Mineral Resources: Geology, Exploration, Economics and Environment

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Lecture – 19

Hydrothermal Processes (Contd.)

Welcome to today’s lecture. In the previous lecture, we had a brief look at the fluid inclusion technique for retrieval of temperature and gross chemistry.

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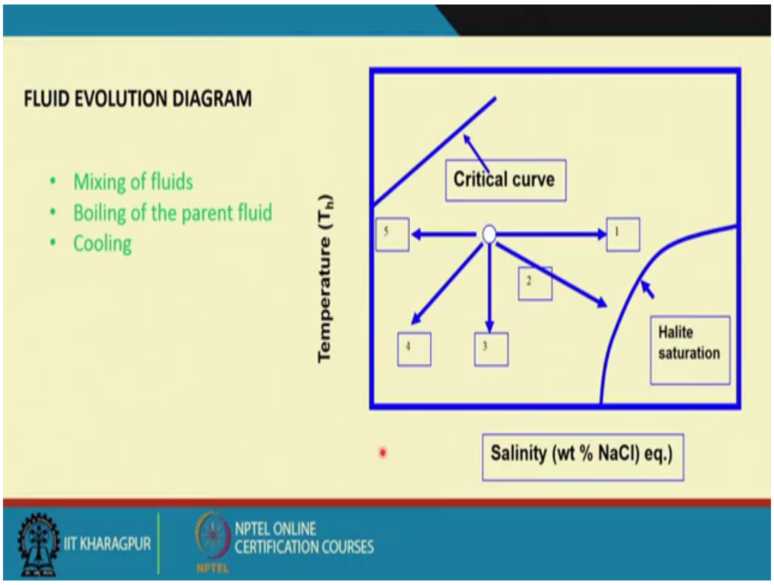

FLUID EVOLUTION DIAGRAM

- Mixing of fluids
- Boiling of the parent fluid
- Cooling

Gross chemical characteristics of the hydrothermal fluid and through systematic investigation or systematic study classification of the fluid inclusions into primary and secondary, and then careful meticulous micro thermometric experiments on them, during heating and freezing experiments on such a large number of fluid inclusions in the host minerals in an ore body, we have to acquired the data for the entire ore body sampling it at particular intervals and with the objective that we would concentrate the thermal and the chemical the gross committal characteristics of the ore fluid.

We saw that from the paired observations or temperature homogenization and salinity determined from the freezing study expressed, as represent anticline equivalent we plot them on the temperature has a salinity a diagram and interpret in terms of the fluid evolution and the processes that generally operate in the fluid in different ore forming environments, are basically broadly can be these processes such as the mixing of the fluids boiling of the parent fluid, cooling and even other processes un mixing and so on which will be seeing them.

So, with respect to this particular diagram, I would just like to highlight only 1 part here which is essentially, the path number 2 which is the boiling, which indicates that the fluid was fluid was boiling. On this diagram we have this curve which is the haulage saturation curve and this point corresponds to the room temperature solubility of about 25.3 weight percent NaCl and these NaCl solubility increases with increasing temperature and we can define something which is that the halite saturation curve. So, any fluid inclusion whose salinity or which falls on this particular field will have a solid daughter crystal of a sodium chloride or a halite and that would you dissolve at a temperature corresponding to this halite saturation curve. Now concentrating on this particular path which looks as if it is a increase in the salinity from this hypothetical fluid of a particular starting solidity, this path represents a path of increasing salinity with decrease, but not so, substantial decrease in the temperature of the fluid. Now we go to the fluid inclusion evidence, so this essentially involves boiling. So, if you go to the fluid inclusion evidence of how do we in the first how do we infer that there has been boiling is by this.

