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

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Lecture - 28
Application of Fluid Inclusion to Deformation, Metamorphism (Contd.)

Welcome to today's lecture. We shall continue discussing on the inclusions, Fluid Inclusions, the change in the morphological characteristics and compositional characteristics when they are subjected to stress or deviatoric stress condition and we just in the last class, we discussed the results of experiments which are done on hydrostatic stress where no much of difference. So, no much of change is brought about to the inclusion other than just the shape becoming more tending to become more regular.

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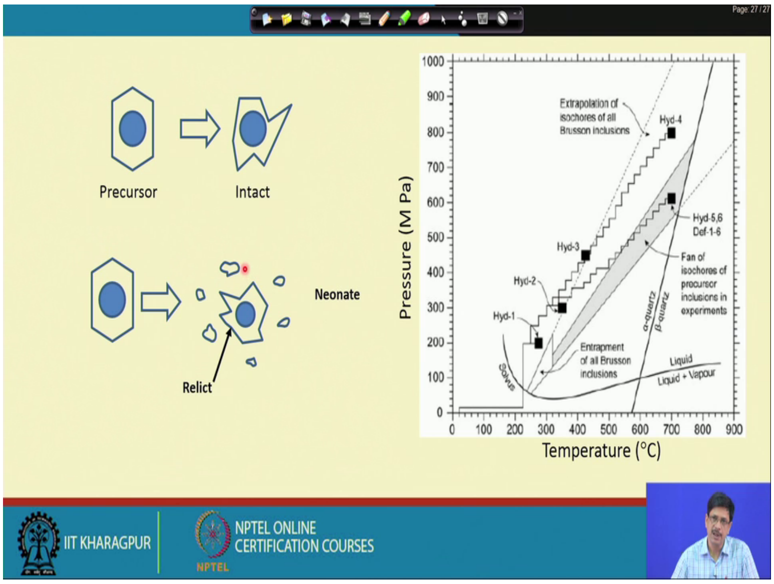

And then, let us have a look as to what happens in the conditions with variable degree of deviatoric stress is applied on the sample where the inclusion where there is inclusions were known to be there and there characteristics is also known. The diagram on the right hand side which is also taken from same experiments which we discussed before.

So, here, this particulars small region has to shown here at the interpret conditions of the inclusions. They represent in the sample corresponding to their original conditions of formation in the area, in the locality from where they were taken in a particular corresponding to particular situation. As I have said that, we are taken from an old deposit which was studied before.

And then, these conditions represent the steps by which the pressure temperature conditions are increased and these correspond to the hydrothermal stress. Hydrostatic stress regimes where the temperature pressure conditions greater than what corresponding to their original conditions were applied. And these are the isochores of the range of isochores from the microthermometric experiments that was done on those natural inclusions and these are this fan shown by the dotted line is basically the region in which this isochores could pass.

And this condition corresponding to the situation where the temperature about 700 degree Celsius and higher and higher the pressure that was given; so, here the deformation experiments conditions were shown here. And without getting into the very detailed discussion on the experimental results which I refer, the refer you to the original papers just to have some idea that in a situation where the inclusions are subject to deviatoric stress in a smaller extent of the deviatoric stress place experiment what basically results in a change in the shape of the inclusion if this is this represents the original intact inclusion.

Then, we could have an inclusion where the shape could possibly be distorted where is the volume and in terms of the proportion or compositional characteristic of the inclusion will remain same and that is why, it could be denoted as intact inclusion.

Now, situation where the deviatoric stress condition is applied with a higher del row, there the situation. What happens is that, if this represents the original inclusion which was there in the sample before the experiment, then if the result of the experiment shows that this inclusion is dismembered, dismembered into something which you can call as a relict inclusion which is in shape which is distorted and also the volume property is also changed from here and is surrounded by this small cluster of inclusions which were basically designated by this authors as neonates.

And characteristically the arrangement, this relict inclusion and this neonate or the newly generated or newly created inclusions; they do follow roughly the plane they are arranged on a planar discardel kind of arrangement and then parallel to the minimum principle stress axes, the sigma 3. When the when the stress sigma 1 is actually vertical, which is applied through the piston apparatus which is used by these by this by this workers here.

