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

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Lecture – 04
Introduction (Contd.)

Welcome to this session of Fluid Inclusions in Minerals. We have been discussing about the fluid inclusions, their optical properties or the way we see them under the microscope, we identify them, they are very distinct by virtue of the optical properties in terms of the because they are fluid filled cavities, they will be having a sharp contrast to light within this solid mineral host. And, depending on the assemblage in which the fluid inclusion is present and we will continue our discussion from where we left in the last class.

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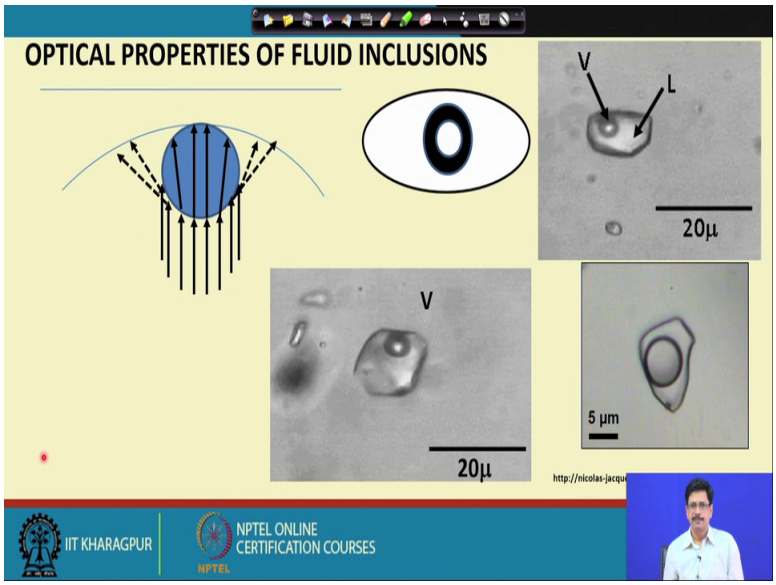

Just to recapitulate that we will; then when you see them, see the inclusions under the microscope. A typically an aqueous bi phase inclusion, we will have the aqueous liquid, will be brighter part with a vapor like this a anywhere within the inclusion depending on the geometry of the inclusion, it could be at a corner, it could just at the center or anywhere. And sometimes executing pseudo Brownian movement and the dark rim around the bright central part of the vapor bubble is explainable, the way we saw them.

So, these are the aqueous bi phase inclusions where the inclusion is present in the forms. So, we call it bi phase because it is present is liquid and vapor and it is dominantly water. Although, we know that this water is not a pure water. In most of the cases it is charged with or it has a dissolved total dissolve solid. That means, the soluble salts mostly fluorides, sometimes bi carbonate carbonates sulfate and so on of many of the cations like sodium, potassium, magnesium, calcium, iron and many of the other cationic species.

And this is what we see that this one type of inclusions which are somewhere and sometimes, they are pretty abundant, because of the fact that we have a water rich fluid in most of the cases, the dominant constituent of the fluid that we deal is water and in many of the situations in (Refer Time: 02:44) conditions.

So, that is why we see that these inclusions are generally constituted dominant number, in any of the samples we study.

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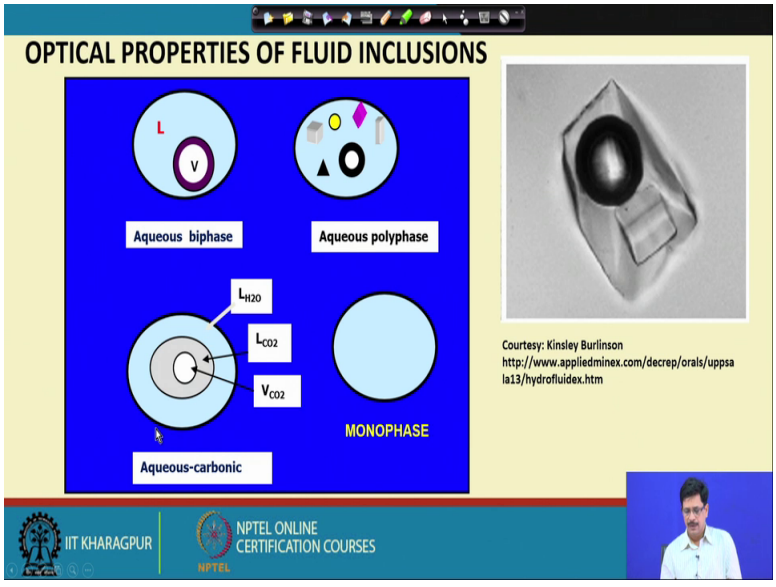

So what are the other possibilities or other types of inclusions that we can see in the n inclusions and we accordingly we classify them. So, this we have already seen that is our aqueous bi phase inclusion with liquid plus vapor.

Now, situation could be; so which will be explaining in terms of very simple phase diagram which we will keep on visiting; revisiting for our understanding. The other

possibility is that in inclusion; we could see that it could be an aqueous liquid, there could be another liquid which is shown in the light grey color here and the within that is another is a brighter part.

So, sometimes we can identify them and through their phase property we could confirm them that this actually is an inclusion where this case of the inclusions is shown here, it is a polyphase inclusion; in the sense that it has 2 liquid and 1 vapor. So, an aqueous liquid which is labelled as L H2O and then aqueous as a carbonic liquid as L CO2. This carbon carbonic liquid could sometimes be mixed with a little bit of methane; not all the time pure carbon dioxide and a carbonic vapor.

So, because and then the another type of inclusion also which call them as polyphase inclusion, they contain in addition to the liquid which is shown here in light blue and liquid and the vapor, they can have either one or more than 1 solids present in them. They are well identifiable, because of the fact that the we are already they are pretty thin, we are seeing them in micron thickness where the as our any other solid can be identified in a thin section, they can always be identified, because they do also have contrasting refractive index compare to the liquid medium in which they are dispersed and just as a sketch it is shown that a inclusion can have many either one or more than one solid the crystal.