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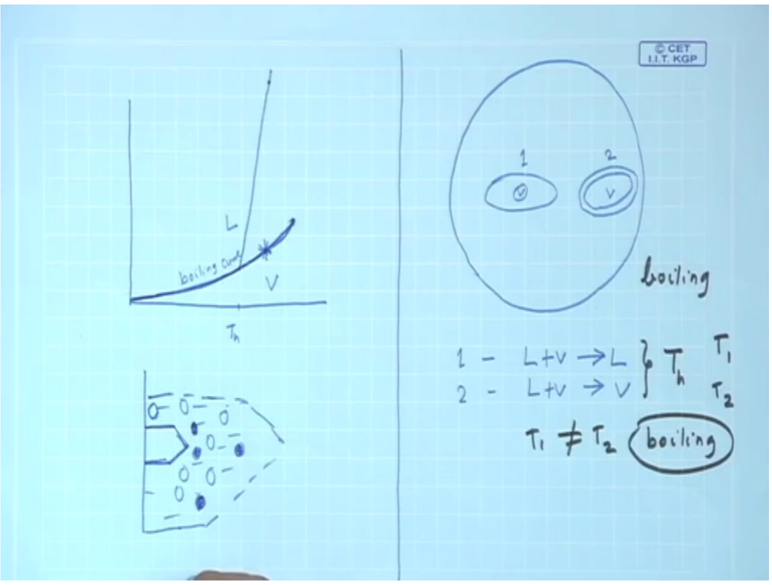

So, with respect to our diagram, so when with respect to this diagram which we just saw to explain the interrupt and phenomena. If we concentrate on this particular curve which is the boiling curve that means, it is the coexistence of liquid and vapour say for let us say for example, this point which is represented over here is the condition at which the mineralisation was taking place or the host mineral was precipitating here corresponding to this particular position particular point. So, this particular point essentially represents coexistence of liquid and vapour, so when this particular mineral was going on any fracture surface which I could represent something like this, this is a crystal which is forming.

So, within the facture space, there it was a this fluid was boiling with the coexistence of both liquid and vapour and when this particular crystal is growing and we know that this crystal will incorporate the fluid from which it is forming, and our assumption is that this the entrapping processes essentially homogeneous. That means, when this crystal would have grown to such larger crystal, then it will have incorporated this liquid and vapour separately, this crystal would have incorporated liquid as well as the vapour, but separately within it is lattice and when you see them in a section under the microscope what we observe is that there are you; since it is a single grain of the host mineral when we make a section, we will see them under the same field of view.

But there is an existence of inclusion as a small vapour and an inclusion with a very large vapour, because the one which was interrupted vapour, we will also evolve on this boiling curve with nucleation of liquid on the rim, the one which is interrupt as a liquid we will nucleate a vapour with further decrease in the pressure and temperature condition on the boiling curve and will give rise to a small vapour.

So, now what will happen here is that, we are doing, so they are occurring the same host grain of the mineral and T his is inclusion 1 and this is inclusion 2, and when we do the micro thermometric experiment inclusion 1 will homogenize L plus v to L and inclusion 2 will homogenize as L plus v to v, but there is a necessary condition that this homogenization of inclusion 1 and 2 must happen at the same T or which generation cylinder temperature homogenization Th. So, when this happens this gives us a very clear cut or the most conclusive evidence for boiling of the fluid. If we find that there are ingredients like this which are existing within 1 host grain of the 1 grain of the host and 1 is homogenizing into L plus v to L, number 2 is homogenizing into L plus v plus L plus v to v.

But these are happening at temperature of T1 and temperature of 2, where T1 is not equal to T2; there we cannot infer boiling or boiling should be ruled out. Now coming to a situation where we do see such kind of homogeneous in behaviour in the fluid quite frequently and when we plot the temperature salinity diagram, when we find that this is what is the trend then we infer boiling; now why you infer boiling. Because when we have a parent fluid of a fixed of a particular value of the salinity, and when a boiling essentially means the separation of a vapour phase going to parent liquid and as we know all know that the solubility of the salts in the vapour is very negligible.

So, whatever liquid will be since where, so this particular diagram is corresponding to the temperature salinity plot of the liquid which inclusion requires liquid it is inclusion; wherever we have seen the homogenization is L plus v to L, and the when we get this kind of a trend it clearly indicates that with and since the separation of a vapour also the enthalpy is partitioned into the vapour and the residual liquid. So, essentially it happens in an adiabatic condition, where the temperature of the fluid is decreasing, because of the heat partition that the enthalpy the heat content.

This partition in to the vapour and the residual liquid is rendered higher in it is sanity, apparent increase in the salinity, because of the fact that the mass fraction which is separated in form of vapour has very negligible solubility of the salt.

This boiling is essentially a very efficient process in bringing about a deposition of minerals, the position of minerals or deposition of the metals from the fluid, which was dominantly transporting these metals in some soluble form, which we will be discussing subsequently.

