Fluid Inclusion in Minerals: Principles, Methodology, Practice and Application
Prof. M K Panigrahi
Department of Geology and Geophysics
Indian Institute of Technology, Kharagpur

Lecture – 21
Application of Fluid Inclusion to Ore Environment

Welcome to today's lecture. During our discussions so far we have now have been understanding about the various types of inclusions. As far as their compositional types are concerned and their appearance at room temperature in combination of different phases liquid, vapour and solid; in different types of crystal environments coming from an ore body of from a rock.

And we now know how to locate them how to see them identify them and then do a background study of petrography fluid inclusion petrography. And then go on to carry out the micro thermometric experiments on the different types of inclusions and then present their data and interpret the data in relation to the variables the compositional variables the intensive variables; like, pressure and temperature.

And then integrate them into other information and address the issue whether it is the issue of a of genesis of an ore body or addressing the issue of the characterization of the fluid in causing the metamorphism and so on. So, in this lecture and the following subsequent lectures we are in this way; we are going to discuss on the application of fluid inclusion studies to understand ore deposits. And to begin with we must keep in mind that those deposits which broadly common with the category of hydrothermal deposits. Means the deposits which ore their origin through the activity of what aqueous fluid, ore fluid, are the ones which are available to such fluid inclusion studies.

And basic objectives in this methodology lies in identifying the nature of the ore fluid, there probable sources from which they have been derived and then the way that that they evolved in space and time. Before we go into this, it would be what pointing out, that the fluid inclusion studies majority of the volume of the fluid inclusion studies carried out over the past half a century or so, majority of them are devoted to study of ore deposits and the hydrothermal ore deposits.

So, the literature on them is dauntingly vast, and it is not possible practically to give a very detailed idea or going into the to an exhaustibles review of the application of fluid inclusion studies to ore deposits. And we also know that essentially the hydrothermal deposits that we know of the hydrothermal deposits that generally we discuss, with always discuss in terms of the possible sources of such hydrothermal fluids.

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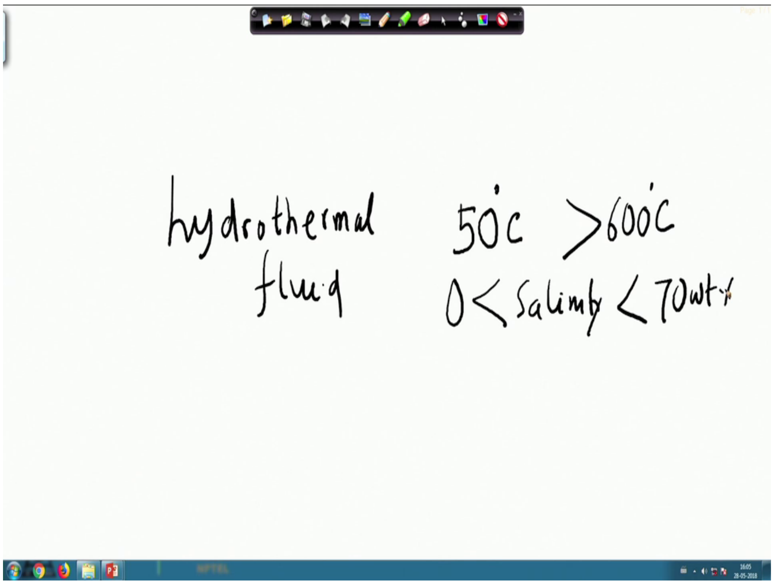

And we know that the hydrothermal fluid the temperature range could be anything from starting from 50 degrees Celsius to greater than 500, even sometimes even greater than 600 degrees Celsius as some of the cases we will be considering.

And the another; so, this is the kind of the temperature ranges, that we see in the hydrothermal deposits. And their composition gross chemistry the way that we have express them as salinity in weight percent it is equivalent can be very close to 0 almost sometimes your water to values sometimes which will be almost like 70 weight percent or upon near about that.

