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

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Lecture - 22
Application of Fluid Inclusion Studies to Ore Environment

Welcome to today's lecture, we will continue our discussion on Application of Fluid Inclusion Studies to Ore Environment. Today we will discuss about an interesting Indian deposit and since, this work is an in house work produced from our laboratory here.

So, it is just to given the intention here; to just to take you through as course in which the fluid inclusion studies from the very beginning to from the occurrence of the ore in the infield and then the different types of ore regimes the fluid inclusion there is sample from them, studied and then presented and how the interpretation was made.

Here it may be that the interpretations and the ideas, which is presented here is not important, but there may be equal (Refer Time: 01:20) they are subject to criticism or they may be still be debated, but the idea here is just to take you through a process since, you will be those who will be beginning to learn and apply this particular technique to their research or their study and pursue these; to learn this to how fluid inclusion techniques are applied this is just as a as an example.

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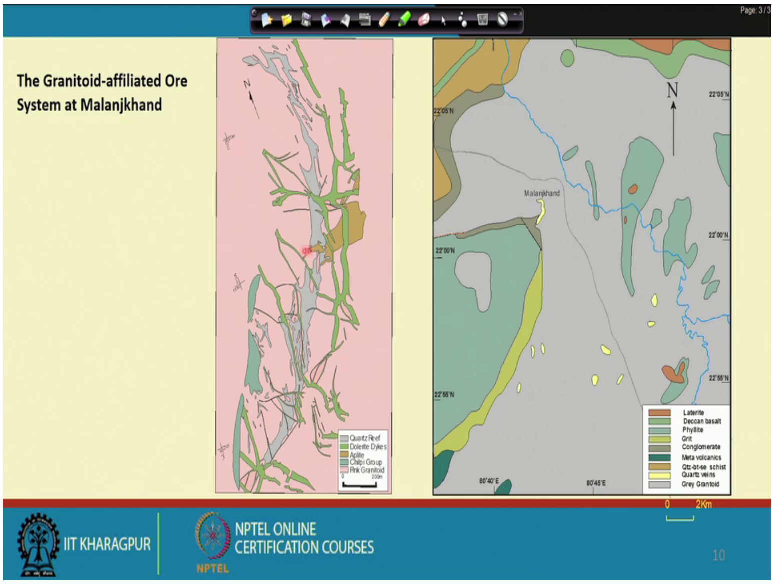

The Granitoid-affiliated Ore System at Malanjkhand

So, this tip of this example has been taken from the Malanjkhand mineralizing system. Which is essentially, is a deposit which is hosted in a magnetic rock as shown in this map here on the ridge on a local scale geological map in one is to 50000. We could see this yellow part is the one which is representing the mineralized ore body and the gray part is the part of the balance con grano de rite, which occupies about the whole the total area of that particular pluton is about 1400 square kilometer.

And within that this particular ore body it its actually, about 3-4 square kilometer at the most the length would be about 2.2 kilometers and the width would be about 0.8 or so. And the rock units, which I shown here in different colors like green and yellow are the younger chilpi hut group of rocks, which are not related to mineralization.

And this we know is part of the northwestern margin of the bastar craton, which is juxtaposed with the central Indian tectonic zone at the southernmost element of it is a C I S the Central Indian Suture. So, this is the geological local mine scale geological map; which shows this arquette body, which is; on the on the surface mine plan. It is a continuous body of quartz, which is actually called as a quartz reef or you can called it is a mega vein, running for about 2.2 kilometer in its length and obtaining a maximum width of even 100 meters at places, but in average of 60 meters or so disrupted by later aplitic small there could there could see a small aplitic body here. And also the separated by later dikes later mafic dikes, which are also conspicuously post ore they do not have any role in controlling the mineralization. So, this is aplitic body and the mafic dikes are all post ore.

