Fluid Inclusion in Minerals: Principles Methodology, Practice and Application

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Lecture – 23
Applications of Fluid Inclusion to Ore Forming Environments

Welcome, to today's lecture. We will continue our discussion on Application of Fluid Inclusion microthermometric data to understand ore forming environments and here we are particularly be dealing with the hydrothermal environment where the mineral deposits result from the activity of hydrothermal fluid and that hydrothermal fluid could have diverse sources.

Before, we attempt to discuss we have already seen it some such examples we should keep in mind that the literature on hydrothermal processes and the resulting mineralization, the wide spectrum of ore deposits of a number of important metals is actually a too vast to be summarized or to be reviewed or to be synthesized in this lecture series under the time constraint.

And, so, we will be just picking up some of the important examples just to demonstrate that how the fluid inclusion microthermomatric data have been interpreted will all be based on the different workers the way they have interpreted and without actually going on to any kind of a critical evaluation of that. And the other thing to keep in mind that the information that is coming from the fluid inclusion microthermomatric data is just definitely a vital piece of information on any deposit that is resulting from hydrothermal process.

But, then at the same time information generated from other sources such as mineral thermometry and ratios of stabilize isotopes like oxygen and carbon. They do also contribute towards understanding of the origin and evolution of the hydrothermal deposits which will not be discussing here now. And there other things to keep in mind is that we do categorize the hydrothermal deposits into different genetic types based on the origin of the hydrothermal fluid.

But, when we see the deposit wise I mean individual deposits in any particular terrain and also the across the geological time scale, then we do find that there they do differ in

sometimes and very significant ways from each other and we even though we always intend to put them under certain specific genetic categories. There are deviations from the common theme that generally we try to formulate. Nevertheless, we it is of course, one of the exercises in where geology to categorize deposits into genetic types and then to explain is observed deviations in different possible ways.

And, the other important aspect is that the hydrothermal ore forming environment is in operation in the earth's crust right from the very beginning of the evolution of the earth's crust. So, we get such deposits as old as the Archean times to even the present day situation that is happening in the ocean floor hydrothermal systems as well as land based geothermal systems.

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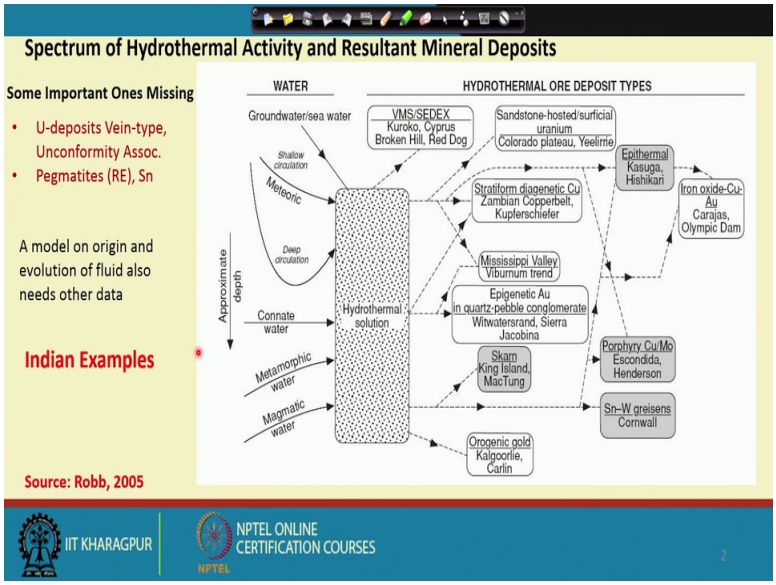

Now, let us have a brief look on this particular diagram which is taken from the book of Laurence Robb on Introduction to Ore Forming Process, where it is a kind of a synthesis or categorization of the different deposit types based on the source of the hydro or the nature of the water or the hydrothermal fluid which is arranged in an depth increasing depth condition. So, this meteoric shallow circulating what meteoric water and the deep circulating meteoric water and water which is trapped in the pore spaces of sedimized, the cornet water, metamorphic water, magnetic water. And the deposits that we get listed here and from the arrows marked here we generally know that what kinds of deposits play their role in formation of such kind of deposits.

It is of course, not possible to take each and they could be some other deposits which we missing here for example, the uranium the when vein-type uranium deposits and the unconformity associated uranium deposit like the rich ones occurring in Athabasca basin in Canada or in the Alligator river basin in Australia and some other places, where we know that these are rich sources of uranium mineralization mineral uranium resources and the pegmatites of course, which sometimes important from metals like tin tungsten, niobium tantalum and also some gemstones. They are the fluid they also need to be placed somewhere here and then out of this, we will definitely will be more interested to see which type of deposits we do get representative ones the well studied one in the Indian context.