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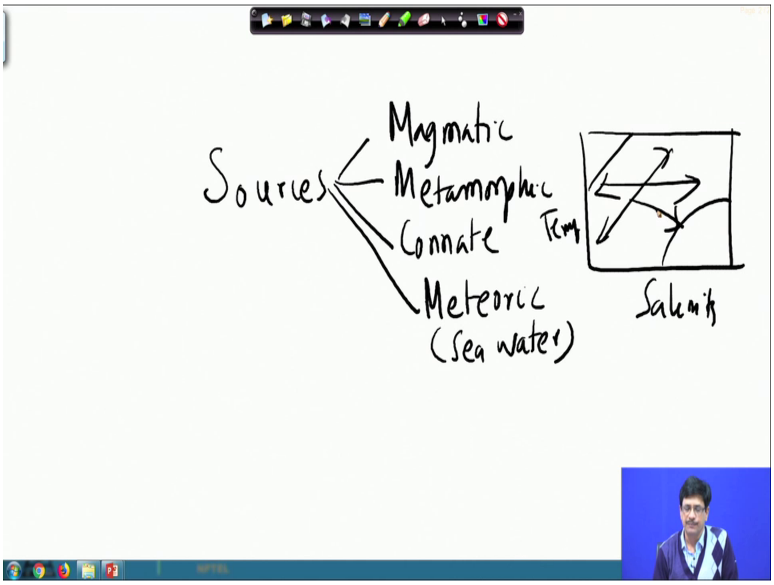

And we also know that these hydrothermal fluids can have a very diverse source. And the sources of them dominantly they could be magmatic, metamorphic, connate and meteoric. A meteoric also sometimes even we can include sea water; which is a modified meteoric water, we know it contains about 3.5 weight percent in terms of salinity. And we know that all these are the dominant types, and some other type like javelin water, it is involvement in ore deposit formation is not that very well-known.

And the magmatic deposit magmatic fluid, metamorphic fluid, connate fluid, meteoric fluid, there all having their own identity in terms of their temperature and salinity characteristics. So, the basic idea is that whenever we are attempting to study the original and evolution of an of a hydrothermal ore deposit through systematic fluid inclusion studies selecting the fluid inclusions and the appropriate ones they classifying them into different types and then taking their micro thermometric data.

So, we would like to essentially (Refer Time: 06:37) the fluid origin or you what we say the ancestry of the fluid. And not only that with the help of fluid evolution diagram that we saw before on a salinity and temperature of homogenization plot, we generally see that there could be many possible trends; like a mixing trend, like a boiling trend, could be different types of mixing trends which can be decipherable from the paired salinity and temperature of homogenization data and then we can decipher about the fluid source, the fluid the path of the fluid evolution.

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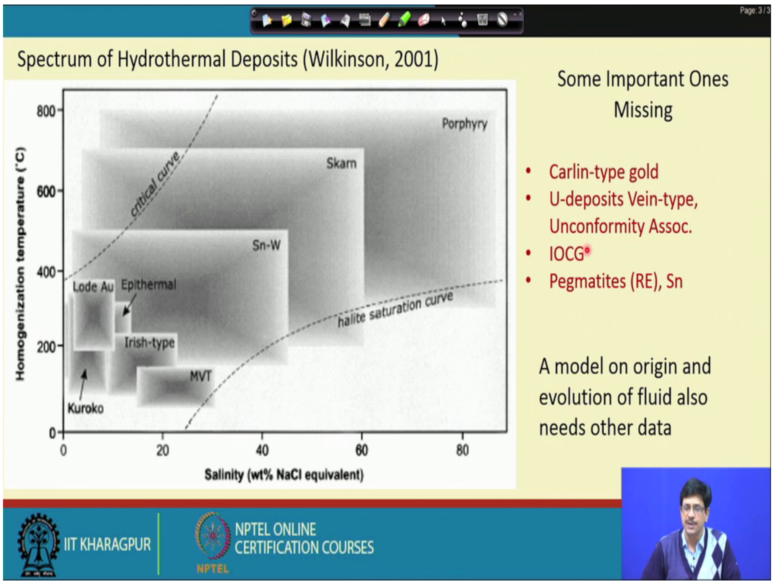

So now on that backdrop, I would just like to start with the diagram. This diagram is a composite diagram on the temperature for say salinity in weight percent NaCl equivalent I shown here and delineating the fields of some important hydrothermal ore deposits. Porphyry copper deposits, the skarn deposits which are the essential the tin tungsten deposits, porphyry copper are the copper molybdenum and gold.