And then it is. So, qualitatively speaking the inclusions then or the original inclusion has been dismembered. So, definitely there is change in the volumetric property. So, we cannot expect that these relict inclusion and the neonate also are present in the compositional also similar to the relict, but some change in the composition which will discuss a little later. So, compositionally, we would also expect that they would have undergone some change.

Now, in addition to the change in volume, this will always make them the density to have been different and would follow a different isochore. The there is it is also quite likely, then what we discussed before that these neonates from these inclusions are, the newly created inclusions will also have the same situation as differential loss of water from the. They would also be because; these experiments were conducted on aqueous carbonic inclusions.

So, this fluid as this member aqueous carbonic inclusions also would are most likely to have undergone the preferential loss of water and are more likely to have undergone some compositional differences, other than the fact they were the condition corresponding to the creation of this new. So, the newly created inclusions are also higher than the pressure temperature condition in which they were formed.

So, they are the isochore of these neonates are also going to significantly deviate from the original inclusions.

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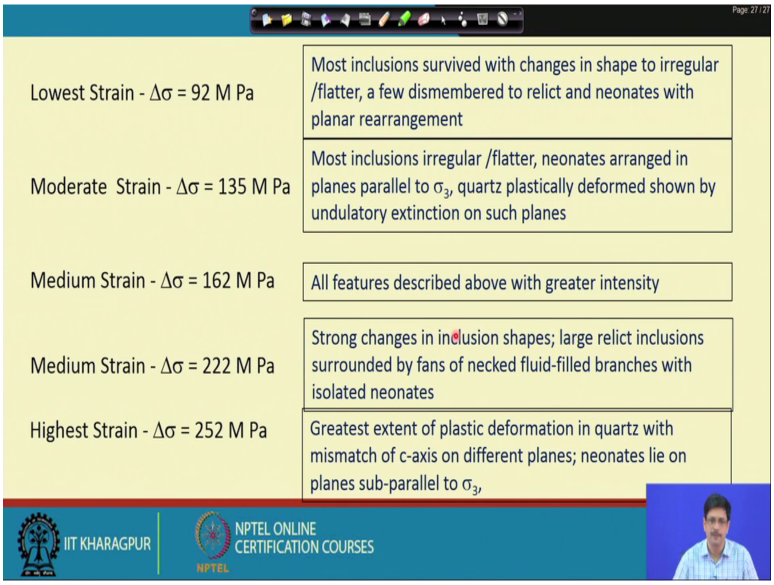

So, the in the lowest strength where del sigma delta sigma is about 92 Pascal. So, most inclusions survived with changes in shape to irregular or flatter. They become flatter in the shape and this plane on which they are flatten is actually sub parallel to the sigma 3. There is the minimum principle stress axes; a few dismembered to relict and neonates with and with the same planar arrangement when the delta sigma is increased to about 135 mega Pascal. So, most inclusions become irregular or flatter and the newly created inclusions the neonates arranged in planes parallel to sigma 3.

And the quartz plastically deformed shown by the undulatory extinction on such planes which is actually is the result of the fact that the water which is preferentially lost from this newly created or the neonates. They do escape and then they facilitate the plastic deformation within the host quartz grain which is very clearly. They come out to be different from the rest of the quartz grain in terms of showing undulatory extension on such kind of planes.

So, when it is medium strain to above 162 mega Pascal, if all the features which are described in step 2 or more of the same with greater intensity and when it is again increased to 222 mega Pascal, there are strong changes in the inclusion shapes, large relict inclusions surrounded by fans of necked fluid filled branches with isolated neonates. And when it is the highest strength and the greatest extent of plastic deformation in quartz with so, what happens is, there is mismatch of the c axis on different planes and the newly created inclusions. The neonates lie on planes sub parallel to sigma 3.

So that, there is a situation which happens; so, the observation is that when the with the increasing delta sigma, it always give rise to greater degree of plastic deformation in the host quartz grain.

