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

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Lecture – 30
Application of Fluid Inclusion to Deformation, Metamorphism (Contd.)

Welcome to today's lecture, we will continue our discussion on Application of Fluid Inclusion studies or fluid inclusion micro thermometric data, to understand deformation in crustal rocks. So, in this context: as I told before we could always look at many of the examples of the work that have been done in the Indian context.

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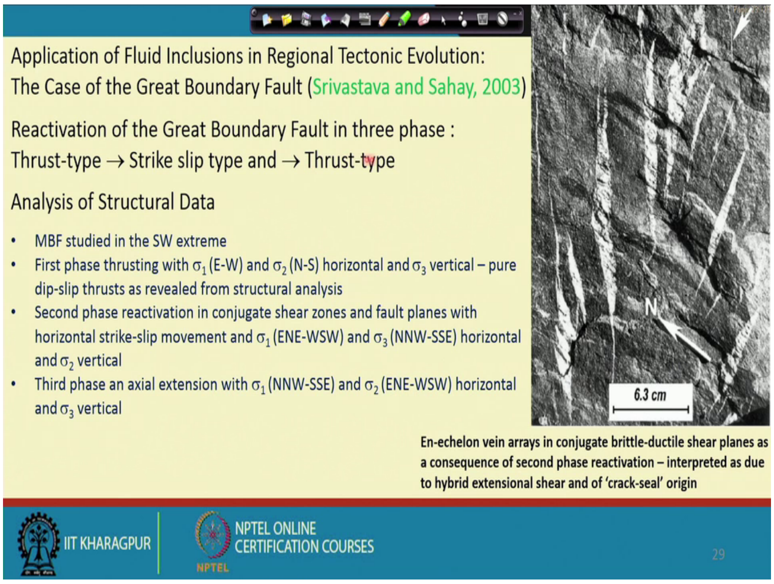

And I would like to site one it is a very interesting piece of work that was done on the great boundary fault by Srivastava and Sahay. And here we get to see a very good example of how fluid inclusion data has helped, in making some important conclusion about the about thrust about the progress of deformation in this particular major crustal structure.

So, this great boundary fault as we know is on the juncture of the (Refer Time: 01:26) Craton and the Vindhyan basin and it has got a North North East; South South West type of a trend which I am not showing here.

And the details of it the geology of it could be obtained from this particular reference, or from standard textbooks. So, this great boundary fault would studied by these authors on its South South Southern extreme, where it is actually just oppose against the Vindhyan sediment, and the (Refer Time: 02:02) Vindhyan group of row of the Kaimur sand stone, where these structures are developed.

And so, the analysis of this evolution of this great boundary fault, in generally understood to have taken in this way initially there has been a it is this particular boundary fault has been reactivated more than once. The initial type was a thrust type and what is followed by a strike slip type again followed by a thrust type.

So, we know that these actually again it is a situation where the principle stress axis is horizontal, it is a compressive stress axis that is acting upon, which just the changing over of the intermediate and the minimum principle stress axis. In one case it gives rise to a thrust type movement and the other it is a strike slip movement and again changing over to a thrust type movement depending on the condition of the far field stress.

Now, here the main boundary fault was studied in its Southwest extreme. So, the first phase of thrusting with sigma one East West and the sigma two, there is North South horizontal and sigma three is vertical. So, when sigma three is vertical you we would expect that the movement will be of a thrust type so, it is a pure dip slip thrust is revealed from. So, good amount of structural analysis has been done by the authors which I will not be discussing in details here.

The second phase of the activation was in conjugate shear zones and fault planes, with horizontal strike slip movement here the sigma three is horizontal and sigma two is vertical. And it was followed by the third phase of axial extension, of this photograph which show is showing shown here again from the authors. That they are the echelon vein patterns vein arrays in conjugate brittle ductile shear planes, as a consequence of the second phase of reactivation interpreted is due to the hybrid extensional shear and of the crack seal origin. These are the typically typical features which essentially are by the mechanism of crack seal process.