Ah some of the deposits which you do not get well studied are well documented in the Indian context, still it would be worthwhile to look at their characteristics in terms of the fluid nature of the fluid, the sources of the fluid and the way the fluid carried fluid has been interpreted to have any world giving the entire spectrum of hydrothermal activity.

Say for example, the Orogenic gold deposits. So, the lode type gold deposits way, they are well documented in the Indian context in the Dharwar craton. We do not do have typically the Carlin type gold deposits which occur in the younger rocks in Mesozoic and later like what happens in the Western American Cordillera sorry western American the Basin and Range Province in the states of Nevada, the famous Carlin type gold deposits which contribute which are rich sources of gold right now. We do not have such representative as a as of now known to be occurring in the Indian subcontinent.

The Porphyry copper deposits are also absent in the Indian shield bearing the deposit Malanjkhand deposit which is been discussed with in some amount of details about the fluid inclusion characteristics which sometimes is debated to be having a affinity like Porphyry copper ones. Then, the tin tungsten greisens deposits like already the one the greisens or this is corn the one which you have already discussed about the Dachang deposit in China, we do not have also much of Indian occurrence.

And, the iron oxide copper gold deposit, the famous the Olympic dam deposit, the epithermal deposits the high sulfidation and the low sulfidation epithermal deposit. We generally we find in the pacific ring and mostly includes special association with Porphyry copper deposits as high sulfidation one and the low sulfidation one deposits

like the one in Hishikari in Japan and some of the other deposits like the Lihir island the Ladhola of deposit Lihir island and on Papua New Guinea. The they are also not represented or not known to be documented in Indian context the Sandstone-hosted, the tabular type of Colorado plateau, uranium deposits often of let there are some deposits in the Silla in the north eastern part of India are coming to be known.

As we know the Indian shield does will have the extra peninsular India still need to be explored for the occurrence of many types of deposits and this VMS the volcanism massive sulphide deposits, the typically the one the Kuroko type and the Cyprus type. They also are not very well known of late there are some deposits in the some occurrences in the South Delhi Fold Belt and the which are and also in the central India which are being described to have close similarities with volcanism massive sulphide deposits, but the only problem is that they are deformed metamorphosed.

So, the original characteristics are lost, but still they could be studied to understand the fluid characteristics. And, the Mississippi valley type deposit they are also very interesting class of deposits. This playing very peculiar very interesting fluid characteristics and the coppered in the red in the red beds like the Kupferschiefer they commit the prexacture of the red bed and the black shells where the Zambian Copperbelt and the Kupferschiefer are not well represented in Indian context as well.

And, now if you look at many such deposits which are characterized with their fluid characteristics, it is always observed that they do have identifiably multiple sources of fluid. For example, in the Orogenic gold deposit which is very well known to have been resulted from metamorphisnic fluid in the green stone terrains. They also do have fluid components which have to which need to be ascribed to other sources sometimes a magnetic sources or meteoric fluid. Meteoric fluid is a fluid which can populate to greater depth and can interact with any other type of fluid to give rise to mineralization.

Sometimes the conditions for example, in the iron oxide copper gold deposit as discovering the famous Olympic dam deposit in the (Refer Time: 10:22) pattern in South Australia and there are many such deposits which are prescribed in the periphery of the close special association with the Olympic dam deposit occurring the same kind of vixia complex and in granite it in intercontinental granite total the ignite.

So, there sometimes the fluid characteristics need to be I mean to involve fluids of magmatic sources or sometimes such kind of fluids also are ascribed to connect sources whenever we get a temperature a little higher, but the salinity to be representing something intermediate or little higher than the get observe being meteoric fluid. Sometimes it remains conjectural is to what exact source we should describe.

Similarly, in a volcanism massive sulphide deposits we would expect that it would be the seawater to play a dominant role, but sometimes we do also get the fluid inclusions and characteristics which a which indicate much higher salinity ranges to be, so that some magmatic sources or some kind of process have to be invoked in them. So, the just says that sometimes the fluid sources remain conjectural and the fluid inclusion data have to be supplemented with other information likes stable isotopes and mineral thermometry.

So, within that framework still we what we find that is the fluid inclusion characteristics in terms they have a salinity temperature and now with the availability of precision and sophisticated micro analytical techniques. It is becoming a little easier to actually characterize the fluid in terms of their ore bearing potential which actually carried the metals. For example, in case of the Porphyry copper deposit or in case of the Orogenic gold deposits, there are many instances in which the inclusions are analyzed with these the topic which will be discussing in a later part of this lecture series about the micro analytical techniques in which various metals could be analyzed directly from the inclusions either by destroying them up in non destructive bit techniques.

