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

Prof. M K Panigrahi
Department of Geology and Geophysics
Indian Institute of Technology, Kharagpur

Lecture – 05
Introduction (Contd.)

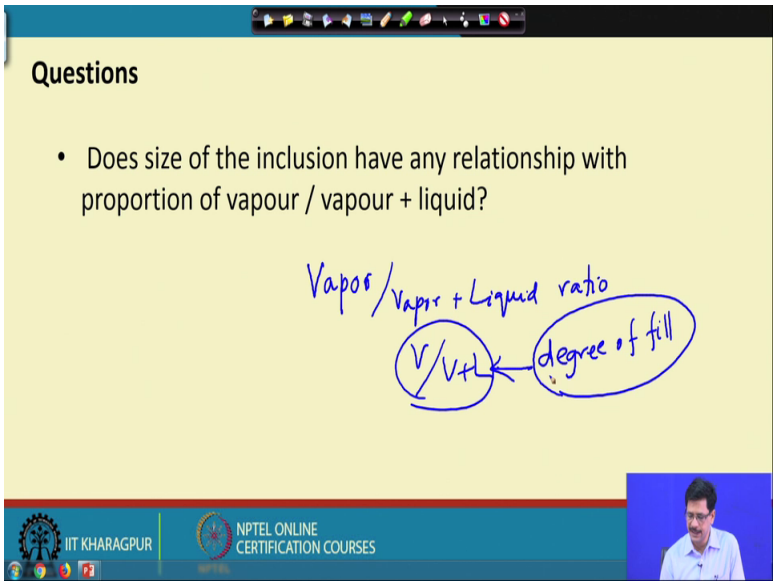
Welcome to the fifth lecture of the lecture series on fluid inclusions, in minerals, In the last few lectures, we got ourselves briefly introduced to fluid inclusions how they are trapped in the host mineral, in because they are trapped as a, sealed cavities in the solid lattice of the host mineral and, we have been trying to understand the basic mechanism of how these tiny cavities are encapsulated within the growing, mineral.

From the, when it goes from the fluid phase or it goes in a constant medium and we have had a, brief look through some of the, images of fluid inclusions from various types of, occurrences like the quartz, veins, in different types of, mineral deposits from magmatites, from, ore minerals from silicates from, minerals like, like anhydrite and I have seen the white possibilities of shapes and sizes that these inclusions, can display, when we observe them under the microscope.

Will again have a, detailed, discussion about how to prepare the samples for the fluid inclusion studies, but for the time being, with this much of background information on the fluid inclusions and when we, move over to subjecting them these subjecting these tiny objects to various types of studies begin beginning with trying to retrieve the information in terms of the physio chemical parameters like pressure, temperature and composition of the paleo fluid through systematic study.

So, it is, it would be, good to just have a to ask ourselves a few questions that, that could be many more I understand the, whether we have seen that the inclusions display a wide range of sizes

(Refer Slide Time: 02:16).=



As low as less than about a micron that we, that is observable in an normal transmitted polarizing microscope, where we can go to magnifications, sometimes at the most of 600 times or 1000 times, with the as we know that higher, that the more the power of the object, the resolution of image generally becomes a little, less and conveniently we can see these inclusions, when we have seen them under a in, a transmitted light microscope, with magnification ranging from 500 to 600; that means, using a 50 x objective with a 10 x ip (Refer Time: 03:01) a 12.5 ips.

So, we have seen that these inclusions range, in size ranging from less than a micron to more than about a 100 microns or there could be, there is actually no maximum limit, but these are the general, scenario, And we know that the, inclusions get trapped in the host minerals at different stages during it is primary growth and also any time after words. The mineral in a vein or a rock after it has formed. It is subjected to later deformation in the brittle or the ducktail, deformation zones and later fluid, percolates through them and later stages entrapment also take place in these inclusions.

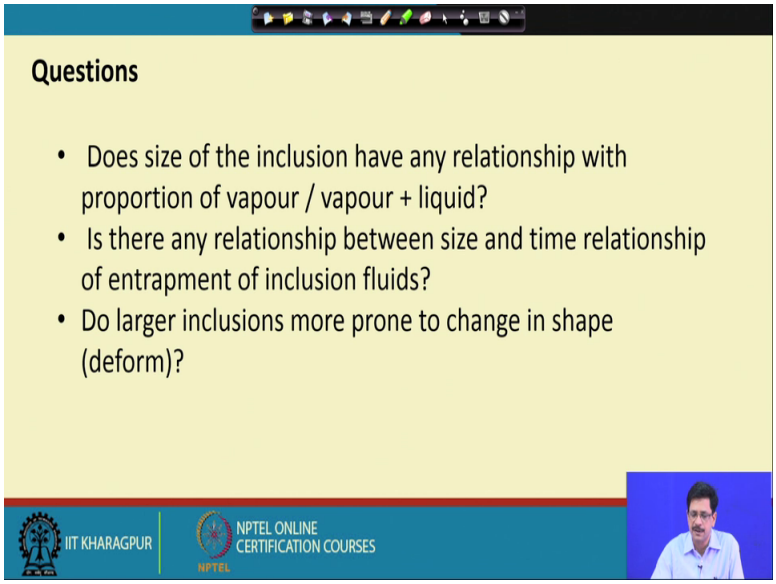
So, we ask ourselves whether there is any correlation with these inclusions size, and the parameter generally, which we see in a, if the context of the aqueous inclusions aqueous biphase inclusion, which is a vapor liquid and vapor situation. And we see that the vapor, proposition visually, differ in great ranges. At the same time we are also remainder of the fact that we are able to only get a two dimensional, view of the inclusions, which is