So, these are the ideal site. So, the fluid inclusion work of this particular work which I am which I will be referring, basically is on the centred on this crack seal veins, which are associated with the second phase of reactivation of great boundary fault. And are the ideal sites to look at the fluid inclusions and to see the fluid characteristics and try to see as to how much they would be helpful in understanding the deformation process.

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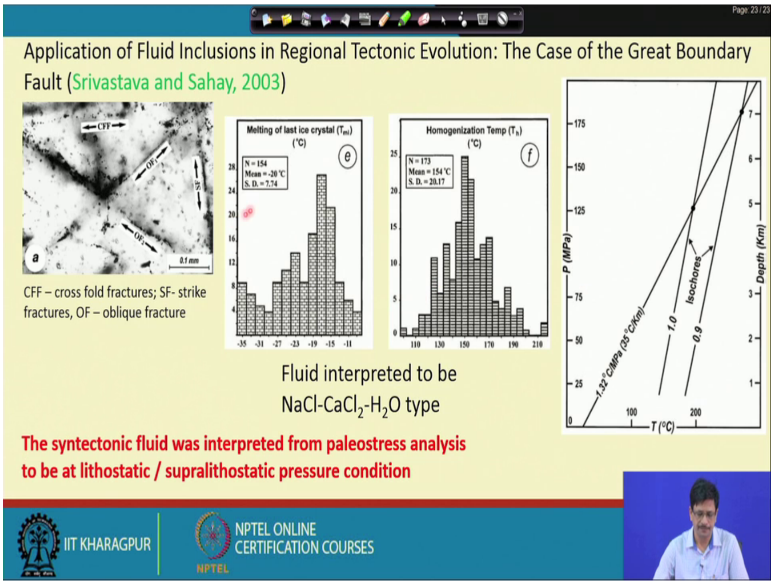

So, here these are the different arrays of the trails of the fluid inclusions, interpreted to be the CFF which is the cross fold fractures the SF is the strike fractures and for the oblique fractures. So, these are the kind of conjugate set of fractures which are present in these veins and which could be studied.

So, this veins the these arrays of the fluid inclusions, content mostly aqueous biphase inclusions, which are interpreted to be NaCl CaCl 2 H 2 O type based on the eutectic temperature that was obtained during the freezing experiment. So, what is shown here is that the range is that the authors obtained, while during the freezing and the heating runs. And where they say that the number of inclusions, were the paired salinity homogenization salinity temperature data could be obtained very less, but that does not affect the outcome of the work.

So, here the last ice melting has been presented, which we could see that there of modernity high saline a kind of fluid and our NaCl CaCl 2 H 2 O type. And the homogenization temperature ranges from greater than 210 to about 110 degree Celsius or less.

Now, these if these inclusions are taken all together, then the densities of the inclusions are calculated and the isochores of the inclusions, the total density range is being covered with 0.9 to point 1 are shown on this particular diagram on a pressure temperature diagram is constructed by these authors. And as you could see that they do so, they represent the ranges of the pressure temperature conditions of entrapment of these inclusions. Now as we know that the isochore themselves will not be able to tell us the conditions.

So, the best alternate or the best option here is to see the geothermal gradient and, then draw the geothermal gradient here. And see the intersection point of the geothermal gradient with the isochore. And that would give us an idea is to what could have in the ranges of the fluid pressure, during the formation of this during this second phase of reactivation of this particular structure, the regional structure that we are talking about.

Now, if you see here then taking a normal geothermal gradient of 35 degree centigrade per kilo meter, which is actually translated is 1.32 to 6 degrees per mega Pascal. So, we could see that they would correspond to some 125 to 175 mega Pascal pressure. So, that value of 125 to 175 you could take an average value of pressure.

