Mineral Resources: Geology, Exploration, Economics and Environment
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Lecture - 21
Hydrothermal Processes (Contd.)

Welcome to today's lecture. We have been discussing about the important aspects of hydrothermal fluids, the fluids in the crust whose activities result in deposition of minerals in the form of various types of mineral deposits. And we have been discussing about some of the fundamental aspects about the how to retrieve the physico chemical parameters especially temperature. And through simple chemical principles, we outlined the solubility of metals in the hydrothermal fluid and which largely depends on the different chemical parameters in addition to temperature.

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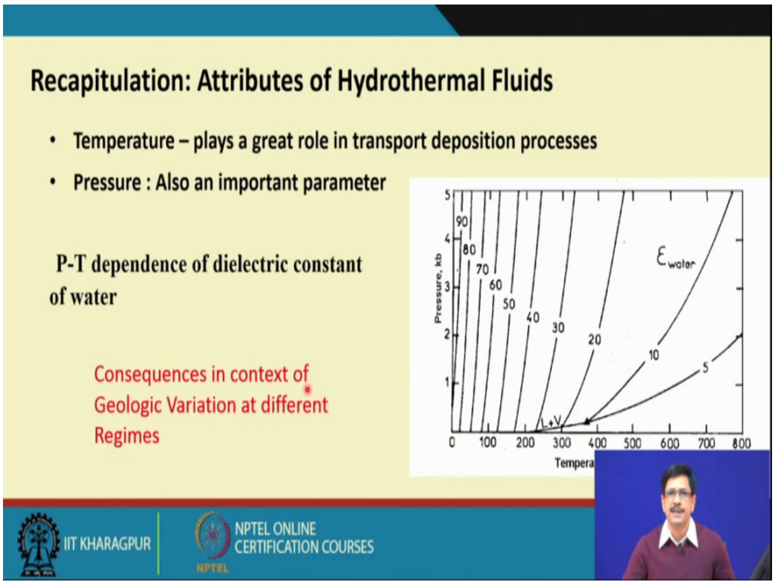

So, recapitulate we have been discussing about the attributes of hydrothermal fluids, and made a brief attempt to understand the role of temperature and the retrieval of temperature through different techniques such as fluid inclusions, mineral thermal variable tree and so that provides us a background in understanding the role of fluid the characteristic of the fluid. The fluid, further we would again see some of the other important aspect or attribute of hydrothermal fluid which is pressure. Pressure is also an important parameter, although in many of the low temperature conditions surface operated process which are governed by solubilities of different elemental metallic species, anionic and cationic species in the fluid which is rather insensitive to variation of pressure. But when we deal with a fluid at deeper conditions in the crust their pressure also becomes an important attribute which we will try to explain through this kind of a diagram here.

As we all know water is a universal solvent and most of its characteristics fundamentally is due to the hydrogen bonding present in the water. And the dissolving or the solubility characteristics of the it electrolytes in water is basically dictated by a parameter which is the dielectric constant of water. And the diagram here on the right, it gives us an idea about the variation of dielectric, the room temperature dielectric constant of water is about 80 which is high compared to liquid of such molecular weight. And as you see in this diagram, the dielectric constant of water in lower temperature conditions is rather insensitive to pressure that is what we say that the surface condition near surface condition when the fluid is operating in the earth crust through different mediums the fractures and force. There the chemistry the solubility of different elemental species metallic species and does not depend much on the pressure.

But as you could see here as the temperature increases towards a higher temperature region, this is a critical point of water, we see that the dielectric constant not only decreases with temperature, but also the dependence and pressure also increases. So, we would expect that as the temperature increases most of the electrolytes will be in their associated form rather than the concentration of the dissociated species will decrease and that will have some consequences in the fluid in the inner crustal fluid. So, it is actually not just the pressure absolute pressure, but the variation of pressure within the different domains where the hydrothermal fluid operate would be more important to us to understand. We will try to just see some very simple cases like the one shown here.

