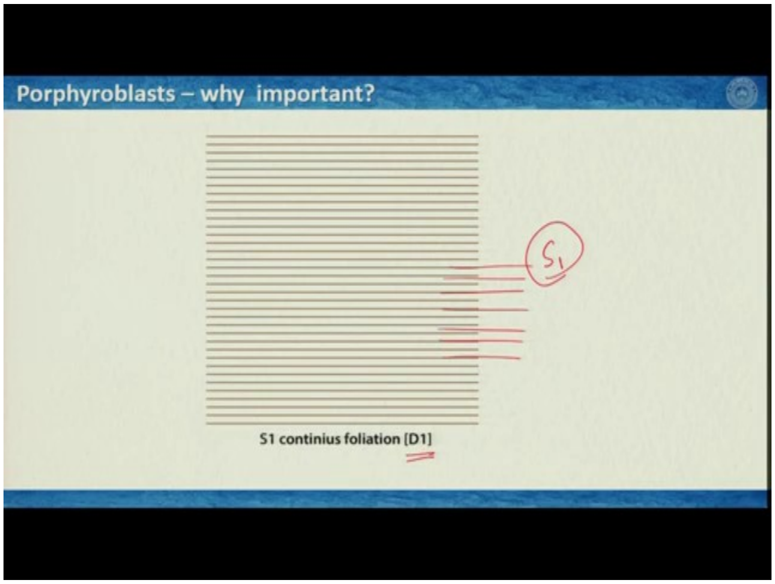
Now this is a fantastic image showing the use of Porphyroblasts or why this is important? What do you see in this image that these are garnet grains, let me consider this one, these are also garnets this a field photograph and then in the matrix we have mostly homogeneous features, we also do not see a strong foliation and so on, but you may figure out there might be a foliation going like this but that is not a very very strong foliation.

However, if we look now inside the garnet grains we see that it contains an excellent fabric, so this fabric must be the fabric which was present also in the matrix at one point of time. Now these garnets when they grew, they tracked this fabric and then the deformation stopped for a while or it continued, but the garnets because they are very strong in the later stages of deformation the fabrics inside the garnet is still there.

But the outside, the host rock or the country rock does not contain any fabric similar to this. So these new fabrics have come in the picture and they completely destroyed the older fabrics. So this tells us that this garnet or this rock has suffered at least two stages of deformation, the first deformation tracks this fabric inside and the second deformation that washed out the fabrics outside. Now of course it may have few other formations, but from this picture we at least can interpret that this rock has undergone two stages of deformation.

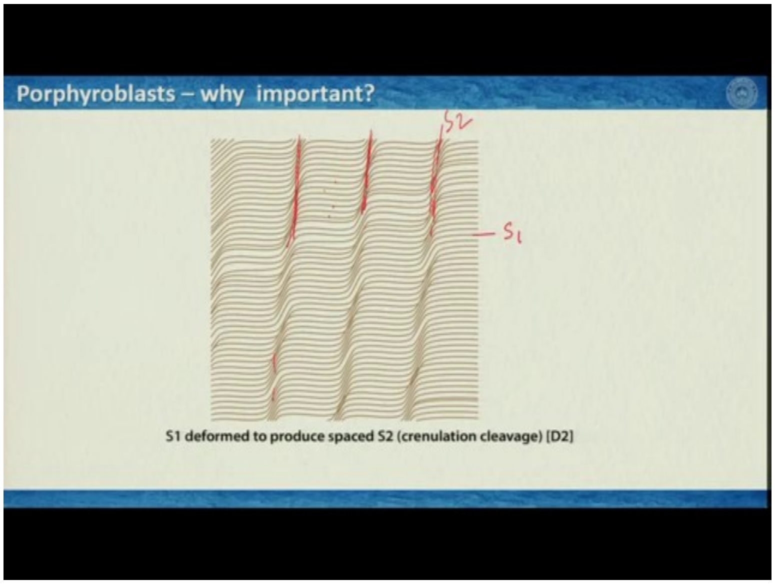
Now in the following slides what I am going to show you that development of this kind of features and so on and the photographs I will use the micro photographs these are mostly derived or mostly adopted from a book called Micro Tectonics written by Passchier and Trouw, so for this particular topic I will refer that book of Passchier and Trouw MicroTectonics that explained the features of porphyroblasts in a very nice way.

