Fluid Inclusion in Minerals: Principles, Methodology, Practice and Application

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Lecture – 02
Introduction (Contd.)

Welcome to this session of the lecture series on Fluid Inclusions in Minerals. We just got ourselves briefly introduced to this particular technique or the methodology that can be used in many different disciplines in Geology.

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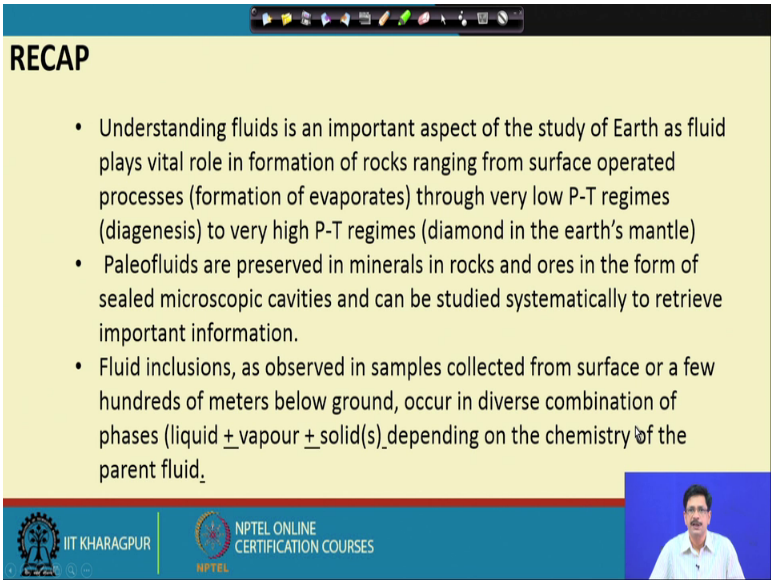

So, just to have a brief recap recapitulation of what we discussed last time. It is very important to understand the fluid in the in the earth. There are many process which are fluid assisted and there are many processors many features which result directly from the fluid activity like a white glass of mineral deposits and there are surface operated processes like the formation of the evaporates, sometimes indicating the composition of the paleo ocean.

And starting from very low pressure temperature regime of diagenesis to very high pressure temperature regimes in the mantle corresponding to formation of diamonds and there are these fluids, these paleo fluids are preserved in the minerals in the form of tiny fluid filled cavities.

These cavities are essentially isolated sealed encapsulated within the mineral during the process of its formation or growth or recrystallisation. And if we carefully studies study these tiny objects under the microscope and carry out several microscopic and micro analytical techniques, use micro analytical methodologies; then, we can retrieve vital information, important information regarding the paleo fluid characteristics; understand the processes that operated in the sub surface.

And they are the fluid that we are sampling as the remnant fluid inside the in the solid lattice of the inclusions are actually collected from the earth surface or may be on certain instances some few hundreds of meters below the surface in underground mines. But, we must keep it in mind that they operated in much deeper regions and they there are the combination of the fluid essentially is present in the in encapsulated cavities in the minerals, in the form of liquid a liquid plus vapor plus solid.

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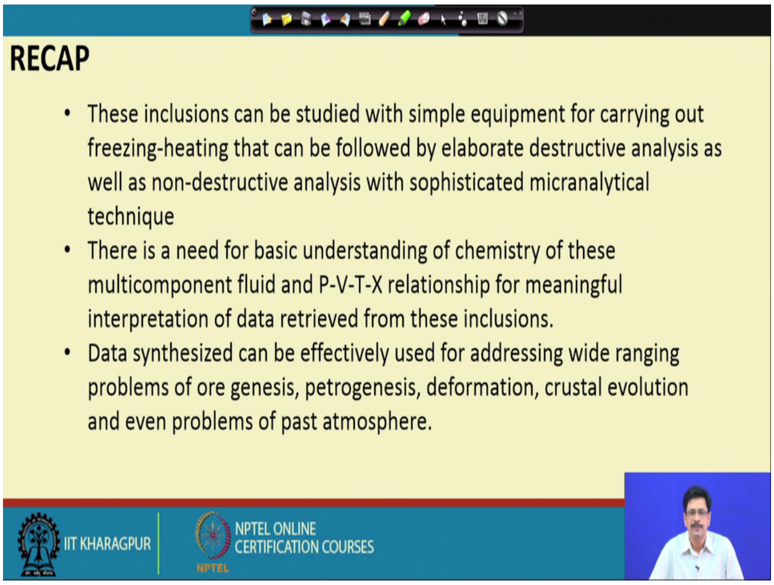

So, depending on the chemistry of the paleo fluid and this is the inclusions and it they sometimes are the very basic information generated by using simple devices along with a microscope and can go up to very very highly sophisticated micro analytical techniques. And they provide useful information about chemistry of the fluid the physio chemical environment in which they operated. If we apply principles of the phase relations, phase behavior and the pressure volume temperature composition relationships in such fluids; keeping in mind that this fluid which is essentially dominantly water is also charged with various variety of a electrolytes, the chlorides, fluorides, bromides, carbonates, bi carbonates sulfates, sulfides and so many anionic, so many species or so many compounds of different cationic species like sodium, potassium, calcium, magnesium, iron and so on in their in them depending on the condition in which they exist in the interior of the earth.