So, this is how the science is being forwarded and we should always keep some of the limitations in mind while trying to apply the fluid inclusion data in to understand different types of deposits.

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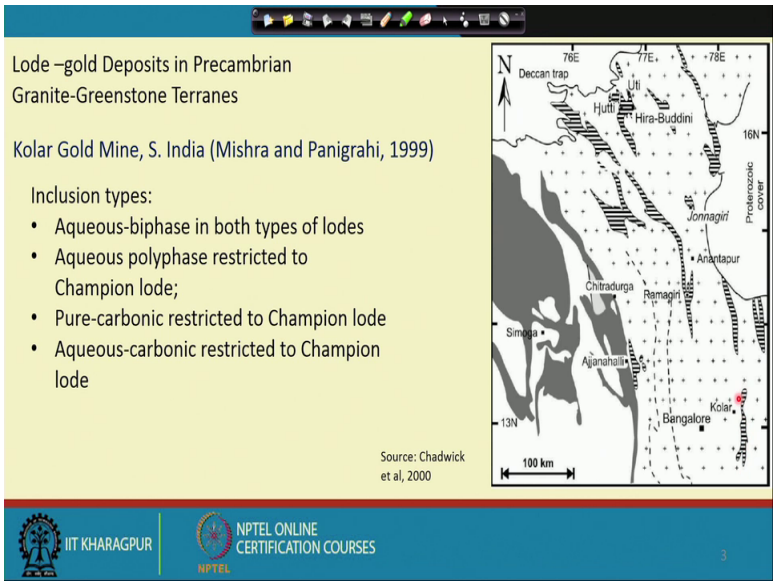

So, I would like to give a little bit of idea about the or the low type deposits in the green stone granite terrain and we know that the Dharwar Craton, we have occurrence of such a deposit which have been producing gold for almost more than one and half centuries before, like the one which is Kolar which is shown here this is the Kolar schist belt this deposit has been closed down because of the falling rate of gold I will depth and one of the deepest gold mine in India.

And, some of the presently working deposits is in the Hutti Muski schist belt here and if the Ramagiri Penakacherla. They are also not currently producing some deposits that in the Chitradurga schist belt, then the western Dharwar craton which are also being still some exploration and discovery being done. So, if we examine typically I will just go by the example of the Hutti Muski schist belt and the inclusion. So, what exactly is done is the lodes requires and requires goals are quartz gold lodes of the quartz gold sulphide lodes which are present within the meta basics which are essentially and privileged or altered and privileged or to alter to a chloride returned of rock and they are present as lodes in the schist's rock. This quartz is sampled from this kind of these lodes.

And, so, one thing was also we should keep in mind while interpreting or trying to use fluid inclusion data. It is always necessary to have a very good understanding about the general geological set up. The constitution of the ore in terms of the mineralogy of the ore and gangue minerals and the overall and the deformational phases the stages in

which the ensemble has evolved because finally, that is what is going to be integrated to build up the story of origin and evolution of any particular hydrothermal deposit.

So, taking the example of the Kolar gold mine which was studied some time back so, the inclusions that we see in the Kolar gold mine in the different reefs [vocalize d-noise] which are the gold quartz reef for the gold quartz sulphide reefs. So, there it was by phase in this. So, the two different types of lodes one is the gold quartz lode and the [gor/gold] gold quartz sulphide lodes were studied from the Kolar region in two different mines, but that the same lode which is exposed. And, the aqueous biphase inclusions, aqueous polyphase inclusions which are restricted to the champion lode pure carbonic restricted to the; again the champion lode which is essentially gold quartz lode where divide of a sulphide. And the aqueous carbonic inclusions also restricted to the champion lode.

So, that means, when we come to see the lodes the pure gold quartz lodes seen to be the once which contain the appreciable carbonic component in the fluid compared to the ones which at the gold for sulphide where the carbon if you are seem to be lacking.

