Mineral Resources: Geology, Exploration, Economics and Environment
Prof. M. K. Panigrahi
Department of Geology and Geophysics
Indian Institute of Technology, Kharagpur

Lecture – 26
Hydrothermal Processes and Resultant Deposits

Welcome to today's lecture. in the last week, we had a brief overview of the hydrothermal systems, the magmatic hydrothermal system which is exemplified by the porphyry copper deposits, with the typical occurrence in the form of small plug like intrusives as a part of a larger magmatic system with very well identified and characterized alteration zones. And the metal the mineralization being dominantly of copper, with large tonnage and moderately low-grade mineralization. We looked into the mineralization associated with hydro plant with metamorphic hydrothermal system the low type old quartz deposits.

The sediment hosted gold deposit which is the carlin type where the mineralization is not exactly associated with the process of sedimentation, but is much later in time and also in a different tectonic setup. And we cannot strictly classify it under a magmatic hydrothermal system although a magmatic component is very well identified. As you have seen in general, that, the deposits being included in any particular category such as a magmatic hydrothermal system or otherwise, we will essentially be depending on what fluid component has been dominant. And in that process we completed the magmatic hydrothermal systems and the carlin type deposits.

So, we will be we just started to discuss and also we saw the occurrences of a large number of deposits which are called the epigenetic deposit. Epidermal deposits which are associated with young volcanic islands, in the pacific circum pacific region the pacific ring of fire. We just started our discussion on the seafloor hydrothermal systems, which have a very direct relevance to one of the very important class of a ore deposits, which are the ridge sources or resources of base metals like copper, lead and zinc which are known as the volcanogenic massive sulfide deposits or the VMS deposits.

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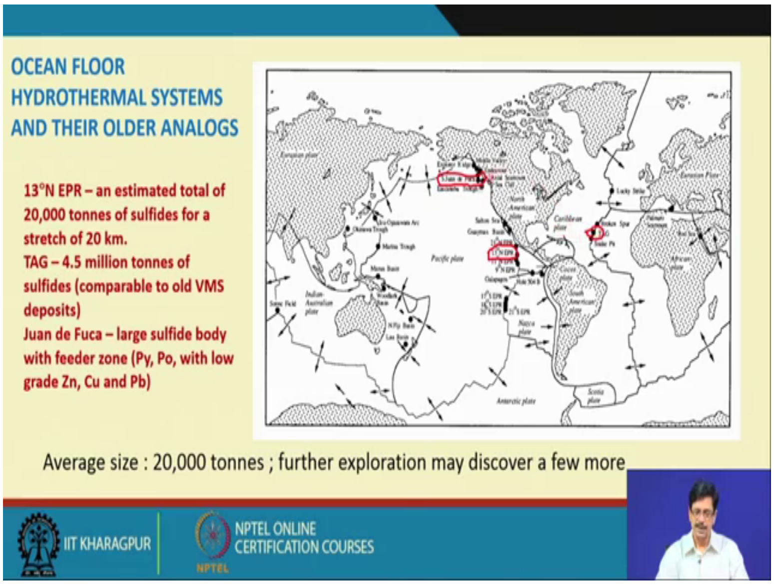

Before going to the VMS deposits, let us try to have a relook of this diagram on this figure. Where the world ocean ridge system which is which runs for about 55000 kilometers length. And there are many such important locations on this ocean world ocean ridge system such as the trans-atlantic geotraverse here and the 13 degree and the 21 degree north east specific rise.

And they here is the some of the other basins like for example, juan de fuca ridge over here in the western part of a north American continent where the tectonic setting is a little different from what we observe in the mid oceanic ridges like the mid-atlantic ridge or the mid or the east or the east pacific rise as we know them.

And all along there are many such seafloor hydrothermal systems which have been directly observed examined, studied by going to the go by reaching to those great depths and through submersibles sampling the fluid there, sampling the minerals, sulfide minerals that are precipitating the forming there. And as we stated that these kind of ore forming present day ore forming systems give us a definitive idea conclusive idea about the ore forming processes which possibly would have operated in the distant geological past.