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Just to have been taken from the photographs have been taken from the same source as shown here. Just for, because it is not possible to make a very detailed description in this particular and the whole objective is to just discuss. Some of the important aspects which would always be which would always be carried in mind while looking at the inclusions in natural samples, when we do this as the routine work on the fluid inclusions in different types of terrains different types of samples.

And with the fact that these kind of textural changes in the inclusions is also has a strong dependent on the size of the inclusion. That is what for the inclusions which we which were discussed here. In most of the cases, we see that the deformation or the change in the shape is more in case of larger inclusion, then in the smaller inclusions.

So, this is one situation where in the in the deformation experiment. It is good seen here if this is the and in these kind of experiments, there is always a limitation because to get back the exact same inclusion on which the earlier data were taken or the inclusions which are earlier studied and again after the cylindrical course where caught from such sample and they were subjected to the experimental conditions and then again studying them under the microscope, the definitely involves a little bit of uncertainty.

But those uncertainties not notwithstanding the results of such experimental work, definitely give us very very important useful insights to the study of fluid inclusions in general.

So, what you could see here that, this is an intact inclusion and it definitely the inclusion in it is surrounding. It clearly shows that the same inclusion is the one which is after the after the deformation experiment and it is clearly has become flatter and the surrounded by the by this kind of features which shows the result, gives a very good idea is to what exactly happens and this is in a higher extent of the deviatoric stress where this inclusion is very much thoroughly changed in it is shape and in it is and having the neonates arranged on the on a plane on a discardel plane which is parallel to sigma 3.

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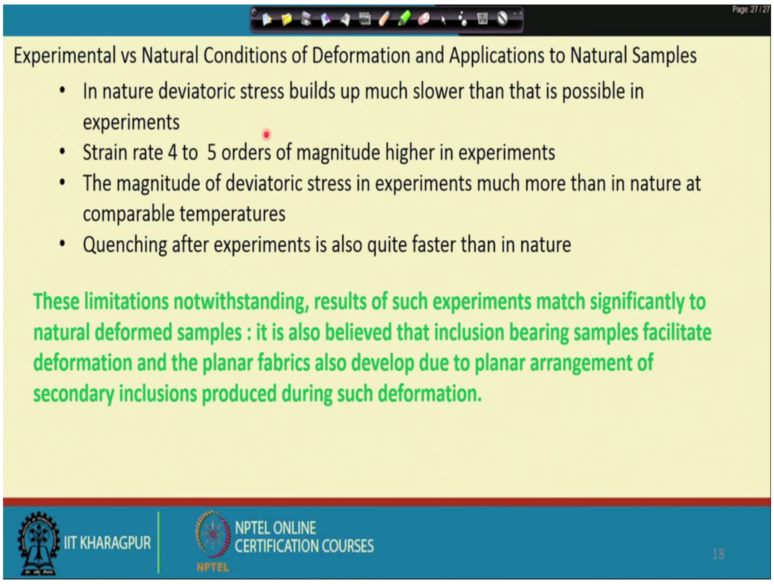

Such kind of experiments, the results while extrapolating to natural conditions of there are certain points which would be kept in mind that the kind of deviatoric stress that is applied in these kind of experiments is built up in a much faster and the experiments than what generally happens in nature, where the process operates much slower.

And such slow build up of deviatoric stress is possibly cannot be done in an experiment and that would definitely give rise to some difference in what we observe in the experiment experimental run products and the natural inclusions. And the nature this deviatoric the magnitude of the deviatoric stress also is high in the experiments compared to what happens in nature. The rate at which the strain is applied is almost 4 to 5 times 4 to 5 orders of magnitude higher than the experiments higher in experiments than what happens in nature.

And then, the quenching after experiments is also quite faster than what happens in nature because, if a particular set of inclusions which were trapped in a host mineral pertaining to certain conditions of pressure temperature and it is being subjected to deviatoric stress and the recovery or the reactant which the samples the is actually quenched in nature is much slower. Then also, what is possible in the experiments?