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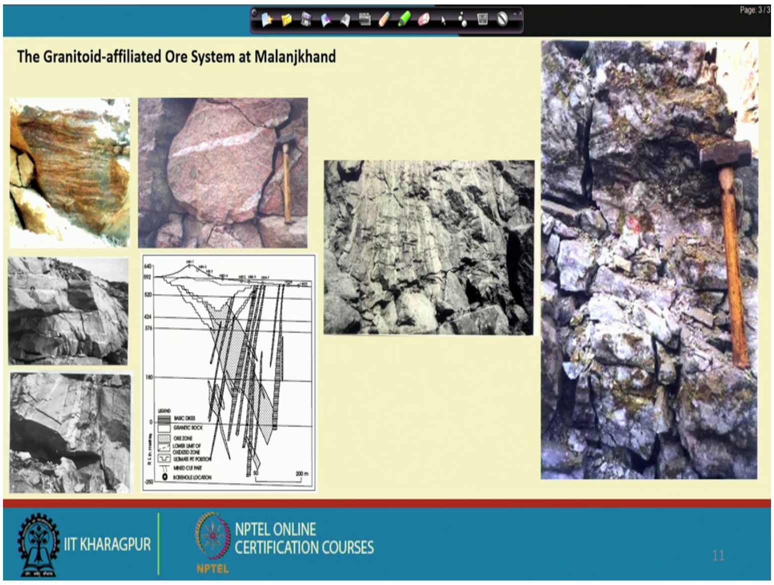

The Granitoid-affiliated Ore System at Malanjkhand

Now, if we look at the different domains the way the ore occurs in this particular deposit. This is a typical look of the quartz reef containing rich occupy red mineralization and that is the one which continues for 2.2 kilometer long distance.

And the other situation in which that, we could that the surrounding run it does have this is quartz, which you call them a stringers or veinlets of quartz. In near to the quartz reef they do have such kind of a parallel disposition and in the moving away from the main median located quartz reef, which contains, the bulk of mineralization the bulk of the reserve is coming from this particular reef.

And it has this kind of randomly oriented stringers, quartz stringers, sometimes quartz are fills with the continuing variable percentage of variable propulsion sort of potash feldspar and they are also mineralized. And the rain pattern sometimes on the exposures on the mine phase scale also look like parallel disposed here, but it is not possible to establish any such time relationship because, but what is more cosific more clear over here is they do not possess any such kind of feature at typical stock work and a vein network.

We generally, is observed in the porphyry copper young porphyry copper deposits, classic porphyry copper deposits in the and we know that in the convergent settings in Chilean Andes and south west American cordillera or in many of the other localities in the world.

So, then the work definitely so if, we are interested to work out the ore fluid and try to character you characterize the ore fluid in to know, what kind of a genetic category it could be belonging to and even without even not having an objective to classify to any existing known genetic type, just to understand the fluid characteristic in this particular deposit. Of course, with the ultimate objective that yes finally, when we synthesize the data, we do have to say, whether it is a porphyry copper deposit or not a porphyry copper deposit if not then what?

So, we sampled quartz from all these entities the main of the quartz reef, which is a cycling of 2.2 kilometer. The only problem is that this quartz reef has undergone later shearing and brittle deformation. Whereas, these veins have survived such kind of later brittle deformation and we sample we sample the quartz from the stringers, we sample the quartz from the reef, we sample the quartz from mineralized thin veinlets like this and also from here.

And this diagram, it just to give you an idea that this mineralize quartz reef is actually nothing but, actually it is a continuous body in three dimensional space, which also which is just giving a one drill quartz section reconstructed. They do have a down depth extension of almost like 800 meters or more, and at depth they generally, have a composite sheeted kind of nature is it happens and is it all this interpretation goes did this quartz reef occupies a fractures zone within the granite.

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Type – I Inclusions in Reef and Stringer Ores

Type – II and III Inclusions in Reef and Stringer Ores

What kind of fluid inclusions we see in them? Essentially if we would like to first question that will that will possibly arise that whether these mineralization in the main reef and the small mineralize stringers in the granite are the same or anything different. So, you sample the get the samples and then look at fluid inclusions in them.

So, when you see the fluid inclusions in them we do not find anyone much of a difference so far as a fluid inclusion types are concerned. The fluid inclusions in them see their old photographs aqueous by phase I could say that they are the type 1 there is the most dominant types of fluid inclusions observing the quartz reef as well as the stringers and even there are some quartzo feldspathic rich veins we can call them as pegmatite kind of vein.

And sometimes also we get disseminations in granite and we have different ore regimes. And when we see the inclusion types we see that these inclusion types occurring them is very consistent, only with the fact that this type two inclusions; which are the aqueous carbonic inclusions or rather very rare in the reef I will come to that explanation later.