The one which is like a cubic shape is a probable mineral which is halite a an inclusion a natural inclusion in quartz example which is shown here. We could see a very nice cubic crystal sitting within the inclusion cavity a beside the vapor and this inclusion is in a quartz taken from a samples Curtesy; Kinsley Burleson web page and this we call as a polyphase inclusion, because we there is a liquid there is a vapor and there is a solid and there could be more than one solid, sometimes, if the original fluid the parent fluid represent a very very concentrated brain; what we say and it becomes saturated with respect to many mineral pages when the temperature is decreased.

So, there could be a prismatic grain like this could be there in this person, this liquid which could be either a gypsum or anhydrite there could be the ROM shape solid is representing either could be a calcite. The yellow circular one could be sylvite that is potassium chloride and there is sometimes the also there are some sulfide which is

showing as a chalcopyrite small micron scale chalcopyrite grain which is within inclusion cavity.

So, this is a means it is not necessarily that polyphase inclusions will always have more than 1; dominantly, we will have 1, but under certain extreme cases that will be discussing later on, there can be more than 1 dot, in a one such solid crystals within the inclusion cavity and in many of the situation. We also see that the inclusion is just occurring as a mono phase without any thing within any content or any other phase in that with tentatively classify them categorize them as one of monophasic inclusion. And, sometimes, they turn out or they give some information later on, but when and these are the situations that we see and are basically corresponding to the room temperature condition.

So, when we basically subject this particular inclusion which is monophasic atomic temperature to different temperature conditions, we might actually know what it is and many of the times sometimes, we are also not able to know a phenomena which is called beta stability which will discuss later.

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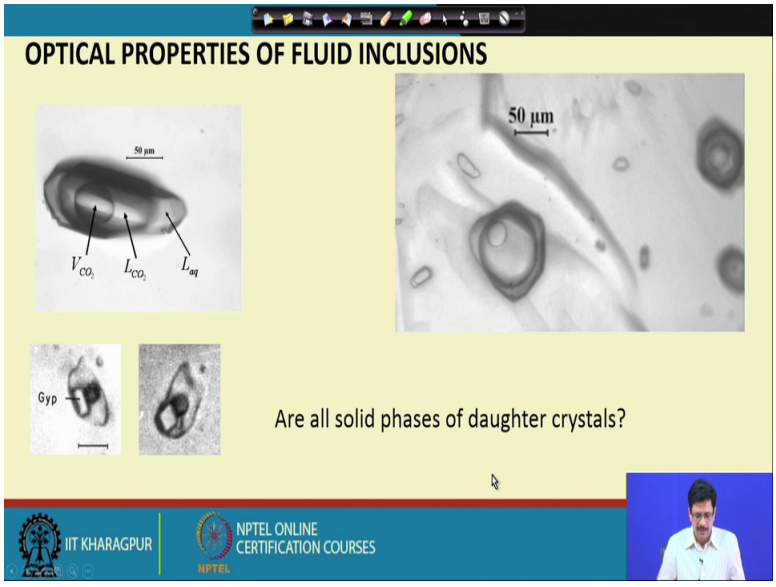

The example of a polyphase inclusion with a 2 liquid that is an aqueous liquid here the carbonic liquid and the carbonic vapor; this inclusion as you could see the micron bar, it is a very large inclusion measuring more than 100 micron in its maximum dimension is a

more or less regular shift elliptical kind of shape inclusion. And in which we could see, this is a very good example of this is this inclusion is occurring in a topaz.

And there are several such inclusions like we shown here in the same topaz grain, where you could see that as against the liquid water and the water vapor the case which we just saw before where it formed a very dark rim around the vapor.

In case of carbonic liquid and carbonic vapor because of the low or the less of the contrast in the ri of a carbonic carbonic vapor and a liquid this rim the dark rim is pretty thin separating the liquid carbon dioxide and the vapor carbon dioxide. Similarly the boundary between the two liquids the aqueous liquid and carbonic liquid is also very distinct and can be very well observable.

So, these are a examples of some of the polyphase inclusion continuing a single gypsum crystal and here is an inclusion continuing a single calcite crystal they are taken from the mineralized quartz body in the copper deposit. So, although we will be discussing and correlating them to the phase relations, in simple systems like water; water or water plus salt.

One thing we must a it should be worthwhile to tell now that this solid phase is that they are occurring here or even in the previous case. Now like this these solid this crystals which we find in the inclusion cavities either there are mostly, it happens in aqueous inclusions the polyphase inclusions bearing daughter minerals. In majority of the cases or in the almost all the cases, happen in aqueous inclusion, because of the very simple reason that when there is sub appreciable amount of nonelectrolyte dissolved in water this solubility of the salts decrease which will see them in greater details when we look at the phase diagrams.

But for the time being, it would be worthwhile to just remind that the daughter crystals which we are seeing them in the inclusion cavity, they are the ones which are likely to have been precipitated from the fluid. After the fluid was encapsulated within the solid host of the mineral solid mineral host, but at times it nulls may also. So, happen that this particular crystal actually did not crystalize or did not precipitate from the fluid that was encapsulated in the host mineral, but actually was captured as it is along with the fluid along with the along, with a liquid when during the process of entrapment.

So, it could be that this solid crystal was accidentally entrapped within the inclusion cavity. We will discuss little bit more about them later.

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So, here the whole idea is just to get yourself acquainted with certain unusual situations; where we see that; we have already seen; how the inclusions look like some of the aqueous biphase inclusions aqueous polyphase inclusions dominantly the aqueous inclusion or the even the aqueous carbonic inclusions.