So, that this faster quenching also does give rise to some other kind of features from the sample such as some later horizontal cracks. Of course, they can be distinct. This they could they could be distinguished because there will not be any in fluid inclusions and trapped in such kind of cracks which develop as a in the process of rapid quenching.

So, these limitations notwithstanding results of such experiments match significantly to naturally formed samples. It is also believed that inclusion bearing samples facilitated deformation and the planar fabrics also develop due to the planar arrangement of the secondary inclusions produced during such deformation, is actually in many such natural sample examples are there that, if such kind of preferential loss of water is actually what is happening in nature? Or whether the any aqueous fluid that actually is coming to play at any particular time during the process of deformation and recovery from the deformation.

These they facilitate the plastic deformation and they sometimes the very closely spaced inclusion field micro cracks. They do give a fabric to the samples we generally is not a feature which is primary to the samples in which you are studying.

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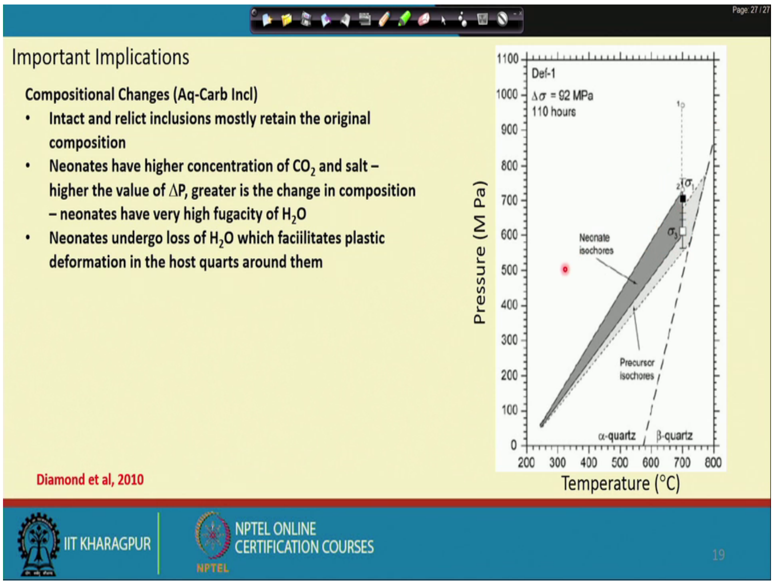

Just a little bit of scenario which is different from what was; this is what has been just described here; so, compositional.

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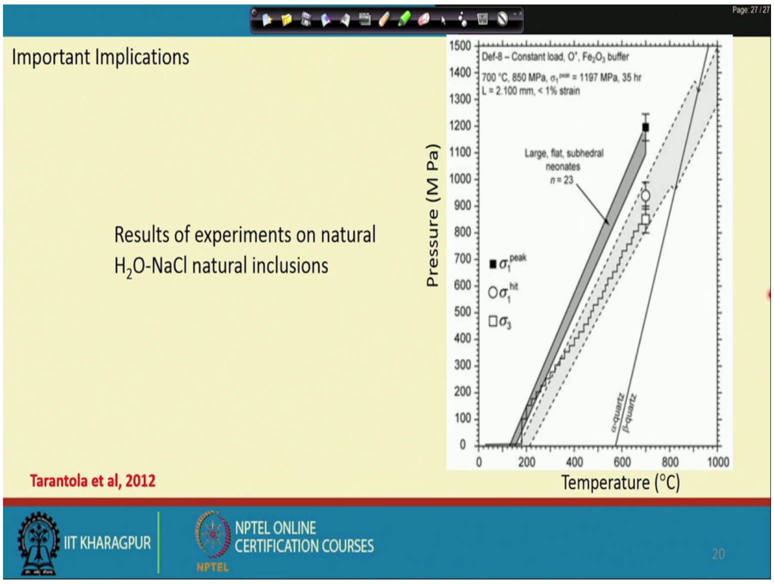

So, you could see here that the this as we as we discussed that these neonates are through the new newly created inclusions will have volumetric properties which will be different, will be shifted from the inclusions which had originally studied.