I would like to draw your attention to these 3 prominent locals or localities on the world ocean ridge system. Where, is the trans-Atlantic geotraverse is tag here this is the 13 degree north east pacific rise here. And the sun these juan de fuca ridge over here. They do have some differences here it is a open ocean this trans Atlantic geotraverse here this ridge which being proximal to the continent is receives a huge amount of classic sediments.

Now, if you go back if you look at the economic aspect of it or the mineralization part of it. In 13 degree north east pacific rise, it has been estimated that there is a total of 20 thousand tons of sulfides for a stretch of 20 kilometers in this system. In the trans Atlantic geotraverse, that is TAG is almost of the tune of 4.5 million tons of sulfide which generally compares to the a fossil ocean floor geo hydrothermal systems which are the VMS deposits like the ones occurring in Noranda in Quebec in Canada and other places like the Cyprus deposit in the Tudors. Where the quantity of the mineralization can go to the order of 6 billion tons of the sulfide ore and this juan de fuca ridge over here which is also a large sulfide body with a feeder zone that we once had a look on the morphology.

And also ridge in pyrite in pyrrhotite ore with low grade of zinc copper and lead. So, what is expected? Or what is anticipated? Is most of the sites which is which have been visited by such submersibles and have been studied. they turn out to be rather moderate size of 20 thousand tons of object kind of a size, but it is anticipated that further exploration might give us some even richer localities or richer ore deposits. In the present-day ore farming systems like this and which might which basically are projected to be the resources for the future generation and with the available technology, we might be able to exploit those resources to meet the demand of this base metals.

So, the coming to the geology part of it, if we want to make a direct correspondence with this, there they are quite diverse as we initial part of the discussion which we saw that in situations like this the Japanese arc which is essentially the zone of convert convergent plate tectonics setting.

We also do get volcanogenic massive sulfide deposit and the difference being the here and the different and the bonds which are on the mid Atlantic ridge. They do differ in the composition of the volcanics here, which is dominated by the seafloor basalt where it is dominated by bimodal volcanism and sometimes is more of a felsic component which dominates here like antisocytic type of bodies.

And there are many such like this the situations in back arc like this law basin is essentially sometimes the tectonic settings is of a mixed type or a composite type. Where a convergent setting is also associated with a back arc a spreading center where, we get the bimodal type of volcanism and the desired conditions or the conditions for the formation of such kind of a mineralizing system. Which are essentially they resulted by the setting up of wave of huge hydrothermal convection cells.

Where because of the through the heat that is generated from below receive water, which percolates through the factored dense fracture network in the seafloor basalt. And interacts with the now with the seafloor with the seafloor basalt and gets enriched with respect to the whole constituents the metals. And then deposits them in the form of sulfides on the vents disturbs vents of this hydrothermal fluid when they get discharged on the way up after they become buoyant which will have a look

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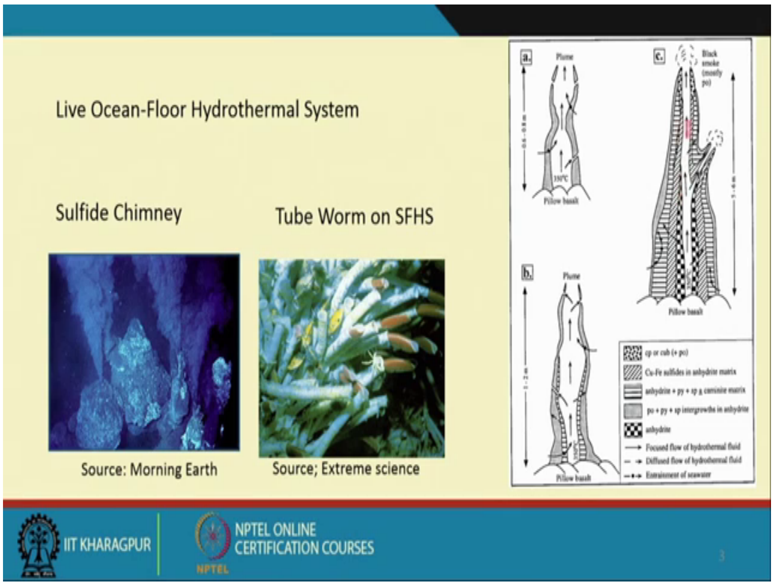