They can dissolve substantial amount of this electrolytes and also non electrolyte species like carbon dioxide, sometimes they reduce species as methane or sulphur species like sulphur dioxide H2S argon, nitrogen also remain dissolved and that is how it becomes a multi component fluid with various electrolytes and non electrolytes species and they interact with rocks to give rise to you know various minerals and various products inform of modified rock, in form of mineral deposits and so on. So, the data have to be synthesized very effectively to understand broader processes of crustal evaluation, petro genesis and past paleo atmosphere and so on.

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So, we can broadly see this process classify even though it is not an exhaustive list, that the processes are generally which are very much dominated by the fluid we call them as the Hydrothermal processes and give you rise to different types of rocks and different types of mineral deposits. And such values of fluids are preserved in minerals like Quartz, K-feldspar, Calcite, Fluorite, Topaz, Gemstones then, Cassiterite, Wolframite… to some of the name some of the ore minerals as Sphalerite and also if we use specialized microscopic techniques like the infrared microscope, we can also study this fluid inclusions in minerals which are opaque to a ordinary light.

By using an infrared microscope, we can study inclusions in any of the Sulfide Minerals like Pyrite, Molybdenite, Stibnite in fact, any of this sulfides should be suitable for study of this fluid inclusions in them. And we can have processes which are surface operated evaporation process. So, you can study the minerals in should study these inclusions in minerals like Halite, Gypsum, Anhydrite and so on. We can study them in Metamorphic Quartz, Garnet, Cordierite and even sometimes many other metamorphic minerals which recrystallize in the presence of fluid and also in fluid in deep earth, we can see fluid inclusions in diamond.

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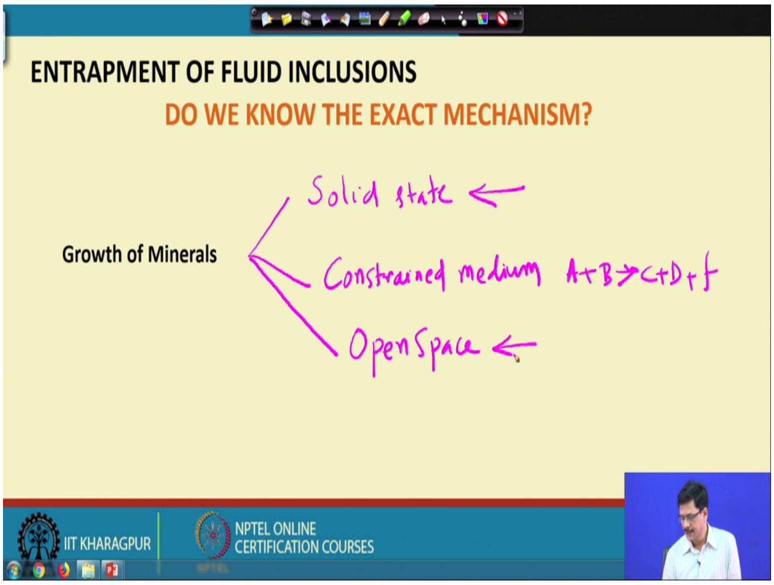

Coming to the one of the important aspect of these fluid inclusions, we generally ask ourselves that do we know the mechanism by which these fluid inclusions are entrapped or encapsulated in the solid lattices of the minerals from which I mean the minerals which grow in the presence of fluid or directly from the fluid precipitating from them.

This definitively constitutes one of the fundamental subjects of study is crystal growth about which direct applicability to geology situations operating in geological time scales are not very well known. But we still can within that frame work. We can still try to understand the mechanism of by which this fluid inclusions are entrapped in this one in by the minerals in their solid lattice. So, if we go by the basic principles that this fluid inclusions, they are getting entrapped in the minerals necessarily means that this process actually representing the position the thing that we are getting represented is essentially that the mineral is getting deposited or this recrystalizing in the presence of a fluid phase.

So, the mineral has to grow. So, if we talk about mineral growth of minerals, then we know that minerals can go either the minerals can grow in a Solid state. For example, there is a metamorphic recrystallization of a and giving rise to mineral assemblage. So, there in the absence of a fluid the minerals grow a as a result of diffusion of elements in an appropriate thermal environment and there we generally do not expect to because hypothetically this particular process is not taking place in presence of a fluid phase.

So, the other way that minerals can grow in presence of a fluid is that they can have a, they can go grow in a Constrained medium in a polycrystalline aggregate. For example, one particular mineral assemblage giving rise to another and if any of this reacting mineral phase happens to be a hydrospace; for example, if we if you say that A plus B giving rise to C plus D plus f fluid phase. This fluid phase is actually evolving during this particular process of reaction and this mineral C and D are forming.