And situations like a mixing, mixing could happen with a high temperature high saline fluid with a low temperature low saline fluid, for generally we observe in many situations and when you come to some such individual deposit types, we will discuss about them; mixing of a low temperature low saline which will almost like a metallic fluid with a load with a moderate temperature or low temperature, but very high saline, in that case it could indicate mixing of cognate fluid with the maturic fluid, it could indicate a magnetic fluid with a with a maturic fluid and many several such situations which we observed when we look at the fluid characteristics of the spectrum of hydrothermal deposits, that we listed in the last lecture.

And a trend which would show as a cooling trend also is possible theoretically, because metal solubility is a function of temperature. So, is the temperature is high so solubility will be high, and when the temperature drops the metal solubility will decrease and resulting in precipitation of the metals and different forms of minerals.

So, this fluid evaluation diagram helps in getting some firsthand information some preliminary idea about the gross thermal and chemical characteristics of the hydrothermal fluids of different origin, and fluid inclusion characteristic or fluid inclusion data also helps in pointing the dominant process involved in the mineralisation, abdomen involved in the deposition of the minerals.

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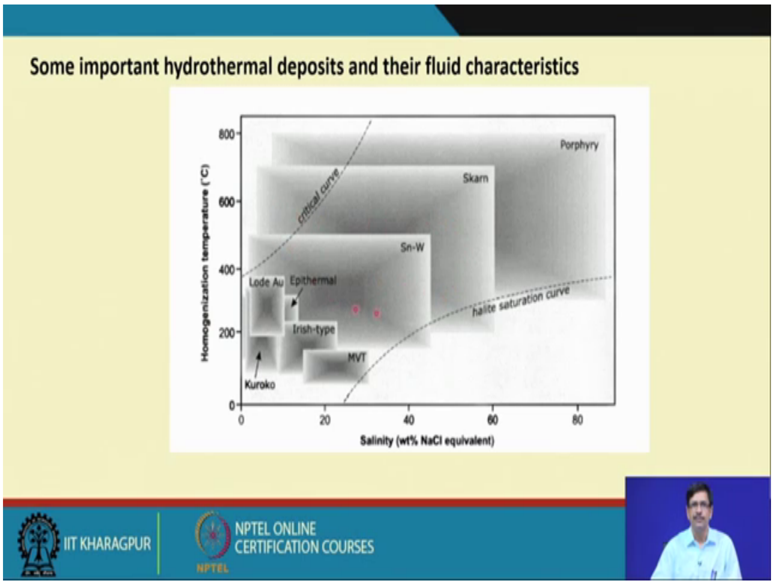
Some important hydrothermal deposits and their fluid characteristics

So, this diagram which is taken again from the from Wilkinson 2001, is a scheme on which the gross fluid characteristics of a good number of hydrothermal deposits, the power free essentially is corresponding to the power free copper deposits, which we see them in the convergent plate boundary continental archetype convergent plate boundary they are the skarn deposit, we which we see in continental interior or maybe in the some of the active continental interior part of the active margin, associated with Felsic magnetism.

So, it could be you could see the field for example, the power free couple will also involve the very high temperature high saline, even up to going up to 80 weight percent NaCl equivalent and lower temperature discount is also accordingly and these are some of the tin tungsten bearing grenades, sometimes giving rise to rain type, tin tungsten deposits and here we could see the low type gold deposit or the ones which are associated with the green stones in most of the curtaining areas.

Their fluid characteristic is that they are essentially to be understood to be low saline, but temperature moderately high as metamorphic fluid; this is from the volcanogenic one of the typical type of all volcanogenic massive sulphide deposit, this is from the temperature is still very low of even less than 2 or less than 200 of the order of 150 degrees Celsius, this is the Mississippi valley type deposit.

And this is the iris type volcanogenic massive sulphide deposit. So, we could possibly see or fit in many other, that but these are the dominant and represent the spectrum from magnetic to deposits which are sometimes involve the basin or brain like the Cornett water the metamorphic water and so on. This also again to again reiterate that this diagram, which is the fluid evolution diagram is essentially constructed from the aqueous or the water reach or the aqueous Fluid inclusions in the minerals, but the fact is that we do get the crustal fluids, which are quite more complex than just build whatever water charged with only the dissolve solids. The fluid which we see in the different ore forming environment in the crust, do have some times appreciable amount of carbon dioxide dissolved in it. So, if we look at in that case we have to see or just maybe briefly you could see.