There are some pegmatite related tin tungsten deposits the epithermal deposits which occur in the in the top brittle deformation zone of the earth's crust. And the lode type gold deposits are known as the orogenic gold deposits, the Mississippi valley type deposit what we can see here, that this kind of a broad framework can be possibly proposed collating or synthesizing information from a numerable such ore deposits of occurring in different parts different continents. And then summarizing the data and trying to make a generalization, although exceptions will always be there from such generalities.

And these are the different types of different areas like the porphyry deposits skarn the tin tungsten deposits, epithermal deposit, Irish deposit, lode type coal deposit, Kuroki deposit and Mississippi valley type deposit. And the some of the as I told you that such kind of discussion can be very it is very difficult to make an exhaustive summary or exhaustive review. As we know that there are many other such important deposits also which are missing from this synthesis. There are the important very rich the carlin type gold deposits which occur in the western United States in the states of Nevada mainly.

And the unconformity related uranium deposits like the Athabasca basin and the MacArthur basin in Canada or Aligatha river basin in Australia. And the iron oxide copper gold deposits these of the type of the famous Olympic dam deposit; where there are each mineralization of copper gold and uranium in a single locality and in the area in the golden crater on in south Australia. And different pegmatites rare element bearing pegmatite tin tungsten bearing pegmatites which also do have some very characteristic fluid in term very and their characteristics of fluid is very important. And they are also an important class of the ores; which contribute different types of metals and minerals to the industry.

So, essentially we these kind of diagrams will always be always be pertaining to the characteristic of the aqueous strip, because we are we should also keep it in mind that we are plotting the homogenization temperature versus salinity.

So, we and at the most these kind of diagrams can have the data from the aqueous biphase inclusions, from where we determine the salinity from the depression in freezing point of eyes, and the temperature of homogenization. This data also to include the halite bearing polyphase inclusions, where we also determine the salinity as you can see the halite saturation curve which also plotted here compared to the diagram which represented the fluid inclusion composite fluid evolution diagram. Here it is the critical curve.

So, it would be interesting to see when we are introducing this particular course for beginners, and to appreciate the application of fluid inclusions and to pick this topic up for their further study pursue this particular methodology and technique for the research. It would be always necessary to look into some of the case studies, or detailed analysis as to how a particular model on the origin and evolution of the ore fluid could be formulated, could be could be sort of synthesized from fluid inclusion data right from the point that we identify inclusions and classify then, take their homometric data and at even I present them on conventional plots.

So, this whole process we have to demonstrate through a through some selected case studies. And while doing so it is also important to note that at the model on origin and evolution of ore fluid in any deposit is definitely not solely based on the fluid inclusion data, and right at this when this was so when there were no much of sophisticated instrumentation available and maybe 3 4 decades back when or the such fluid evolution model could be presented solely based on fluid inclusion data.

But it is also important to substantiate or correlate or make the fluid inclusion data corroborated from other sources such as the stable isotopes which also isotopes of oxygen and hydrogen sometimes even carbon and sulfur. These are also analyzed from agent when their possible either through the alteration minerals or from the fluids which is extracted from the fluid inclusions.

So, that the model on the fluid origin such as a fluid mixing model or a boiling kind of model or cooling kind of model. It is more so for the mixing kind of model, which need to be corroborated or is better corroborated substantiated through data, such as other data such as stable isotopes. So, with this backdrop we would like to just make a brief look in some of the ways that the data have been presented.