So, there is every possibility that during these process of growth that minerals will, these minerals will encapsulate the fluid which was present and these fluid is more likely to be present in the intra granular spaces facilitating the diffusion of the elemental species for the growth of this kind of this process to take place or the mineral minerals can possibly grow in a in a free or open space, fill in the open space.

For example, if there is a extensional deformation zone in the cross fractures are created either within the very shallow region in the earth's crust or there are some shearing going on in which some dilatational zones are created high strength zones in which fluid will accumulate and start precipitating the minerals from the fluid. So, in this case the fluid is actually giving rise to the minerals and the mineral is forming from the fluid and in this case also the minerals that they are growing from the fluid are likely to entrapped the parent fluid as inclusions in the solid lattice of this minerals.

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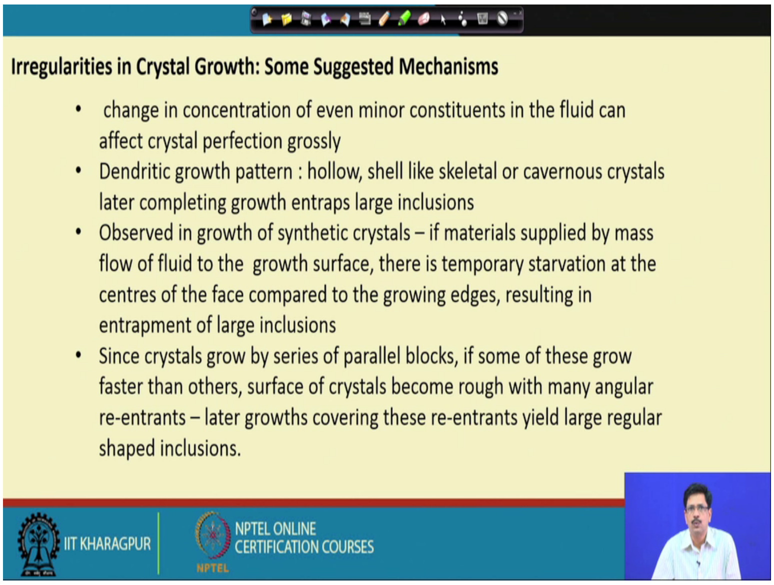

What is actually told in the context of the entrapment of fluid inclusions, in the solid lattice of the minerals is essentially because we know that is the mineral is growing. Suppose, you take the case of a formation of the mineral in open space fluid filled cavity; so, if the mineral will go from the fluid starting from a point of nucleation and free and grow in a free space; if the crystal formation is perfect. Then, there is no possibility of the parent fluid getting entrapped within them as inclusions.

Whereas, so, essentially the entrapment inclusions arise because of what we can tell them is irregularities in the crystal growth or defects in the crystal growth and some of the mechanisms that that have been suggested for this kind of to explain the and the entrapment of the fluids is that. Even if there is any small change in the concentration of any minor constituent during the process of growth of this crystal, it would give rise to the gross imperfection in the crystal growth. And then, sometimes what basically we see is a crystal sometimes with very well developed phase or either we see which is a very well developed phase.

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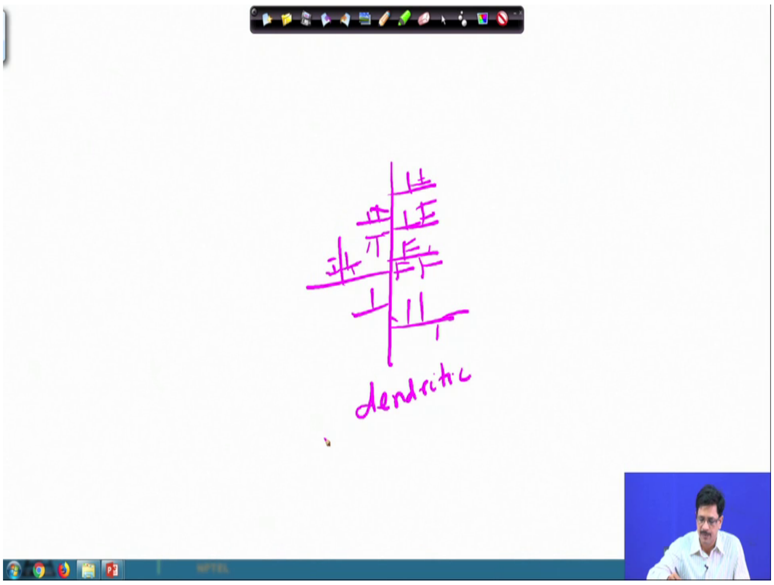

But, actually what has been what is actually observed in the in the experiments of crystal growth that the crystal actually grow like in a very irregular manner depending on the. This basically what we can say that this particular crystal which grows from this from the fluid, where there is supply of nutrient to the growing phases of the crystal will not grow in a very systematic way with all the phases developing at the same time and because of these, what is essentially termed is a dendritic growth of the crystal.