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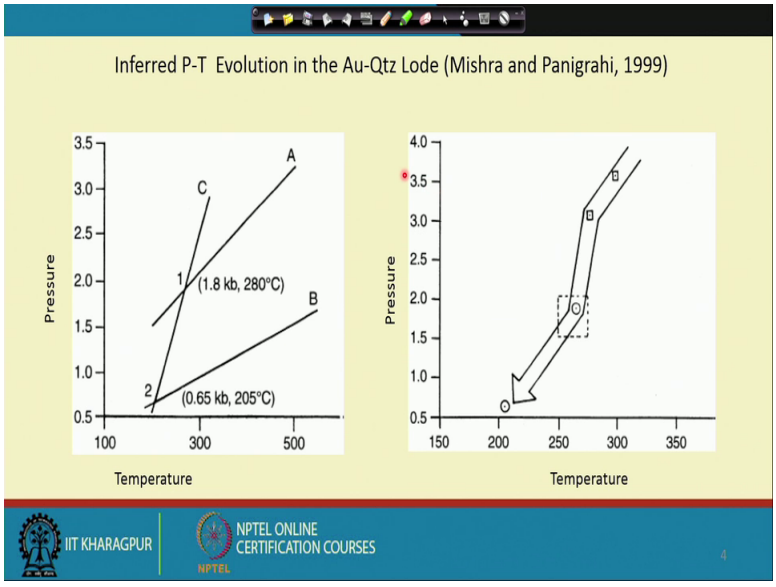

And, so when we observed this data so, the fluid inclusion the microsmatic data generated and then we know that we could and we could use them in constraining the pressure from intersection or isochores wherever we get coeval existence of pure carbonic and aqueous inclusion from their isochores. We do also can constrain the

minimum pressure of entrapment from the aqueous carbonic inclusion from the total homogenization temperature which the methodology which we discussed and also they aqueous biphase inclusion by their freezing runs can see their salinity and temperature distribution.

So, we get the ranges in which it definitely indicates that the fluid in a ranges in the salinity and temperature from low temperature low salinity to high temperature, low salinity to high temperature moderate salinity kind of fluid which may not be that very easy to explain by invoking only one source. But more or less fluid which is a low serine carbon dioxide being fluid, possible metamorphic derivation was ascribed as the as the over fluid and from the pressure temperature estimation that was made from the to isochore intersection and from the aqueous carbonic inclusions, some kind of a path this kind of a evolutionary path was did deduced. And, it confirms or it agrees with the fact that the original fluid which is or the parent homogeneous fluid which is an aqueous carbonic fluid carried the transported the gold and the with the drop of pressure, this particular fluid got separated by underwent unmixing. And that unmixing is a weaknesses by the coeval existence of pure carbonic and pure aqueous inclusion from which from the intersecting isochore further evolution of the fluid to the lower pressure temperature condition should be deduced.

And, a picture of evolution of the fluid with the physical the change in the physic-chemical parameter physical parameter mostly pressure in temperature that could have given rise to the mineralization in the gold quartz lodes could be ascertained.

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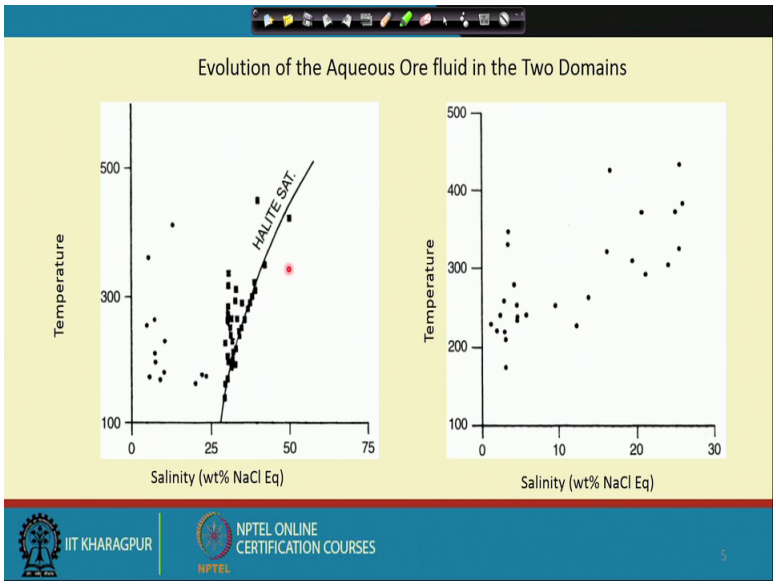

At the same time when we find that the lodes the aqueous component fluid is also pretty high in his salinity went to through 40, 40, 50 percent weight is from the poly phase aqueous inclusions. So, here it is from the gold quartz lodes and this is from the gold quartz sulphide lode. There we see that even the in case of the gold quartz lode even we get soil fluids which of much higher salinity. So, that is why the situation led to proposition that the fluid definitely a higher temporal high saline fluid definitely which should be in it is identity be close to a fluid could be of magnetic derivation must have then involved, ok.