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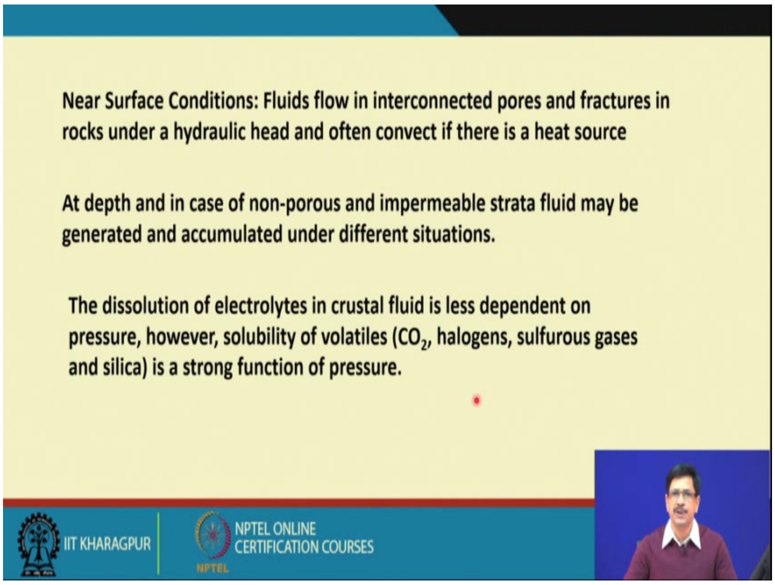

In the near surface conditions, the fluid flow in interconnected pores and fractures in the rocks, where the movement of the fluid is generally in response where a hydrostatic head and fluid such as groundwater, they move through the porous medium of the rock abiding by certain simple physical principles which we will not be discussing in details here. Our concern mainly will be in relation to solubility of different species in the higher thermal fluid and the consequences of variation of pressure. At depth and in case of non-porous or the rock rocks are not porous or they are not interconnected through the pores, so the permeability is low and there through some impermeable strata, so then fluid will be generated within the deeper parts of the rock layers in the crust. And the fluids will get accumulated in the in the rocks.

And the dissolution of the electrolytes in crustal fluids is where which you know is less dependent on pressure, however, solubility of some important gaseous species like carbon dioxide volatiles like carbon dioxide and the halogen species chlorine fluorine, sulphurous species like sulphur dioxide and H 2 s which play a very important role in controlling the solubility metal transporting deposition phenomena. As we saw some saw through some simple example, we will have some consequences on the variation of pressure within the fluid.

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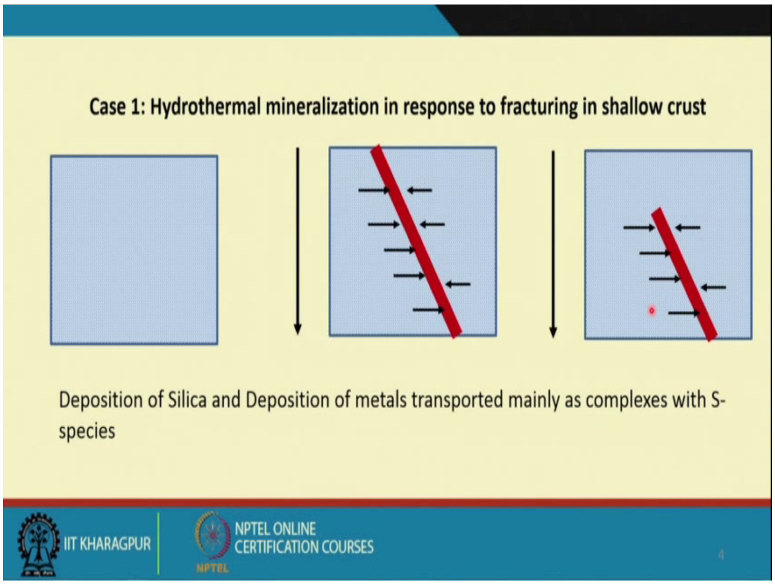

If you look at the case, case one, where the hydrothermal mineralization is in response to fracturing in a shallow crust. Let us take for example. This is a massive rock which is porous and there are pore spaces inside this rock which is filled up by water. And take any arbitrary depth variation within the from surface to any deeper part of the earth within the rock layers, the pressure should vary as per the lithostatic pressure which we know how to calculate it from the rock density, and the height of the rock column at any particular point. And the pressure at any point if this rock is just I mean not interconnected with any pores, and then the pressure will be lithostatic pressure and will increase with depth abiding by the simple formula taking the specific gravity of the rock the acceleration due to gravity and the height.