What we generally observe? There are some interesting features which will for general knowledge as well as for the situation to have to be aware of what exactly happens there, the seafloor hydrothermal systems wherever there is a venting of the hydrothermal fluid on such kind of ridge axis which is a complicated structure.

Because, it is an extensional domain we what we see in the form of columnar structures from which we see this kind of plumes rising which are essentially the black smokers, cost consisting of the black sulfide particles dispersed in the water and the rise with the precipitation of the sulfide when this hot seafloor hydrothermal fluid comes in contact with the cold seawater. The deposition of the sulfide takes place and in the form of plume.

And they essentially emanate from structures which are called the sulfide chimneys. before I go to the sulfide chimneys is one of the interesting features which are also associated with this seafloor hydrothermal system is that the proliferation of this kind of organisms which are called the tube worms. And even this kind of tube worm remains or signatures of such kind of tube worm in on the whole seafloor hydrothermal system or even observed in sit in places like the Tudors flow light which are in all which are based definitively can be put into the category of the volcanogenic massive sulfides, arising out of the seafloor hydrothermal activity that typically happens on the ridge axis on the extension domain.

So, the sulfide chimneys which the form essentially, they have been visualized to have to evolve in this kind of a way. In which, we could see the seafloor below basalt over here. The fluid is getting vented or discharged at a temperature almost of the order of more than 300 degree centigrade on this kind of a discharge vents and as in when the fluid comes in contact to the cold water, the sulfate in the seawater gets deposited in the form of anhydride. And this deposition of this anhydride because if this anhydride is porous and there is mixing of the seawater through this medium of this hot hydrothermal fluid. And then that gives rise to in the in the initial phases this gives rise to the deposition of pyrrhotite pyrite and sphalerite type of a ore minerals integral with anhydride.

So, it gives a kind of a porous framework through which the there is mixing up missing of the fluid with the seawater and this deposition continues. So, these chimneys they grow subsequently thicker and taller with this kind of an anhydride collar. And for the precipitation of the copper minerals the chalcopyrite sometimes cubonite which is Cu Fe 2 S3 will be and this evolves into a matured structure almost come also almost rising to a to height of almost like 5 6 meters after which these chimneys collapse.

And this chimney scholar’s chimneys have been very well observed on the on such kind of a seafloor hydrothermal sites which have been investigated by direct observation. And going through the submersibles and these chimneys were once one chimney collapses. In the next, immediate vent place of venting there is another chimney which starts to grow likewise this process goes on. And on the vent side we get these sulfide minerals enriched in the form of these collapsed chimneys. And in the in the form of wolvers growth exactly what we have seen in the typical VMS morphology.

And again, which are covered by the later sediments and volcanics and give rise to what we see the typical morphology of the volcanogenic massive sulfide deposit, which can be in a simplified way.