(Refer Slide Time: 16:21)



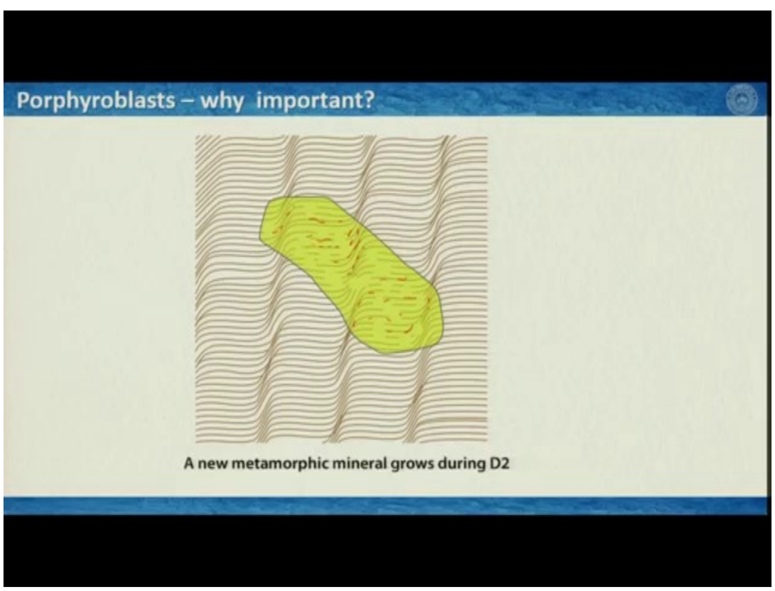
So, what we see here in this image we are going to see that how these porphyroblasts successively develop. So we can imagine that all these straight lines here these are as we have learnt in the previous lectures that these could be considered as continuous foliation and we can assign them as our S1 that means foliation or schistosity that developed at the first deformation. Now, we will see what we can do with this foliation which is S1 foliation and that has formed in the stage of deformation D1.

(Refer Slide Time: 17:01)



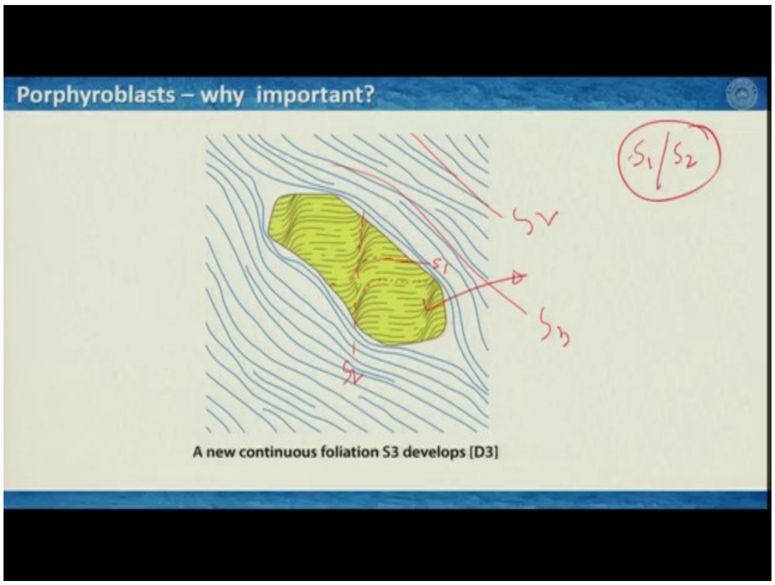
Now, this foliation can get further deformed this S1 and can produce a crenulations cleavage which now is oriented like this and we can assign them as S2 whether this one was S1, so S1 got crenulated to develop S2 and this is crenulation cleavage because this is the cleavage domain and these are the microlithon domains and microlithon domains here at least in this illustration contains the fabric, so this is why this is crenulation cleavage.

(Refer Slide Time: 17:45)



Now, at this stage what can happen that a reaction can go on and the rock can produce a metamorphic mineral. For example, in this case this yellow grain. Now, when this yellow grain has grown it tracks the crenulation cleavage within it, as you can see here it has the foliation not necessarily as continuous as it was outside, but it has the foliation within it which is mimicking also the foliation outside. Now this mineral grain this yellow mineral grain can track or can host this foliation for a quite a long time and can protect this foliation while this outside can be deformed further and which we are going to see in the next slide.

(Refer Slide Time: 18:36)

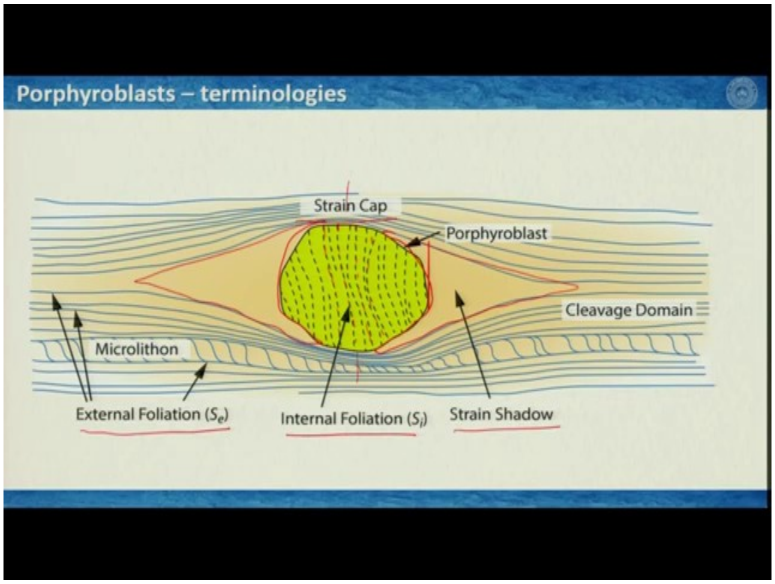


What you see here this crenulation cleavage outside is now completely washed out because of a third stage of deformation. So what we have developed here this is the traces of S3 and there is no trace of S1 and S2. So just looking at if I do not have this mineral grain here this porphyroblast here I probably could not figure out that there were at least two stages of deformation and this rock had S1 and S2 foliation within it.