That means some of the phases or some forms of the crystals will grow much faster and that is where leaving behind some of the spaces in between which will be later on filled up and will lead to encapsulation of the parent read in form of the of in the form of inclusions. So, such category such this is one of the process which is suggested. So, you can say that it is a dendritic growth pattern: hollow, a shell like skeletal or cavernous type of crystals and the later completion of this growth leads to entrapment of inclusions.

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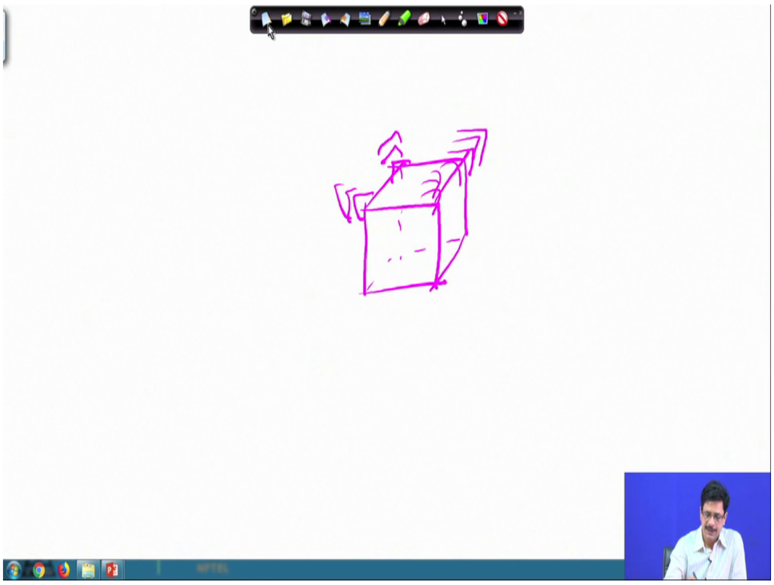

And sometimes it is so happen that we think of a crystal, the growth irregularities with some times the growth imperfection is such that the crystals starts growing only on the on the edges. And thus, there is a starvation of the nutrients to the center of the phases compared to the edges and the this also gives rise to something which is a little all variation from what we discuss at the dendritic growth.

At this also is responsible in leaving behind spaces in which the parent fluid is entrapped and the later growth of the crystal results in the entrapment of this, this parent fluid is inclusions. And so, these are some of the mechanisms; sometimes a crystals grow by a by a by a series of parallel blocks as the diagram just I just discussed and some of them grow very faster than the surface of the crystal become rough with many regular real entrants and later growth covering this reentrant angles giving gives raise to entrapment of this inclusions.

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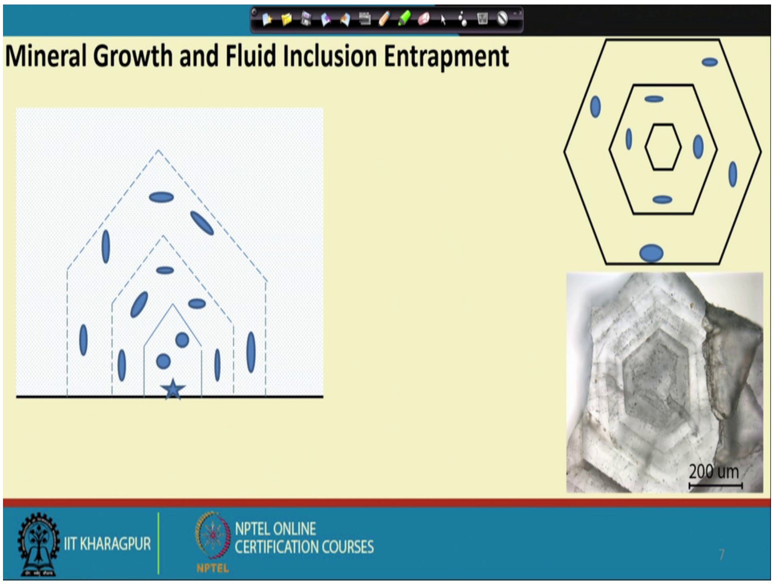

Here, I just would give a illustrate what exactly I mean by this. So, we are considering the situation in which the crystal is growing in an open space fluid fill cavity. So, suppose that the this point represents the point on which the, this is the solid substrate on which the crystal start to nucleate and this is represented the point of a nucleation. So, now the first a phase of the growth is represented by this phase and entrapped end of the parent fluid and these growth of the crystal is taking place in sequence of zones series of this developed these will developed a phases which are actually advancing to the open space which is filled with the fluid from which the crystal is growing.

So, this is a this schema, this is an illustration schematic illustration of exactly what happens in a in a in a growth from in an open space just showing a as if a single crystal is growing. Now, if we make a section of this; if we happened to be getting this particular in the form a vein, then we get a section take a section perpendicular to this c axis. Suppose there is a quartz crystal which is growing and we take a section perpendicular to the c axis and it would look like with these kind of the subsequent growth zones which are shown and the distribution of this fluid in the fluid cavities which are essentially randomly distributed without following any particular pattern.