These photograph been taken from some of the migmatitic gneiss from Eastern Ghats belt. And there they in fact, can be occurring anywhere from any sample that you pick up from any of the geological terrain you see cavities which almost look like just dark cavities I mean there is nothing as if there just. So, some of sometimes they are described as just empty cavity, because when we will be again seeing them. Later, that if we subject them to some macro thermometric experiments they do not respond or they do its not they do not come out very clearly indicating their compositions.

So, it is possible that they could possibly have been cavities. So, the content have been totally lost from them, but in some of the cases, they also they do represent that they are essentially inclusions which are just vapor they do continuous vapor. And in majority of the cases, they turn out to be containing vapor of carbon dioxide and why it is. So, we will be explaining through the appropriate diagram phase diagram when we see for these particular systems.

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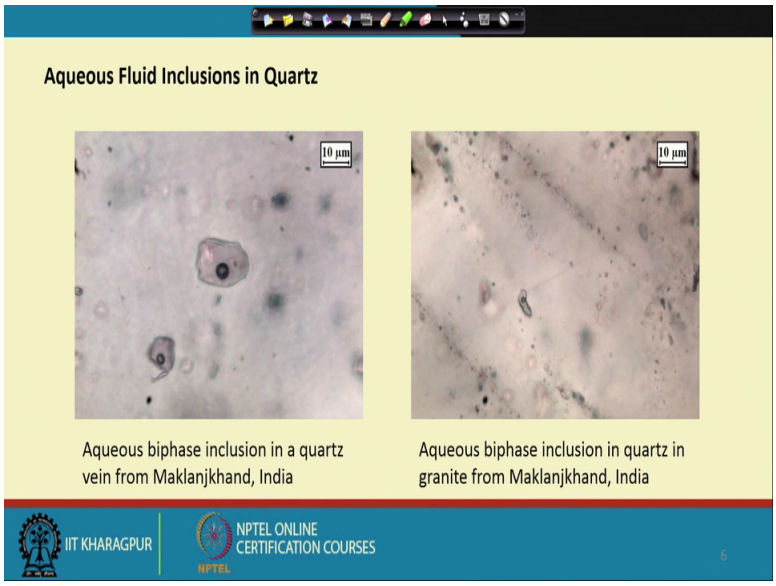

We will have a very short tour to just bring home to you that what are the diversities in the shapes and sizes of this inclusions to be in general we see that and when we see them in quartz as you majority of the host mineral; when you see them in quartz or in any other host mineral for that matter, we can get an idea about what are the diverse sizes and shapes in which we can see them.

These are the example of aqueous inclusions in quartz, this particular one this is taken from the Maklanjkhand quartz over body. And we could see the what general; we mean by the inclusions which are the part of the random three dimensional network not following any particular trail or particular linear array of this inclusions, there could be just and we could see the can have a an idea about the sizes.

While looking at the sizes of this inclusions we also can have it in our mind to just to see that what kind of a proportion that we could see of this vapor, when we take at the liquid and liquid plus vapor within though, we know that we are not able to see the third dimension. So, knowing the exact proportion of the vapor in this particular inclusion would be not be very accurate because we do not know the third dimension; so these sizes and the shapes of the inclusion which is more characteristic that the inclusions can actually attain any shape.

So, the question remains that whether the shape of the various shapes that we see the inclusions; whether it is a characteristic which is inherent or representative very very

primary characteristic or the growth the various shapes could also result because of later modification of the inclusion cavities shape, because of any other reequilibration process or any other perturbations later on. And, that is been one of the major topics of research in the later part; in the recent; there has been many such experiments which are not been done on them. We will discuss them in due course of time, but before that; it should be worthwhile to just see the various types of possibilities.

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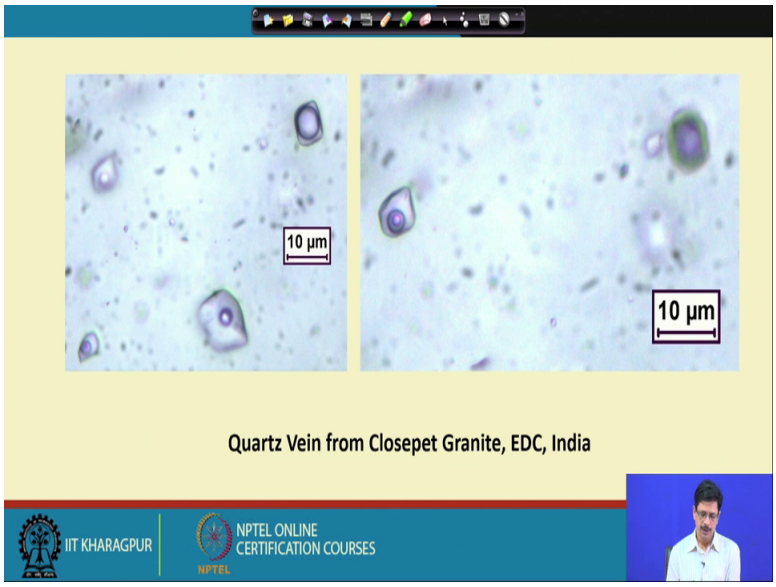

We could see the why diversity of the shapes and size and also the phase proportion here, this is a inclusion assemblage. Generally, we put in the term I will come to this particular wordage inclusion assemblage when we discuss more about fluid inclusion petrography.

So, we see this 2 inclusions; one here and one there and this particular one which little out of focus also is an aqueous carbonic inclusion, where this cavity this particular part here is the carbonic liquid within that having a carbonic vapor and the one which is here is also an aqueous carbonic inclusion. But the difference between them is that one in the first case, it is a the aqueous part is much more dominant even though we do not know the third dimension, but still we can make out that in this case, the aqueous part is far more dominant then the aqueous part over here or the reverse is that this particular inclusion has a far more proportion of carbonic liquid the carbon dioxide carbonic component compared to this.