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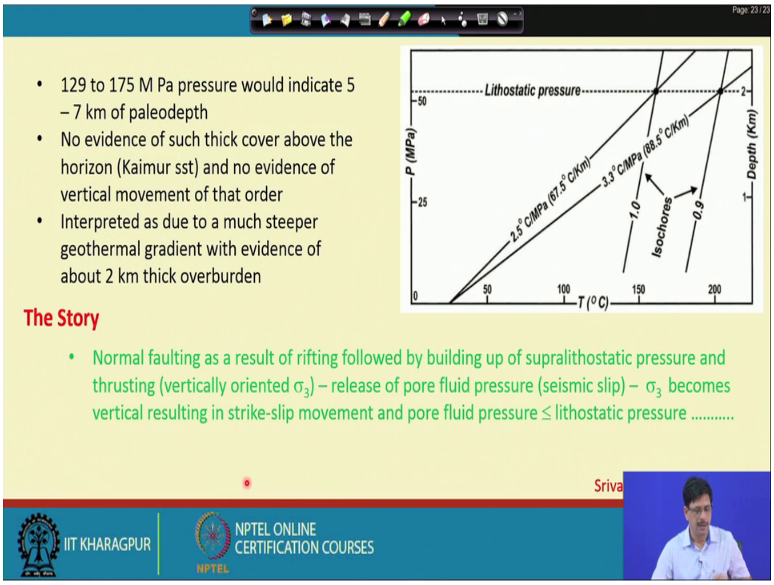

So, it is around 129 to 175 mega Pascal pressure that would indicate about 5 to 7 kilo meter of paleodepth. Now, the situation is that here also the similar type of situation as we just discussed in case of the in organic gold mineralising system here, also the situation is more or less the same, during the process of the initial phase of processing. They are the fluid which build up the supralithostatic pressure. And then with this with the rupturing, then this strike slip movement then the fluid pressure drop.

And it is kind of (Refer Time: 09:06) the conditions of the pressure the fluid pressure. And that would be translated to around 5 to 7 kilo meter of paleodepth. Now, the situation is that these values of 5 to 7 kilo meter of paleodepth would indicate that there at least to be 5 to 7 kilo meter of overburden to have been there. During the time of the of this reactivation of this particular strikes fault in the form of the strike slip movement; of course, then one would like to look for the whether there are evidence of existence of such thick overburden on this particular situation or not. It depends if the available evidence support. Then this could possibly we taken as a taken as the value of the paleodepth and the pore fluid pressure and the interpretation could possibly made in that way.

Now, if there is a there is a suspicion that there is no indication of or the evidence of having a 5 to 7 kilo meter of overburden, does not exist or is not feasible not enable, then some alternate model has to be thought out. And suppose in this case from the from various other configuration. It is possibly agreed upon that instead of 5 to 7 kilo meter of value of paleodepth, or having over burden of 5 to 7 kilo meters it could have been just about 2 kilo meters of overburden around that time above this the situation, where the reactivation took place from the available geological evidence in terms of the sediment cover.

So, in that case what could agree to about a 2 kilo meter of overburden, see it can only be possible if the geothermal gradient instead of being what is shown here as 35 degree centigrade per kilo meter. If it is as high as 67 to 88 degrees per kilo meter, then only under the existing condition of the isochores that we are constructed. Then it is going to intersect the isochores at condition which is which will agree to about 2 kilo meter of paleodepth 2 kilo meter of so, that would correspond to the pressure which is about 50 mega Pascal and that would correspond to about 2 kilo meter of paleodepth interms of litho static pressure.

So, since there was no evidence of such thick cover above the horizon there see Kalmur sand stone of Vindhyan succession and no evidence of vertical movement. So, in addition to that also there should be some evidence that, they must have been some amount of vertical movement so that the overburden of 5 kilo meter could have been agreed upon. So, finally, it was interpreted is due to a much steeper geothermal gradient with evidence of about 2 kilo meter of thick of overburden.

Now, the situation is that it so, this would agree with the available picture of crustal evolution in that particular segment. So, such high geothermal gradient could only be possible, if there is some kind of rifting phase that is associated. So, this story goes like that the normal faulting as a result of rifting followed by building up of supralithostatic pressure and thrusting. There is vertical sigma 3 release of pore fluid pressure seismic slip, sigma 3 becomes vertical resulting in strike slip movement, then the pore fluid pressure, and then again litho static pressure.

