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

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Lecture – 27
Application of Fluid Inclusion to Deformation, Metamorphism (Contd.)

Welcome to today's lecture we have been discussing about the fluid inclusions in minerals and especially in relation to the characteristics of the fluid inclusions, the change in their morphological characteristics, the shape and the content of the inclusions. When such inclusions once entrapped at a particular pressure temperature conditions, in relation to the environment in which the rock is forming in the primary environment. And then when these rocks subjected to conditions different from the conditions of their original formation.

And in particular if they are subjected to higher temperature or higher pressure, or lower temperature, or lower pressure conditions pertaining to tectonic activities that happens in many of the terrains like collision zones orogenic belts, or sometimes in many other types of geological situations.And we have seen that some such features that we see in natural samples, when the inclusion shapes and the morphology deviate from what we presume to be something ideal, either regular shaped inclusions or some negative crystal shaped inclusions regular shaped inclusions, when they the change in their size shape characteristics become very unusual or far away from the what should have been their original characteristics. That leads to situations to suspect there is something would have happened, after the inclusions were entrapped in the host mineral.

And in the last class we briefly discussed some such a situation in which this kind of situations like isothermal decompression, or isobaric heating leading to expansion in the volume of the inclusion cavity and or the situations pertaining to isothermal loading, or isobaric cooling. The processes which lead to contraction in the inclusion cavity of the confining pressure becoming more than the internal pressure, there the kind of morphological changes that happens to fluid inclusions could be demonstrated through experiments, as we discussed as we saw them in the last lecture through the discussion.

But the fact that these experiments are performed under very different conditions and it is very it is difficult to mimic processes in nature in the laboratory. But, what we what we

get from such experiments it gives us valuable and important insights; so, that we could see these inclusions and acquire their data and interpret the data, with some precautions at the while we are interpreting them and considering the fact that these are the possibilities which remain.

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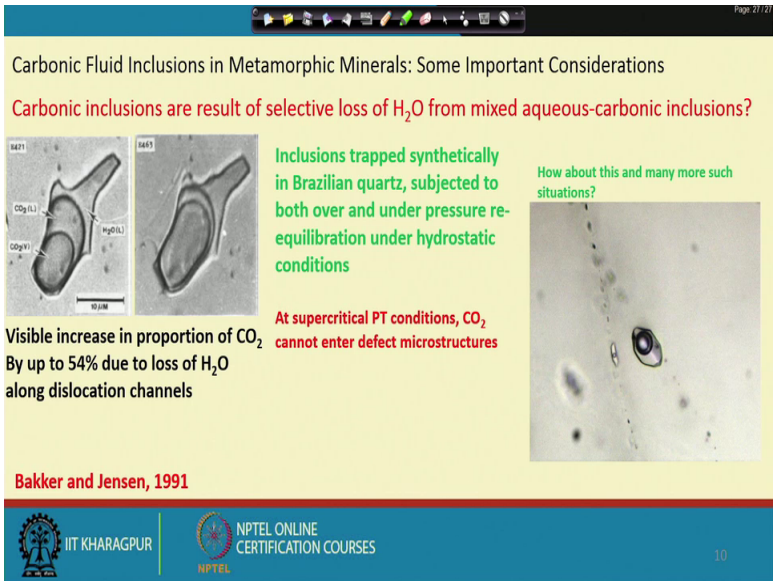

And as discussed before the of the past the some of the results of the experiment which were conducted, in some laboratories like the one which was discussed, in the last class the experiments were conducted by RJ Bortner in Virginia polytechnic in the fluid inclusion laboratory.And today we are going to continue discussing on this topic and see some different other situations. And so, that what other possibilities also, we can think of while doing the petrography and acquiring the microthermometric data and their interpretation. This is the situation which being depicted here, is very interesting it is a fact that in diverse geological situations, whether in the ore farming environment or in metamorphism of rocks.