Now, let us think of a situation where there is a discontinuity in the form of a fracture which is created in the rock which could which possible if there is some kind of an extensional deformation the force acting here. Then it gives rise to this thick little red line is representing the width of the fracture. So, the moment there is a fracturing if the fracture is opened to the surface, then this fractured zone essentially becomes a zone of reduction of pressure. And fluid from the surrounding will flow to the fracture in response to this pressure gradient. And any of the species chemical species which are there in the species there in the fluid, the most common which you can consider is silica.

The solubility of silica which is commonly very low in the crustal fluids water dominated fluids in terms of millimole per kg will undergo deposition because with the response to the reduction of pressure and the pressure difference will always be a function of depth. Because they present the fluid if the if the fractures the fracture is open to the surface then if the fluid is occupying the fracture space then the pressure anywhere within the fracture will be the hydrostatic pressure which will be at least roughly about 1 by 2.5 of the pressure any point here the lithostatic pressure.

So, this will create a pressure gradient and the fluid will converge into the fractured zone. And in response to that we will start depositing the materials especially for example, silica and that is how we get lots of quartz veins in the crustal rocks under diverse types of rock composition. But since silica is one of the most dominant and the most abundant chemical species we can get the silica remobilised from the rocks to the fracture zone. So, here so any degree of a pressure difference where which will be increasing with depth will create or will result in the deposition of the solutes. So, here we could also have some of the important metallic species also who are getting deposited in the form of their ore minerals.

There could be a situation which could be that they and the fracture which has been created in this rock mass does not open to the surface. So, the pressure of the fluid on a any of the point within the fracture space would be something which will be intermediate between lithostatic or hydrostatic this pressure will not be exactly hydrostatic will be somewhere intermediate between hydrostatic. So, we see such kind of situations where this kind of brittle deformation within the brittle deformation zone of the earth's crust gives rise to formation of the mineralized veins, and such kind of situation sometimes lead to an interesting phenomena which we discussed previously.

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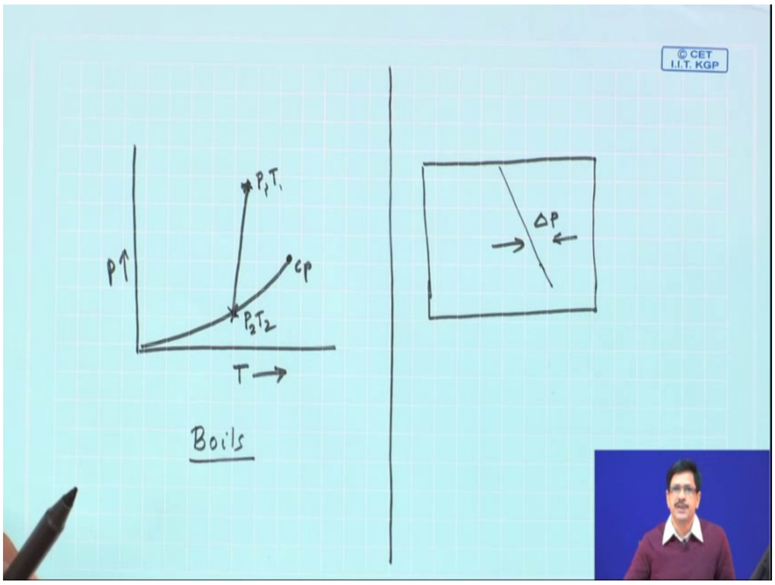

And that can be also understood with the help of a simple diagram here. This is a critical point of water. If we consider that our fluid to be anywhere within kind of a region in the one phase liquid field with a higher pressure and temperature, it is in a one phase liquid field. And then if the situation that we described here is something like this was the original rock in which the pore fluid rock with the pore fluid was present, and there was a fracture which is created in the rock. So, this difference in pressure which is can be represented as the del P here.

And if that coincides with a situation then the fluid from this pressure and temperature condition reaches a temperature and pressure condition corresponding to this P 2, T 2, then as we know that intersects the boiling curve. So, that means, the fluid which was present within the rock in unconnected or impermeable region where the fluid was the lithostatic pressure. When the fracture is created in response to the pressure difference, if this pressure difference happens to be exactly in quantity similar to the pressure that is required for the fluid to intersect the boiling curve, then the fluid boils.

And we have already discussed about the importance of boiling in as a process in the hydro thermal transport deposition phenomena. And because this boiling results in a lot of difference in the change in the chemistry of the fluid, which ultimately deposits these metals. And we see many such cases in hydrothermal systems where the deposition is due to boiling and which is preserved as imprint in the fluid inclusion evidence in minerals which deposit along with the ore minerals.