But they definitive do a distributed in the subsequent growth zones of this of this mineral; let us say for this example it is Quartz and it is a it is an example of a natural Quartz crystal, where the section shows the growth zones and this dusty the things which are looking like a well populated very small particles like the dusty inclusions are essentially fluid inclusions. Here, we could see the scale which is 200 microns. Many of this situation it is so happens that under the microscope, we most of the cases we are not able to see these kind of growth zones.

In the host minerals, when we see them in the polycrystalline aggregate and sometimes some specialized techniques such as a (Refer Time: 18:46) is used to ascertain whether this particular mineral that we are study had any such primary growths on presence. And this topic, we will come back to in a later date when we take about the timing of the entrapment of this fluid inclusions visa ve the history of formation of this particular mineral which is one of the very important aspect of fluid inclusion study.

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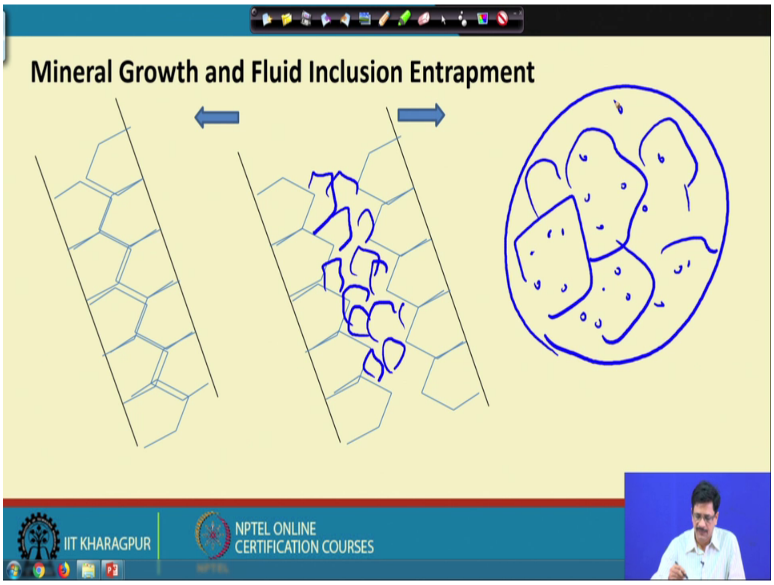

So, this diagram here, it just represents again a schematic representation of suppose this is a fracture. So, this represents a fracture and on this fracture, there was fluid. This fracture has been created by some kind of an extensional deformation and the development of the crystals from both sides of the fracture wall is shown here and.

So, now suppose this particular fracture wall is further because of continued extension this fracture again or may be because of some fluid pressure either some pressure which is being exerted, some fluid pressure which is exerted as some kind of mechanism of hydro fracturing or in association with also a extensional regime in which this fracture is gradually opening up and suppose this fracture again opens and this part is again representing that there is again fluid flowing to this particular fracture space. And so, that gives rise to.

So, there is filling up of the fluid of this fracture and this leads to further growth of the mineral. The same mineral on this already formed, you can call it as a way that requires when is forming in the in an open space and that is now giving rise to. And when, we see this when we when we are taking a section of this particular vein in the microscope and then we can see Quartz crystals and within them, we see the inclusions which are trapped ok.

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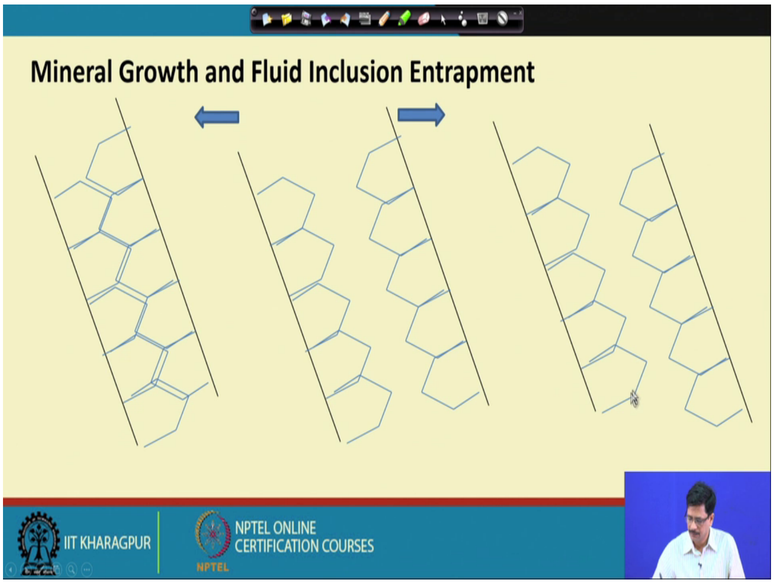