actually in three dimensions. It could attain any shape, any regular shape or any irregular shape and we are able to see the, bubble vapor bubble is. It might, it might give us a false impression about the proportion of the vapor bubble, when we examine them under the, microscope.

So, this is an important parameter which, people used to, use the vapor by, vapor by vapor plus liquid ratio V by V plus L and in some literature you will, find that this particular, ratio is being labelled as the degree of fill, which is, somehow analogous to, a mass by volume kind of a parameter density, which will discuss later.

So, this, as we have seen through the range through the various, they occurrence of the inclusions in various types of mineral, host minerals we find that actually there is no much of a, relationship that could be observed between these vapor, by vapor plus liquid ratio and the, size of the inclusion, that could vary randomly. One large size inclusion visibly having a small vapor bubble and a small size inclusion with a large vapor bubble might turn out to be the same, when we retrieve this, parameter by, systematically after our micro thermometric experimental results, which will discuss and that does not seem to be much of a relationship.

(Refer Slide Time: 06:21)



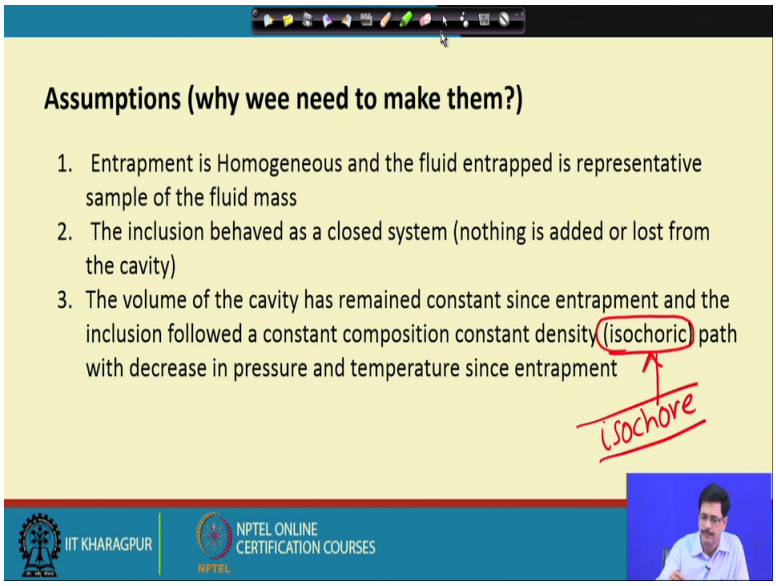
So, again we could ask is there any relationship between size and the time relationship of entrapment of fluid inclusions? Because there again the fluid inclusions are entrapped during the primary growth of the mineral as well as any time later. So, is it that there is

could there be a relationship between the size and the time of entrapment we have seen that even when they are occurring as part of the random three dimensional network there is a variation in size from very small to very large even when they occur as trail bound or as heal cracks the inclusions when they get entrapped during the process of healing of the cracks by later fluid.

There also we see that the variation in the size is quite significant. So, that does not seem to be any relationship between the size and the timing of entrapment of the fluid inclusions here we also ask ourselves because we have seen the inclusions, which look to be some time pretty regular in their shape confirming to a circular or a oval or elliptical or a negative crystal shape and we have also seen inclusions, which are which look to have been undergone a change in the shape and sometimes. So, this rather confirms to our general observation that the larger inclusions that the inclusions, which are generally greater than 20 30 microns or even more than 40 50 microns in theory maximum dimension.

These inclusions are the ones which are more prone to getting re I am changing their shape of the of the of them at any kind of a hook shape or an annular shape, which will be a point of a discussion when we go to the very important topic of re equilibration of this inclusions under changing conditions of pressure and temperature or any kind of a disturbance or later disturbances, that we can visualize happening in a geological environment ok.