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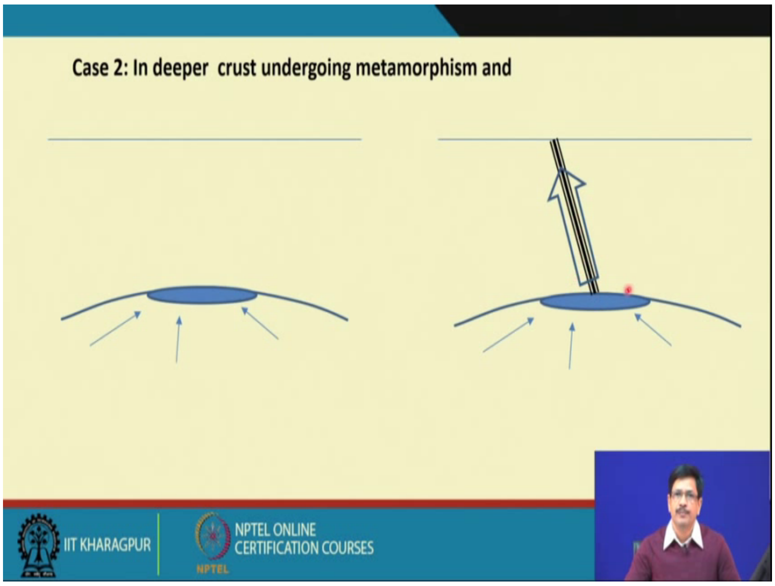

There are situations corresponding to as a shown here. If you look at the first diagram here, the situation here is that it is this is the surface and it is represents something which is happening in the deeper part of the crust where the rocks are undergoing metamorphism under high pressure and temperature conditions. And this metamorphism is resulting in extensive devolatilization that means the fluid which was initially bound to the hydras mineral phases within the rock are undergoing dehydration or devolatilization reactions even also some amount of carbon dioxide species or sulphurous species which is also generated here. This is happening at a much deeper part of the earth where the fluid is not able to escape or not able to move out because it is bounded by some kind of a ductile layer over here which is acting like almost like a lead and is not and so that is how the fluid which is accumulating here. And if it also happens to be a zone where there is active deformation going on compressive in a compressive regime in far field stress condition.

Then this fluid within here will be experiencing a flow a pressure which is even a little over what is expected to be lithostatic pressure here which we call it as a supra lithostatic pressure here. And just about in this region, if we bring about a crustal scale deformation something like a shear zone, then this allows this creates a channel way for the fluid to escape through such kind of crustal scale zone. And this fluid will escape through this fracture zone through which it will experience a sudden change in pressure and deposition of whatever is dissolved which we know that very high pressure temperature condition materials like silica remains dissolved in substantial amount.

And if the fluid is channelized through such kind of crustal scale shear zone then it gives rise to the, what we observe in many of the situations is large quartz reefs which sometimes be a rich mineralization especially with respect to the precious metal which we will discuss in due course of this lecture. So, this process is essentially it shows how pressure is important in hydrothermal fluid and when we are talking about the fluid which is of a deeper source. And in all probability, and this also could this process which is shown is much of a simplified form it could take many, many complicacy such as involvement of some other processes here, but this is why it could be looked at very simplified way.

Now, this crustal scale shear zone which will experience deposition of the materials say quartz reef, we will get filled up or will get sealed. After the fluid is deposited and again the pressure builds up here and this fluid itself will either cause a hydro fracturing or as has been proposed in many of the cases. It may be in response to a tectonic activity like a like an earthquake in which this shear zone again can be reactivated or reopened. And there could be subsequent batches of fluid released from this from this region where it is accumulating in response to the increasing pressure temperature condition and the devolatilization and accumulation of the volatiles the fluid water is fluid in this region. So, this how we could visualize the spectrum from surficial low temperature pressure conditions to much deeper conditions.

So, with these kinds of simple explanations we give a bit of a background understanding to the hydrothermal fluids. And we demonstrate or we at least make an understanding that when we say that a mineral deposit formation is earths own mechanism of beneficiation, then we have come to a stage to realize that yes this hydrothermal fluid is one of the most efficient and effective agent to do that beneficiation earth zone beneficiation mechanism which gives us a wide range of mineral deposits as we have seen when we classified them under the broad category of hydrothermal deposits.