So, in case of the aqueous carbon inclusions, the intact and the relict inclusions mostly retain the original composition. This deeper shaded region which is actually the here the isochores fans of the newly created inclusions of the neonates and the lighter gray side actually the isochores of the precursor inclusions.

And, as we as discussed these experiments, the resulting intact and relict inclusions, the mostly retain the original composition the neon newly created inclusions. The neonates have higher concentration of carbon dioxide and salt because of the preferential leakage of water and this kind of higher or the increase in carbon dioxide is also higher where the del P is greater.

So, we as del P is increased, the inclusions proportion become more and rich more and more richer in carbon dioxide and that is the reason why, this newly created inclusions are very high fugacity of water and this is also is one of the reasons why the water would tend to escape through the from this new newly created inclusions through the defects or the dislocation planes in the host crystal.

And that facilitates the plastic deformation in the host quartz and these observed is greater extent of undulation extinction on those kinds of planes on which the newly created inclusions are arranged along with the relict inclusion. So, as compared to the just described situation in which the experiments were done on natural aqueous carbonic inclusion, this similar type of experiments were also conducted by the same authors on pure aqueous inclusions or in H 2 O Na Cl inclusions.

And what inside we can get the situation is more or less, the same. They do also develop the newly created inclusions which are arranged on plan planes which have parallels sub parallel to the minimum principle stress axes sigma 3. In addition to that, actually, here it sometimes when we study natural inclusions in the from draw different terrains. And if there is been a fluid, sometimes it is difficult for us to know exactly the stress condition. Because, the pore fluid pressure could be ascertain, which will be discussing in one of the case studies.

So, if you look at this diagram, then it will be of some use like it has been shown here that they the experiments were basically the results to be looked here is within the stability of the alpha quartz. And these are the isochores of the original the pristine inclusions and these are the isochores of the large flat Sabadell neonates. So, here since the temperature is known is 700 degrees or in this case, whatever because, we know the temperature of experimentation and these are the isochores of the neonates.

So, we can always get the pressure corresponding to the neonate and that could give us some idea as to what is in the value of the maximum principle stress in such kind of situations. So, these could be result some such kind of experiment and the isochores constructed on the newly created inclusions. As seen from here, they give us the idea about the value of the magnitude of the of sigma 1; that is, this corresponds to the sigma 1 and this circle corresponds to this sigma correspond to the field square corresponds to sigma 1 and the open square correspond to sigma 3. So, we can get the values in natural conditions; such kind of stress state of stress in the particular rock in which while we were studying them.

So, with this and it has to be kept in mind that the accuracy or dependability will always depend always be a function of the accuracy by which were able to calculate the inclusion density and the isochore. This is more applicable to the aqueous carbonic fluid where the for example, in this case, when the aqueous carbonic isochores were drawn up to pressure of almost 7 8 kilo bars.

There we also do have to consider what formulation we are using and how much of error it involves and we always tend to get more refined or to (Refer Time: 20:32) relationships in such kind of fluid mixtures. So, that there applicability to natural conditions will be much more definitive and better.

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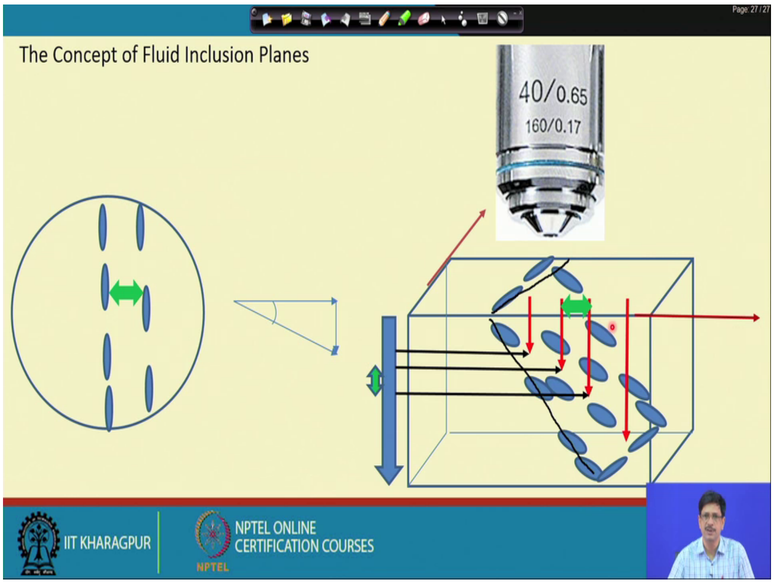