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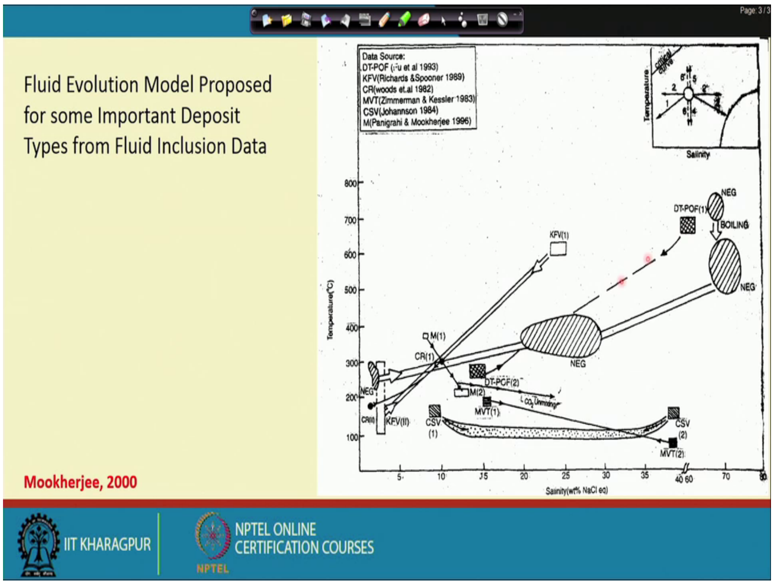

So, this diagram has been taken from Mookherjee 2000 a book of Ore Genesis Holistic Approach. Where we try to make a diagram for general understanding as to what are the different possible scenarios that have so far been presented in the context of some important deposit types. The ones with is this kind of hatching which is labeled as NEG the new England batholith in Australia in the South England batholith, where there is occurrence of a tin tungsten mineralization.

So, we could see that this deposit of fluid has been in interpreted to have evolved in such a complex manner, starting with a very high temperature very highly saline fluid, boiling fluid which is evolving down to intermediate temperature and salinity values still in the 2 phase field. And then with gradual warning of the magmatic phase with incursion of low saline low temperature meteoric water, it is actually giving rise to a mineralizing system, which starts with beryl, quartz, topaz kind of rock, and then with veins of a cassiterite quartz and then finally, giving rise to the sulphides the veins in the late alteration assemblages.

This is an interesting scenario the melange khand scenario where this is the fluid there are there is mixing of 2 fluids which is interpreted which we will be discussing in the little bit a little bit of greater details. This is the kind of a mixing trend which has been interpreted for a vein type deposit. And what is (Refer Time: 16:21) here a CR 1 is the is the epithermal crew deposit from Colorado and the kind of salinity temperature variation that we get again with a mixing trend.

And the one which is shown here is MVT 1 which is the Mississippi Valley Type deposit and 1 and 2. There also we find that there are mixing trends which are established between fluids of higher high salinity to moderately low or low salinity kind of fluid all are both being falling in the lower temperature within resin. And this box joining the dachang polymetallic deposit, here also a mixing trend is established between the fluid with very high temperature salinity to very low temperature and low salinity kind of fluid.

So, these are these cases whose references will also be detailed in the in a handouts. It is always good to look at those work and look at the fluid inclusion characteristics. How this kind of model or somehow this kind of synthesis has been made to understand the fluid evolution like the one which I was showing here, this is the scenario taken from calidronide sulphide in the sulphide deposit in the calidronide in Sweden.

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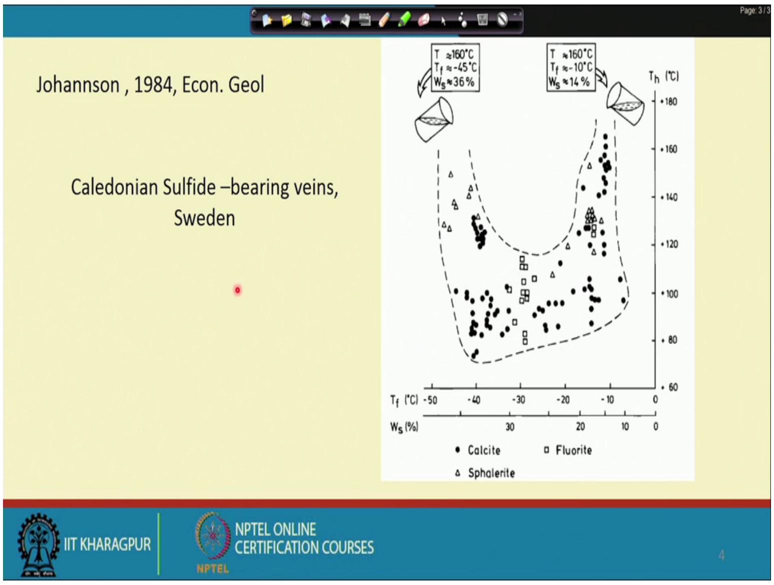