Now, how do I know this? Yes, this mineral is going to give me the clue, what we see within this mineral that it had a fabric and that fabric got folded, so you must have a deformation to produce this first fabric which was your S1 and then you have the second fabric that was the S2 and these two fabrics were also present in the matrix, but the matrix could not protect them due to the third stage of deformation, but because they were already included in this mineral grain they could protect it.

So, we see that this rock at least suffered three stages of deformation and this we can only know because we have a porphyroblast that has grown during the third stage of deformation or between second and third stage of deformation. So these are therefore are very very important, if you see them in your thin section, then it is very important you try to figure out if it is containing some information or not. Now these Porphyroblasts can grow before, during and after the deformation.

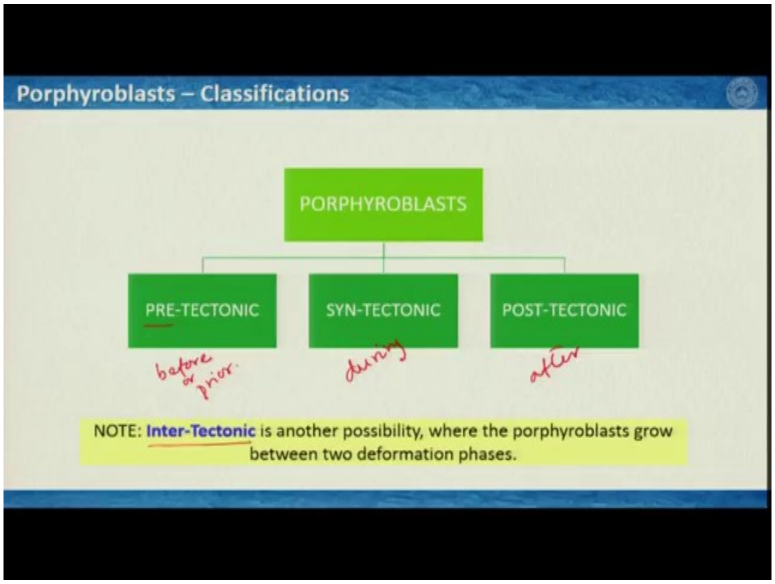
(Refer Slide Time: 20:29)



So based on that we classify the porphyroblasts and we will learn it in the next slide, but before that let us have a look that how we can sort of figure out that what are the different parts that we need to look at to understand the porphyroblasts. So in this illustration what we see that this is the porphyroblasts this yellow grain and these Porphyroblasts contains a fabric which is going or which is being shown by these dotted lines and these will refer as internal foliation or Si.

Now whatever stays outside will refer it as external foliation or Se, now within this Se we can have cleavage domain, we can have microlithon and so on, we will not go into that and because we have a rigid porphyroblast, then we can also expect some sort of areas around this porphyroblast which on the both side it can be symmetric or asymmetric or in different shapes we will learn it later and these are known as strain shadow. And at the top and bottom of this porphyroblast in particular the foliations are somehow wrapped or they are squeezed together and these are known as strain cap as you can see here. So these are the basic anatomy of a porphyroblast related features.

(Refer Slide Time: 22:08)