So, with this little bit of discussion on the application of fluid inclusion studies to natural samples, where there are indications that the samples or the terrain has been subjected to later deformation. And, indicating that the inclusions which are trapped in the original conditions were subjected to evolution or non-isochoric path.

We gain some important insights from such kind of experimental work and hope that much. Such experimental work will be done on situations more closely or more corresponding to diverse compositional characteristics of the inclusions and taking into consideration or refining or improving upon most of the difficulties in such kind of experiments and the uncertainties in the interpretation of the results.

Now, we will come to we discuss something on the same situation as the application of fluid inclusion to study of deformation of rocks. And in this, we just like to discuss this concept of what is known. As the concept of fluid inclusion planes through this curtain, I have just try to explain what would exactly it will be. First of all, we are we intend to apply fluid inclusions to understand deformation of rocks are broadly to structural geology.

And here, the most fundamental aspect all the this kind of exercise or this kind of work is that, we do collect the samples from the field with proper referencing of the of our identification of the different types of planar features from the rock, the fabrics and which we ascribe it to the different stages of deformation corresponding to the. And then, when we reconstruct in terms of the stress ellipsoid in terms of the maximum and the minimum principle, maximum intermediate and the minimum principle stress axes.

And, collect what we call as the oriented sections oriented samples from the field with the proper marking of the azimuth. The orientation with respect to whatever planar features that you have identified in the field and they ascribe to what kind of deformation stage in the rock, which phase of the deformation and which exact plane that we are looking at, what actually represents.

So, once we, I would definitely suggest to consult some experts as well as what is available in the in terms of the method. That is to be adopted where for collection of such kind of oriented samples in the field and not only that once the oriented sample is been collected from the field.

The sectioning also has to be done in such a way that, the surface of the section, if the top is representing the surface of the section. The surface of the section is also very well referenced with respect to whatever planar elements that we have that we are interested in with the with the fact that in a natural sample the what we are looking at.

So, essentially would be the inclusions which will be arranged on planar arrays corresponding to the brittle fracture with the mode 1 fractures fracture field and these are the fractures which are filled with the fluid. And later on, they are seen with the host mineral as secondary inclusions the inclusion plane.

So, there may be multiple sets of secondary inclusion the or the fractured planes fluid filled fracture planes. So now, here just looking at this particular example, what has been shown here is that, let us hope, let us see that there is a there is a plane. This is the plane on which the inclusions are arranged and now.

So, when we were seeing them, when the microscope, it is possible to not only just to identify or to ascertain the arrangement of this particular area of inclusions which is arranged in this particular plane. And let us say that, there is 1 plane of this is one this constitute one fluid inclusion plane.

So, this fluid inclusion plane in terms of the attitude that what is the deep of it and the direction can be very well. A certain if we have a graduated microscope adjustment log with a scale and which could be very well calibrated and the measurement can be done taking into account the least count or the kind of error which is involved with it. And, as shown here, when we are seeing them under the microscope.

At a particular position of the microscope stage, we will see the inclusion plane the array as like this on it would on the 2 dimensional field of view of the microscope. If we raise or lower the microscope stage this particular array of this particular linear array of inclusion would tend to move in a direction. For example, which is shown here, if we are raising the stage of the microscope, then we are focusing the plane at deeper and deeper parts. And so, this array would look to move to the right.

Now, we know the amount of the movement in the in the horizontal direction and also if we have calibrated our microscope adjustment knob in a way that exactly what is the vertical movement that has taken place for this particular horizontal movement. Then, we can easily calculate what is the deep of this particular fluid inclusion plane.