There are who is which the authors represented in a very decorated manner. If the salinity and temperature recorded from different like for example, the black dots I representing from calcite, the triangle from sphalerite and the square from fluorite.

So, these inclusions fluid inclusions their salinity temperature characteristics are falling in this kind of band, which the author interpreted in terms of mixing of 2 fluids as shown by the fluids into beakers the identical temperature and one the one component having salinity as high as almost 36 weight percent NaCl to temperature of 14 weight percent NaCl and these being interpreted as 2 different types of fluids.

Now, when we get such kind of missing trends, it is definitely is a subject of debate or discussion is to what origin or what ancestry we would assign to this particular fluid components when there is a mixing. Normally any fluid which is a lower temperature, but a salinity high salinity sometimes varying to 25 30 weight percent NaCl. We generally ascribe them to be a connate source, because those are the fluids which are mobilized from the sedimentary strata and are never subjected to very high thermal perturbations. And they generally migrate a long distances and the carry the metals and deposit with encountering some different physicochemical environment.

So the general idea whenever we see a very high temperature and very high saline salinity fluid the salinity going to 70 percent or more. There the there the general idea is that this fluid must be magmatic fluid. Because it is a this magmatic fluid generally a result from exhalation of the volatiles from crystallizing granitic magma and during the time during this situations corresponding to a first boiling or a second boiling kind of condition in a granitic magma. The fluid which gets partition into the fluids which gets separated from the crystallizing melt the most of the volatiles and the light elements and most of the species are getting transform; in addition to the base metals as well, get transported into the volatile phase and that becomes very high saline.

And then generally in fluid which will be very low in a salinity and temperature is generally ascribed to a meteoric source. Because that meteoric fluid has retaining it is signature, chemical signature has only been generalized to the fracture network in the rock. And that is all it potentially we can mix with many other fluid sources like a connate fluid or a magmatic fluid and give rise to mineralization.

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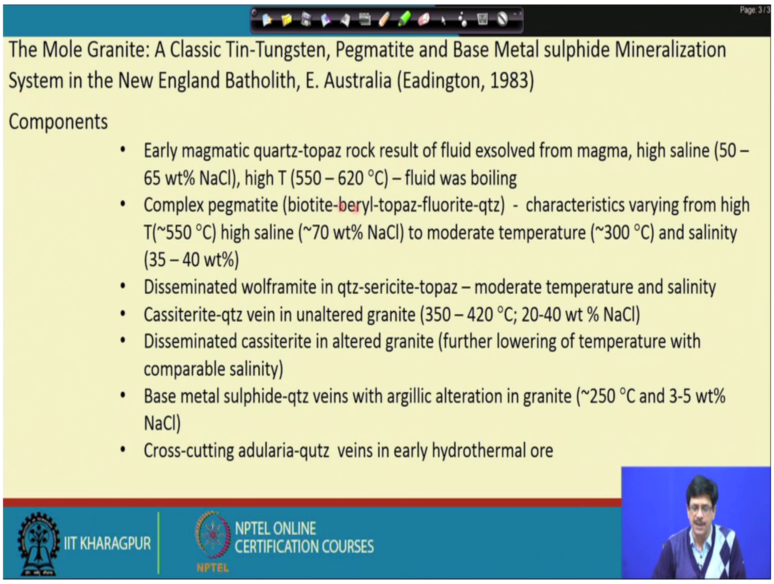

So, will just see one of the this is of course, from old literature this is from adding. So, 1983 it is from the mole granite, where a classic tin tungsten pegmatite base metal sulphide mineralization system in the New England Batholiths in Eastern Australia. So, the component of the mineralization is an early magmatic quartz topaz rock which I stopped which is the stage at which there was no much of deposition of the ore minerals.