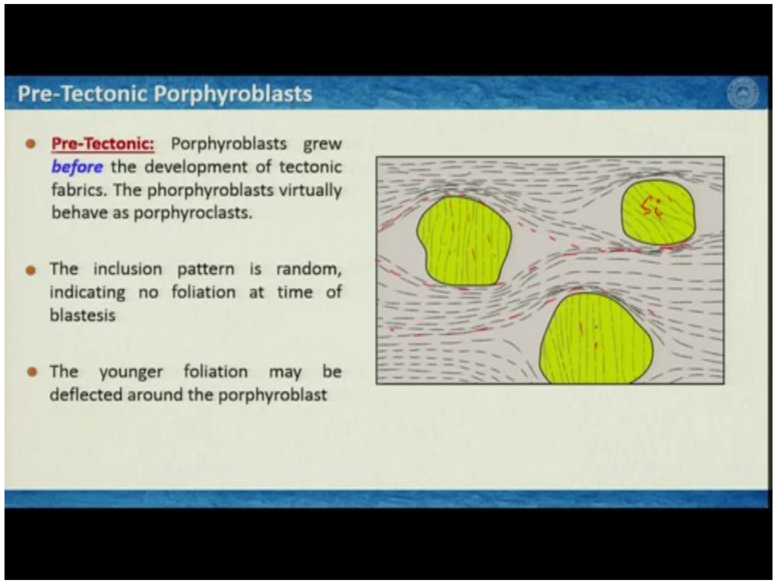


And now we will see the classification of Porphyroblasts. As I said that we can have three basic types of porphyroblast, one is pre-tectonic, another is syn-tectonic and the third one is post-tectonic. The pre-tectonic porphyroblasts as the name suggests pre that means they were before the deformation or prior the deformation, syn means during the deformation and post means after the deformation.

So the classification is very straightforward and simple porphyroblasts if you grow before the deformation then it is pre-tectonic, if the porphyroblasts are growing during the deformation it is syn-tectonic and when the deformation seized and then you have developed the porphyroblasts then it is post-tectonic porphyroblasts. Now there is another category which is known as inter-tectonic porphyroblasts, so this is another possibility whether or where the porphyroblasts grow in between two deformation phases.

So one deformation has happened, then a porphyroblast has grown, then a second deformation came, so that is also a possibility which is known as inter-tectonic, we are not going to learn this inter-tectonic porphyroblast in this lecture particularly. But if you are further interested to go ahead with this topic you certainly can consult the book of Passchier and Trouw MicroTectonics.

(Refer Slide Time: 23:38)

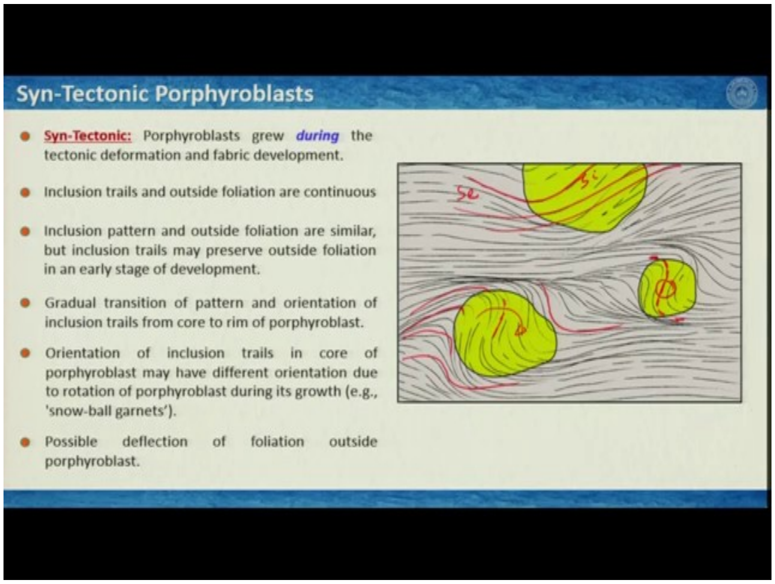


So let us have a look of these three classifications that we have just learned. So first we will take over the pre-tectonic porphyroblasts. Now as we said that pre-tectonic porphyroblasts, they grow before the development of tectonic fabrics. So the porphyroblasts you can imagine that they are actually with respect to the deformation they can behave as porphyroclasts because they actually appear as or they are present in the system as old grains.

Now, if the Porphyroblasts can have some sort of fabrics within that so the inclusion pattern would be random or there should be no foliation so indicating that there is no foliation at the time of blastesis. And the younger foliation also because the inclusions you have already there the porphyroblasts you have already new systems so younger foliation may wrap over this.

So as you can see here you may have some sort of random foliation within this which does not make any sense, just because it is not connecting with the foliation outside. So you may have or you may not have Si in internal foliations within the blasts. But interestingly you can see that the foliations as you can see here these are wrapping around, so that means that porphyroblast you had since the beginning of the deformation.

(Refer Slide Time: 25:09)



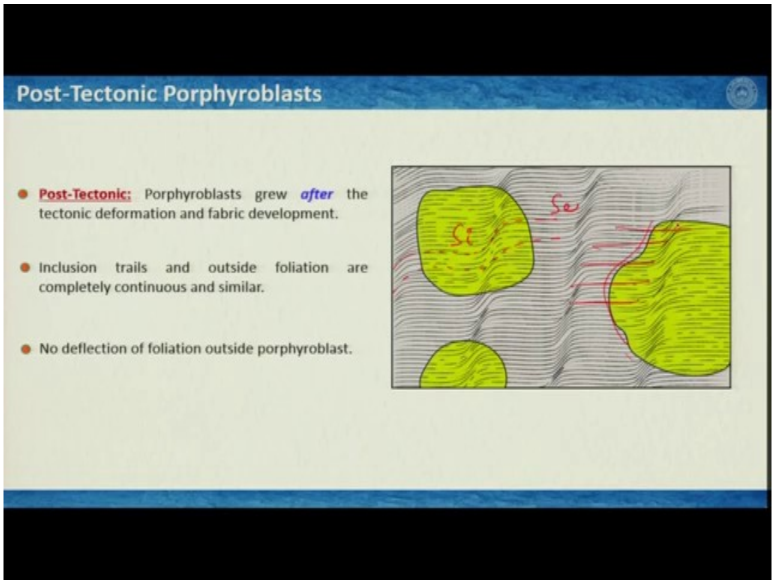
Now syn-tectonic porphyroblasts, these are very interesting porphyroblasts that we study a lot. So they grow during the deformation or during the development of the tectonic fabrics. Now inclusion trails or outside foliation or inside foliation in a way Se and Si, they are continuous as I can see here this I can consider as Si and outside I can consider as Se, so you see here in this schematic illustration the Si and Se they are continuous.