So, this looks to be simple, but definitely it needs a lot of good amount of exercise and to measure the or to ascertain the fluid inclusion plane and know exactly calculate what is the attitude of this particular plane. And then, once we know, then we can always put it in the reference of which the surface, fluid inclusions the section. The surface of the fluid inclusion section is what plane does it correspond to and what direction and so on.

So, these fluid inclusion planes are being studied by my many workers many of the experts who apply who intend to apply the fluid inclusion techniques to understand deformation in rocks.

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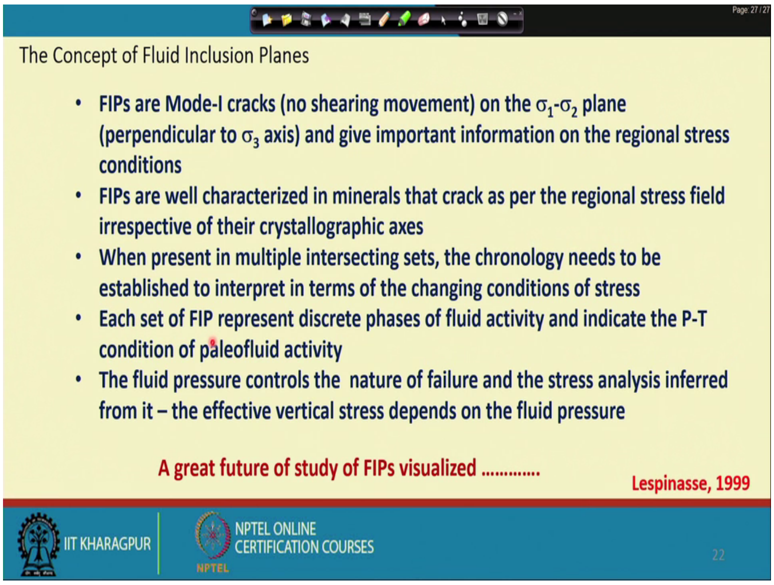

So, the situation is of the exactly what we are getting from this kind of fluid inclusion planes that, the fluid inclusion planes are definitely they mode-1 cracks. That means, there is no shearing and there on the sigma 1 sigma 2 plane perpendicular to the sigma 3 axes and give important information on the regional stress conditions.

And the fluid inclusion planes are well characterized in minerals that crack as per the regional stress field irrespective of the crystallographic axes and quartz very much satisfied to this particular condition and. So, when present in multiple intersecting sets, the chronology needs to be well established to interpret in terms of changing conditions of stress. Each set of FIP represents discrete phase of fluid activity and indicate the P T conditions of paleo activity.

So, here is the expertise. So, once if this particular work is fluid inclusion work is being done, then most of the part are essentially that the understanding about the mechanism of the formation of the crack and the direction of the have done good amount of the stress analysis and the field and depend. And after on this particular background, when this fluid inclusion planes of measured and there multiple sets of fluid inclusion planes.

And there, since there fluid inclusion planes, they are likely to be to have interrupt fluid of any particular composition; means, they could be aqueous, biphasic aqueous polyphase or sometimes as we have shown before, they could also be aqueous carboning inclusions which are likely to be entrapped in such kind of fluid inclusion planes.

And they using microthemometric can be done on such fluid inclusion planes, their salinity density and their isochores also can be plotted and they will be the ones which are going to give us the important information about the paleofluid activity in terms of the fluid pressure which could be determined from the isochores of these inclusions. The fluid pressure which controls the nature of the failure and the stress analysis infer from it.

The effective vertical stress depends on the fluid pressure because, that is the one which we are mostly interested in to calculate to know the effective vertical stress which is essentially the function of the fluid pressure.

And the early workers like the one which is referenced here. They very strongly paused for such methodology of fluid inclusion studies in relation to structural geology and they visualized a very bright future for the study of the fluid inclusion planes and as we will be elaborating from a couple of case studies.

We will see that. Yes, fluid inclusion planes are greatly helped in understanding the ways that the rocks have deformed. It is not only just that much more much greater implication in terms of the tectonic evolution of any particular terrain. So, we will continue discussing in the next class.

Thank you.