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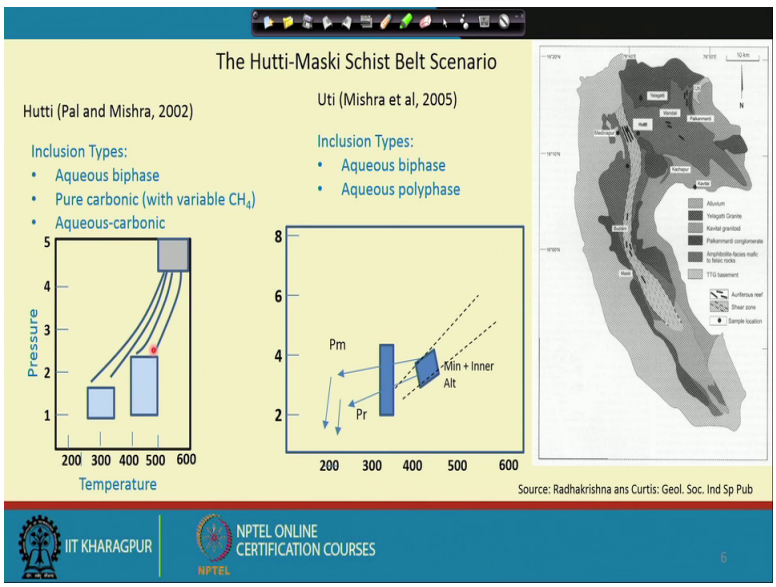

So, look at similar such situation [Vocalized-Noise] from the Hutti-Muski schist belt. We know this is the map of the Hutti Muski schist belt, where this is the presently producing mine Hutti with multiple lodes shown here and here there is one deposit which is very close to the granite younger granitic body Yellagatti granite which is exposed. Here this is the Ooty deposit and here there are wonderlly and Hirabuddini prospects which are also it within the Hutti group of metaphysics rocks.

And so, fluid inclusion strategy were conducted are in the Hutti and the Ooty deposit so, I could give a comparison. Here what we could see from the similarly we see aqueous biphase inclusion pure carbonic and aqueous carbonic inclusion.

Similar thermal barometric exercise when combined with the metamorphic conditions of the host meta basic rocks as well as some mineral thermometry combinedly give a picture of the evolution of the mineralization and the ore fluid which is up which is interpreted to have when initially been derived by depolarization reactions and beyond the apograde metamorphic pass of the host metasediments and then with the further drop in pressure and temperature condition the fluid also underweight on mixing phase separation to carbonic and the aqueous component which resulted in drop in the solubility of the metal and deposition of the gold metals and different lodes.

As you cans that so, here in this situation of Hutti you see that there are occurrence of carbonic by the fluid is fluid has an appreciable carbonic component. If the deposit and which is within it just about the northern part of the Hutti-Maski schist belt in close proximity with the younger granitic rock, they are the fluid inclusions examined with it was observe that this particular fluid inclusions where sample from the quartz in this deposit.

There was no carbon dioxide bearing inclusion which was observed it was only the aqueous biphase and aqueous polyphase inclusions and there the temperature salinity plot also do give some idea about the changing nature of the pressure temperature conditions during mineralization and these are the isochores of the extreme density aqueous inclusions which are observed and this kind of box is coming from the alteration conditions in two different stages and these are the much later situations where the low pressure temperature kind of alteration situations which combined with all three give a picture of evolution of the ore fluid.

So, here the point only to be noted is that if we ascribe the orifice ore fluid to be derived only from a single source like a metamorphic metamorphizanic source and that fluid could be characterized by a low salinity carbon dioxide bearing and sometimes with appreciable amount of H 2 S or any other sulfur species. Then the scenarios in some situations seem to be different and so, were fluid of a possible magnetic derivation also could be speculated.

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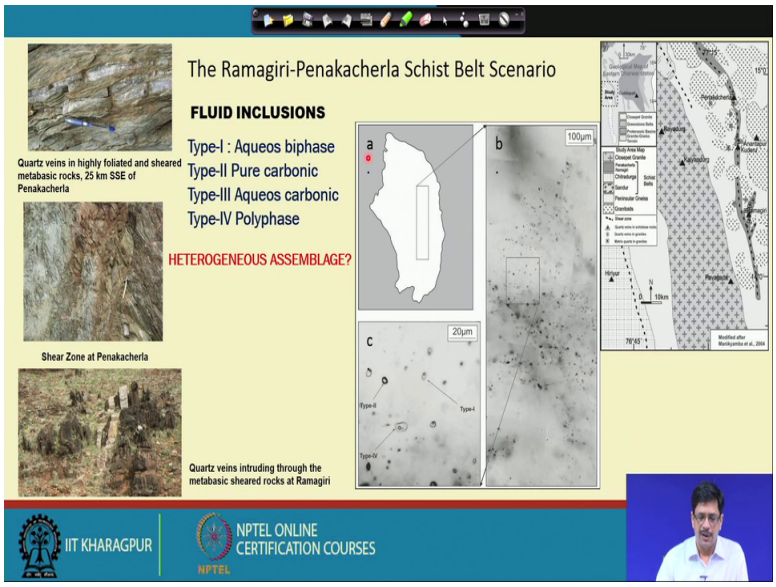

Here some results which were obtained from the Ramagiri-Penakacherla schist belt also I need to be what you have discussion. These are some of the fluid photographs from the Ramagiri Penakacherla schist belt where we see the quartz aventue within the meta sediments and that is what exactly the way the mineralization. Even we sample the quartz from here we also do get occurrences of gold grains along with sulphides and these are the typical occurrence in the Penakacherla Ramagiri schist belt.