(Refer Slide Time: 08:30)



So, with these, kind of a ground information, as we have been discussing that we subject these tiny inclusions to various types of experiments micron, micro, microscopic as well as microscopic experiments and micron analytical, techniques. We say that, we are sampling the paleo fluid, the fluid which are active in distant geological past in terms of hundreds or millions or years, thousands of millions of years to even very recent. We, intent to retrieve, information on the physio chemical parameter like pressure and temperature compositional characteristics of this fluid inclusions.

Now, when we are attempting to do that, it is very natural that we have to take some assumptions and the number one assumption is that the entrapment is homogenous and the fluid that, that was entrapped is essential as a representative of the same fluid mass; that means, the, fluid that we visualize that to have operated in any geological environment, in the subsurface and the sample that we see in the inclusion, in a mineral as the tiny inclusion is actually representative of the pale fluid and the entrapment is homogenous and the second assumption is that, the inclusion behaved as a closed system. So, here it is very important, because once the, because we, we think that this inclusion is trapped say for about, say a thousand million years back.

So, since it is entrapment till today, it has remained there as an entity. So if we, if it has, if there are indications that the content of the inclusion has been, has been changed the

somehow it is exchanged material with the surrounding then a whole of our exercise will become futile.

So, this is a very very important assumption that we make and in any scientific, investigation we the basic tenants of this subject that we definitely go with some set of basic assumptions, and it goes without saying that such kind of assumptions will be subject to critical assessment questioning and again, reaffirm. Such as some assumptions that how far these assumptions are valid or under what kind of situations such kind of assumptions will become invalid or how to take care of situations, where these assumption or these, this system seem to have, violated this particular assumptions. We will be discussing them all, but in the majority of the cases, this assumption holds good.

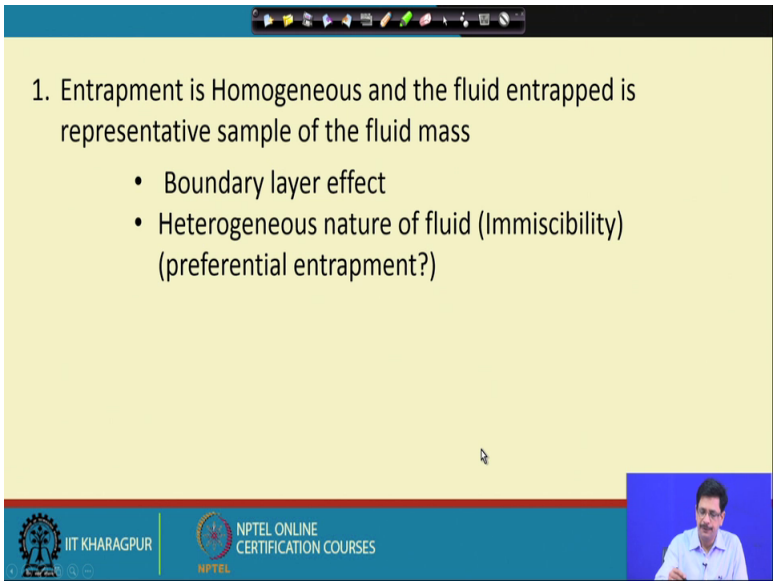
The inclusion once trapped behaves as a close system means does not exchange, material, pattern with the surrounding; that means, nothing is added or subtracted from the cavity and in the another important assumption is that, this cavity ones entrapped it behaves as a, I show the same, similar same volume, the volume remains constant.

It behaves as a iso volume, iso compositional, system. What I basically, say that it is, is iso core is isochoric, which will explain what it is. Basically, the word has come from the, these isochoric means actually what we are isochore is essentially meaning that the system has behaved as a iso, the composition has remained unchanged.

The volume of the cavity has remained unchanged and it is, even though we know that this inclusion must trapped at a condition, which is pretty different from where we sampled. It means we sampled it almost near the surface and the mineral in it is, surrounding in a rock or in a vein which formed in a greater depth at a pressure temperature condition, which is different from and then it is evolved through the decrease of the pressure and temperature and that particular inclusion cavity within talking of the individual inclusions. Although, we know that they occur in huge number in millions.

So, each of them has evolved in a constant density, constant composition path.

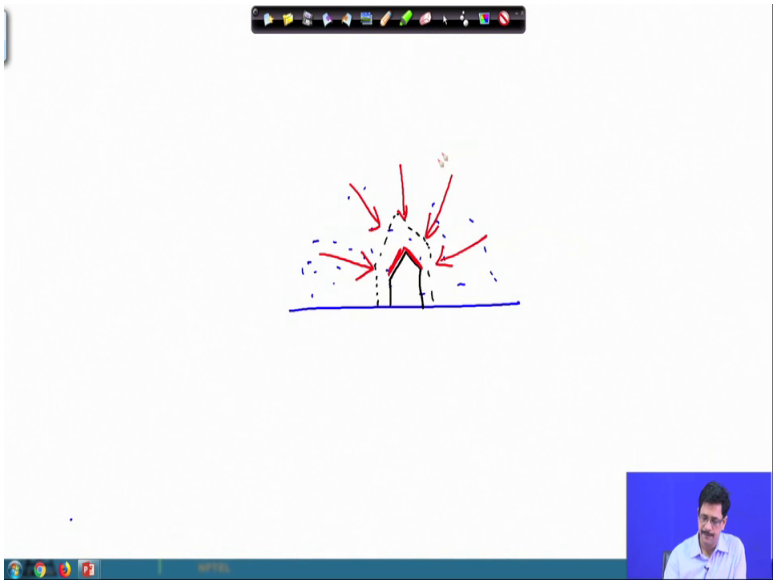
(Refer Slide Time: 13:10)