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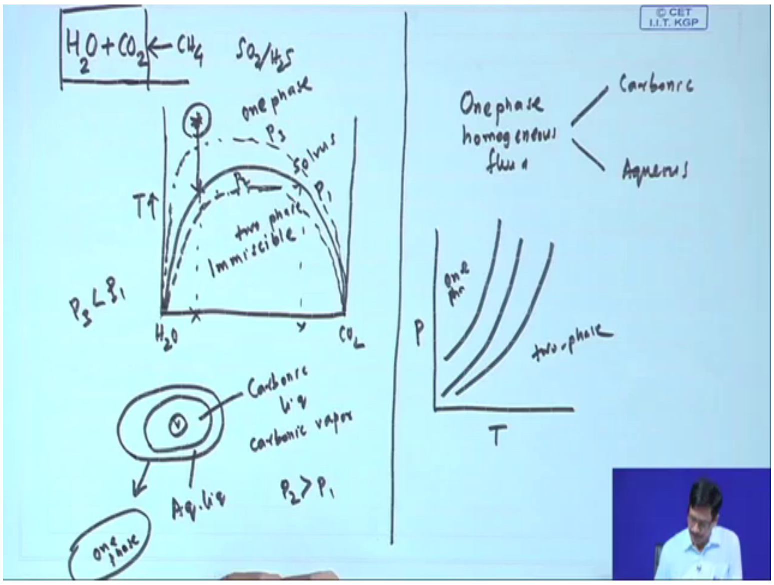

So, the water the above hydrothermal fluid could be a fluid, which could be a mixture of water plus carbon dioxide. And we all know that they are not very miscible with each other and carbon dioxide solubility is a strong function of pressure, and this carbon dioxide also could be sometimes not a pure carbon dioxide could be charged some reduced species such as methane. So, our hydrothermal fluid is essentially is a very complex mixture of water dissolved electrolytes and gaseous species like carbon dioxide and methane, and the sulphurous species like sulphur dioxide or H 2 S and many other species, so thus making it a very complicated fluid. So, here I will just take up that the carbon dioxide component of water, and it is relevance to understanding the fluid characteristics using the fluid inclusion technique.

You would also, can see just in the form of a simple binary, where it is water and carbon dioxide and this is temperature. So, what do you observe here is that, this is a two phase distinct what immiscible this is the immiscible regime, where a water reach liquid and a carbon dioxide reach liquid coexist. This is the one phase homogeneous region and then we can use our standard with our and basic understanding on these phase diagrams of such nature. So that means, if we imagine a fluid of any of a composition somewhere here and with the decrease in temperature as at, so this is the boundary or we this can be called as a solvers.

So, is in when the temperature touches this solver reaches at this point, the fluid gets split it up into 2 components one here and one here and with gradual decrease in temperature; this water each part gets more and more richer in water and the carbon dioxide part gets more and more richer in carbon oxide. And so the occurrence of the fluid inclusion as I showed before for example, here this could be a aqueous liquid, this is a carbonic liquid and this is the carbonic vapour, the vapour which is here is a carbonic the car P or carbon dioxide vapour or carbonic vapour.

So, one is to understand the phase relationship of this system, which simple binary as a carbon dioxide in water in the low temperature and then correlated with the freezing study or the freezing behaviour or how these inclusions response to the freezing cycle, and then from that to correlate fluid inclusion behaviour and then try to understand what exactly was happening during the hydrothermal mineralization process.

And this particular solvers is sensitive to pressure. So, if this represents a particular pressure say P 1, and we can it is generally this dotted line would represent P 2, where P 2 would be greater than P 1. So that means, the situation would be such that we depending on the fluid in the temperature and pressure condition of the fluid at the regime at which the fluid is active. Mineralization system there whether I mean how the fluid evolved if the fluid has been a high temperature and high pressure homogeneous fluid which is having appreciable carbon dioxide concentration and then this fluid can evolve either by a simple decrease in temperature or in decrease in pressure because, if this is a pressure which is P 1 and the fluid is here and if the pressure suddenly decreases to P 3 suppose, where P 3 is less than P 1 or any other lower pressure, then this particular fluid which was a initially was a one phase homogeneous fluid we will split up into 2 components a carbonic component and an aqueous component.

And such kind of process is very very important in the to the mineralization process, because this involves quite a change in the chemistry of the aqueous part on the both the parts which is splitted up especially the aqueous part which is splitted there will be substantial change in the chemistry, corresponding to what has been the pattern fluid. And such kind of series of such diagrams if we construct a different pressure conditions on this kind of ts we can translate it to the P T diagram also where this would represent the one phase.