So, the essentially quartz topaz rock where the salinity of the fluid is from 50 to 65 weight percent NaCl, and temperature is high almost more than 620 degree Celsius. These are all determined from the homogenization data, but these temperatures are also not pressure corrected as suggested by the authors. Then it gives rise to a complex pegmatite, biotite beryl topaz fluorite and quartz, characteristics varying from high temperature to high salinity again and to moderate evolving down to temperature low as 300 degree Celsius.

Then it gives rise to a disseminated wolframite mineralization quartz sericite topaz. And the then the main cassiterite quartz vein in the unaltered granite; where the temperature is decrease substantially and also the salinity. And then disseminated and then the base metal sulphide quartz veins as shown in the diagram, with the argillic alteration in the granite, and cross cutting products veins where there is adularia and quartz veins in the early hydrothermal ore which is the sulphide.

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So, this is just for our own visualization, that whenever we say that the fluid was a very high salinity, hence definitely this fluid must have been manifested in form of polyphase or halide or halite or even more than one total crystal bearing inclusions as shown here. This is a diagram for the multiple daughter phase bearing aqueous inclusions in topaz from the quartz topaz rock representing very high temperature and very high salinity.

These are the polyphase aqueous inclusions in quartz from the complex pegmatite. The polyphase aqueous inclusion in beryl again with complex pegmatite and these are the polyphase inclusions from the quartz cassiterite veins, till this stage that the fluid is maintaining it is high salinity condition.

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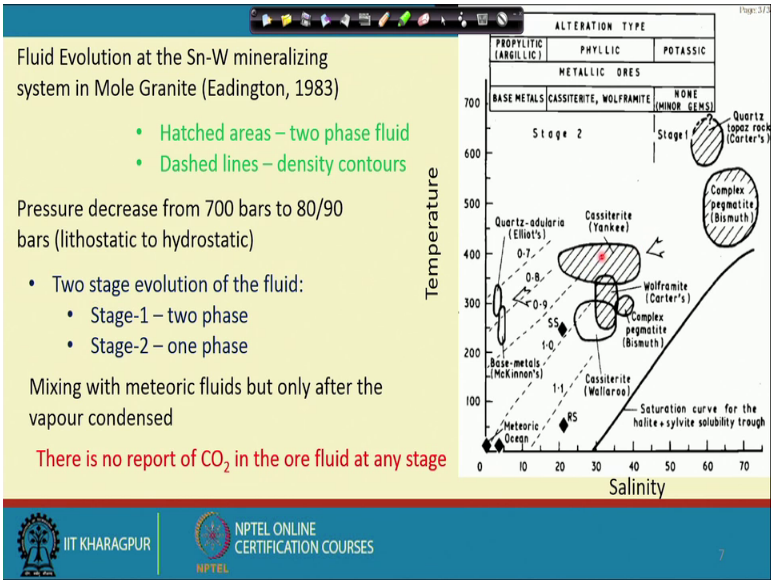

The composite diagram which just I showed it is a taken from here only.

So, this represents the temperature of the order of 600 or more. This is the quartz topaz rock from which inclusions where study in topaz. This is the complex pegmatite where the inclusions are study from also beryl as well as quartz. Most of the times inclusions could be studied in more than one such minerals of the constituent ore, and interpretations can be made. And So now, they had the interesting thing to observe here is, this area which are marked by hatching is essentially the situation in which there was a the fluid was in the heterogeneous condition means vapour and liquid coexisting conditions or in other words corresponding to a boiling situation.

So, that means, the fluid was in fact, having a high salinity liquid thus a low saline vapour. And as interpreted by the author. So, this existence of the vapour in the 2 stages 2 and the 2 phase condition of the liquor of the fluid did not allow the extraneous fluid or the meteoric fluid to get into the system into dilute. Only when the temperature substantially reduced and the vapour condensed, then only it the condition was more conducive for incursion of the meteoric water low saline low salinity meteoric water to come and mix with the system.