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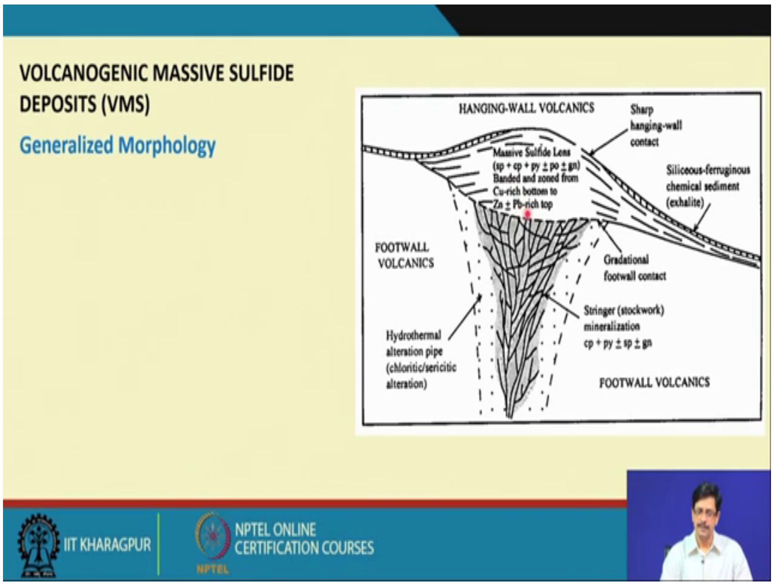

Can be represented with the federal stock work kind of a zone in which that is disseminated sulfide mineralization and surrounded by an alteration hallow which is basically chloritic sericitic. A kind of alteration, where they seafloor basalt is altered to chloritic mass and this is the stringer stock work mineralization. It has a gradational contact with the footwall zone, which will be call as the footwall which is occurring below.

The some massive sulfide lens this is the massive sulfide lens constituting of a ores of copper zinc. Sometimes, little bit of lead also and it exhibits a very good lateral and vertical zoning starting from copper going to zinc and land laid in both literally and vertically which have been explained in many possible ways like decreasing temperature. the solubility of copper decreases and zinc and lead still remain in the solution and that is how the zoning takes place.

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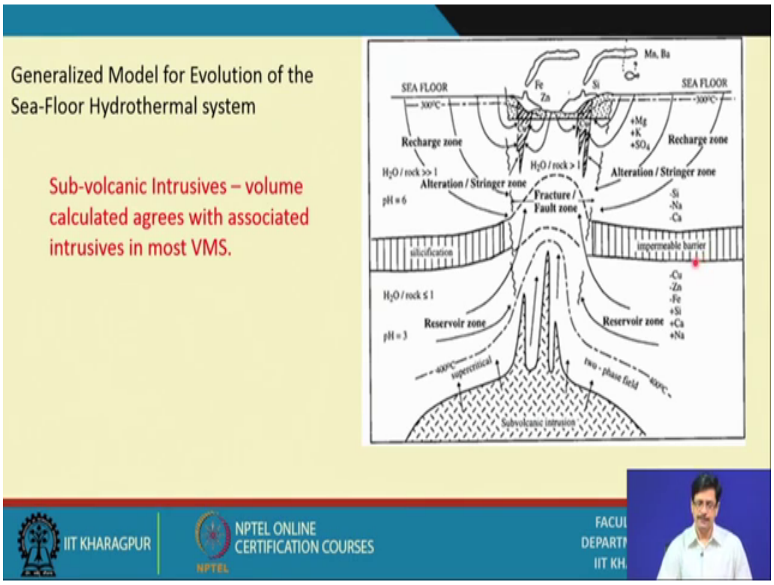

The model for this kind of the formation of the volcanogenic massive sulfide deposits have been worked out. there are essential components of this model is that it should have a sub volcanic intrusion to provide a sustainable source of heat. For the for the process to operate in these zones and initially and this zone is Si is invariably the associate associated with a zone of calcification impermeable barrier, which is dominantly constituted of quartz. It could either be a result of a very low pH in which most constituents could have been leached out from this particular area and only been converted to a silica rich zone. Impermeable barrier or it could be any kind of a process of actually deposition, through some 2 phases kind of material which could have formed this impermeable barrier.

So, by that process in this zone, where the fluid by rock ratio is low and the pH of the fluid is very low as well. And it builds up the pressure and then there are channel waves which are created in the form of these faults, which is shown here, and if we rises and on this particular zone which is above this barrier. The sea floor is the hydrothermal circulation cell as I was talking about is shown here with this arrow and the fluid.