And there are instances so, we have dominantly 4 types of inclusions; the type 1 the aqueous by phase inclusion as shown here, the type 2 are the aqueous carbon inclusion with a 2 liquid and carbonic vapor and the type 3 are the pure carbonic inclusions as you have described them before, they are either occurs in the typical mono phase or appearance of a vapor bubble on cooling slightly from the room temperature. So, they are the pure carbonic inclusions.

And then we subject them to micro (Refer Time: 09:27) metric runs, what we observe is that; the temperature range of homogenization that we get for the aqueous by phase inclusion is more or less similar in almost all the ore regimes that we have sampled. Even there are some veins which could be distinguished as containing molybdenite or the greater proportion of molybdenite then chalcopyrite they could also be categorized the something as a different entity during sampling and during categorizing them sample wise distribution of fluid inclusions.

So, they also are similar so, that gives a firsthand information that; the mineralization the fluid that caused the mineralization in the main quartz reef, the rich quartz rich chalcopyrite chalcopyrite pyrite mineralization with variable concentration of magnetite and very small proportion of sphalerite and this is and simple mineralogy.

So, they are they do not indicate having any difference in the fluid chemistry of the fluid characteristics as for the mineralization in different domains are concerned. And here, as you could see the salinity is varying from almost very very very low to greater than 40 wet percent (Refer Time: 10:41) equivalent in both the dominant regime.

The temperature of homogenization of the by phase inclusions not corrected of course, for pres[sure]- pressure also do have a maxima at ore 160-180 degree Celsius and this also gives you an idea, how we draw the histogram. In case of this we take a histogram of 4 weight percent initial and in this we take 20 degrees interval in the class interval for the floating of the homogenizing temperature in the histograms.

So, this gives us an idea that well, the in terms of the thermal regime there is the characteristic of the fluid, which was responsible for the mineralization are more or less the same. (Refer Time: 11:35) Mention that this fluid inclusion work is very well corporated with the mineral paragenesis, only when we assure that quartz put position is a continuum and has spanned the deposition of the sulfide minerals in this deposit from a thorough textural study of the sulfide and silicate in this particular ore body.

Now, the interesting situation here is, that well they a type 2 and type 3 inclusions are rather very rare in the reef or the quartz reef main quartz reef, but in the stringers vein ores and the mineralized stringers mol branded bearing stringers and many of the chalcopyrite bearing veins which are very very frequent close to the main reef and then generally, die out as we move away from the main reef. They do contain carbon this carbonic inclusions, aqueous carbonic inclusions and pure carbonic conclusions.

So, if we just as we were discussing about the thermo barometric exercise. So, we have a rough idea about the temperature range, only in the case of the as we mentioned before these type 2 inclusions are the difficult inclusions because, most of them leak before their total homogenization temperature, the same thing also happened and see number of data obtained from them is rather small compared to the total number of inclusions that was studied in this particular deposit.

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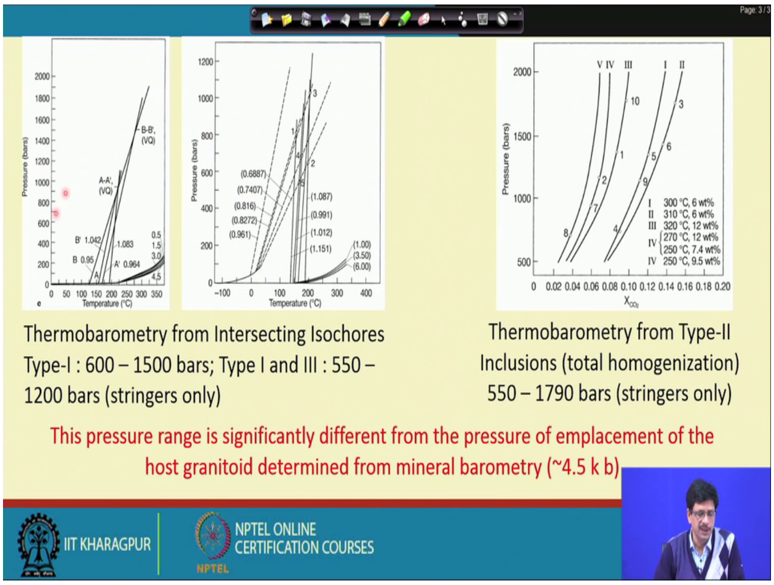