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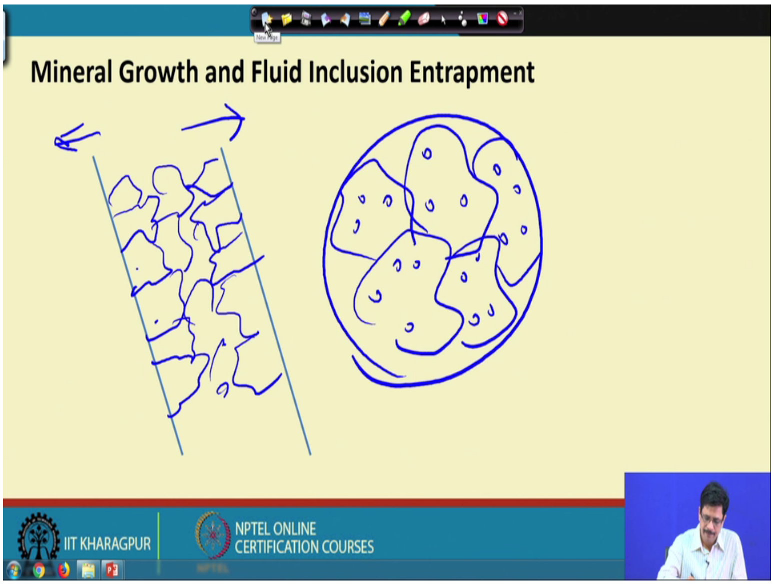

Now, what happens is in most of the cases that what we discussed right now, we are we just considered as if all these, the situation where the crystals are growing on the fracture surface and each is able to grow to perfect crystals. But what happens in a in actual in that in nature is that there is this growth essentially take place in kind impinged manner, each of the when many nucleation points are created on this sub state and the crystals many crystals grow at the same time from the fluid.

The growth of 1 impinges on the other and this gives rise to a and suppose the way it is been explained before that it is gradually the fracture is opening up and several generation later generations of fluid have also come and filled up this particular fracture space and we then see this Quartz grains which are of irregular margin and we see the inclusions in these Quartz crystals. On situations where these particular polycrystalline aggregate of this mineral Quartz has been able to anneal to perfect polygonal grains which might have happened because of the migration of the grain boundary

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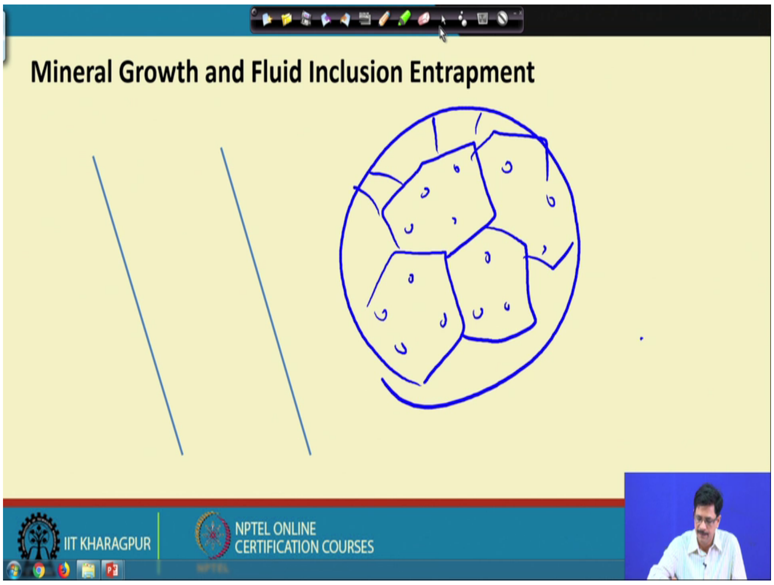

Because of the because the aggregate is subjected to aniline and then, these inclusion feature already present in them, are likely to be re equilibrated or likely to re adjust likely to change their shape and then, we see them in a different kind of situation when we see this particular aggregate has actually been able to anneal and give a different kind of a situation to us.

We will be discussing more on this is to what happens with the inclusions which are originally trapped in the mineral which grew from these from the fluid and when they are subjected to any kind of later recrystallization of the host and what happens to them? This is also going to be a one of the topics of our discussion this.