Inclusion patterns and outside foliations are very similar and this can also happen, you see that these are going more or less in a very similar way. The gradual transition of pattern and orientation of inclusion trails from core to rim of porphyroblasts. So for example, you can see here that there is here the fabric is oriented like this, then like this, then like this and then like this and here as well. So there is a gradual transition from the core to the rim and then to the matrix, so this transition also indicates that this is a syn-tectonic porphyroblast.

Now orientation of the inclusion trails in the core of Porphyroblasts may have different orientation due to the rotation this is exactly what we are talking about and we will learn it soon that if this is rotating this way, then it was actually initially straight but then it has been rotating. So therefore, you do not see them aligned the foliation outside and these are typically known as snowball garnets because garnets generally show these kinds of structures but there are other minerals that also produce this kind of features.

And you also should have a possible deflection of foliations outside like you see that it got deflected outside like this and like this and so on and here on and here on. So these are the typical features of syn-tectonic porphyroblasts.

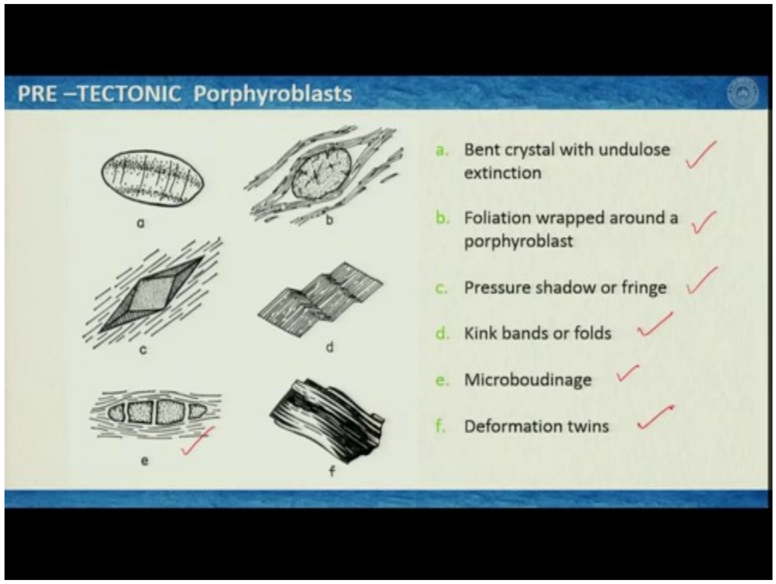
(Refer Slide Time: 27:15)



Now post-tectonic porphyroblasts on the other hand that do grow after the tectonic deformation and fabric development. So, what we see here the inclusion trails outside and inside or Si and Se are exactly similar, so it just continued like this. But this is also a condition we imposed for syn-tectonic porphyroblasts but in syn-tectonic porphyroblasts this internal foliation or Si has the very similar trend of Se, so it is not rotated or something like that within the Si.

So therefore, this is an example of post-tectonic porphyroblast and you also would not see any deflection or foliation because deformation is over deformation is switched off so these new minerals are just growing over it so you do not see any deflection of foliation outside this so they would be extremely straight away entering into the inclusions or porphyroblasts.

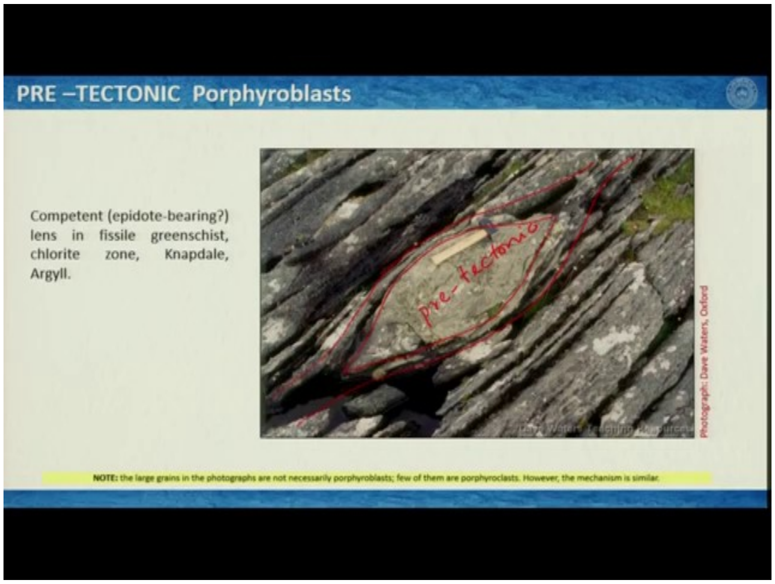
(Refer Slide Time: 28:24)