The sea water percolates through this fracture network gets heated up, interacts with the rock here, here the water wave rock ratio is high much more than one and also pH is higher compared to the fluid over here which carries the metals and also the metal which is leached from the sea floor basalt. And here they this is essentially the site where the hydrothermal fluid vents out and the deposition takes place in the form, what we have just seen the form of the sulfate chimneys or the dominant sulfide minerals they keep formed.

This is the situation where we are essentially looking at the process which is giving rise to the massive sulfide lens, exactly on the site where this kind of a hydrothermal venting is taking place. So, such kind of a sub volcanic intrusives which is required for this process to be carried is agree agrees well with most many of the fossil hydrothermal or the VMS deposits, which is which we see in older catalytic blocks and deposits on it varying edges that they are is. In fact, associated with such kind of a felsic intrusive body in the subsurface and the volume that is calculated for the generation of the heat agrees well.

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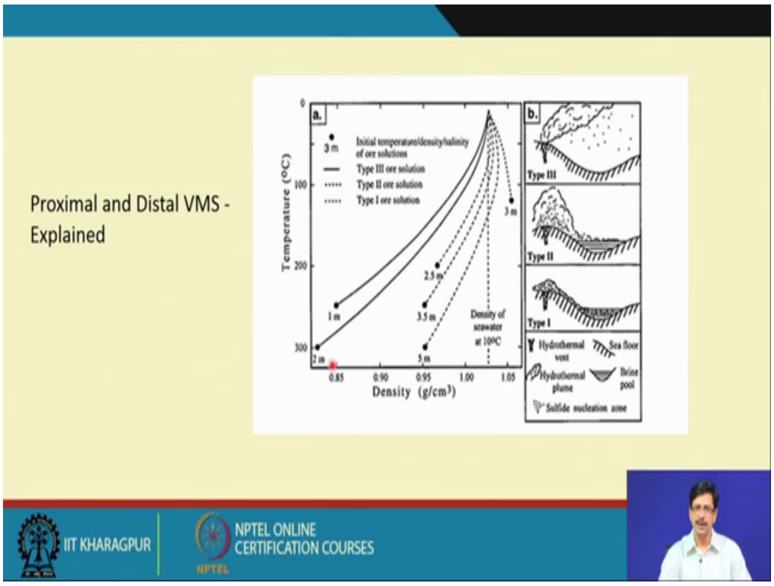

This volcanogenic massive sulfide deposits the morphology which we saw of the cypress type, the kuroko type and saw their classification are generally, on the basis on the basis of the this the relative position of the formation of this sulfide body they mineralized body or essentially can be divided into the proximal or the distal type, where the proximal type will only have the morphology in terms of a fader stock work zone preserve or present whereas, the situation where the deposit is a distal type; that means, away from the zone of active hunting of hydrothermal fluid, where the sulfide minerals are just deposited in the form of shower on the sea on the available surface.

So, those kind of situations will divide of such stock work, feeder zone and the alteration pipe which will be missing from such occurrences. So what really how this kind of proximal or the distal volcanogenic massive sulfate deposit will form can be explainable on such kind of a schematic, it is one of the hypothesis or the mechanisms which are suggested. For the formation of these proximal and the distal hydrothermal VMS deposits; this hydrothermal fluid which is venting at the it only reads axis which has a very intricately deformed and fractured network.

So, the fluid could imagine. So, this dotted line is the density of the sea water at 10 degree Celsius which is about just about little over 1 degree 1 gram per cc and the different types of possible fluid are shown here on through this solid and the dotted lines. This is corresponding to about just about 5 percent Nacl which can be expressed the salinity can be expressed in the Nacl weight percent and the temperature also the temperature is increasing here.

So, density of this kind of fluid at this temperature of there about 300 degree centigrade and the fluid is about 5 weight percent salinity. It would be much less dense than the sea waters which the value is about little over one. So, if that fluid is will be venting out which is shown here on the first diagram, which will basically be called as a type 3 fluid shown by this solid line.