So, if we just try to examine that our first assumption is that the entrapment is homogenous and the fluid entrapped is representative of the sample fluid mass, if we without getting into much of the details at this particular movement, if we think that let us try to examine our assumption that this fluid. This, small mass of fluid which is encapsulated is in inclusion cavity. is it representative of the fluid from which it is formed.

So, if it is not, what are the possibilities? So, what we, what people propose what are, the way the discussion is sometimes, made is there is something like a boundary layer effect.

(Refer Slide Time: 14:13).



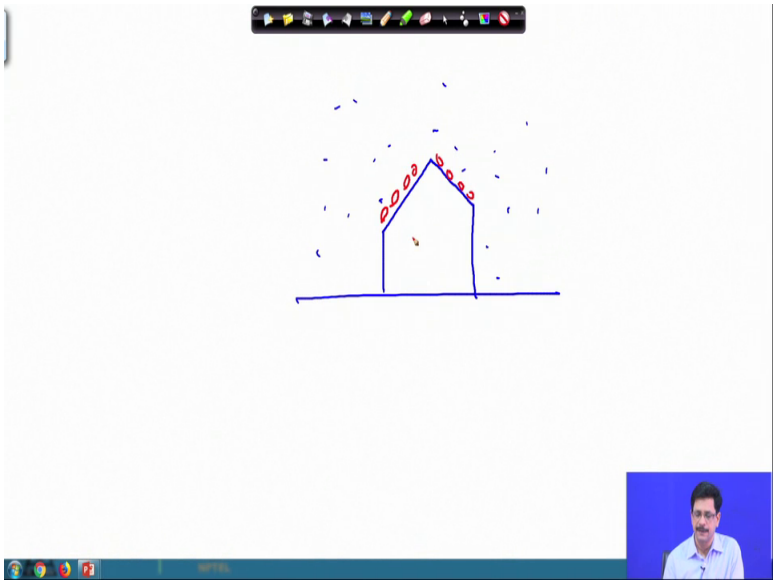
For example, we have that this is a substrate and, we have some kind of an open space, where the crystal is growing and let us say that the crystal is going from here and in a manner that, we showed before that, it will go layer wise.

So, the thing is that the, the immediate, contact immediate, interface of the, liquid and the solid and as we know that if this is the fluid medium, the, constituents are actually being transported from the surrounding, diffusion through the fluid and is coming to the front on which this crystal is growing.

So, in this process it is quite possible that there could be some kind of a concertation gradient, which will be existing there and the fluid considered at a very-very small scale, just at the interface of the, liquid and the solid it is composition might be a, little different from what is the bulk? Bulk compositional characteristic of the fluid could be.

Now, the thing is that it is not very well quantified as to what kind of a concentration gradient, will be existing? Some amount of speculation are there, but in general it is and in this context what is, said is that.

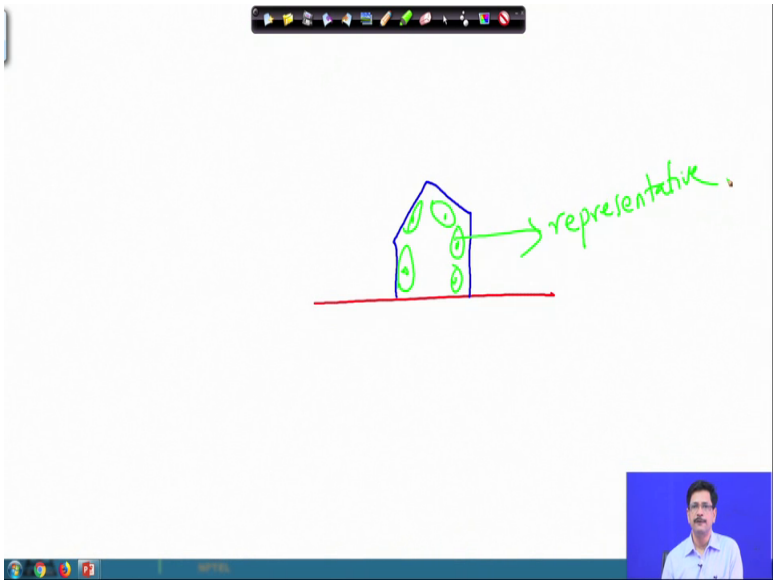
(Refer Slide Time: 16:05)



If this is the crystal which is growing it from the fluid and this is the fluid, this is the medium the fluid medium then the inclusions, which are trapped here.