And so, the these are the dashed line are the density contours. So, the 2 stages so, the authors now from the inclusion data where the homogenization was mostly obtained through. So therefore dissolution of the daughter crystals and whatever was available to calculate the salinity density, and it was a 2 stage evolution stage 1 it was a 2 phase fluid and this stage 2 after the condenses then the vapour it got converted into only one stage. So, that means, in the lower temperature region the inclusions were only like as been shown here there all the liquid rich inclusions. Sometimes containing the rotary crystals with high salinity as well as towards the warning phase to the base metal stage the fluid changed its condition from a to a low temperature and lower salinity character.

Now interesting situation here is that in this particular deposit occurrence, there is no report of occurrence of in carbon dioxide which inclusions is always been a aqueous fluid. Although, there are many other such situations where the transportation and deposition so, when we are talking about in this case it is the deposition of cassiterite tin which gets transported in the form of any conditions where it is an SN 2 plus condition where the condition is supposed to be reducing. And then it has to encounter a condition. So, those kind of reducing conditions or sometimes subscribed to the presence of carbon component the fluid which is not observed in this particular case of mole granite.

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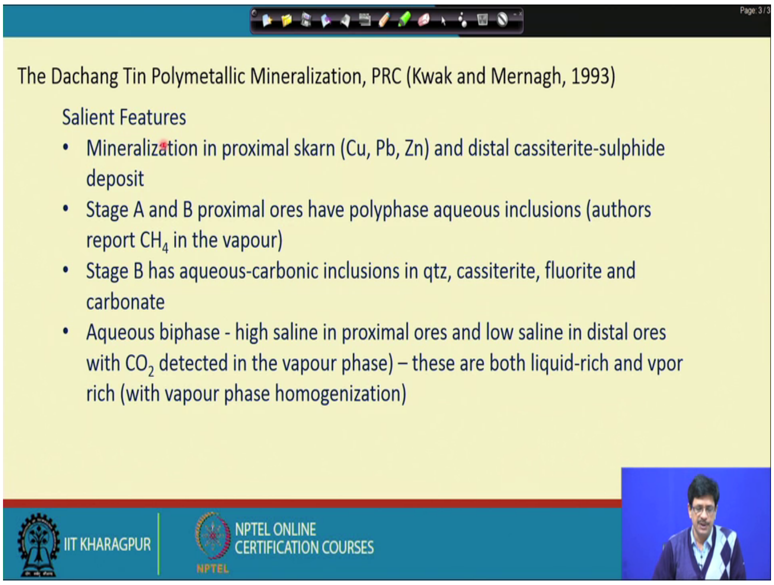

So, we are discussing these as; and then coming to another situation where we discuss about another polymetallic mineralization involving a proximal skarn, and a distal skarn the proximal skarn constitutes of copper lead and zinc mineralization. And the distal skarn is cassiterite sulphide deposit. So, here the authors have interpreted a multiple stages of the fluid activity in this proximal as well as the distal skarn.

And even though it is not when time or this scope within the scope of this discussion it does not allow us to go into the details of the mineral parazenes that was reduced by the authors. But such kind of the proximal and the distal skarns and the fluid inclusion studies in the different minerals, is has to be very much backed up with a paragenetic sequence reduction of the paragenetic sequence. So, that we know exactly which fluid we are sampling from which stage of the evolution which stage of the evolution of the fluid.

And in this where in the stage A and B proximal ores have polyphase aqueous inclusions; the stage B has aqueous carbonic inclusions in the quartz cassiterite, and fluorite and carbonate in this dachang polymetallic deposit in People’s Republic of China, has been taken from Kwak and Mernagh in 1993. So, the aqueous biphase is high saline in proximal ores. And low saline and distal ores with carbon dioxide detected in the vapour phase these are both liquid and vapour rich.