So, this fluid will be less dense than the sea water and it will intend to rise in the form of flume and can move over to 100 submitters away from the vent site. And will be deposited anywhere away from different sites and will be deposited along with the sediments. They are forming the massive sulfide lenses of the bodies all confirmable to the whatever is depositing in the nearby areas and they will be forming the distal VMS.

The situation corresponding to type 2 fluid, which will be here, the density of this fluid will be a little bit closer in the density of the type 3 fluid will always be less than that of the seawater the density of the type 2 fluid. Which is where the salinity is increasing here we will see it is about 5 weight percent here it will be 10 weight percent it will be about 12 weight percent a in a cell equivalent. So, this fluid density initially will be lower than that of the seawater or it may be sometime even be close to or a little higher than the seawater. That is shown here is a type 2 fluid which will rise, but not as much as the type free will form the massive sulfide here and also the situation which will be corresponding to that the feeder dike.

So, in this kind of situation we see that we can have a bit of a proximal mineralization and also distal and the type 1 fluid, which will be always be denser then the seawater. Will tend to just flow down on this flank of the mid ocean ridge axis which is has the slope and will be deposited. And also, here it will form in this situation it will form the sulfide chimneys and the massive sulfide body and will form a proximal VMS. And that is this is one the possible explanations for this formation of the proximal and distal VMS volcanogenic massive sulfide bodies. And the associated features the alternation the stock work zone which is that in the football.

So, this is how the model goes. So, this is all about the volcanogenic massive sulfide deposits they and there is discussed there small, but front of a little higher in the metal content of the base metals copper lead and zinc.

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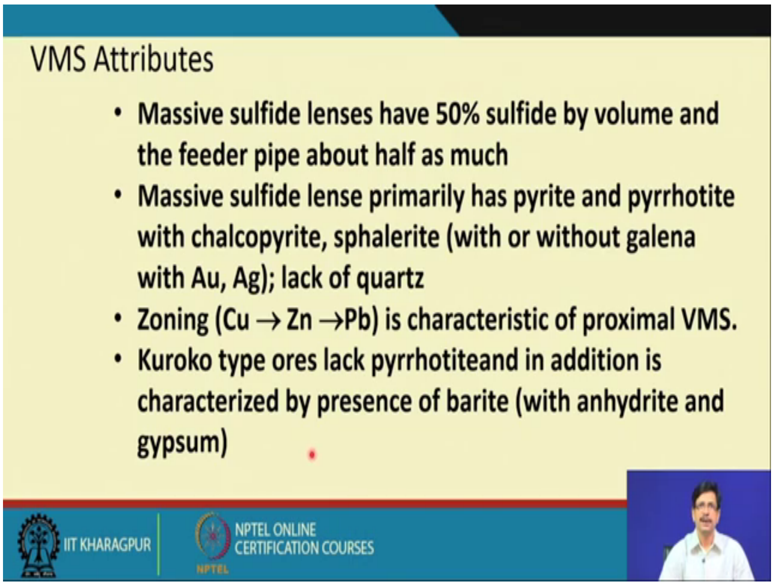

So, the attributes are they have about 50 percent sulfide wave volume and the feeder pipe has about just 25 percent the passive sulfide lenses. Primarily have pyrite pyrrhotite with chalcopyrite sphalerite with or without galena lay where the kuroko type will essence will be laid in zinc rich type. And so, they will have galena and sphalerite much more in abundance than that of chalcopyrite where is the copper zinc type the Cyprus type and the bessie type will have chalcopyrite as the dominant sulfide mineral. The zoning literal as well as vertical copper zinc and lead this characteristic of the proximal VMS.

And one of the important mineralogical characteristics by which these volcanogenic massive sulfide deposits have started to been identified, in areas where they were not known to be existing. So, barite presence of barite is also one of the important indicators and along with anhydride and gypsum, which we saw that the anhydrate is an is a mineral which precipitates, in the very beginning, of the formation of the sulfide chimney in the sea floor hydrothermal systems.