These inclusions which will be trapped here as the crystal will go, if this inclusions happened to be very small then the chances of the fluid encapsulated within these inclusion cavities been different from the rest of the bulk of the fluid is a little more whereas, if we think that the inclusions which are the inclusion which will be forming in this crystal and will be of reasonable large size.

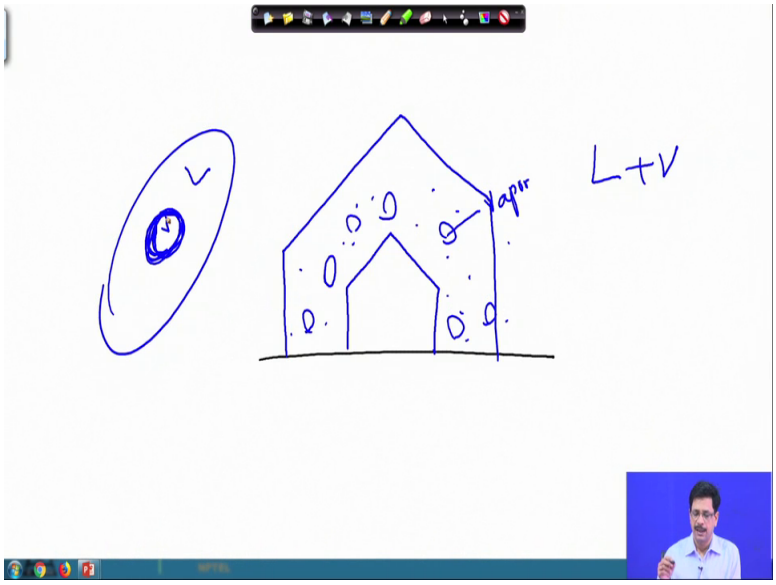
(Refer Slide Time: 16:57)



These inclusions is, more likely to be representative of the paleo fluid compared to, the inclusions, which will be much smaller then the size and the another assumption that we have made, that the fluid is, at the time of it is entrapment is homogenous.

So, the other, possibility that the fluid, if this situation might deviate from all though, it as will see in majority of the cases, the assumption is very valid, but at place where the fluid is, in an immiscible regime; that means, mutual solubility of the two phases that will be considering is, negligible is less or actually they are immiscible then at any point of time in the growing, crystal.

(Refer Slide Time: 18:24)

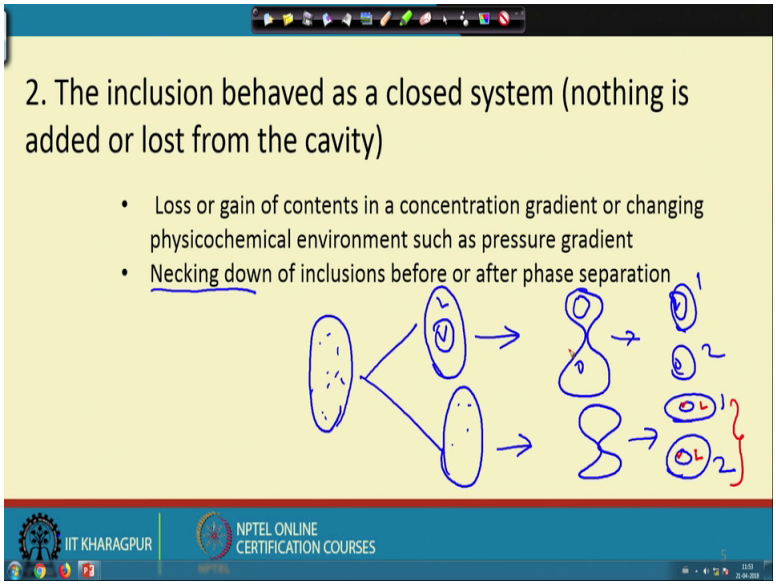


For example if, for example, if there is a crystal, which is growing and the fluid there if we are considering about the fluid to be water, then these representing vapor bubble and these dot representing the liquid; that means, the surrounding liquid, the surrounding fluid is actually is in homogenous condition; that means, the existence of liquid plus vapor.

So, there is a possibility that the growing crystal, which is the crystal is growing in this medium will entrap a combination or a mixture of a little bit of liquid plus vapor even though we will see them see the inclusion as a bi phase inclusion as we have seen them liquid plus vapor, but this particular inclusion will have a history that during the entrapment. It has actually entrapped, small amount of a some amount of liquid plus vapor, together.