Thermobarometry from Intersecting Isochores
Type-I : 600 – 1500 bars; Type I and III : 550 – 1200 bars (stringers only)

Thermobarometry from Type-II Inclusions (total homogenization)
550 – 1790 bars (stringers only)

This pressure range is significantly different from the pressure of emplacement of the host granitoid determined from mineral barometry (~4.5 k b)

So, here I will be presenting you with a situation which is of course, very rarely reported in nature. The interpret intersection of aqueous inclusion themselves, which only as a requirement that they have to be coeval inclusions, they are in the same grain of the host mineral as part of the three dimensional network. And the only condition is that the inclusion which is homogenizing at a lower temperature will have a lower density, then the inclusion which is homogenizing at a higher temperature which can be explainable as sort of the special cases, which I will not be discussing in details.

But the as far as the presentation of the data so, they were all the salinity and density we have calculated with the standard methods that we discussed. And these aqueous; such some such sets of coexisting aqueous inclusions, when we intersected the their isochores for the reef ore, as well as the stringer ores and all the ore types together. They generally give us temperature pressure values of about 600 bars -1500 bars and the temperature within range of about 300 degrees - 200 and 220 degrees Celsius.

Now, we could possibly have some idea is to what kind of what is the degree of pressure correction that we may be needing so, when we do the see the temperature maxima is about 160, 180, 1-200 degree Celsius. Then we know that the what kind of what is the magnitude of pressure correction will be needing for such inclusions and we infer about the characteristics of the ore fluid.

So, in a way what we observe here that the gross thermal characteristic of this; fluid is in no way comparable to the very high temperature magnetically derived fluid, that we see in porphyry copper deposits. So, the generally, here a point of inference comes here that well this situation is possibly different from what we see them in typical porphyry copper deposits.

And then here this is the that the diagram with the photograph which showed that the coexistence of the type 2 and the type 3 and type 1 and the type 3 inclusions; like the one here this is a type 1 aqueous by phase inclusion. And this is the type 3 that is pure carbonic inclusion and we know that under this circumstance, we and there if we find them in the same grain of the host as we can see the see here the photograph they are very much on the same grain just on a different plane so, this is why the type 1inclusion is out of focus.

So, if we plot the and we got some about 10 pairs of such coeval occurrence of these type 1 and type 3 inclusions. There we see the temperature and pressure value what we get is all very much in conformity about 550 -200 bars and temperature within that 250- 300, 200 are being less than 200 degree Celsius. Because this should represent a lower temperature regime, where the fluid was actually in its immiscible two liquid condition, then we could still expect a little bit of lower pressure and lower temperature. So, they also conform to the 550- 1200 bars condition.

Now, coming to the type 3 inclusions as discussed before out of a good number of such inclusions, which are observed and whose compositional characteristic as in terms of their per shell homogenization of the carbon dioxide were obtain or finally, just about 10 inclusions, which are reasonably the small sized inclusions for which reproducible total homogenization temperatures were obtained and all of them were homogenizing into the aqueous phase.

And when we the exercise, which we elaborated during the thermo barometry exercise using our modified routledge Kong equation and the methodology which was discussed and we could see here that the pressure and x c o 2 values, that we arrived at or falling on the isotherms and these give us a little bit of higher from 550 to about 1790 bars of pressure.

This gives us an idea that yes if the mineralization took place it more or less a comparable crustal depth, then the pressure condition must have varied from something; which is intermediate to lithostatic hydrostatic or completely hydrostatic. And they would represent if it happens to be pure purely lithostatic to hydrostatic, then they would represent some 4, 5 kilometers depth of the mineralization taking place and if we make it to be a hydrostatic condition is 500 bars also correspond to that.

So, that would give us an idea that, well this particular mineralization what is the temperature and pressure with the depth condition of formation. So, when we, when you compare that what is the situation as far as the mineralization is concerned or we can better use this diagram to understand.

So, this is the host granite and this is the mineralization. So, if the mineralization and the host granite were at the same crustal level, then we should get similar pressure also from the host granite, but when we did some thermo barometry exercise on the host granite, we got pressures of the order of 4.5- 5 kilovolts, we representing about 13, 14 kilometers depth of beginning of the crystallization of this granite.