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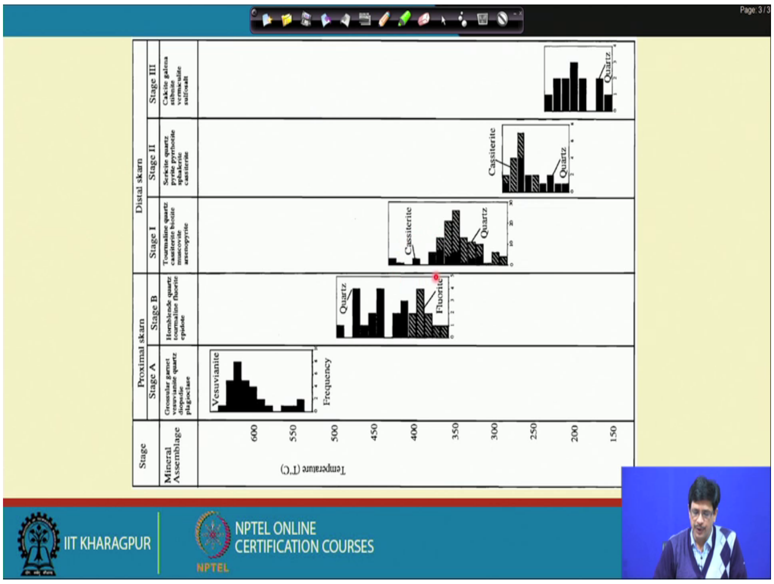

And this diagram is again a composite diagram, which will see the situation is somewhat comparable to the one which we discussed in case of the mole granite. But here it is a typical skarn deposit. And this proximal skarn and the distals skarn, as you could clearly see here also the proximal skarn which is essentially developing a (Refer Time: 29) mineralogy typical skarn mineralogy.

And it is fluid inclusion characteristics are with very high temperature more than 600 degree Celsius, and high saline and the fluid gradually evolves to the distal skarn the stage 3 of the distal skarn in which it is calcic; calcic sort of where the fluid becomes more I mean more and more in pH.

And it give rise to deposition of calcite sulphides, legalina stibnite deposited in the distal skarn in the (Refer Time: 29:45) sulphide stage. And we could see the situation in which all these histograms are representing the temperature of homogenization of the fluid inclusions. Fluid inclusions aqueous see aqueous see here started from cassiterite and quartz both.

So, these also is a situation in which similar involvement of less evolved low saline low temperature a fluid with high temperature high saline fluid of magmatic derivation is giving rise to the mineralization, ok.

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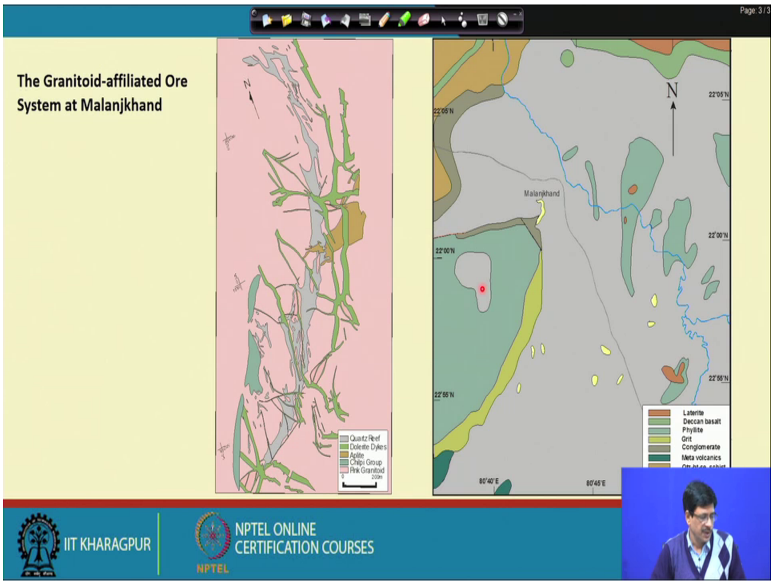

So, we will continue our discussion on the application of fluid inclusion studies to the ore environment. And we will take up other case studies which will also give us some more insight as to how we can judiciasiouly interpret the fluid inclusion micro thermometric data. And with our knowledge on the solubility of metals, the chemical control on transport and deposition of the metals will correlate and we will continue discussing in the next class.

Thank you.