The explanations some of the sometimes if that is a situation, then our micro thermometric experiments intending to retrieve information on the temperature of this fluid will become invalid or we have to see that under that circumstances how what are the measures we can take for such corrections or what kind of other inferences which you can make from these situation.

(Refer Slide Time: 20:37)



So, the second one that the inclusion behaved as a closed system nothing is lost or added from the cavity. So, that they though it is assumed though those this assumption is mostly valid in most of the cases, but and under circumstances there is a suspicion, which grows that well the inclusion cavities once they are trapped they might have there has been situation, in which they would have lost they would have exchanged component to this surrounding either loss or gain.

So, it could have happened in when this initially formed mineral in the in the particular rock or a mass of vein is actually emplaced in the crossed on a different crossed on a environment in terms of the physio chemical parameters and there may be a concertation gradient, which may be established or something kind of a pressure gradient which could also be established, which will allow for change in composition of the fluid which is encapsulated within the cavity and there is another situation in which the fluid might not behave as a closed system that happens during that during the process, which is and the

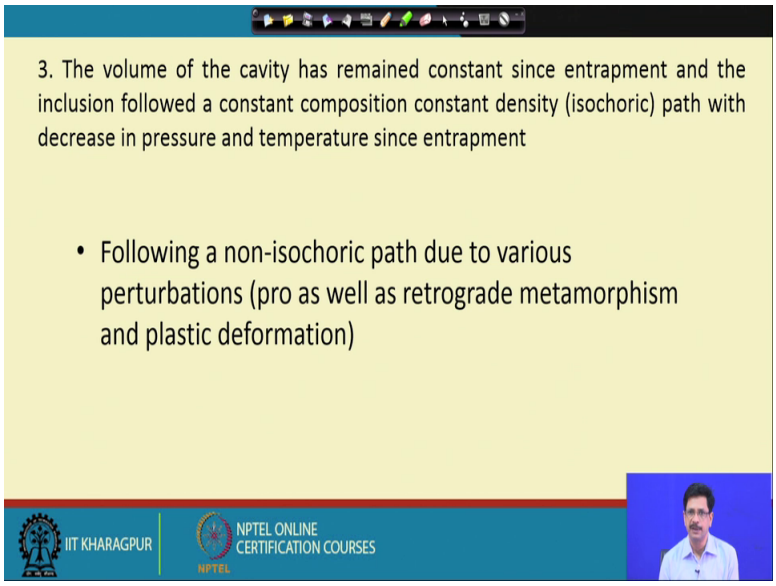
other situation in which these assumption this important assumption might be violated is sometimes, which corresponds to a situation where the inclusion might neck down.

So, what we essentially mean by neck down necking down if we have a original a fluid which is entrapped a homogenous fluid and either of the situation that it is already formed it is already evolved into a two phase situation as a liquid and vapor or it has remained as a same situation as liquid and this particular inclusion will get neck down to two components finally, to two individual inclusions; inclusion 1 and inclusion 2 and if it had a vapor then they will have an un disproportional splitting of this vapor and in that case the original composition of this particular fluid inclusion is lost.

In the other case if it, if the, necking down of the inclusion takes place, when it was actually in the one phase state and then it evolves in to the two independent inclusions, inclusion 1 and inclusion 2, where they also do have a situation, where it is, liquid this, this, this part is vapor. This is liquid and this is vapor and this is also in this case, this is liquid and this is vapor. Then these two inclusions are more likely to have preserved, the original composition and these assumption will be valid in situation where the necking down took place after the vapor phase separated out of the, inside. The cavity as a post entrapment change then in this case, the, assumption will actually become invalid.

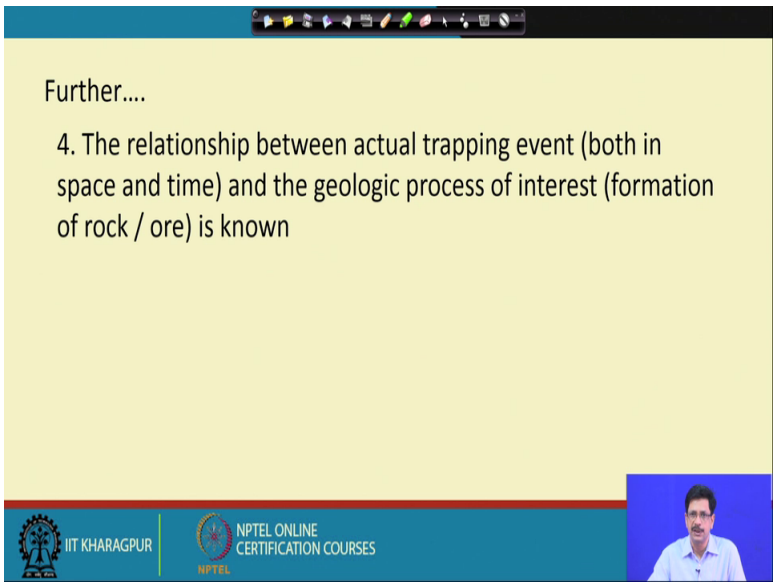
So, there are ways and means to establish such kind of process and to, take the measurement on those fluid inclusions where we could ascertain that such kind of assumptions is actually will be valid. The, this is also a very important assumption that the volume of the cavity has remained constant since, the entrapment and the inclusion followed a constant composition, constant density isochoric path with decrease in pressure and temperature since the entrapment.