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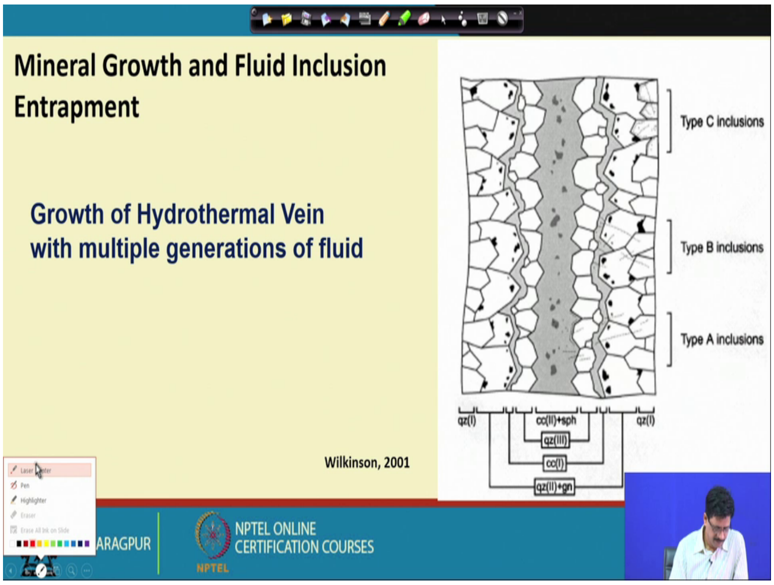

So, this is a situation which; so now, what actually this the thing which need to be explained or the thing which is actually the matter of concern is that when a if crystal is growing in an open space like the situation which you have depicted. The actual time that actually elapses during this actual time that is that is that the mineral takes to form is definitely variable depending on the various geological situations.

Like say for example, this particular diagram which has been takes from Wilkinson, 2001 depicting the formation of mineralized when in such kind of an open space, where the subsequent what has been shown over here as the this is the first layer of the quartz crystals which formed on the sub state which was the fractured surface. And then, this particular fracture surface has undergone this particular vein did undergone fracturing and further widening up.

Let us say street deposited the second stage of the host mineral quartz along with these sulphide minerals and so the fluid inclusions will get trapped. Depending on this particular sequence is operating in for time frame if this different batches of fluid occupying the fracture space with opening up of the fracture happens in very quick succession. Then, we will essentially be dealing with the same fluid with much of variation of its characteristic if it happens in the short span of time.

Whereas, it might so happen that the later stages of fluid activity resulting in such kind of fracturing of these initially deposited quartz and then, later deposition of the quartz happens in a gap of a substantial time period. Then it might so happen that the fluids coming in 2 different batches may not be very similar to each other or where essentially be sampling fluids which will be entirely different in the compositional characteristics.

So, the fluid inclusion study intends to actually meticulously record or observe such kind of fluid inclusion characteristics in them. Then the measurement of several microthermal matric and micro analytical measurements which can be done to reveal or to work out the evolutional of the fluid in terms of it's composition and the physicochemical parameters.

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We will just quickly see some of these suggestions. So, this mechanism of entrapment as is suggested they the rapid feathery growth. So, akin to a dendritic growth pattern which can be shown here, like this particular crystal is having a dendritic growth pattern and after the later growth of the crystal this it is again; so, these feathery growth actually is responsible in entrapment to this particular fluid is inclusions.

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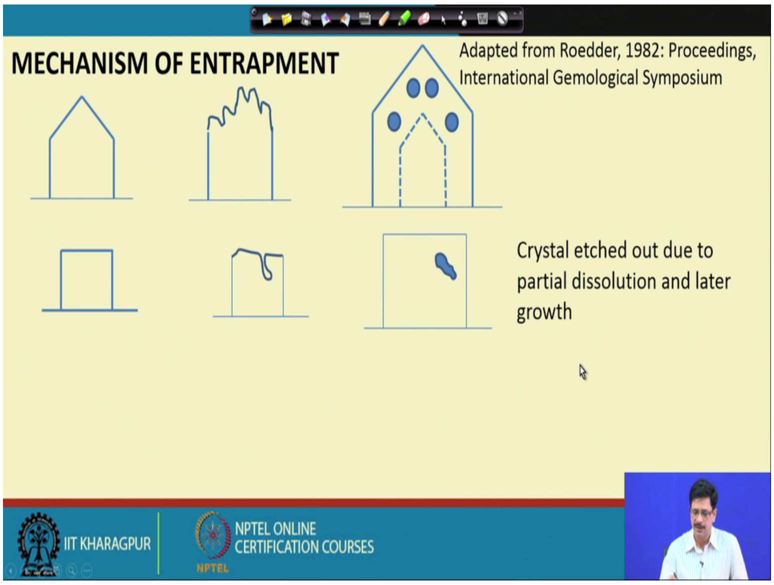

And we can have a situation where there could be some kind of is to begin with this was a crystal and there has been a small dislocation dissolution cavity which is formed in this particular crystal and then, with further later growth on this particular crystal this space which was left behind has resulted in entrapment of the fluid in the form of an inclusion.

So, this actually the crystal it is something like a crystal is etched out due to partial dissociation and later growth which happens very commonly in a take for example, the common mineral like quartz such kind of dissolution and re precipitation is very very common. Because the fluid is precipitating the same quartz and because of minor fluctuations local fluctuates since in the compositions of the fluid results in such kind of etched out due to the partial dissolution and later. So, then this gives us some idea is to what kind of the feature of the inclusions also we would expect.

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This is situation where again this is also some irregularity that is the velocity this is a trapped growth spiral in which some such kind of a irregularities developed during the growth of the crystal and on further the position of the same mineral on the surface inclusions will be trapped.