We are we are certain about one thing that the fluid, in addition to water as the dominant species do have variable proportions of carbon dioxide. And that led to the study of the phase relations in the mixed water carbon dioxide, sometimes and also salt bearing systems to understand the pressure volume temperature composition relationship and also to delineate the domains of miscibility and the conditions pertaining to phase separation, or immiscibility in such kind of homogeneous aqueous carbonic fluid.And

the way they are entrapped in the host minerals, under diverse conditions, for quite some time the observations what is come from observation is that in many situations like say for example, in high grade metamorphic rock like the (Refer Time: 05:56) in the quartz we see a lot of inclusions, which are essentially pure carbonic inclusions, we do not see any perceptible presence of water in them.

And also from many of our previous descriptions of the case studies that we discussed, in certain ore forming environment even in case of porphyry copper deposit or the situation in some of the Skarns and in particular the situation which was discussed on the malanjkhand copper deposit we do see that there are pure carbonic inclusions, sometimes they do coexist with pure water pure aqueous inclusions. And sometimes they do occur without much of associated aqueous inclusions, that led to people to suspect that what exactly happens, the how do you in theoretically it may not be that very possible to get a very pure carbon dioxide fluid even though it is not impossible.

Then in this context one particular experiment that was conducted some time in 19 the work was published in 1991. This experiment was conducted on synthetic fluid inclusions the inclusions and here, these in unlike the previous case which was described, these inclusions were mixed aqueous carbonic inclusion and the experiments also designed that in an in a in the equipment a mixed aqueous carbonic fluid could be entrapped at a predefined conditions of pressure and temperature.

Now, these inclusions are essentially synthetic inclusions trapped in the fractures which were generated before the hydrothermal experiments, with an intention to trap these inclusions on the fractures that were created. And there essentially corresponding to what we see in natural conditions a secondary inclusions in healed micro fractures.And these after the entrapment of these aqueous carbonic inclusions in micro fractures in synthetic inclusions, they were subjected to some situations which is different, like the one which was discussed before.

And then the observation that was made by these authors is that an aqueous carbonic inclusion, which you could which is the original the inclusion after it was entrapped the fluid inclusion which is the carbon dioxide proportion, which is shown on the left side of the photograph.And after it was put into a condition which is different from the condition of entrapment and was kept for a certain amount of time, it was observed that there is an

apparent increase in the carbon dioxide proportion in this particular inclusion. That led to believe that this particular inclusion, water has somehow preferentially has been leaked from this particular inclusion.

And then the authors of the work the people, who conducted the work; they examined the host a quartz crystal with the help of transmission electron microscope and scanning electron microscope, they observed that these surrounding of these inclusions which were trapped here, there are some dislocation planes there some crystal defects and dislocation planes, which were which could be traced out with the help of transmission electron microscope.

And then the, it was proposed that since water molecules are smaller compared to carbon dioxide. So, there these water molecules could easily get transported we diffuse out or move out from the inclusion cavity, rendering this inclusion apparently withhigher carbon dioxide content. And it is could be seen here there was a visible increase in proportion of carbon dioxide by up to 54 percent due to loss of water along dislocation channels.

So, and under that kind of a condition in a supercritical condition, where the carbon dioxide in the water and mutually soluble and that corresponding to that kind of a condition the carbon dioxide could not enter the defect microstructures, because of the larger size of the molecule. And also there are other mechanisms being suggested for example, water having a in smaller weighting angle with the host mineral and could easily that is why it could weight the dislocation planes, they could move out regionally escape out of the inclusion cavity.

That led to people that led to led to the belief that in most in many of the situations where we see, that there are pure carbonic inclusions in the samples it may be because of the fact that water was water would have possibly been lost from the inclusion cavity, along such kind of crystal defects of the dislocation lattice dislocations planes.

But then this kind of the situations we know that this corresponds to a very specific situation, where the inclusions are initially trapped on micro fracture. And the fact that, in many situations like the one, which is shown on this side it is a we could see clearly, that there is an inclusion which is nearly regular shaped inclusion which is placed

already on a hill track. This sample is taken from one of the samples from nice from a from the from Himalayas just about near the (Refer Time: 12:05).

And it is not just it is just in not the only one, but we see while examining natural samples and inclusions in different types of geological situations, we do see that there are aqueous carbonic inclusion pure carbonic inclusions, which have which occur in this samples in the host minerals. And then we also do see host there are host like host minerals like garnet and other minerals also which host pure carbonic inclusions.