So, we would assume; that is the after the granite actually started to visualize it was the it definitely moved way up in the crust and then finally, after getting a rested at a lower at a soluble condition corresponding to 4, 5 kilometer of depth this mineralization took place.

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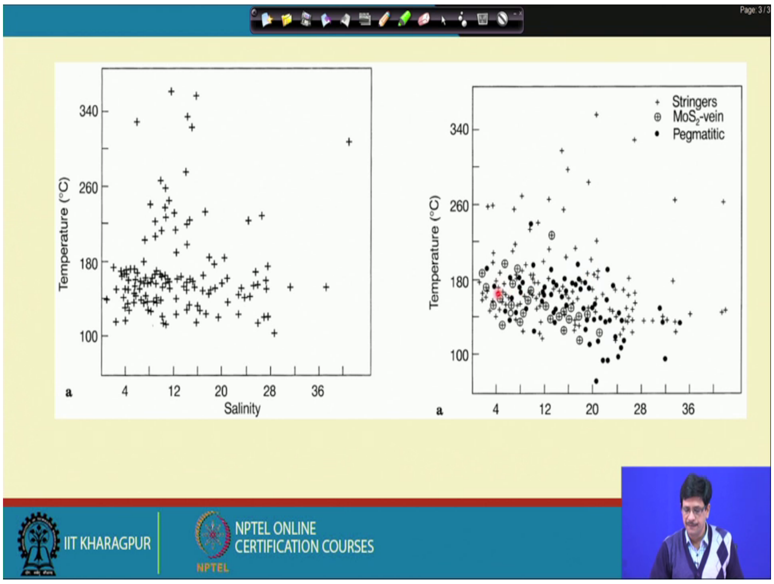

This scenario is also quite different from what we see in the typical porphyry copper situation.

So, now when you we in this case we are plotting the temple pair salinity temperature data for the entire samples, that we studied in this particular deposit. Now this is the salinity temperature diagram, we see that there is a lot of scatter and we could possibly think of fluid mixing because, of low salinity and moderate temperature to very high salinity moderate temperature and sometimes the temperature is also high.

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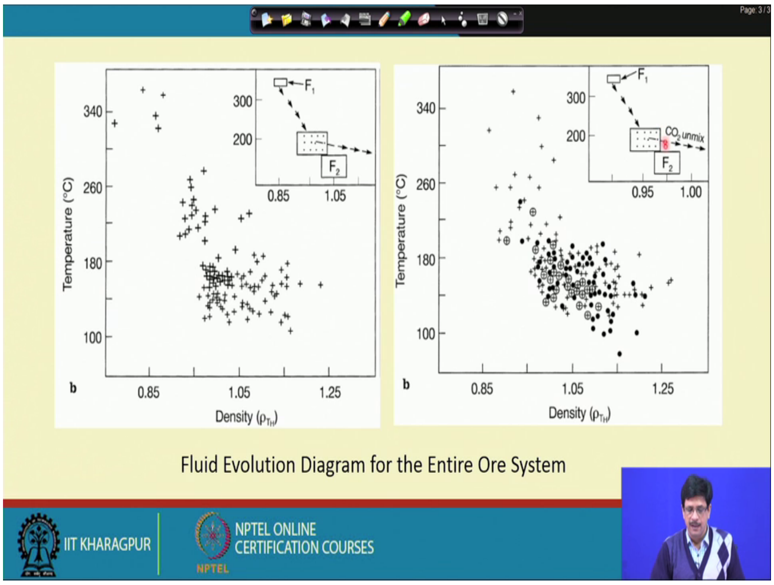

Fluid Evolution Diagram for the Entire Ore System

So, this only; this is the diagram where the temperature and density are plotted, and these only gives us a little bit of advantage, because the data compressed and we can interpret the data more conveniently if we put them on a temperature density diagram.

So, if you put on the temperature density diagram, it can be visualized that this particular situation both same in the reef as well as in the stringer domains the vein domains, we see the same path of evolution. We could consider them that there were 2 fluids; we could consider that the this is the F 2 fluid which is which would correspond to a higher salinity and higher density moderately high because, here the salinity value cluster it about under the high salinity value you can go to 35 40 degree centigrade or maximum points are clustered about salinity of 25-30 weight percent.

