Mineral Resources: Geology, Exploration, Economics and Environment

Prof. M. K. Panigrahi
Department of Geology and Geophysics
Indian Institute of Technology, Kharagpur

Lecture - 14
Sedimentary Processes and Resultant Deposits (Contd.)

Welcome to today's lecture, we discussed about the surface operated process like the residual concentration and try to just see an overview basic idea as to how this process operates on the surface and the necessary conditions and the topographic and the climatic conditions that is needed for getting these materials enriched to and to the ore grade for aluminium, nickel, gold or for that matter even iron ore.

So, we will discuss another such important enrichment process, where actually it is essentially processed by a, by which a primary ore gets a enriched or gets concentrated in a definite part of it, by the process of interaction with the it interacts on the meteoric water which will existing ore body so we will look at this.

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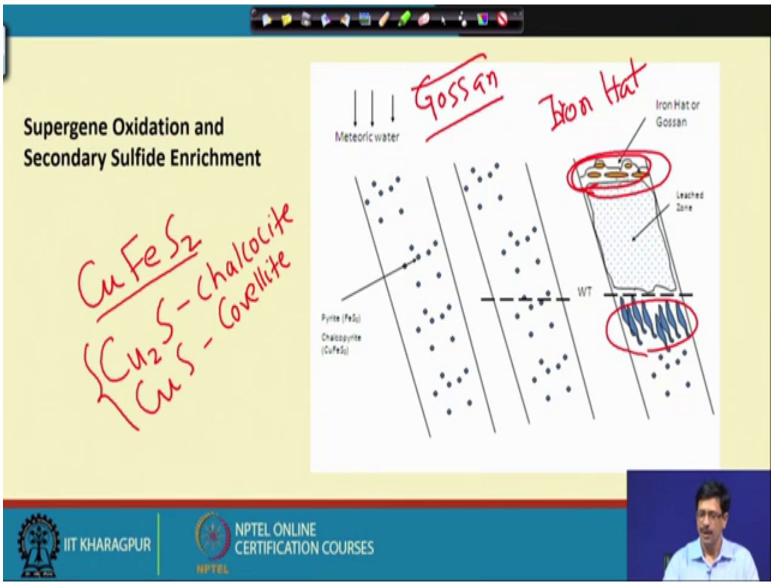

Supergene Oxidation and Secondary Sulfide Enrichment

$CuFeS_2$

Cu_2S - Chalcocite

CuS - Covellite

So, we call this process essentially as the super gene oxidation and secondary sulphide enrichment process. If you look at it this is just a cartoon that depicts the scenario here what is shown here. For example, say it is a tubular or a tubular ore body which extends to depths of several even several hundreds of meters from the surface, this deposit definitely formed at a deeper conditions in the crust when it formed primarily and now this deposit has been exposed that is exposed to the surface and this is when a has been a primary ore body of a metal sulphide and has abundant pyrite FeS 2, as the dominant mineralogy along with other sulphide minerals like it could be chalcopyrite or it could be galena sphalerite type of a sulphide minerals.

And suppose this particular body now exposed to the surface, look at this if in relation to this diagram what is what is shown here is SWT is the water table. We all know the water table is the surface is indicates that if we dig a hole here, the water level at which we will get water, there is a surface which will be essentially in an unconfined condition is the water table. So, above the water table the condition here is actually known as the zone of aeration, where the pore spaces in the rocks or the fractures are either partly filled up with water or are filled up with air and that is how we call it as a zone of aeration or zone of oxidation, and below the water table this zone, where the pore spaces are fully filled up with water and this zone is a zone of reduction.

The significance of this with respect to this ore body which is exposed at the surface is like this, we have the primary sulphides essentially dominantly pyrite on the surface. So, 1 of the necessary conditions for this process to operate is that the ore body has to have a certain abundance of the mineral pyrite, why is it so we will just see in a while.

So, what happens here that the primary pyrite gets oxidized in the presence of water and oxygen and generates huge amount of sulphuric acid H 2 SO 4 and this S 2 SO 4 which is generated here in this zone, is it actually dissolves the other metals like lead or zinc or copper, which are there in minerals like chalcopyrite or pyrite solid item galena and then they are soluble then they are converted to their very soluble sulphide form and they trickle down or they essentially they descend because, this zone is essentially the zone where the permeability's is essentially high through which this dissolved form of the metals like copper zinc and lead they go down and is not when they and they cross or the cross this water table and encounter reducing environment, all the sulphates get again reduced to form their secondary sulphides.

So, in terms of the process the results are that below the water table, we get some joule which we call as the secondary sulphide enrichment zone; in which the primary sulphides of the ore like perolite chalcopyrite of galena or sphalerite or replaced or by the secondary sulphates of them.