So, there is a series of compositional suppose x co 2 will be the co 2 concentration will be higher and higher suppose it any particular temperature . So, this will be 1 phase and the, this will be 2 phase. And similarly we can also have any particular homogeneous fluid which was entrapped at any particular pressure temperature condition, we could also have the fluid ISO core to be drawn or we also assume we can also assume the same thing, that this fluid was initially a trapped is homogeneous interruptment and followed an isochoric path till the time it got splitted up into 2, and such kind of homogenization for example, if we take this particularly inclusion we can also do a homogenization experiment till until this becomes one fringe. It means this carbon dioxide fridge will get dissolved within the within that phase and it will give rise to and one phase a liquid corresponding to a temperature and homogeneous and exactly, the way we saw in case of an aqueous inclusion. Now we are we are discussing about the retrieval of pressure and temperature conditions of the over fluid from the fluid inclusion data.

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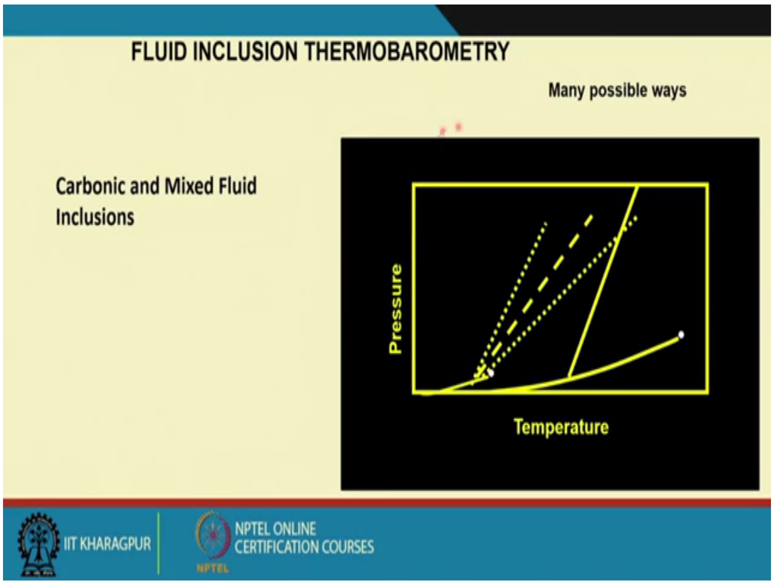

FLUID INCLUSION THERMOBAROMETRY

Many possible ways

Carbonic and Mixed Fluid Inclusions

So, here so far we were discussing about the fluid, which was only an aqueous fluid evaluation diagram, which was an aqueous fluid this gives us a an idea if we have a mixed system of carbon dioxide and aqueous fluid, we do have still can we do have a good opportunity to constrain the temperature and pressure of the fluid during the time of the deposition of the mineral of the formation of the minerals.

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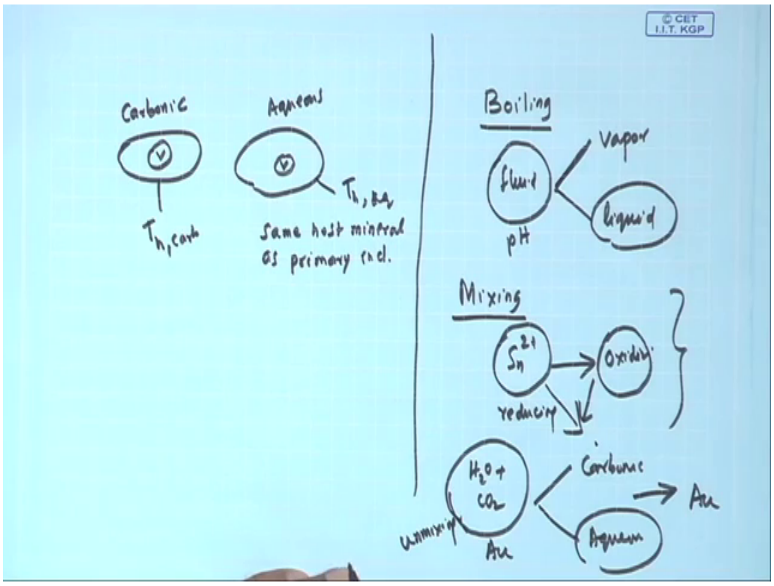

Suppose in a in a particular mineral host mineral, we are getting inclusions like this, this is a carbonic or I can say carbon dioxide inclusion, this is an aqueous inclusion.