So, this makes a very coherent in the consistent picture, when the fluid inclusion data is integrated to whatever other information have been gathered from the structural analysis and from all other geological considerations taken together. So, this kind of geothermal gradient can only be a is possible, only if there is a rifting in the in that particular segment of the lithosphere.

So then this only, this particular irrespective of whether this model is finally, than acceptable model or whether there could be some refinement done to it or, whether more of such evidence to be looked for to get a better picture of the evolution here. That is besides the point, but what is evident or what is more important here is that fluid inclusions have come up in a way. In making some conclusions which are actually far reaching and the very important conclusions that only reminds us of the fact, that these objects will be tiny, but the conclusions drawn from the information obtained from them is great.

So, with that I will conclude the discussion on the application of fluid inclusions, in broadly to be called as application in structural geology, or understanding deformation and crustal evolution in many different. So, there are innumerable such work which can be seen in many different parts, in from many different continents by experts and they will give us a good, good amount of information. And idea as to in what way fluid inclusions can be utilized fluid inclusion data can be used, in the conjunction with such kind of studies ok.

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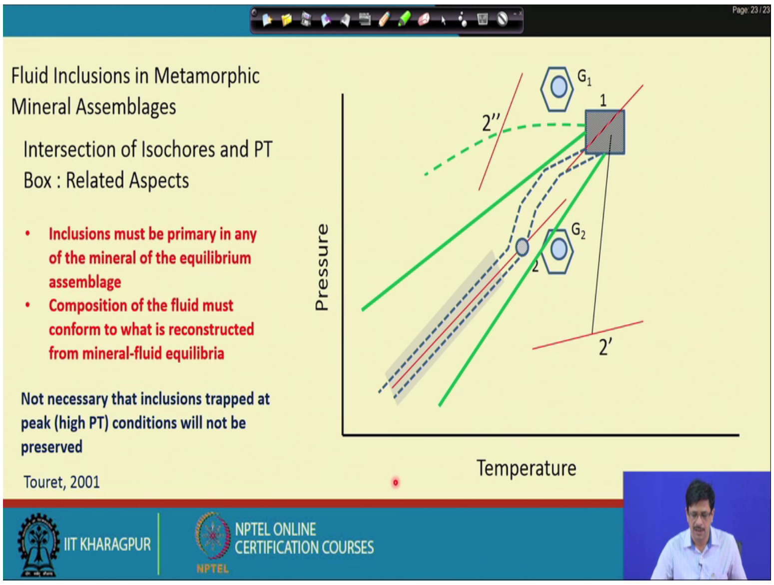

So, we will now get into a little bit of a discussion on the fluid inclusions in metamorphic mineral assemblages. I will not use the term metamorphic rocks, because after of course, the rock is constituting of the mineral assemblages and any particular mineral assemblage in a metamorphic rock is in is indicative of the physical process.

And also the physicochemical process rather that was operate that operated in that particular segment of the thrust. So, the fluid inclusion it is also that literature on the application of fluid inclusion studies to metamorphic rocks is also quite vast, to make an exhaustive review or to site many cases. So, that will also be very selective and only go by the very simple principle of how we can use the fluid inclusion data to understand metamorphism. It is very obvious that: yes, if we see a particular assemblage of minerals. Then out of those and if we could establish that this belongs to this, this is an equilibrium assemblage, corresponding to a particular pressure temperature condition. Then it is we could always look for the minerals within this assemblage in which we could study fluid inclusions.

The metamorphic minerals as we have said before of course, quartz is always is a uses host of fluid inclusions and fortunately it is present in a wide diversity of mineral assemblages in metamorphic rocks, as in many other crustal rocks, but then minerals like granite cordierite. And many other metamorphic minerals even sometimes there they could be observed in pyroxene. And other metamorphic minerals which actually nucleate in within the process of metamorphism, we can study fluid inclusions in them. The fluid inclusions will of course, view of the compositional type that we have or that we know of they could be gaseous I mean could be the mixtures of carbon dioxide, or carbon dioxide plus methane plus some type nitrogen and organ or could be aqueous inclusions or could be mixed aqueous biophase inclusions.