And here also even these 2; in these are the 2 different photographs, but they are from very nearby inclusions the one which is out of focus over here is on brought to focus here and the one which is on focus here is out of focus here. And so, you could make out that the difference in the proportion of the carbonic component in the same aqueous carbonic inclusions.

These are to be noted. And we can discuss them when we go back to their phase diagram and the entrapment conditions and a bit of details on them.

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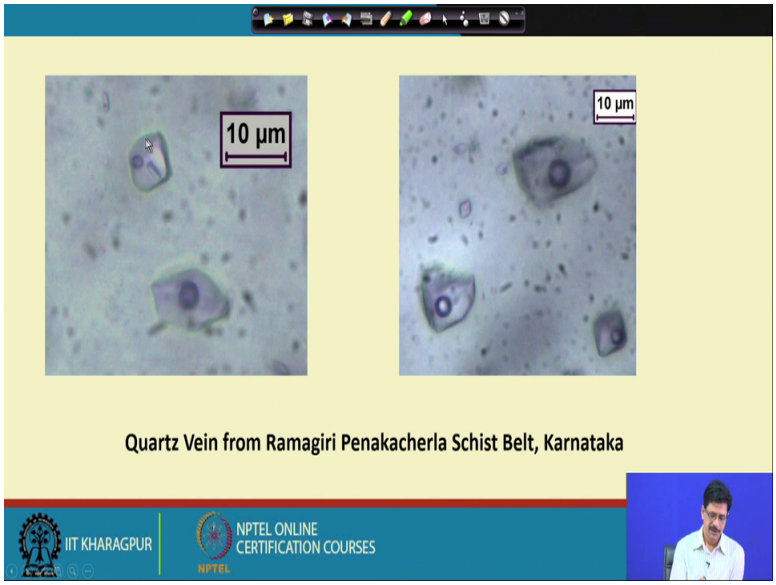

This also here; this is that example of a fluid inclusion aqueous inclusion and within which you could see a very clear crystal prismatic crystal which is present there and here again, it is a aqueous carbonic inclusion with a. So, we can see that the kind of various kind of shapes that these inclusions represent, they could be sometimes could be when we take the two dimensions there could be circular there could be elliptical and sometimes, they are just 2 very irregular in their shape which will.

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So, as we are discussing, that a this is a section of the, this is a wafer taken at a much lower magnification and we can see the part of the quartz over here. And we, could see as we are just discussing that when they go in or when they form from the fluid phase the inclusions within them are could be just randomly distributed.

Very quite often or quite on certain instances, we see that there is a difference in the inclusion population compared to the central part of the grain compared to the periphery it also happens. And we will discuss them in due course, and this part which is been just magnified over here and even we could see that within the same trail there are so many diversed types of shapes of inclusions that are present.

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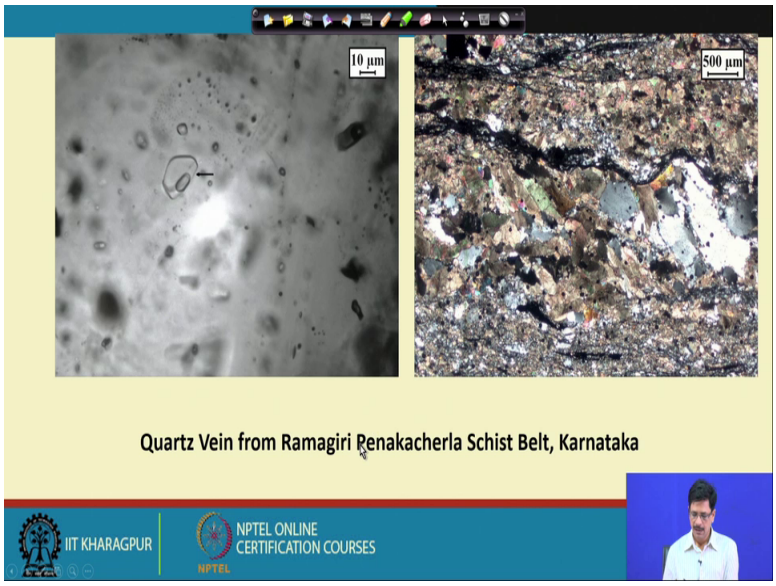

This also is a sample from the Ramagiri Penakacheria Schist Belt which is been taken here. And we could see that in the rock which essentially is a schistose rocks, within that this particular quartz which represents a they very incipient vein that is formed within the shear plane. Within these schistose rock and a magnified view of particular part of this quartz is showing the distribution of the inclusions the aqueous bi phase inclusions which are far more diverse in their shapes and sizes.

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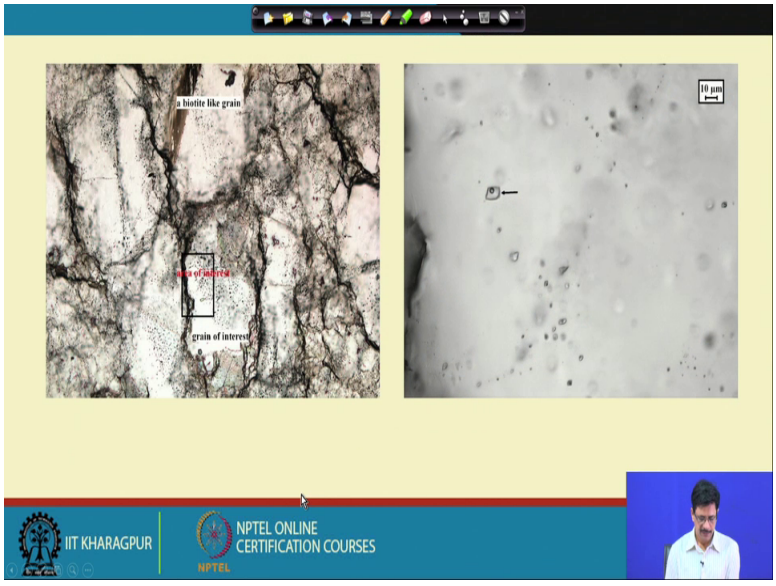

Now, this is an example again from the same Ramagiri Penakacheria area to show the quartz aggregate of the quartz. And there are many such quartz grain which are present here we could see that on hill cracks as well as the plasters and also same; the grains of quartz with. For example: this particular grain is having a population differential population of the inclusions in the core compared to the periphery and the same is the situation here. And when we magnify this part we see the inclusion population with diverse sizes and shapes.