So, such kind of observation although is very important and gives us some important insight, cannot be very generally applied to all geological situations where we see pure carbonic inclusions. So, and also the fact that they can still be considered and the proper explanations as to how such kind of pure carbonic inclusions could be entrapped, could be looked into through more studies.

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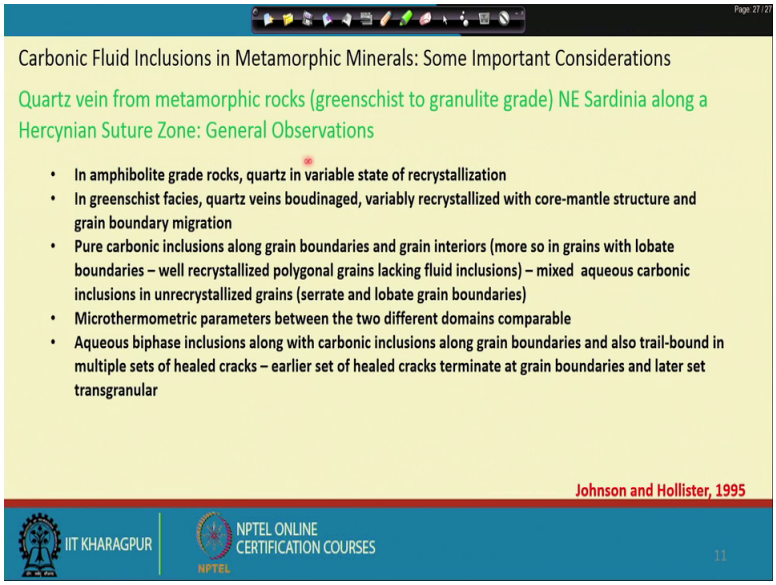

And in this context there is another piece of information which also is what we have mentioned, is the one which was reported from the north eastern sardinia along a hercynian suture zone has been referenced here. Now, in this particular study the their inclusions were described from rocks of amphibolite grade to greenschist facies and, most of these inclusions with described from quartz the quartz in the amphibolite grade rocks, were generally exhibit variable degree of recrystallization.

And if the greenschist facies the quartz when represent in vein in boudinaged form and there also variably recrystallized with core mantle structure, and the recrystallization in the quartz has taken place dominantly by grain boundary migration kind of mechanism. Now, in some such situations the from the study area in the hercynian suture zone in Sardinia; where these authors also tried to explain the occurrence of the carbonic inclusions and giving some explanation is to what actually what exactly happens, when there is aqueous carbonic fluid and the rock is undergoing deformation.

So, there were pure carbonic inclusions along grain bound. So, what was interesting we object was that the pure carbonic inclusions, where occurring within the crystals along grain boundaries. And also in grain interiors and the population of such kind of carbonic inclusions, where more in grains which have got low bit boundaries switcher, or the low bit boundaries.

Where is the quartz crystals which have under gone recrystallization, resulting in will develop crystal straight lines and polygonal grain grains, they do have a scarcity or they do lack in inclusions in terms of the inclusion population. And the mixed aqueous carbonic inclusions are also present in the unrecrystallized grains which also having serrate or the lobate grain boundary. So, the observation which was made was that that the carbonic inclusions their present in the grain boundaries as well as on the grain interior. And where the there is a positive, or lag or scarcity of inclusion population in grains, which have which have apparently have gone undergone recrystallization to have undergone some kind of a milling and the resulting in triple junction points and polygonal grains.

And the interesting to the microthermometric parameters between inclusions which occur in these two different domains like the grain boundary, and the grain interiors are comparable there same, when is the aqueous bi-phase inclusions along with the carbonic inclusions along the grain boundaries and also a trail bound in multiple sets of healed cracks. And these kind of healed cracks when they occur within the grain grains, they happen to terminate on the grain boundaries so; that means, these healed cracks which are essentially the micro cracks which are which are created within the grains as a result of little deformation.So, those kind of cracks they originate from the grain boundaries and the aqueous inclusions, they seem to be somehow more restricted towards such kind of trails.