So, when we see the inclusions in them. So, as we discussed before whether we are applying it to a particular area of geology, it has to be integrated with whatever the information independent information can be obtained from that particular study for example, when we are looking at the metamorphic assemblage we will use our concepts of phase petrology and by the mineral chemistry. And then by using the concepts of equilibrium thermodynamics, we could have several we could establish or calculate the pressure temperature conditions, dealing which that particular mineral assemblage would have formed. So, there are many ways many possible many thing many of the all expertise of in the field of metamorphic petrology, which I am not coming to any discussion.

But it is a fact that we could put some kind of limits to the decipher tile pressure temperature conditions and can represent them in kind of a box. And we always talk of situations as a pro grade or a retrograde path and the pro grade path would have progressed with changing of the mineral assemblages in a sequence, when the higher pressure and temperature conditions are encountered.

Earlier mineral assemblages through reaction giving rise to new assemblages which stable under that particular pressure temperature conditions and, sometimes we talk of something which is a peak metamorphic condition which possibly, where the compositions are frozen there in the constituent minerals like say granite or pyroxene penile etcetera.

And that particular situation is basically designated is the peak metamorphic condition. So, we need to work out its not only peak metamorphic condition, but we always aspire to quantifier to work out the path precisely, whether it is a clockwise path or a counter clockwise path, looking for evidence of the minerals whether there were some retrogression some, development some, of some reaction texture some corona some bream somewhere and then try to complete the story. So, the basic idea here is that suppose we have a pressure temperature box defined by taking the mineral assemblages representing the peak metamorphic condition.

Now, if we have either one or more than one mineral Assam mineral members of this particular assemblage, where we look for fluid inclusions and we get see fluid inclusions as they are in the form of primary inclusions. Then we at least us to presume that well that could be the fluid that are trapped during the peak metamorphic condition. And look at the fluid of what nature what composition it is whether it is a mixed aqueous carbonate type or a pure carbonic type or pure aqueous type.

So, acquire the thermodyno thermometric micro thermometric data and, then draw the isochore. So, if that isochore happens to pass through the PT box, defined by the biphase petrology, then we kind of conclude that this represents the peak metamorphic fluid that is what is the characteristic of the peak metamorphic fluid; if the isochore does not pass through the peak metamorphic conditions if like for example, in this particular diagram which has been taken from 2 a paper.

Here again of course, whatever we have discussed in context of the situation corresponding to the preservation of the fluid inclusions, when they had subjected to there the subjected to conditions, which far deviator or far different from what could have what could possibly be dictated by an isochoric path. For example, if this is the isochore of this particular inclusion which was passing through the box. It will all the way down if the pressure temperature conditions would have changed exactly dictated by the isochore. Then we would there is no reason to suspect to this particularly inclusion will not be preserved in its form the way it was entrapped primarily.

So, today puts this kind of for points here that the intersection of the isochores and the PT box is definitely one of the prerequisites to really conclude, then a particular fluid that we are actually looking at is the peak metamorphic fluid or not. Of course, the condition goes without I mean saying that the inclusion must be primary in any of the mineral in the equilibrium assemblage.

If they happen to be once their secondary of their present in (Refer Time: 23:10) cracks, hill cracks then the interspersion will be different. The composition of the fluid must conform to what is reconstructed from mineral fluid equilibria, this actually is a very implicate exercise. Because, if we write the if there is a mineral assemblage in which there we are able to write a reaction to be representing the particular assemblage.

So, if that reaction happens to involve a fluid phase. Then by working out the reaction equilibria and the thermodynamic considerations, we will be able to reconstruct the composition of the fluid in terms of the ferocity of the (Refer Time: 23:58) the components that is presence. For say, for example you could say if it is interpreted to be fluid which is which is been responsible, or which was a part of the reaction of this mineral assemblage with the fluid has definitely been entrapped is inclusion in this minerals (Refer Time: 24:15).