And, the fluid inclusions when we examine, we also do get the aqueous y phase and here. If we look at this map, then this is the Ramagiri schist belt is tried and shipped here and this is this is Penakacherila. So, they are all surrounded by younger prolific younger granitic activity which are exposed in the as shown in this map here to the left of this is the major granite body which is the close for granite which is a prominent granite body in the Dharwar craton roughly marking with boundary between the western and eastern

the Dharwar craton here. But, this belonging to this particular granite body belongs to the eastern Dharwar craton.

So, we have a scope of sampling the quartz and study inclusions in the veins within the meta sedimentary rocks like here in the Ramagiri Penakacherla schist belt as well as the matrix quartz indo granite and the quartz veins and pegmatitic material in the granite, so that we could possibly establish a relationship if I tell exist between them. So, these are some of the ways the fluid inclusion petrography has been done taking the sample and then the magnified area as shown here.

There are all the four types of inclusions aqueous biphase pure carbonic aqueous carbonic and polyphase inclusions they occur and almost all these host minerals and coming from the schistose rock as well as from the granite. There are now certain chemical differences for example, the aqueous carbonic inclusions which occurring veins and magmatitic materials and the metrics quartz in granite. They are pure carbon dioxide without any methane being in them whereas, the quartz veins which are occurring the oriferose quartz veins in the schistos rocks and Penakacherla Ramagiri.

They are there the carbon dioxide is a carbon dioxide has a appreciable methane in it is in the fluid which are detected by laser amongst macro spectrometric as well as from the depressed the depression in the melting point of carbon dioxide. So, we see the assemblages are quite heterogeneous like the one which has been shown here.

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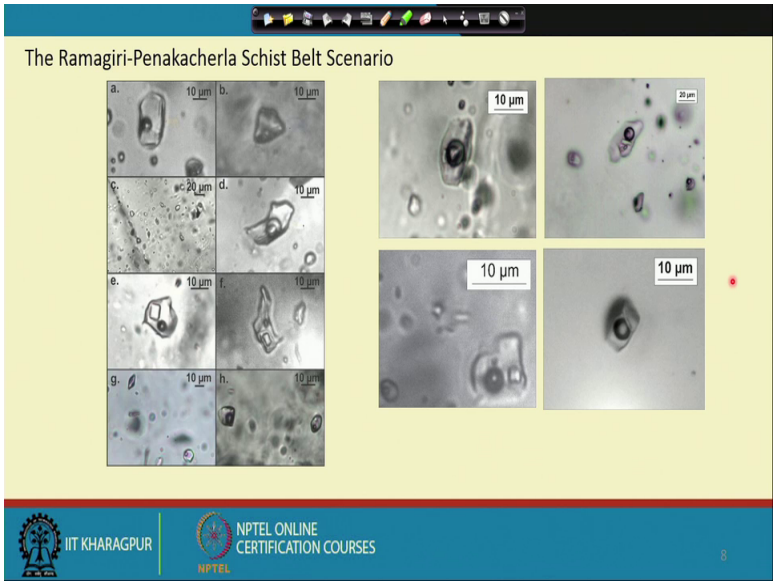

You could see in the same samples. Aqueous biphase inclusions of low solanatic carbonic aqueous carbonic inclusions and sometimes very high saline inclusions exemplified by polyphase halite bearing daughter crystals here and the coexistence of pure carbonic and pure aqueous inclusion. And, also very interestingly some high saline aqueous carbonic fluid which are having some daughter crystals in them which gives us an idea that the there must have been some multiple source of the fluids in this particular area and that is how it gives us a heterogeneous. These are some of the interpretations which could always be having there some interpretations you should always have some different opinion.