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These are very interesting here there is a these inclusions have been taken from several very different generation of Migmatitic rocks from the Eastern Ghats mobile belt. We could see these are aqueous inclusions and within that we see that these inclusions sometimes take very characteristic shapes like that of a; we this kind of a curved or hook kind of a shape in population of other ones and the extreme case. The extreme case you could see here that even this the one which is being focused here is an aqueous inclusion which as taken the shape of almost like an ring or we call it an annular kind of a shape.

These the probable reasons for these inclusions attaining such kind of a shape will discuss. And we see the same kind of a situation these are inclusions which are little regular in shape almost the shape of bullets and the one which is like which is an aqueous carbonic inclusion which is sometimes. We describe them as tubular or elongated kind of inclusions and the size, we can measure this is a inclusion which is

almost measuring more than 20 microns in its maximum dimensions and similar; this is also an area where these inclusions are all part of the random three dimensional network.

They are not aligned on any healed crack, but you could see the characteristic shape of these inclusions and in all these the host is quartz.

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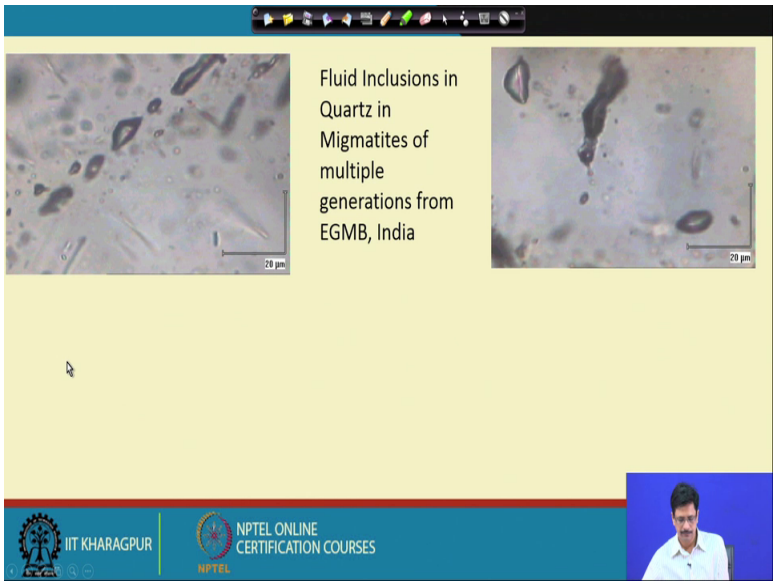

And the one which I just showed before some inclusions which is almost look like dark and the sometimes represents, sometimes interpreted as cavities or empty or the vacant spaces or just as if the content is been just been lost, but in other instances. We see that in majority of the cases that they are actually vapor is inclusions and they also do represent different types of shapes.

So, what generally it emerges that inclusions which are on the heal the cracks on the inclusions which formed during the process of the healing of the crack in the host mineral on fractures which are created later some such inclusions have a tendency to change their shape or become more I mean kind of what about the shape ranges. We have seen compared to the ones which actually are present in the part of the random three dimensional network and more. So, this smaller the inclusions they their tendency to retain their regular shape is more than the inclusions which are larger.

So, just to put it in a quantitative term which is we know that the inclusions can range in sizes from even, because we are seeing them under microscope where the magnification

go to 400, 500, 600, at the most. And the visibility range is can start from like almost 1 micron and we see such tiny microns inclusions and the maximum can go to 100-200 microns the some of the photographs of the aqueous carbonic inclusions that we show here.

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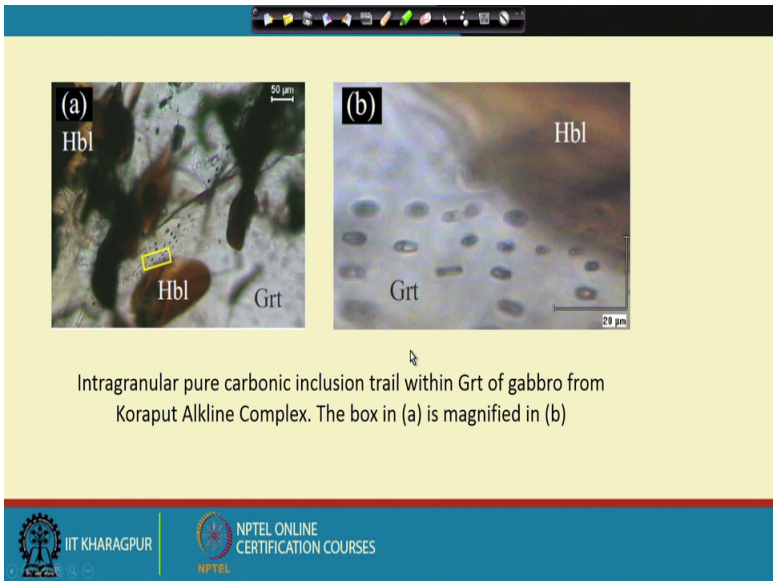

Well, there are some examples of the inclusions in hosts other than quartz this is this is been taken from the gabbro in the outline complex in Koraput. We could see the inclusions in garnet and this is the magnified view of that these are all carbonic inclusions of the similar kind of sizes size ranges.