(Refer Slide Time: 24:36).



This is also valid in majority of the cases as will be, shortly discussing about the situation and there are, there are situations in which, the fluid inclusions after their entrapment would have traversed a path away or deviating from their isochoric path and will see under such what kind of conditions it might happen. So, there must be some kind of perturbations either thermal or load, I mean the temperature and pressure conditions which could have fluctuated or could have become different from what could have been an, path of a constant composition, constant density path.

(Refer Slide Time: 25:36)

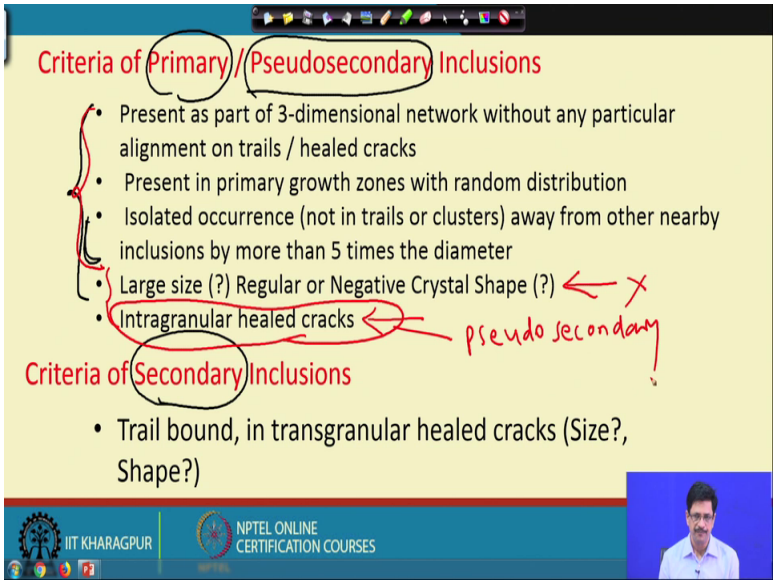


This particular, assumption is of course, is very obvious that whenever we do this fluid inclusions studies, we presume that we are actually talking about the fluid that is prevalent in that particular Geologic environment. So, that relationship between actual trapping event and the Geologic process of interest, that we know and this relationship in a way actual. We are we try to establish this relationship and sometimes in we, sample the several generations of the fluid within the same, host mineral as we have discussed before.

The several generations of fluid might have acted at a very close time interval, where the compositional characteristics would not have changed much and then it is possible on our part to the actually reveal or actually workout the evolutionary path of the fluid that give rise to this particular feature, either an ore deposit or any kind of a, interaction with rock.

So, this, assumption is very much there in our mind and we only have to change, or it will be or basically on the interpretation that will be making from the results that will finally, decide that whether this the fluid that we have sampled is actually, is related to the process that we are talking about or we are more interested to work out.

(Refer Slide Time: 27:03)



So, now, coming to the very important, topic we will be discussing this again and again during the course of our lecture and this is one of the very important aspect of fluid inclusion study that, the inclusions that we classify them as primary or secondary.

Here we are using, another word as Pseudo secondary. So, Pseudo secondary when we were use a word pseudo secondary means actually it, meaning, meaning is that it is actually primary means, we are talking about broadly two, categories of fluid inclusions that we observe in the minerals one, we can say that the primary inclusions, the other ones are the secondary inclusions and, we believe that it is the primary, we are interested in the primary fluid, because we want to know the exact condition in which the particular mineral has formed in nature.

Although, many of the situation as we discussed before, a fluid that just acted a little later then the or there are the then in the sequence where a (Refer Time: 28:13) was forming with continued fracturing and fluid activity there the, difference the, the subsequent stages of fluid active is you could actually represent one and the same fluid.

But another situations, the fluids that we see is, secondary or the fluid that, acted later on, could be a part by several hundreds of millions of years and they totally be unrelated to each other. So, then the, quartz of the problem is that how to distinguish between these primary and the secondary inclusions. So, that the data, that we retrieve we can treat them with that much of caution in our mind, that what kind of fluid which we actually, we have sampled.