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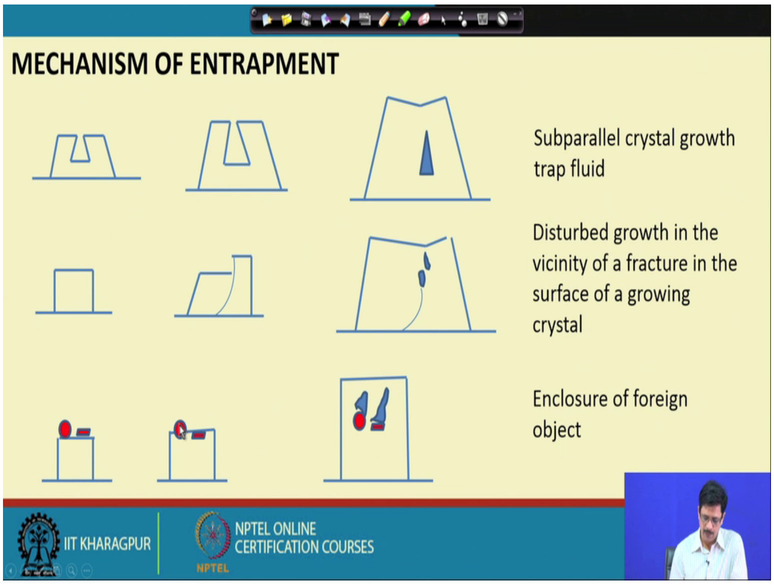

This is some kind of situation where there are some sub parallel units of the crystal that is growing and leaving behind some regular shift cavity and which also will be resulting in the encapsulation of this parent fluid in the form of an inclusion. So, this is a case of disturbed growth. For example, the crystal is growing just as we are discussing that on a structure surface when the crystals are actually growing from both the walls and once the structure space is filled up by the first generation of the quartz crystals, if there is there is a fracturing; then the first page of crystals that are growth they will undergo fracturing and some such kind of fractures which will develop.

But again, when there is fluid coming to the fracture again and depositing the same quartz on top of it; it will leave it will leave behind some kind of a situation that this inclusions will be form in the form of trail just at the tip of this fracture which was created as a disturbed growth during the original crystallization. And this is also very interesting that if during the growth of this particular mineral, if there are some solid particles which are implanted on this growing phase of the crystal and then, there is subsequent growth of the crystal from again by deposition from the fluid. Then this, there will always be tendency for this parent fluid to get trapped in the form of a imprison just in the immediate vicinity of this foreign object.

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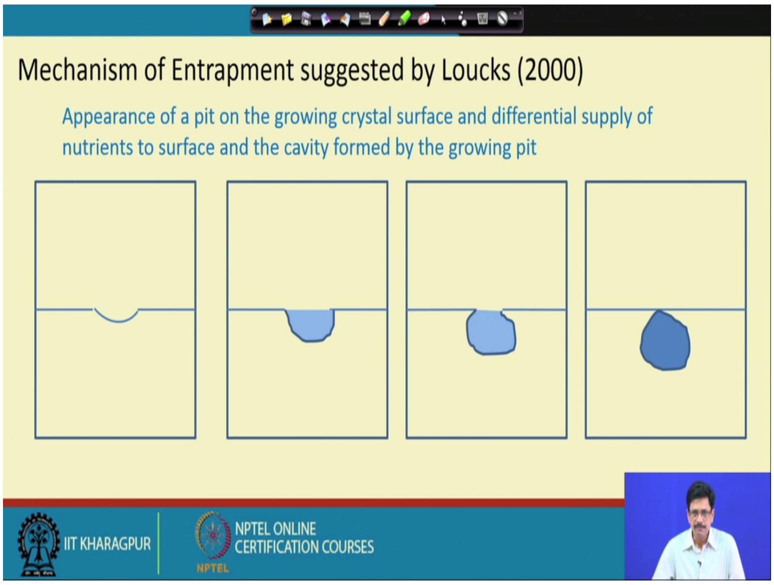

This is again which is something very interesting which was suggested by Loucks in 2000, that the crystal surface which is growing will develop a pit initially and as the pit is developed there will be less of nutrient coming to the in inner part of the tip of this pit compared to the growing surface. So, with the growth of the mineral on this particular growth phase, so this pit will become further deeper with further decrease supply of nutrient to the to the inner part of this particular cavity. And finally, it will give rise to an inclusion which will be trapped the parent fluids which will be trapped.

So, this gives us some idea that even though we have not been able to understand the intricacies of the crystal growth in geological situations, the way we depict them as constraint growth in the constraint medium or in growth in the open space from fluid. But there can be some idea some concept which could be something could be conceptualized is to why the parent fluid will get entrapped or encapsulated within the solid lattice of the growing crystal. So, we will continue discussing on this on further aspects of these fluid inclusions.

Thank you.