Now there are some examples that tell you that yes these are porphyroblasts and these are pre-tectonic porphyroblasts. Now you can imagine if I have a pre-tectonic porphyroblast so the porphyroblasts also suffered the deformation, now based on the composition, based on the mineral and based on the orientation of the minerals with respect to the overall deformation access and so on it can produce a series of micro structures which are extremely useful to identify whether they are pre-tectonic or not.

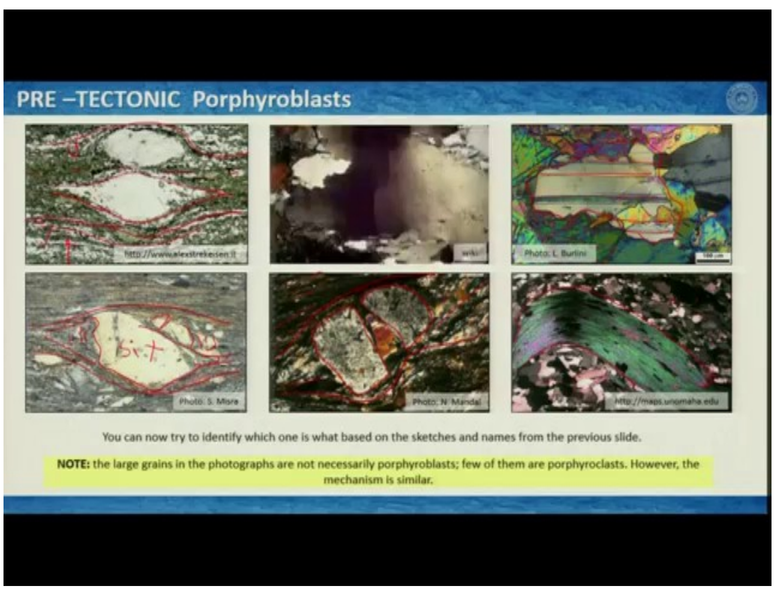
And these include bent crystals with undulose extinctions, the foliation can wrap around a porphyroblast, pressure shadow or fringe, kink bands or some sort of folds if you have phyllosilicates or tabular minerals in your tabular porphyroblast in the rock. You can have Micro Boudinage, the drains can fracture as you can see here example E, and of course you can have deformation twins or deformation lamella. We will see this in the next example.

(Refer Slide Time: 29:32)



For example, you see here this is a competent lens and you see the foliation outside wrapped around this, so this must be a pre-tectonic blast. Now it can be a purphyroclast as well but in this case we can consider for our understanding that this could be a pre-tectonic porphyroblast.

(Refer Slide Time: 30:08)



Now here, there are a series of examples as you can see here these are all pre-tectonic porphyroblasts but they can be also porphyroclasts, but the mechanism is very similar. The first image you see that is a trails so probably this was the grain and because it was deforming compression was from this, in this side you develop the foliation here nicely and you see this grains are stretched so this is indicating that this is a porphyroblast. Also you can see that the foliations are wrapped around this or here you see in a fantastic way. So these are typical examples of pre-tectonic porphyroblasts.

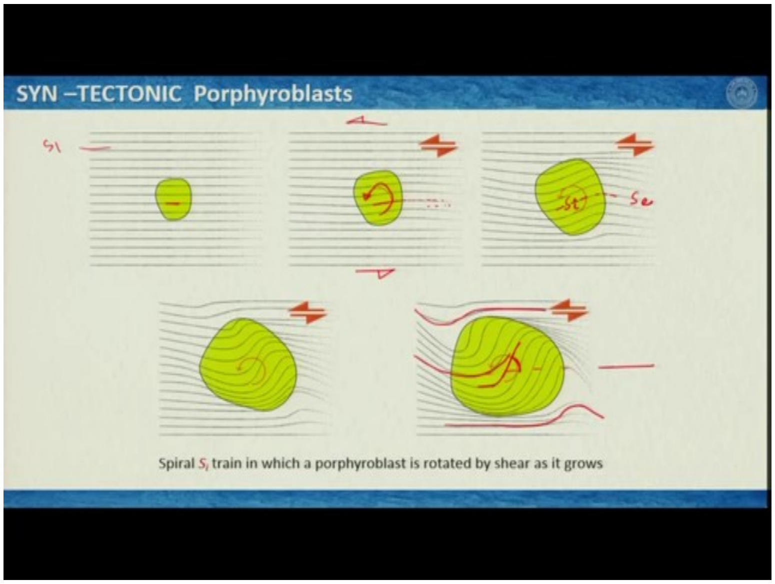
This is a gif image that I have collected from Wikipedia and you see the stage is rotating and you see a continuous undulose extinction going on in these quads and you also see that outside the matrix is extremely fine-grained and this grain is pretty large, so this could be a porphyroclasts as well, but it is showing an undulose extinction and therefore this must be there in the rock before the deformation.