Remembering what phase relationships we just discussed, if this is a carbonic fluid and this is an aqueous fluid and they are occurring in the same host mineral as primary inclusions, because they have to be they have to they have to be primary, they have to be coeval, entrapped at the same time, the same temperature and pressure.

So, we will do the homogenization experiment on these two, this carbonic inclusion is homogenizing into it is temperature of homogenization for the carbon dioxide, this also a homogenizing to it is temperature of homogenization in the aqueous following the phase diagram, which we depicted before; and we from this we can compute the densities of this fluid, at the temperature of homogeneous and using standard pressure volume temperature composition relationship and so, is the case with this aqueous phase where we can compute the density, using standard formulation on pressure temperature composition using a either a pure water or determining it is salinity from the water NaCl system. And what is shown here is that we are we are in a position to construct the ISO core for this aqueous inclusion. And also the ISO core for the carboning inclusion and this diagram is a schematic diagram which shows that if this if such a situation exists then we can oh the ISO cores of the carbonic.

They dot this dot dot and dash are represent in the carbonic inclusion ISO core, and the solid one is representing the aqueous inclusion ISO core, they can intersect at a point to give it give rise to give me that unique value of temperature and pressure of the of the fluid. Again reiterating the fact that such type of data have to be acquired for a good number of inclusions within the host mineral from the mineral deposit that we are studying, and we have to synthesize the information and get the gat in terms of the total variation of the pressure temperature conditions to understand the nature of the over fluid it is source and the process.

For example, this our objective is that weather will be in a position to decipher unequivocally without any doubt as to whether what data we have got or whatever information we are getting from the fluid inclusions, is actually able to tell us not only the characteristics of the ore fluid, but also the important process involved in it because it is its very essential. Because for example, the boiling, boiling is a is a very important process because it whenever there is a parent fluid and it undergoes boiling means it gives rise to a it is splits into a vapour and liquid, there is a substantial change in the chemistry of the of the residual liquid here. At least we know that many of the volatiles will be getting partitioned into the vapour phase and the initial pH of this fluid is going to change a lot in the residual liquid after partitioning of the many of the components which we were responsible for imparting the acidity to this fluid.

And since metal solubility depends a lot on many parameters like temperature, oxidation state pH of the fluid. So, it becomes easier for us to understand the process of the process of formation of this mineral deposit. Similarly mixing sometimes is important as we see from the fluid inclusion evidence, take for example, a originally a fluid was reducing and it was transporting a metal like tin in it is plus two state, where it is soluble and this particular fluid in order to deposit the metal in it is oxide form needs to encounter a more oxidizing condition.

So, under that is situation when if this particular original fluid was a magnetic fluid and was reducing in it is nature by virtue of the original composition of the magma from which it was absolving, and the through the process or interaction and it mixes up with a with a fluid which is oxidizing. Let us say it could be a meteoric fluid which is oxidizing fluid.

So, then it will result in the deposition of the tin in form of the insoluble metal oxide which will cause the. So, here a fluid mixing has been the dominant process. So, it is the fluid inclusion data which will give us conclusive evidence about the processes such as boiling mixing and cooling and also more importantly un mixing.

For example there was an original fluid which was a mixture of H 2 O plus C O 2 I would represent carbon dioxide is carbonyl because thinking that this carbon dioxide also could be mixed with a bit of methane or other reduced species or it could be say if some such fluid was originally having a solubility, substantial solubility of metal like gold which will be seem in details when we will be examining such deposits. It splits up into a carbonic part and an aqueous part and this, if the carbon dioxide present was responsible in transporting the gold then here by the process of splitting or unmixing.

It is a process essentially of unmixing, it will result in the deposition of gold either in the form of free gold or whatever is the environment allows. So, this unmixing process is also is conclusively deduced by studying the fluid inclusions in this ores.

So, to sum up we can combine stabilized sort of oxygen and sulfurized sort of data mineral thermometer thermometric or thermo barometric data, and fluid inclusion data in a we synthesize the information together and then it gives us the idea about the fluid characteristics in terms of it is source the dominant mechanism that is involved in formation of the hydrothermal deposits. So, we will continue our discussing about this process and the hydrothermal deposits in the next class.

Thank you.