And this is just for example that how these inclusions in a way, it may not be possible to really distinguish by from the photograph unless it is told that which is the host mineral from which the mineral has been whether the inclusions has been picked up. And it is also true that when we see them under higher magnification the in a reasonably moderately crystalline, I mean course the grain size of the host mineral.

We would not be able to see many grains at the same time until and unless we look at them at a lower magnification. And then see the distribution of this trans granular cracks the hill cracks or the intergranular cracks or the distribution or the population of the inclusions. And then only if when we look at the inclusions we examine them to know the phase proportions or the content in them it has to be done on a higher magnification at which we cannot see many grains at the same time.

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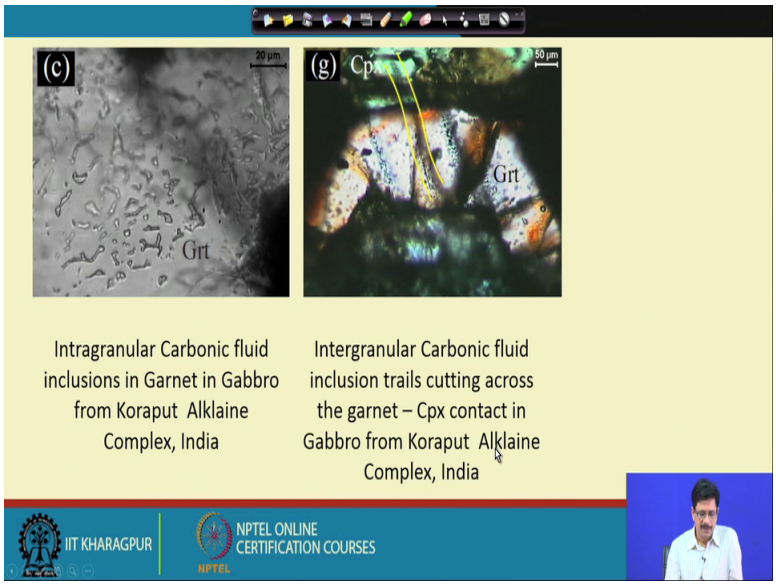

So, this is a again the magnified view of fluid inclusions in garnet the same host from the same rock assemblage where we could see the inclusions have attained some all such possible shapes such irregular shapes then we can almost I mean like they become just very irregular.

We cannot describe them as to what this shape are, but they just very irregular and this is an example of this same inclusion trails, this is also a trail which is magnified here as we saw before the interior or the grains the smaller inclusions where almost of a regular shape whereas, in the inclusions which are present in the heal cracks. There of many different shapes compared to what we call possibly we can call as a regular shape and here, it is an example of a garnet and clinopyroxene in a gabbro and where we could see the trans granular cracks traversing between the clinopyroxene and garnet.

So, this definitely indicates that this particular fluid was a later fluid during any during the compared to the stage at which this garnet developed. And if we can somehow establish the time relationship, and we will look at the inclusion characteristics, then we definitely can tell something about the metamorphic evolution of this particular rock.

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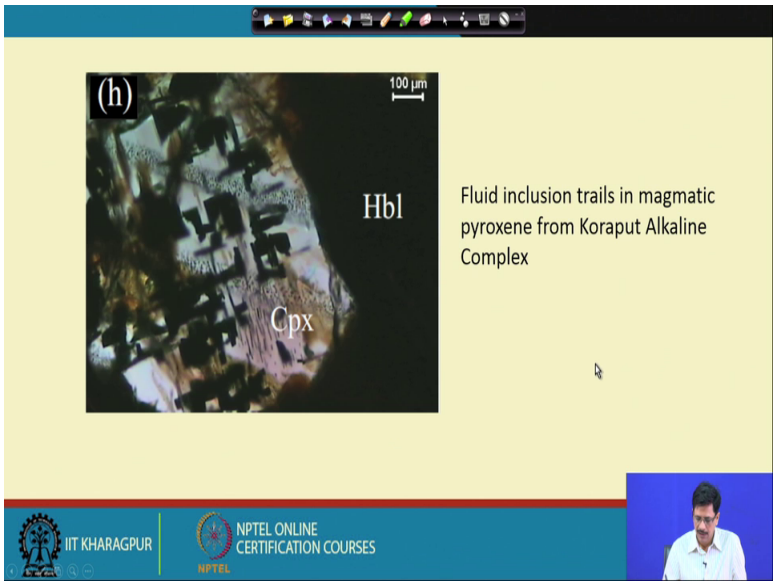

And this is just for an again for an; example this is a inclusion trail in a clino in a pyroxene from the same complex that is Koraput alkaline complex. Just to bring this fact to you to your knowledge that we can see inclusions in almost any mineral as I told that.