So, it would be possible through that particular reaction it will react to arrive at values of the ferocity of these constituents if for example, water or carbon dioxide. And from that it could possibly be the composition in terms of the mole fraction, or the mole fraction or the mol molar proportion of the different components could be established, or could be could be estimated.

So, that should that has to agree with the fluid inclusions which we were seen, because we can analyse them by using some kind of a non-destructive micro analytical technique and can calculate the concentration of the different species. Even though we do not see that much of detail work or, but this definitely remains as one of the prerequisites for a particular inclusion, for to represent the peak metamorphic condition.

So, in that so here also that that is discussed in the context of what we what exactly we discussed a few lectures before, about their non-isochoric path of evolution of the of the rock, or the or the mineral the mineral assemblages of this particular rock in the later part of its evolution. If it would have undergone an isobaric cooling or it would undergone isothermal decompression. And, we also have fair idea as to what kind of distribution in the temperature of homogenization we would expect, if it is isothermal decompression or an isobaric cooling.

And qualitatively this author has put kind of a limit like this, these two green lines represent is if like a like a safe corridor means the inclusion is unlikely to be reequilibrator and unlikely to be destroyed, or its chemistry to be changed or the shape to be distorted. If the pressure suppose if this is the isochore then it is kind of the deviation, what kind what degree of deviation could possibly be there.

So, without actually destroying the inclusion this of course, will remained qualitative but we know that when we are looking at by remembering the series of series of experiments on the reequilibration of these inclusions the deformation. They are change in chemistry that we discussed and we site at the experiments done by many experts in this particular area; that whenever there is an inclusion group of inclusions or an assemblage of inclusions. And they are subjected to path which a which harp deviates from their isochoric evolution, then there are all the chances that many of those some inclusions to survive depending on the size of the inclusions, and how exactly to look at the inclusions and to make interpretations and put the caution in our interpretation of our data, if any such situation should have happened.

So, the in summary when we talk about looking at fluid inclusions, to understand the metamorphic environment or to understand, because we are more concerned here with the fluid, that the fluid chemistry of the fluid characteristics, and what we can derive the intensive parameters like pressure and temperature. This we know that if we have we could get some kind of agreement when we constructers. So, such kind of PT boxes could always be in a complete path of the evolution, where there would have been a peak metamorphic conditions. Then would have followed by a process of retrogression and if such mineral assemblages are also preserved in sequence within the same rock.

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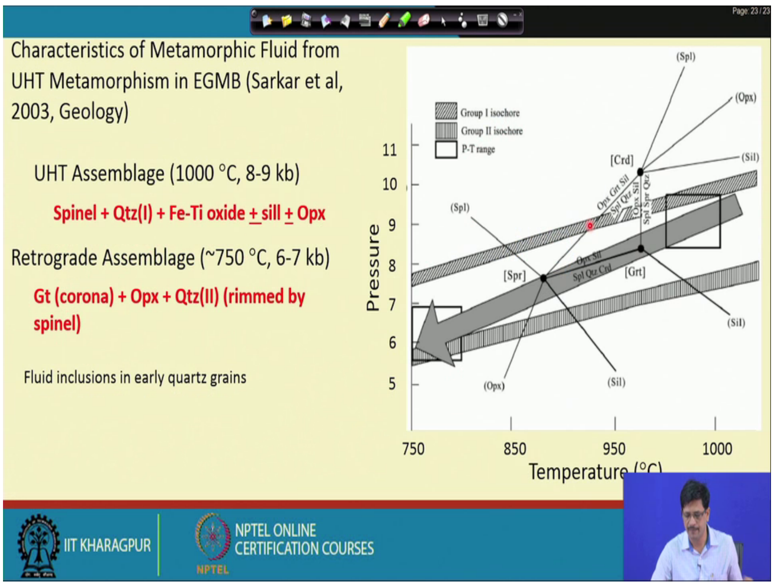

Then we can always study the fluid inclusions in such kind of different assemblages in the same rock, I would like to site one important piece of work in this context, which was done in the (Refer Time: 28:49) metamorphic belt by Sarkar et al this reference also is provided. I would without getting into much details of the phase petrology part of it, we can all I can still we can still concentrate on what important conclusions were drawn, from the fluid inclusion data.