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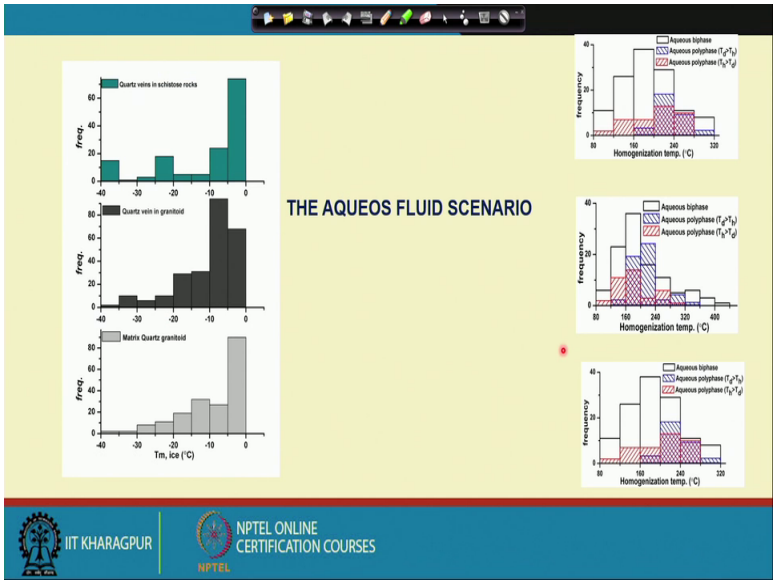

And, you could see the aqueous fluid scenario here where the histograms are plotted. So, the salinity variation it could see going from almost near very low saline near 0 to a to salinity value as high as 50 – 60 weight percent to it the inclusions which are represented as the polyphase inclusions here. So, they are the quadrants in the schistose rocks, these are the quadrant in granitoid and the metric quadrant in granitoid. And, the temperature also what we observe here the temperature homogenization which are not pressure corrected go to values 300, 400 degree or above and we see the distributions of the aqueous biphase of the aqueous polyphase and the situations where the dissolution of halite is more than that of temperature with homogenization or the reverse situation. They are a more or less has a good overlap in the temperature interval.

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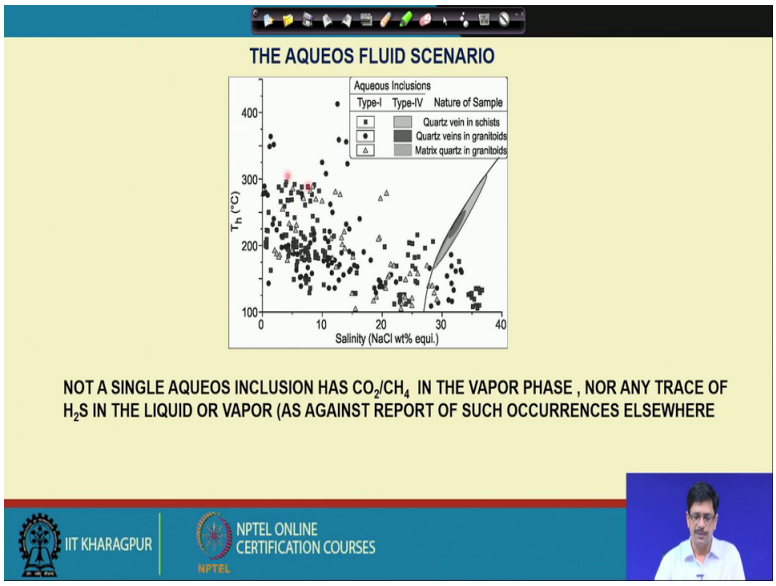

And, when the data parted on as fluid evolution diagram we could see a complete continuum in the fluid and sometimes we also do get high saline fluid without having any daughter crystal present in them because of the many of the reasons that we have discussed before. There could be saline highly saline fluid, but not of the dominantly chlorite type.

And, so, the different inclusion types are plotted here as you could see the symbols the squares floated from the quartz and industries, where we could see a continuum and the solid circles the quartz when in the granitites and the triangles represent in the matrix quartz in the granitites. So, here we see that they do have very interestingly overlapping characteristics.

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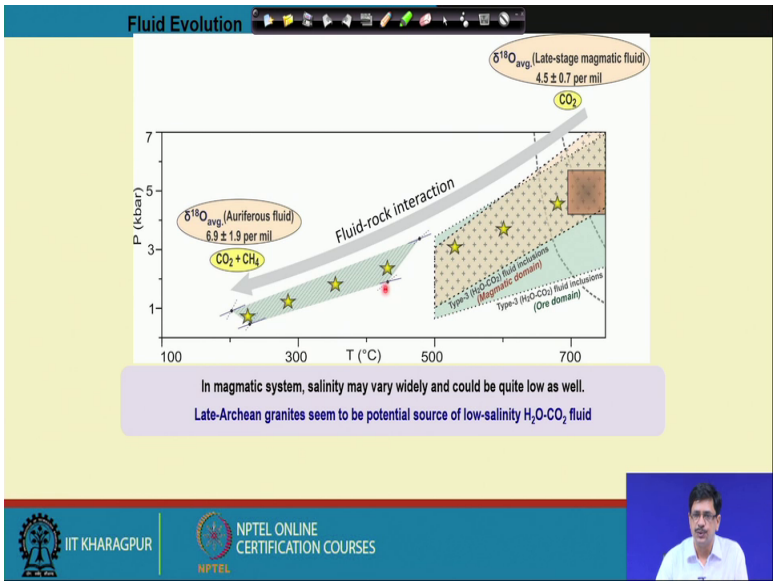