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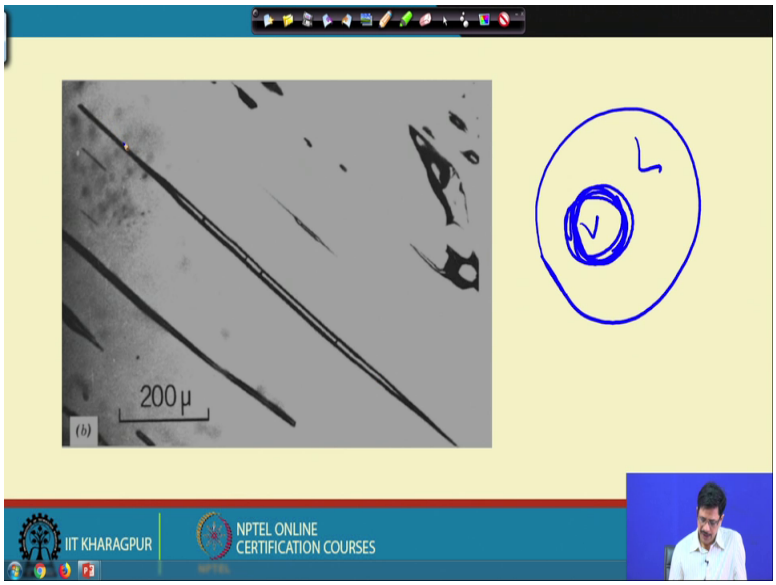

And these are some of the very very usual and rather very interesting situations. This photograph has been taken from the book of the ore microscopy and ore petrography where is if we could this microns bar which is 200 micron then this thing this is entirely a aqueous biphase inclusion in casseterite.

As you stated before the minerals like cassetorite wolframioire are also amenable to fluid inclusion study and they are regularly being studied for fluid inclusions. And here one thing which is very interesting that this particular inclusion it has got two vapor bubbles, this elongated vapor bubbles, because if we as common sense would say that if there is a there is an inclusions cavity if there is an inclusion cavity and this is liquid, there can be only one vapor possible because vapors are all miscible in all proportions.

So, it is not possible or it is not theoretically it is a getting more than one vapor bubble in the same inclusion should be a case which should be considered a unusual. And here the geometry itself is very characteristic in the cassetorite and because of this flat geometry of this inclusion these two vapor bubble even could not also coalesce to form one.

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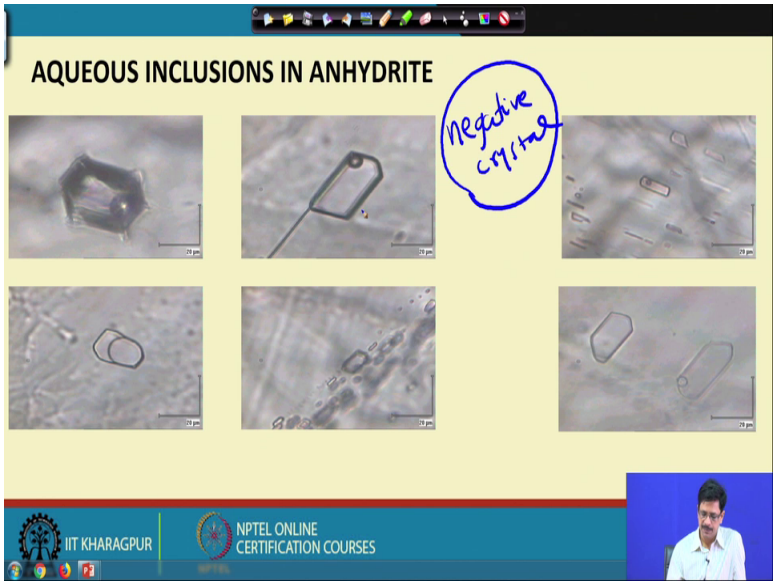

So, quickly we could just have a look on the different possible types of shapes of the inclusion that we can see these inclusions have been taken from anhydrite from some of the some of the area in the South Delhi fold belt; what is observable here is even in these diagram these inclusions in anhydrite even if they are present in healed cracks or present in the part of the random three dimensional network here, there, they do tend to attain a very regular almost mimicking crystal.

So, that is why the word negative crystal has been used for them there is nothing like that cannot be a negative crystal, but when an inclusion cavity is mimicking a regular crystal shape or a the crystal phases or what basically look is looking at as if its mimicking the

crystal system of the host mineral. So, that is they are called as a negative crystal which is very often used in literature and.

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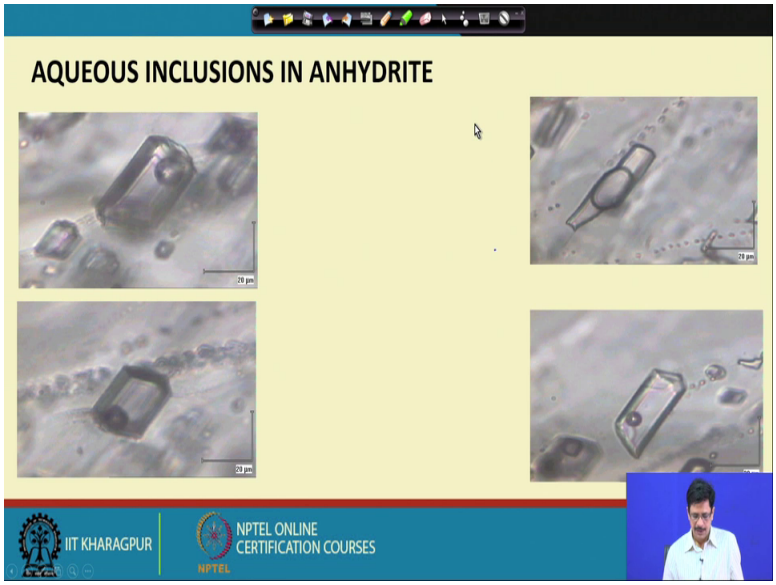

This is also we could see here the same anhydrite where some very very interesting aqueous biphase inclusions mimicking the geometry of the host crystal going by what they are called in literature. That is negative crystal shaped inclusions you could see on all just, but one leaving only leaving aside only one which is a flattened geometry inclusion where the vapor bubble is not even truly circular.