And then this if this could be imagined is the second the one of the component of the fluid and this is another component of the fluid and if I mix the 2 just show as has been shown here on the on this diagram. The only thing is that, the any mixing process, if the fluid volume are unequal, then it will always be the larger volumes characteristic which will predominate and that is what has happened it is what is visualized in this case.

So, we visualize that it is because of the mixing of 2 fluids one is one signature is of a low temperature, a lows are low density, fluid and a moderately high salinity and low temperature, moderately low temperature of the order of 200 degrees or so, because these are pressure uncorrected.

So, this is the picture that could possibly we best explained the scenario. Now, if the 2 fluids are mixed, if this is the mixing domain, then how is it that we are getting fluids of a higher salinity also in this situation. So, here as discussed before, when we construct such fluid evolution diagram, we only have the scope of considering the aqueous fluid.

But then, the carbonic fluid also has been an integral part of this ore fluid. So, is it possible to have or incorporate some of the features of the carbonic fluid and then visualize the situation even though, we cannot plot anything on there here.

So, what actually is possible that ok, if we if we this is the F, F 2 and this is F1 and this is the mixing line and this box; would represent the maximum in the deposition of the host mineral quartz along with the sulfides, then the further increase, if we go to the salinity diagram also it is why it will be more clear, that we have further increase the salinity after the mixing of this particular fluid.

Now, here the carbonic fluid characteristics could possibly we considered here. So, as we know that if there is a mixed aqueous carbonic fluid, and then this particular fluid is undergoes or mixing means it is a separates a carbonic fluid is separated out of the aqueous fluid.

Then the solubility of these salts will be very negligible in the carbonic component. So, the remaining aqueous component, would have an apparent increase in its salinity that stage it happens in case of a boiling; when the vapor phase gets transfer get separated out of it because, of the negligible solubility of the electrolytes in the vapor, the residual liquid gets apparently more higher in this concentration of the total result solid and there is increase in salinity in the boiling condition.

A similar kind of situation could be visualized, then there is increase in the salinity of this fluid after the mixing process after the and then after only the unmixing of the fluid took place, which is very muchsupported by; occurrence of pure carbonic and pure aqueous inclusions in this host mineral.

So, the occurrence of pure aqueous and pure carbonic inclusion testifies to thus this kind of a mixing process and very elegantly explains; that well this mixing process brought about the deposition of the qua sulfide ores, but then after that the fluid unmixed, because of further drop in temperature pressure condition from changing from a lithostatic to hydrostatic or the situation.

Where the unmixing took place and the fluid became more saline with this unmixing process. So, this is just only very it is only a process like of how a an idea can possibly evolve, how the fluid inclusion data could be integrated and a model of fluid evolution could be depicted.

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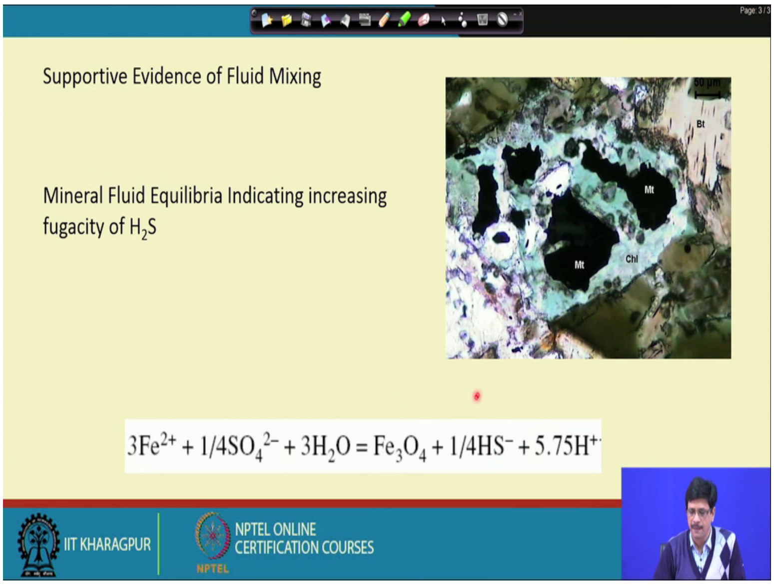

Supportive Evidence of Fluid Mixing

Mineral Fluid Equilibria Indicating increasing fugacity of H_2S

$$3Fe^{2+} + 1/4SO_4^{2-} + 3H_2O = Fe_3O_4 + 1/4HS^- + 5.75H^+$$

Now, this as I told that, this fluid in fluid evolution diagram, whatever we visualized it has to be corroborated from other independent considerations also. If it is corroborated then the model is more trustworthy and if it is not, then we will always be subjected to some questions and needs to be later clarified.