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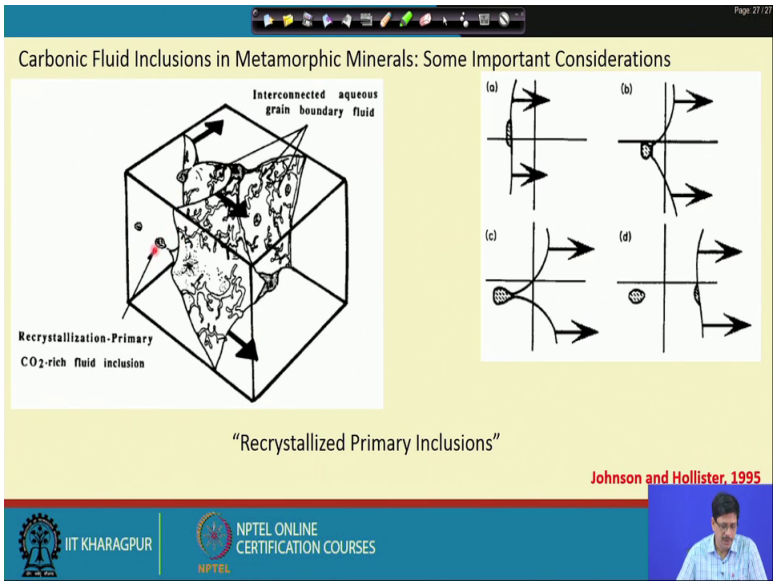

So, it was the explanation was given in this way that if there was originally the aqueous carbonic fluid was present and was entrapped in the quartz matrix and, when this quartz is undergoing recrystallization it. So, happens that the aqueous fluid actually occupies the inter granular space, because of the fact that quartz has got a acute weighting angle with respect to the host mineral which is quartz.

And the carbon dioxide part actually is stays within the interior of the grain and also sometimes, because of the grain boundary migration as has been shown here, in this diagram it was explained by the may Johnson and Hollister if this was the original situation of there is a carbonic aqueous carbonic or the carbonic fluid which is entrapped here. Then during the grain boundary migration this because of energetic considerations, this particular grain boundary cannot migrate just across this carbonic inclusions at the inclusion at the beginning and at the end when this grain boundary has migrated and, this undergone a recrystallization to a polygonal grain this particular carbonic inclusion is left.

So, this particular carbonic inclusion which remains within the grain interior as well as some part of it within the boundary; so, we see that the carbonic inclusions are arranged on just along the grain boundary as well as in the grain interior, where as water been having acute angle acute weighting angle with respect to quartz and weights the inter granular areas. And then later on with the creation of the fractures, we had the or the

micro fractures they get aligned on this field micro fractures which is which terminate on the grain boundaries.

So, this particular phenomena explains that sometimes what we see as primary inclusions in recrystallized matrix in the host mineral like quartz. The inclusion which would satisfy the characteristics to be called as a primary inclusion, the term recrystallized primary inclusions was coined for the first time for such kind of inclusions. And it is also proposed that these inclusions, which are the pure carbonic inclusion result from the unmixing of this aqueous and the carbonic part. During such kind of recrystallization process, because of this because of the fact that its helps in splitting of these two over the homogenous aqueous carbonic fluid.

And the water aqueous part of it, because of its acute weighting angle with the host mineral gets aligned on the micro cracks which are generator later. So, there is a this happens in a continuous process of recrystallization of the host matrix. And that is how the primary a homogeneous aqueous carbonic fluid is entrapped a separate pure carbonic and aqueous carbonic aqueous inclusions.