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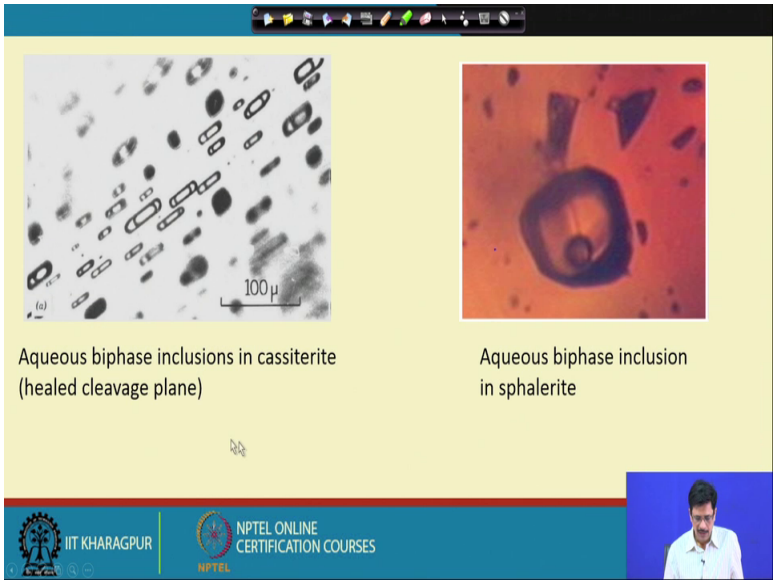

This is an example of inclusion in casseterite tubular inclusion this is an example of inclusion in sphalerite.

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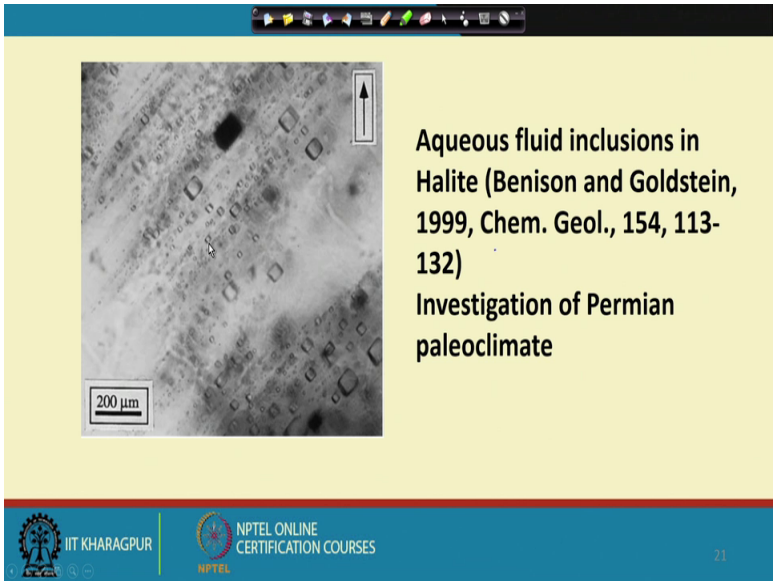

And this is against still very interesting this is an example of inclusion in halite the sodium chloride and this photograph has been taken from this reference which is cited here. And these authors were essentially investigating the Permian paleoclimate and they took evaporate the salt from the sodium chloride crystal from the evaporate bed. And they were trying to understand the characteristics of the fluid to the Permian paleoclimate. And you see this inclusions also they are basically mimicking the crystal structure of sodium chloride which is cubic as we all know.

And even though the distribution of the crystal over here are the in the terms of size that there is a wide range in the variation of the size, if we look at the micron bar, but most of them each of them do have some something which you call them the negative crystal.

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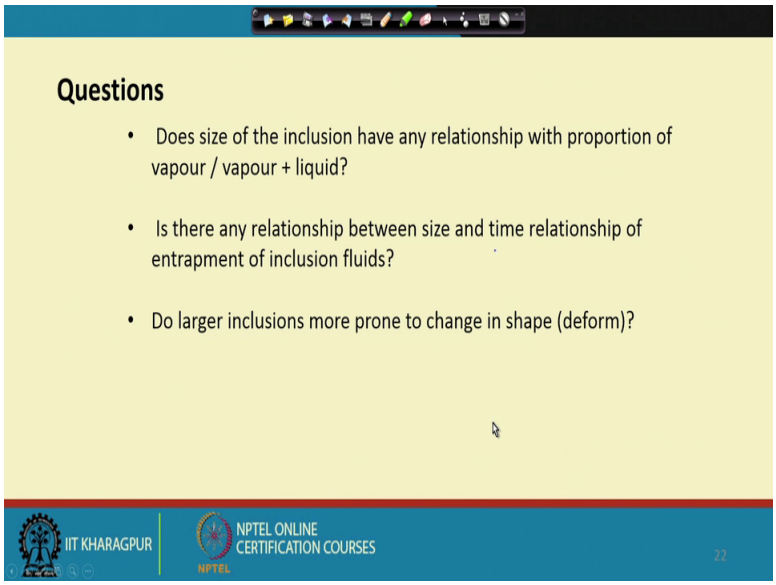

So, it cannot be exhaustible description of the all possible sizes and shapes that is possible in fluid inclusions. But the some of them which are been presented here would possible give you an idea as to how varied the inclusions fluid inclusion populations can be irrespective of what they are compositional characteristic, whether they are aqueous biphase or whether they are carbon dioxide liquid bearing or polyphase inclusions bearing crystals.

They do have display a wide variation in their sizes and shapes. And you can ask such basic questions does size of the inclusion have any relationship with proportion of the vapor where vapor plus liquid is there any relationship between size and time relationship of the entrapment. So, we always look for the relationship trying to categorize them. So, we will address these issues ask these I have to try to answer these questions in the next lecture.

So, will continue discussing about these fluid inclusions and discuss something about the. So, come to the very important aspects of categorizing them doing their petrography, and then go to the experiments micro thermometric experiments and continue with the further and the lectures to follow.

Thank you.