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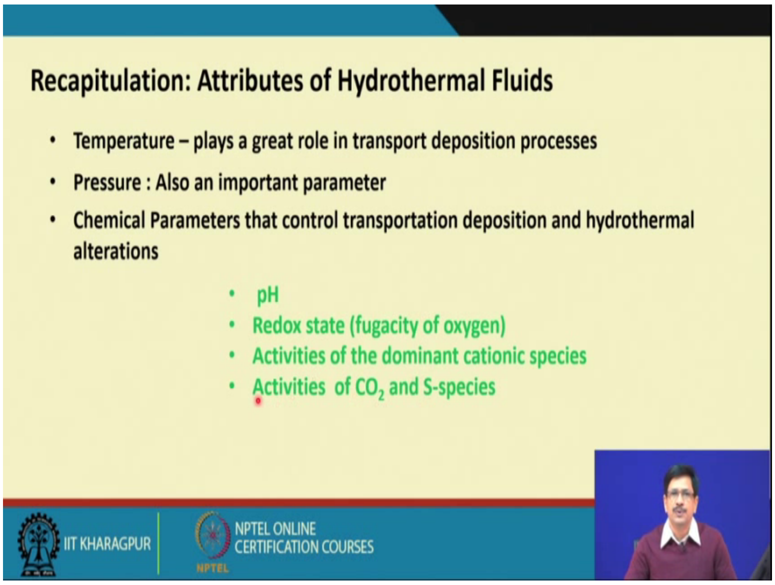

In addition to that, so there are many other chemical parameters that control the transport deposition phenomena which we have seen the pH the acidity of the fluid is a very important parameter where the normal variation of the hydrothermal fluid the pH could be anything two or three units layered positive or negative from the neutrality. The redox state the fugacity of oxygen and on the surficial process we use parameters such as the redox potential eH and pH to explain formation of many different types of ore deposits of the surficial conditions.

Then with the activities of the dominant cationic species the dominant like potassium, sodium, which are in abundant calcium, magnesium and the anionic species like sulphate and chloride. And we try to understand or plot their stability fields in response to change in effort to pH to understand the chemistry of the processes and also the activities of carbon dioxide and sulphur bearing species. So, this is how we can give a brief idea about the hydrothermal fluid.

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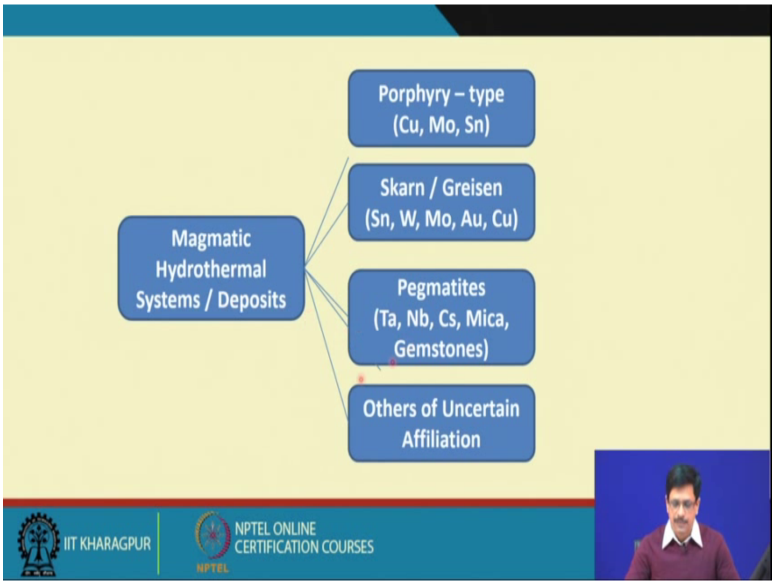

And now we will make a brief survey of make an overview of the different types of hydrothermal systems. And in terms of the origin, we saw we discussed that magmatic hydrothermal system or magmatic hydrothermal system is one important class of the hydrothermal fluid based on the origin that the fluid is essentially having a magmatic origin. So, under this category, we have the porphyry type deposits, copper, molybdenum, tin and we have the skarn and greisens, the pegmatites. And there are many other deposits which are of uncertain affiliation where magmatic source is sometimes suspected like some of the uranium deposits, some deposits some special circumstances where a magmatic affiliation is only suspected through retrieval of temperature and fluid sources from stable isotopies. So, we will be considering them of some special cases, but we will look at.