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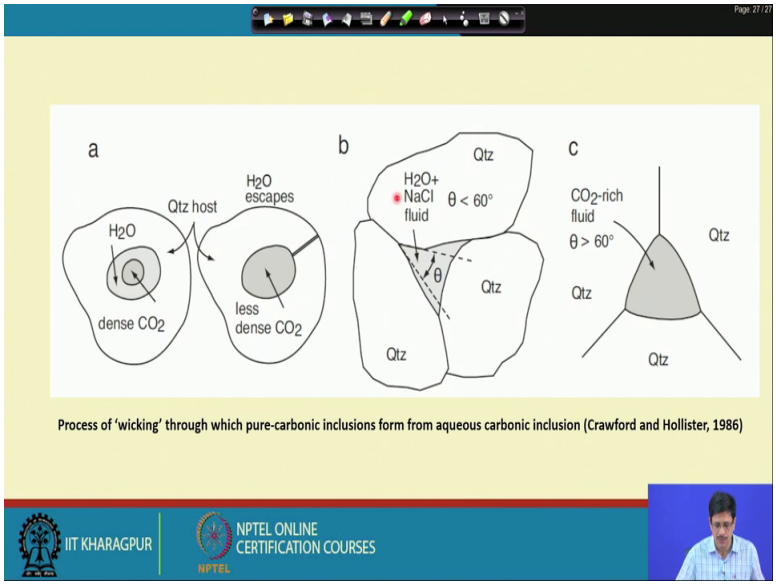

So, this gives us the explanation it has been taken from Crawford and Hollister, this is a rough sketch of exactly the to explain the situation that if this is a aqueous carbonic inclusion, which is entrapped in the grain interior, which is a dense aqueous carbonic inclusion this is the quartz host. So, this water escapes from the original aqueous

carbonic inclusion. And finally, the what this water which has got an acute angle which is represented as theta here, and there later on entrapped is separate and where is the carbon dioxide has got a contact angle of greater than 60 degrees. So, they occupy the inter granular space here and later on entrapped on the grain boundaries and the water part of it is separated.

So, these are the some of the explanations which were suggested, when we see the inclusions aqueous and the carbonic inclusions, pure carbonic inclusions and the aqueous inclusions, which are which do have loop slow a difference or slightly different conditions of the entrapment at the same host can be explainable on such kind of recrystallization process. And the concept the we can use them, or you can treat them as the recrystallized primary inclusions and the aqueous inclusion which are trapped on the micro cracks which are created later.

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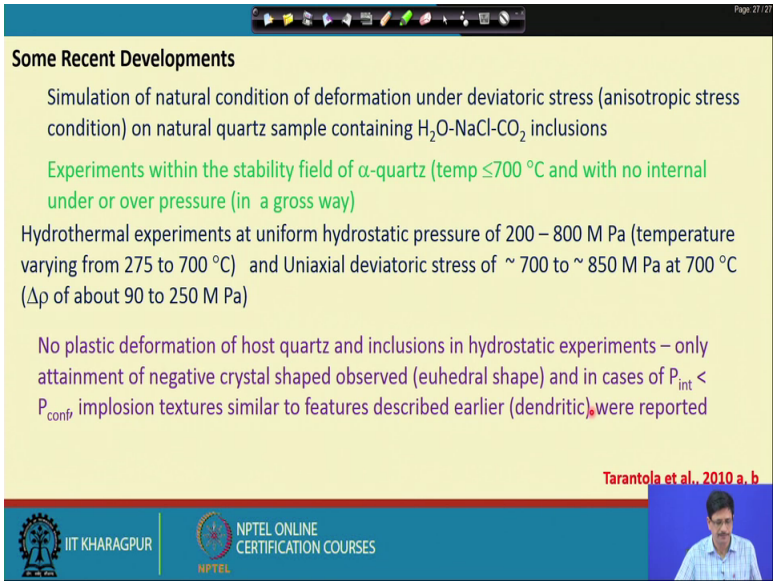

So, those are the situations which could be explained by experiments in the laboratory, studying the inclusion behavior during reequilibration process and finding out explanation as to what would be happening to the aqueous carbonic, homogeneous aqueous carbonic fluid. But as we have as I have mentioned that there were situations in which it does not necessarily have to be very, but generalized that in all instances of occurrence of carbonic inclusions that there product of such kind of splitting as a host crystal host entrapment recrystallization of the host mineral.

And as a general rule when we see that the situation when we are seeing them, that they are they recent phenomena like for example, in many of the volcano associated epithermal situations, or in recent sedimentary basins like or very recent process very recent processes like digenesis, or even where we know that we are actually dealing with rocks which are which are very recent.