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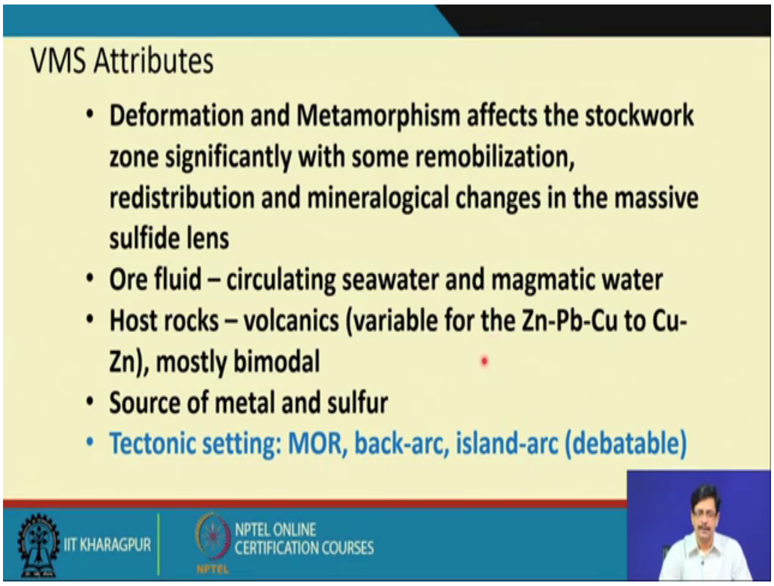

These massive sulfide deposits, when they are occurring in the older terrain, the old ones because these deposits are very the Cyprus type is almost uniformly distributed in time, from starting from the Archaean time. As the exemplified by the noranda deposit and they occur in different parts like the iberian pyrite belt and many other the Tudors of your light. So, the old ones at least occurring in the in close association with the greenstone belts have undergone metamorphism and deformation.

Metamorphism only possibly helps in a little bit of redistribution and sometimes they the proportion of pyrrhotite. Increase in the proportion of pyrrhotite is understood to be due to the metamorphism of these at higher pressure higher temperature conditions. And deformation can always distort the geometry from what we see for this typical morphology and the feeder zone will always have a changed mineralogy with higher grade of metamorphism. Giving rise to an fuels and pyrogin minerals as well sometimes there are some scorn type of situation also where observe.

And the ore fluid is in all probability there is a circulating seawater and a component of magmatic water being present. As we see and there is a always a subsurface felsic intrusive that is existing which provides fluid, as well as heat. These all come from systematic study of fluid inclusions and oxygen isotope and sulfur isotope signature of the minerals.

So, a dominating a component of seawater is all the time very clear and with magmatic involvement host rocks are always where the volcanics, but variable from the zinc lead copper to be copper zinc. Mostly bimodal and that is how in most of the cases the a mixed type tectonic setting where a kuroko type deposit which is supposedly to be forming on a convergent plate tectonic setting. Is also associated with a bit of backer kind of spreading exemplified by the opening of the sea of Japan which is which actually will be able to explain the presence of such kind of bimodal volcanism.

Ah, but situations corresponding to the mid-Atlantic ridge where we see the hydrothermal venting. There the components will be definitely less and the. So, source of metal the sea floor rocks and the basalt sea floor basalt is definitely the source of metal which is acquired by the fluid through the rock. In fluid work interaction, at high temperature sulfur is mostly the as is found out from the sulfur isotropic studies mostly the seawater with some little magmatic component.

And the tectonic setting always will be varying there from mid oceanic ridge to back arc, island arc kind of mixed kind of set up in many of the situations like the most of the situations like they will always in or the other kind of situations. Where we see it is a mostly a hybrid type of mix type of tectonic setup and. So, that is what we can have as an overlook on these systems which are seafloor hydrothermal systems giving rise to a mineralization and the resultant ore deposit.

We will continue discussion on the other dominant type of hydrothermal deposits.

Thank you.