So, in this what we will do we will take this porphyry type deposits as our type example and the ones which are the most studied to understand the magmatic hydrothermal process. And then briefly touch upon others which will have. So, once we make an understanding as to how this magmatic hydrothermal system works we will be able to understand the other variations giving different types of other metals. This porphyry deposits an important sources for copper molybdenum and tin, and also gold.

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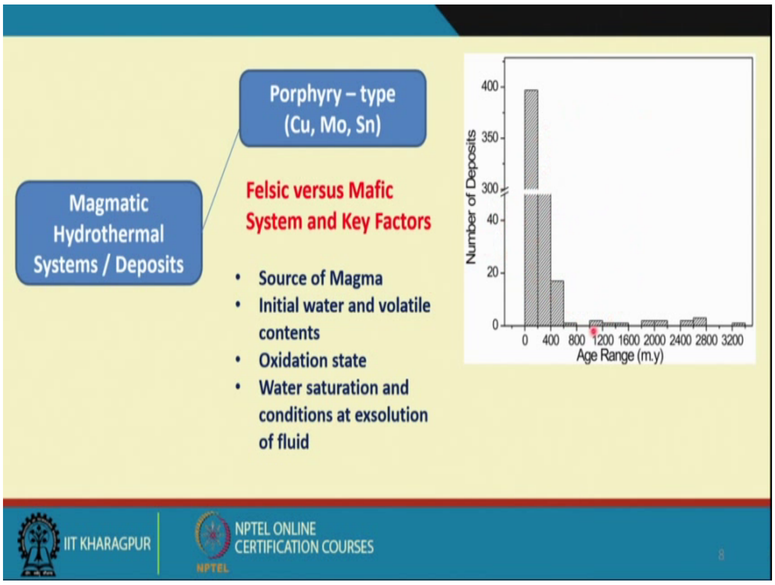

Now, what we discussed about the magmatic deposits when we discussed about the chromite and other deposits which are essentially ortho magmatic in nature; so this is a domain in which we have primarily been dealing with felsic magma. Whenever we say magmatic hydrothermal system by default we mean it is a felsic magma, which is responsible in giving rise to the mineralization. So, we must understand what is so special about this felsic magma is compared to the mafic magma which is dry this felsic magma. We can call them as wet magma or the magma which is charged with lots of volatiles water being the dominant species. The halogen species, chlorine, fluorine, sulphur bearing species sulphur dioxide and H 2 S depending on what is the oxidation state of the magma is.

So, therefore, the we must first understand the basic difference, so that is why when we consider the ortho magmatic deposits of associated with mafic magmatism we only looked into the mechanism of a crystallization of the melt. Here we do have to take into consideration in addition to the crystallization of a felsic magma, we do also have to look into more critically on the melt fluid regime where a fluid phase involves from a crystallizing felsic magma and what are the different possibilities that we see.

Number one is that it depends on the source from which the magma is generated. In most of the cases we know that the magma generated either in the lower crust region, the magma which is generated in the continental arc subduction zone, melting from the subducting slab often involving the mantle wedge. So, they give rise to the calc alkaline magma. And the magma is derived from a source where the where there is ever plenty availability of the volatiles mainly water and other halogen species. And in case of the porphyry copper deposits which are coming from the active continental margin like the andean margin we know that this type of magma is coming out is because of the melting of the slab which was generated the mid oceanic ridges, and it has a long story of interaction of the seawater.

So, it essentially is a modified or a changed material along with the ocean floor sediments and it is getting subducted in the subduction zone it is getting undergoing high temperature presa metamorphism and melting partially where it is giving rise to the magma. And this magma with which the porphyry copper deposits which we will be discussing associated are generally called as being classified as I type magma or the magma which a source from I. I stands for igneous source even though we know that it is not exactly a igneous detected igneous source, but the seafloor basalt with this along with the other material when it is getting metamorphosed to almost like an (Refer Time: 24:42) is undergoing partial melting as and when it goes down into the asthenosphere and encounters higher and higher temperature.

The initial water content and the volatile content is a very critical parameter. And in dictating what the hydrothermal activity will be the oxidation state is also related to what exactly we are labelling this I type magma is supposed to be or is observed to have a higher oxidation state which is indicated by the dominance of the oxidized sulphurous species. And which is an important bearing on the evolution of the hydrothermal fluid.