So, in the in the ore assembly, so here what exactly we are visualizing? We are visualizing that there a mixing of 2 fluids. Now when, which is not shown here; when we examine the fluid characteristics in the host granite, in the granite quartz there we find that the correct the salinity temperature characteristics of the fluid in the granite quartz has a has similarity with a F 2 component in terms of the temperature and salinity characteristics.

So, we presume that the majority of the ore fluid was actually contributed from the granite, where the fluid was actually present internally evolved into a low temperature and moderate salinity characteristics. And that fluid actually, was that fluid actually converged when this fracture was created when this fracture was created then fluid from the fluid present in the granite in this fracture network actually it converged into the main fracture zone, where the mineralization took place. And in this fracture zone only the mixing of the 2 fluids took place because, there is one main source of the fluid which came from the granite. And there is another source another fluid, which is suspected to have played a role on the site of mineralization and that is possibly the 1, which might have carried the sulfurous species and fraud over the mixing and the mineralization process.

So, is it possible to have such a situation; where there will be 2 fluids one fluid will have dominantly the metals. So, let us say iron and the copper and most of the majority of the metal is actually taken or contributed by the granite, evolving from the very stage of it is crystallization evolution process and converging into the fracture zone at a later stage modified in its temperature and salinity characteristics to a moderate saline and moderately low temperature.

If that fluid is channeled through the fractured zone and is now mixed with a fluid, which is little higher in it is temperature, but lower in salinity, but could possibly be charged with these sulfur species.

Then, such kind of a mixing is could possibly be accompanied by such kind of inorganic reduction of the sulfur species to give rise to magnetite and then, releasing of the sulfur species reduce sulfur species either in the form of H S minus or H 2 S. 1,1can write such a reaction in a way, so that either it could be H, H S minus and the H plus ion being liberated or H 2 S and also similarly H plus ion in being liberated.

So, what is the consequence of such kind of mixing process is that, when we in the ore we see that there are magnetite or this magnetite are early and later on late they later on give way to a sulfide stage of deposition of minerals like pyrite and chalcopyrite. Then this early magnetite is very much associated with a with extensive fluidization of the ferromagnesian minerals present in the granite.

So, this possibly in the in the close vicinity of the ore body so, what we could visualize that, what a from a fluid inclusion data the mixing process and the consequence of mixing has giving rise to mineralization with attendant with the sulfate, when they will be precipitated there will be increase in the P H of the fluid, and then the unmixing of the aqueous carbonic fluid to aqueous and the carbonic component, and such also would result in late calcitive veins very much agrees with the observed fact even though they are very small in proportion.

And also, a situation corresponding to a chloritic alteration of the (Refer Time: 29:11) close vicinity of the granite where such kind of a reaction. And this chloritic alteration will be very well explained by liberation of the H plus ion, which will so initial this H plus ion will be consumed or will be they will these ferromagnesian minerals will be acting as the sink for the H plus ion, which is generated with this kind of process.

So, is a case study I mean the right or wrong such kind of a systematic investigation beginning with the looking at the ore body, its mode of occurrence different types of the different ore domains the mineralization. And then sampling the appropriate host mineral, because in this case we have not been we have not studied any of the fluid inclusion any fluid inclusions in the sulfide minerals, which one can always follow it up and then to a systematic fluid inclusion studies on the different ore regimes.

And then look for what kind of differences they do display or they are all the same and then from the fluid inclusion diagram integrating the results of results obtained from the all types of inclusions, even this aqueous by phase, aqueous poly phase, and the aqueous carbonic inclusions. And they look at the fluid evolution diagram in such a way that it could give a very coherent picture of fluid evolution, which would also corroborate with the observed mineralogical and associated the alteration characteristics in the ore and the surrounding rocks.

So, we will continue with our discussion on some other typical ore types important ore types. So, we will continue.

Thank you.