So, here we see that from phase petrologic considerations that were two different conditions which were deciphered that the peak metamorphic conditions which almost around thousand degree Celsius, and around 8 to 9 kilo bar. And they actually represented as the ultra-high temperature kind of metamorphism, indicated by presence of spinel and sometimes with also such kind of environments are also, indicated by presence of minerals pyroxene minerals such a suffering.

And in this case the authors describe is spinel quartz iron TI oxide Silliman and ortho pyroxene of bearing assemblage, here is been shown by this reaction with the chemo graphic projection over here, on the PT space. And this represents the peak metam of a condition with mineral assemblages of spinel quartz iron TI oxides sill (Refer Time: 30:11) and ortho pyroxene and the retrograde assemblage with garnet corona ortho pyroxene.

And the second generation of quartz rimmed by spinel. So, this possibly was the ideal condition to study the characteristic of the metamorphic fluid, because we have quartz 1 and the quartz 2, in this assemblage and they studied the fluid inclusions, and the report the both the quartz 1 and quartz 2 to have been populated with pure carbonic inclusions. And this pure carbonic inclusions in the quartz 1, which is in the corresponding to the peak metamorphic condition is of a high density and the quartz 2 same carbonic inclusions are calculated to be of lower density.

I am not showing the histogram or the values of the depression inclusion point of the or exactly the temperature, of homogenization of the carbon dioxide inclusion. So, as expected here the homogenization actually want goes to minus sub 0 level of are going to minus 30 minus 25 degree Celsius. Where here in the so, this two group of inclusions as indicated by group one isochores and the group two of isochores and plotted here on this, super post on the PT grid for this particular metamorphic evolution. So, you could see here that the first generation of quartz at the fluid inclusions in them, they do pass through the box PT box which is constructed from phase petrology considerations. And the lower box also has the second, this group 2 glow (Refer Time: 32:02) carbon carbonic inclusion passing through this particular box.

So, it becomes very so, it is an interesting case of where the fluid of course, it turns out to be a pure carbonic fluid, not getting into the any much of discussion about what could have been the origin of that kind of a carbonic fluid, but the observation the observation is that there are pure carbonic inclusions and the one set which are of high density. They represent the peak metamorphic condition. They pass through the PT box representing the peak metamorphic condition.

And the second group of low density inclusions also do pass through the lower PT box representing the retrograde metamorphism. So, this there are many such examples many many from different parts even some work from the Southern (Refer Time: 32:56) and the Dharwar Craton they reported and many other, cases of such fluid inclusion work along with phase petrology work have been presented, and as has been looking at this particular diagram.

So, if any such situation we do get the fluid inclusion isochorse not passing through the PT box defined by phase petrology either through a pro grade, or a retrograde path. Then we start to think about that what exactly would have happened, what kind of process. And it is of course, necessary to see the manifestation in terms of the fluid inclusion morphology the characteristics the type of re equilibration texture that are expected, whether it is present or not. And then accordingly to interpret the data in terms of their correspondence to pressure temperature conditions is a right from phase petrology.

And once which we derived from the isochores of the fluid inclusion that we studied. So, that brings us to the close of the application of fluid inclusions to different areas of geology, we could cover if some brief have some brief idea about applying them to over farming environments to deformation metamorphism of course, could not been dealt with, but then gives us a very basic idea as to how to go about them.

And maybe that if we could possibly look at some more examples in the later in the last week of this lecture series, if time permits. Otherwise, this provides us to begin with some idea as to how fluid inclusions could be effectively, utilized to understand various crustal processes.

Thank you.