This is again something that you can see that a large calcite grain with some sort of twin lamellas here and these are the twins so this must have grown before the deformation. In a very similar way that we have seen here this image also shows that this is your porphyroblast which was broken here producing some Micro Boudinage and it also shows this strange shadow in a nice way and we also see that foliations are wrapped around this and there is also no internal fabric Si is absent so you do not see any Si within this porphyroblast.

The Micro Boudinage you can see here that two feldspar grains here on this quads mica metrics the foliation goes like this you see the foliation first of all got wrapped like this here and here. And this was a single grain before but because of the deformation the grain got fractured and therefore you see them in two different pieces, so that clearly indicates that this large grain or porphyroblast was there at the beginning of the deformation or before the deformation and therefore it got broken.

You can also see this we have seen this image before in one of the lectures this is a biotite aggregate of biotite crystals and this is a porphyroblast because it got deformed in a (diff) and producing a fold whether the matrix is mostly quartz and feldspathic rich and it is much more finer grain so this is a porphyroblast and because it has a deformation within it, it got folded so therefore it must be in the rock before the deformation. So this is how you identify the pre-tectonic porphyroblasts from your thin section studies.

(Refer Slide Time: 33:07)

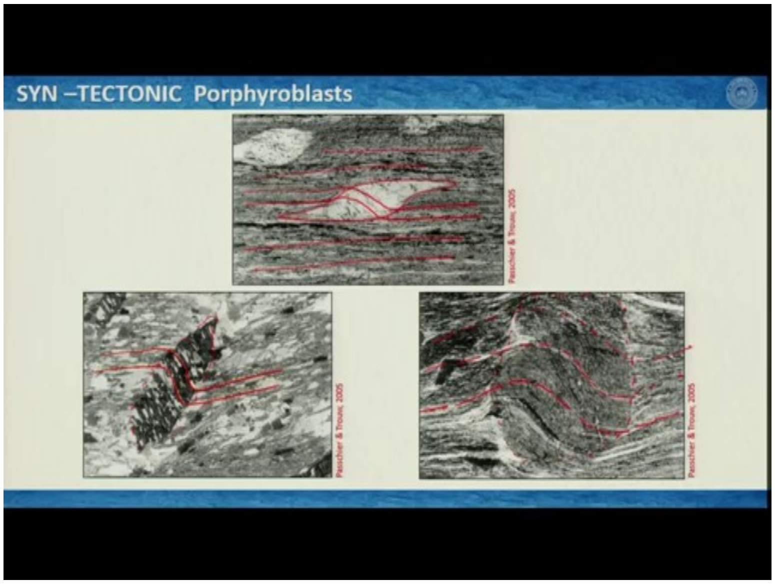


Now the syn-tectonic porphyroblasts they grow during the deformation as you have already learnt and here is a cartoon diagram illustrating how this can happen. So again this is your foliation say for example I can consider a continuous foliation as S1 and a porphyroblasts is growing in this rock and if this rock is deforming or it is under shear, so that means it is having sinistral sense of shear so this inclusion would rotate and this is how the rotation is being shown. But at the same time the inclusion is also growing.

So the foliation here at this stage is already there so it would simply rotate, so you see that this is not as straight as it is, so this foliation would rotate but the outside foliation also is being incorporated within this inclusion. So this is gradually becoming straight or gradually becoming aligned with the foliation outside. Here you see this is Si and this is Se so you see this gradual rotation is happening during the growth and at the same time rotation of this inclusion.