And, then when we synthesize the information all together we could rationalize or we could develop or you could formulate some kind of hypothesis as to what could have happened in this particular mineralizing system.

So, when we see that the inclusion the inclusion characteristics which are sampled from the granite either the matrix quartz in them or the quartz fetch for the grains within the granite do have a very interesting overlap with the. So, this is constructed from the aqueous carbon inclusions in the magnetic domain and also the aqueous carbonic inclusions in the ore domain, where they do present situations which correspond to higher perspective vector conditions because they represent the situation in which the fluid was miscible in the miscible resign higher temperature pressure conditions.

And, that there we find that there is a very high probability that this particular granite during the time of it is crystallization evolution during which a fluid phase generally exalts out of the granite in the process of for second boiling or in or even in cases where there is been no second boiling, but the fluid could be could have just evolved at a greater depth conditions and there is a grooming overlap between the pressure temperature resign reduced for the from the granitic domain and from the ore domain.

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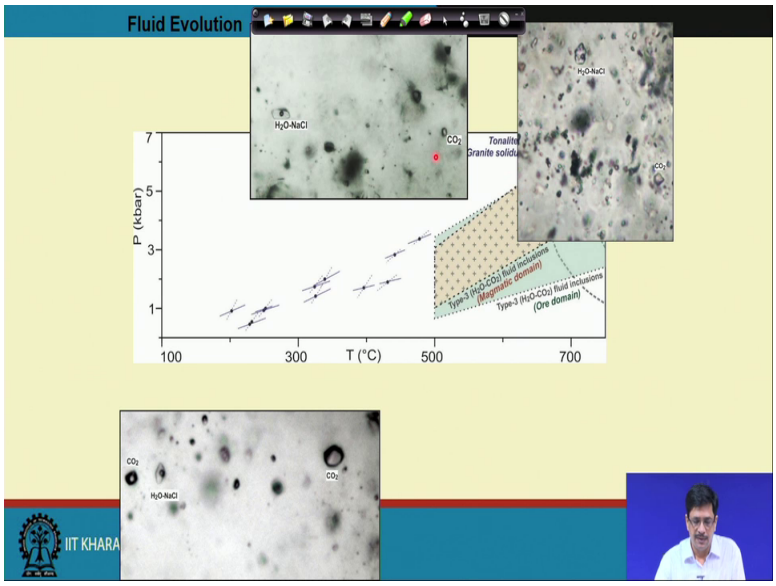

And, so, these intersection points are from the coexisting or the coeval aqueous carbonic a pure carbonic and the pure carbonic and the pure aqueous inclusions which give us a good range in the evolution of the pressure temperature conditions of the fluid combinedly and these are the situations in which the coexisting pure aqueous inclusion H 2 O and the Cl and the pure carbonic inclusion is shown here and the similar situation from the different origins.

So, that leads us to building up or the formulation of kind of a hypothesis on the origin and evolution of mineralizing system in the Ramagiri Penakacherla or for a schist belt. So, that it gives us an idea that of the possibility that there is the fluid considering it is temperature salinity ranges and the indent the similarity in the fluid characteristics in the host granites and the ore domain to have such kind of a evolutionary picture.

As I have said that these kind of interpretations could always be equivocal and need to be substantiated from data from other sources like isotopic data or sometimes even by in if by analysis of individual inclusions from by some destructive under nondestructive micron article technique or sometimes even if even we can analyze by bulk kind of destructive analysis like the cross rich analysis which also will be discussing later on.

So, these are some of the examples of the mineralizing systems hydrothermal mineralizing system and in particularly the cases that we discussed about the lode type gold deposits which are also known as the Oroginic gold deposits in Archaean granite

densineterrain and how a how the resonant here the of the idea is not to get into any kind of for debate on the what has been proposed or what is right or wrong. But, it is only the way is the micro thermometric data have been used and what kind of a logic has been applied.

So, we will continue our discussion on the application of micro thermometric fluid inclusion micro thermometric data to other type of hydro thermal deposits in a next class.

Thank you.