So, quickly going by the, points that the inclusions, which essentially will be a part of the three dimensional network, not following any linear array or kind of, the healed cracks, going and traversing through many of the grains in the mineral, of the mineral host, mineral and they must be present in primary growth zones, which we have also seen through photographs. They should be isolated in their occurrence not as trails and away from linear by inclusions by at least by 5 times the diameter of the inclusions in of the observation. These, three points, these, these, these three points are actually, much more definitive and important.

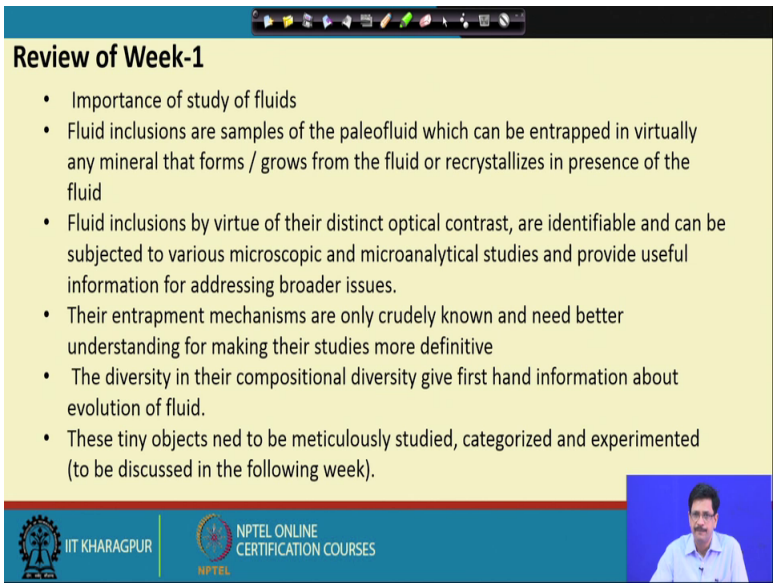
Sometimes, size or the shape is also a substitute with their primary or secondary origin, but they are, they are sometimes very miss leading as we have seen that a negative crystal a host like mineral, mineral like quartz, has very rear negative crystal shaped inclusions whereas, a mineral like, like, like anhydrite, where we see that the primary as well as the secondary inclusions could be of negative crystal shape.

So, this is not a very, not a very definitive criteria for primary and secondary and, as you discussed that in a particular growth process the, the first stage of minerals, which was deposited from the fluid could have undergone brittle fracturing, where the individual grains also would have undergone fracturing and the latest stage fluid would have just overgrown and, over grown on the existing crystals and so, we see the some of, sometimes we see the crystals having fractures within the grain.

The fracture is not, traversing through the, adjacent veins of the host mineral and in that case, this is the one, which here we actually reserve for the pseudo secondary inclusions and, we can only tell that ok. Whenever there is a, there are inclusions, they follow trails, they are trail bound, they are trans granular means across many grains, when we see them under the microscope in the field of view, we can tell them as secondary inclusions or in other words, we can broadly categorize the inclusions to be trail bound or non trail bound.

When they are non trail bound, we have to be very sure that they are part of the three dimensional network, getting focused at different planes. When we see them under the microscope and they are just do not follow any particular, a linear pattern in their occurrence and then size shape and many of the parameters, which can come later.

(Refer Slide Time: 32:01)



So, if we just look back in this particular week of the discussions. So, far in the fluid inclusions that it is a, let us recall that it is very important to study fluids, because, there

are lots. So, there are various their wide spectrum of processes are, processes which are fluid assisted or result of the direct fluid activity and, the fluid inclusions. They sample the paleo fluid that, operated and, they can be entrapped virtually in any mineral that forms grows or recrystallizes from the fluid or in presence of the fluid and the this fluid inclusions by virtue of their distinct optical contrast are very easily identifiable, one is to just have a, proper magnification polarizing microscope and, properly prepared sample.

So, one can always see this, see this fluid inclusions, identify them and can be, can subject them to various types of microscope, microscopic micro, micro thermometric and microanalytically studies and these information that, they are retrieved from them are very useful in addressing broader issues of earth processes.

The entrapment of this inclusion, the mechanism are rather crudely known and, we almost in the we always get our ideas defined the more and more, information that we get from, experiments conducted, in different types of crystal growths and, more importantly, over the last, 3 decades that have been, substantial input coming from many experimental, many laboratories in which fluid inclusions are actually trapped through experiments. They are called the synthetic fluid inclusions and we get to know more and more about them and making this particular study of inclusions are more and more meaningful and more definitive and the diversity in the compositional, composition of the fluid inclusions.

They give the firsthand information about the evolution of the about the fluid in any situation and these tiny entities the fluid inclusions, which are sealed cavities in the solid lattice of the host mineral. There should be meticulously studies categorized and experimented and the following lectures will actually be discussing them in greater details and taking up, specific situations where and then the principles that will be requiring will be discussing them in details.

Thank you.