And another important parameter with this system is the water saturation that the melt which the magma the calc alkaline magma when it undergoes crystallization initial stage when the there is a dominance of the nominally hydrous minerals like amphibole or other non hydrous minerals unhydrous minerals which are crystallizing with a substantial proportion of crystallization the residual melt goes on getting enriched with respect to the volatile and reach a value of saturation. When the magma which are generated in the condition that we have just discussed can have water content in weight by weight percent to almost anything starting from 2.7, 2.8 percent to as high as 6 to 7 percent depending on the availability of the water.

And this kind of magma also could be, so why these deposits which are the porphyry type deposits with the widely occurring under most studied most extensively studied among the deposits of the world. Interestingly, we will see that in this situation as we also gave in the temporal distribution of the mineral deposits, these deposits essentially very young less than even a few million years occurring in the active a continental margins like the Chilean Andes. So, we see that the total number of such deposits which have been at least more than about a 1000 such deposits studied all over the world.

Majority of them are in the post philozoic at least post Mesozoic. And here this and we see that there are hardly any representatives in the older rocks and deposits in the Precambrian are very rare. And we can also say that as we the problem that we discussed that the older deposits generally are difficult to be classified because of the fact that they their characteristics get changed in during later processes.

So, on the on the whole we can consider that these porphyry copper deposits to be the young deposits forming in very recent time. And they are the most studied one ones across the world from many different continents respective major ones are from the Western American Cordillera and the Chilean Andes. Some of the Chinese occurrences are reported and deposits in the circum pacific ring of fire also like Fiji and Philippines, there are reported Papua New Guinea.

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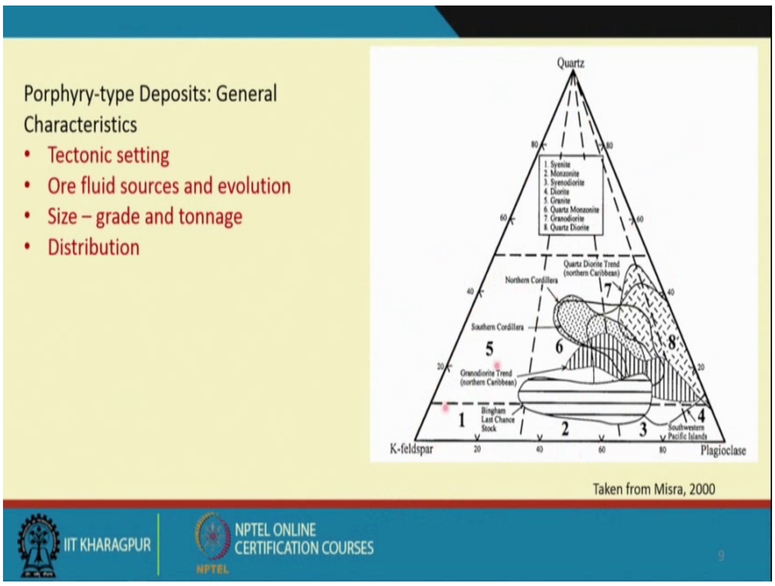

So, these deposits porphyry deposits the general characteristic is that they are in active continental margin convergent type continental margin in continental arc situations. The ore fluid is essentially magmatic fluid which is a some which is very high temperature and high saline. And it evolves in different ways in different conditions these deposits are generally large deposits with very high tonnage going to almost like 700, 800, even 1000 million tons and are generally of low grade the copper percent is going to just about a little over 1 percent.

And they are dominantly the copper dominated which are the porphyry copper deposits though although many of the porphyry copper deposits will have insignificant molybdenum concentration also. There are gold only, there are molybdenum only porphyry copper deposits which will see them and they have a very interesting specificity on the type of rocks that they are associated with which can be explained on the basis of the scores on this triangular diagram.

For you could see that they can be present in diverse composition felsic rocks like quartz diorite, granodiorite, quartz monzogranite diorite even up going up to the syenite monzonite type of composition which is shown in this. And they are coming from different regions. This is the famous Bingham deposit in Utah. And this is the southern cordillera deposits, the northern cordillera deposits and this is the south-western Pacific Island. So, we do see a wide range of this is taken the wide range of variation in the composition when plotted on model quartz plagioclase feldspar. And this is the spectrum of rock types in which they occur and all over the world their distribution I have already said.

So, we will continue discussing in the next class.

Thank you.