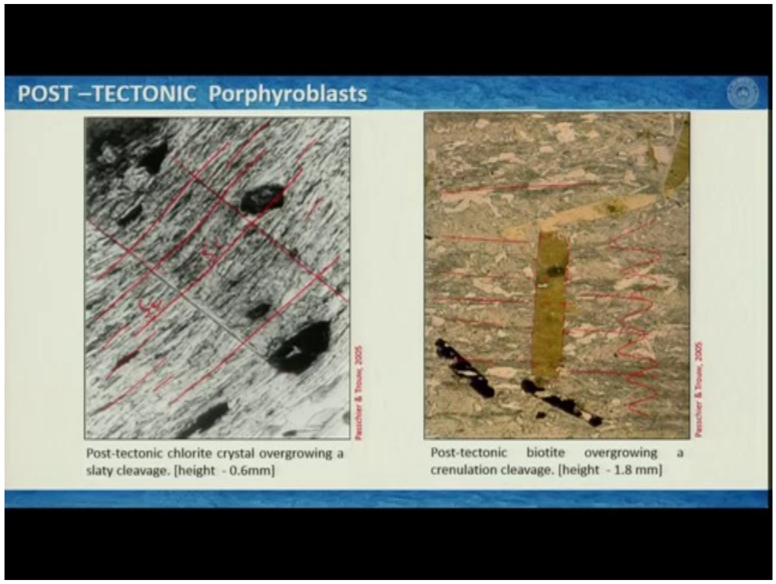
And this continued and finally you see that this is your final porphyroblast and you have the deflection of the foliation, you have rotation of the foliation inside, you have continuity of Si and Se and so on. So this clearly tells you that this if I have this in my thin section and if I see the features inside the thin section like this, this clearly tells you that this is a syn-tectonic Porphyroblasts, not only that we know that this must be aligned with the foliation before so but just looking at this angle you can also figure out how much rotation the grain has suffered, this is a very simple analysis that you can do but it could be much complex as well.

(Refer Slide Time: 35:26)



Now here are examples of syn-tectonic porphyroblasts, all photographs are from the book Passchier and Trouw, Micro Tectonics. And you see here how nicely the foliation you see outside is very much like this the continuous foliation, these are your porphyroblasts, so the foliation is going like that and then you see it went in and going like this. So it is continuous, you can see also here this is a large grain in the fine grain matrix and you see that this is showing a continuous trail or continuous strain of the foliation. And therefore, this is a syn-tectonic porphyroblast. You can also see this here so this is your porphyroblast and this is exactly the example we have seen before so this is how your foliation inside the porphyroblast is appearing. So whenever you see this you can figure out that this must be syn-tectonic porphyroblasts.

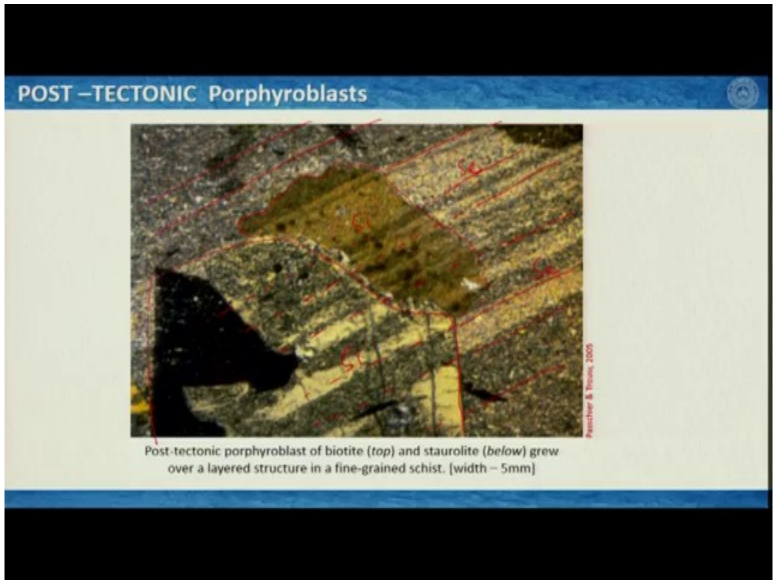
(Refer Slide Time: 36:40)



Now we see examples of post-tectonic porphyroblasts. As you can see here this is a chloride grain here within a fine-grained matrix or showing some very fine cleavage we call it we can call it slaty cleavage and you see outside and inside there is absolutely no difference, the foliation is going like this and the crystal is just like a glass is being placed on that surface. So there is no deflection of foliation, there is nothing no difference between Si and Se. So therefore, this must be a post-tectonic porphyroblast.

As you can see here, this is a biotite crystal which has overgrown this crenulation cleavage you can see the transition cleavage is going like this and you see that it did not disturb anything, there is no deflection of the foliation outside. So foliation is very much straight, here nothing has happened. You also see that this is continuous inside wherever it could track and it did not disturb anything in the matrix it just grew over it, so is again an example of post-tectonic porphyroblast.

(Refer Slide Time: 38:18)



This is another example, so this is a staurolite crystal at the bottom and here you see this is a biotite crystal and the foliation outside goes like this. And here you see that this foliation is being continued through the porphyroblasts without any deflection, without any change of orientation and anything. So these two so Si and Se and here as well Si and Se has virtually no difference. And therefore, this is again an example of post-tectonic porphyroblast.

So with this I finished this lecture, so this was just a little idea that how you can also figure out superposition of deformation not necessarily from the folds but from metamorphic textures together with the study of fabric analysis, we can understand how to figure out the different stages of deformation not always by looking at super post folding but some sort of over printing relationships. And in the next lecture we will start the actual topic of this week which is boudinage, thank you very much I will see you in the next lecture.