Then we can always take them the inclusion characteristics we can take without much of problems, but when we are looking at situations where the minerals in that we are studying the inclusions are likely to have undergone, a process of recrystallization or process of non isochoric evolution of the inclusions, then we need to have some restraints or can be can interpret them with some amount of caution as far as there is the utility of the data and interpretation in terms of the process is concerned.

In this context some recent developments which have taken place also need to be discussed, as compared to the situation which was initially described about the experiments of reequilibration experiments on synthetic inclusion which was done on pure aqueous inclusions. This situation which is in described here, here the experiments were done as has been referenced here. The experiments were conducted on natural fluid inclusions as compared to the previous two cases, where synthetic fluid inclusions were subjected to such experiments.

So, some such natural occurrence were the inclusions where studied before and when present in well developed crystals of the host mineral, which is quartz and in such kind of situation the aqueous carbonic inclusions they were taken and they were subjected to experiments, and here this experiment was with objective to study the effect of deviatoric stress as compared to the previous experiments, which were done on hydrostatic stress conditions.

To have a better comparison with what happens in nature so, these experiments were conducted by these authors are simulating a deviatoric stress conditions of different extent. And then see what happens to the inclusions when there, when there subjected to such experiments.So, the aqueous carbonic inclusions H 2 O NaCl could be approximated to H 2 O NaCl CO 2 present in the host mineral which are present which were recovered from the occurrence, it was it has come from one well studied gold

deposit. Where the initial conditions of formation of this quartz was known and also confirmed through microthermometric study before the experiments.

And then those inclusions were studied well documented mapped and then cylindrical chores, were caught from these quartz crystals at an angle which would be around 45 degree to the to the vertical this C axis of quartz and, then they were subjected to experiments where deviatoric stress could be applied. So, the experiments were done within the stability field of alpha quartz. So, that the problem of the volume expansion in the alpha beta transition could be taken care of temperature of less than equal to seven hundred degree Celsius.

So, there is no internal under over pressure in a gross way. So, the simulation was so, then the samples containing those inclusions which were already one studied and will documented. And the positions were known, they were subjected to hydrothermal experiments initially with the hydrostatic pressure of 200 to 800 mega Pascal means about 8 kilo barand, varying from and in the temperature within the range of 275 to 700 degree Celsius.

So, this was with an intention to do the experiment with a hydrostatic stress condition, only at a higher pressure and temperature condition corresponding to corresponding to the for a conditions of their original formation. And then they were subjected to uniaxial deviatoric stress at 700 around 700 degree Celsius at 850 mega Pascal. With this the del rho which actually is the extent of the difference between the value of the difference in the highest and the greatest and the smallest principle stress axis, this as about 90 to or 250 mega Pascal.

So, then after the experiments; so, I am not getting into the details of the experimental work, because this I would suggest to this particular reference which will be provided to you later to go through the details and there are many situations to be taken care of during the experiment there are certain inherent, problems about the experimental setup those all where were considering all such limitations, the results of the experiments were discussed.

As expected that the in the hydrostatic pressures experiments which were essentially just to see how the how the inclusions were reequilibrating at conditions, different from their original conditions of formation, in the hydrostatic experiments there is no much of

difference in the inclusion characteristics that could be seen. Only chain that could be observed in the inclusions was that they tend to attain more regular or negative crystal kind of shape euhedral shape. In cases where the there is an overpressure like P interior, that the inclusion the pressure inside the inclusion cavity is less than the confining pressure.

So, there where implosion texture which was similar, to the features which are described before in the implosion textures in the context of the pure aqueous inclusion experiments. And so, the basic idea was to so, here all these all those the experiments the people who conducted the experiments. After the each of these high the experimental runs, were over they were gradually brought to the normal conditions and they were again studied under the microscope with the by relocating in the same inclusions, which were the intact inclusions before the experiments.

So, we will continue discussing on this in the next class, about and then correlating these experimental results to natural inclusions that we see in natural samples. So, we will continue in the next class.

Thank you.