As we know that the minerals couple minerals like chalcocite, which is chalcopyrite is Cu Fe S 2 is chalcopyrite and this is a primary sulphide or copper and iron minerals like Cu 2 S that is chalcocite and Cu S like covellite, these 2 minerals with which they rarely form in primary ore bodies of primary sulphide ore bodies, because the conditions that they required the activities of the other fugacity of the sulphur species and the concentration of this ions copper, it does not allow formation of these minerals as primary minerals in the primary ore of any of the sulphide ore body that is forming the are crust.

So, the zone which is which is shown here essentially at the zone in which there will be enrichment on the metal in the form of the secondary sulphide which are the chalcocite and covellite so there. So, this is how the process goes on, and the what happens here is all as we know that iron cannot remain in the soluble Fe 2 or 2 plus form for long on the surface, it immediately gets oxidized to form it is respective insoluble oxide or the or the hydrated oxide. So, what is shown here with this orange colour material is essentially this material is actually called it is like a oxide cap or oxide reach iron cap or this also in mining geology term it is also called as iron hat.

I do not hat this is also very popularly known by one term which is called gossans. So, this part this part we can call as the super gene oxidation, and the immediately following zone just below the area is essentially the zone from which most of the metals copper led at zinc depending on what the deposit is or leached and this is the enriched zone.

And this sometimes this process if the it depends if this ore body the diameter of the ore body is such and also it also depends on what is the immediate host rock, which is their surrounding this ore body, if the immediate because here in the in this initially there will be generation of copious amount of sulphuric acid and that sulphuric acid means that the pH of this fluid will become very low.

If the surrounding rocks which are just around the ore body if they are able to consume the acid that is created they generated over here, then this process will not be able to operate that very efficiently. So, we need to have some kind of favourable host rock here, which will not be first of all the volume of this ore body has to be adequate substantial so, that the heat that they see that is generated will be able to go down.

So, sometimes what happens if this is this zone the oxidation process is remains a little bit incomplete, then we do also get certain other minerals even the metals like copper or led or zinc even they have they deposit on in situ in the form of their respective oxides in which case the super gene enrichment zone will not be there very prominent. Super gene enrichment zone will only be prominent if we have this process operated to it is full efficiency.

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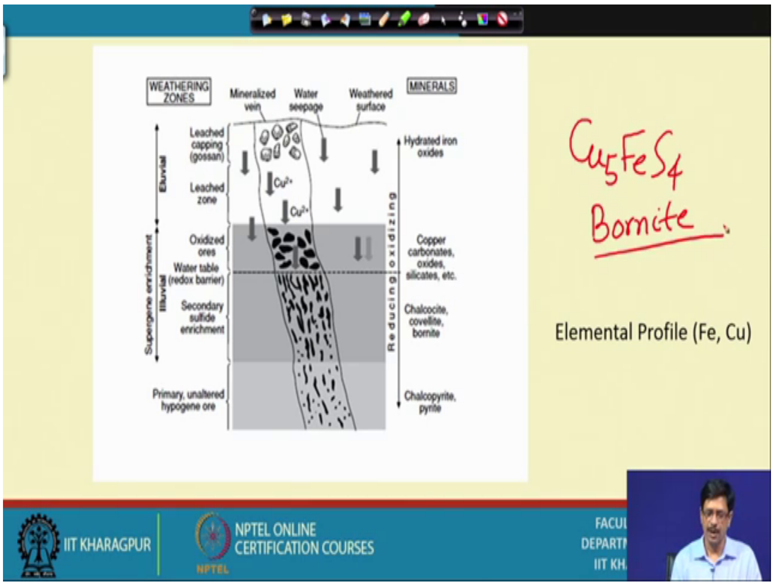

Cu_5FeS_4

Bornite

Elemental Profile (Fe, Cu)

So now let us look at this so, here we can see this profile diagram again shown in a more clear way, where this zone is this is the alluvial zone, this is the leech zone, this is the oxide ore and this is the surface left iron oxide which is the iron hat and this is the chalcocite covellite; sometimes also it does contain some amount of a boride. Like this is also one mineral of copper iron which also forms in the ore body, if you look at this situation and you take a profile of the elemental concentration, then you will get something like this. So, we are doing for copper, so copper will be something like this and we will have an increased concentration in this and goes to the normal value, because below this secondary sulphide energy zone.

We get the primary ore and the copper value is decreased. If we take the iron, then iron will have a value which have a profile which will be exactly like this, which will be high on the oxidation only on the zone and this will be for iron and this will be for copper.

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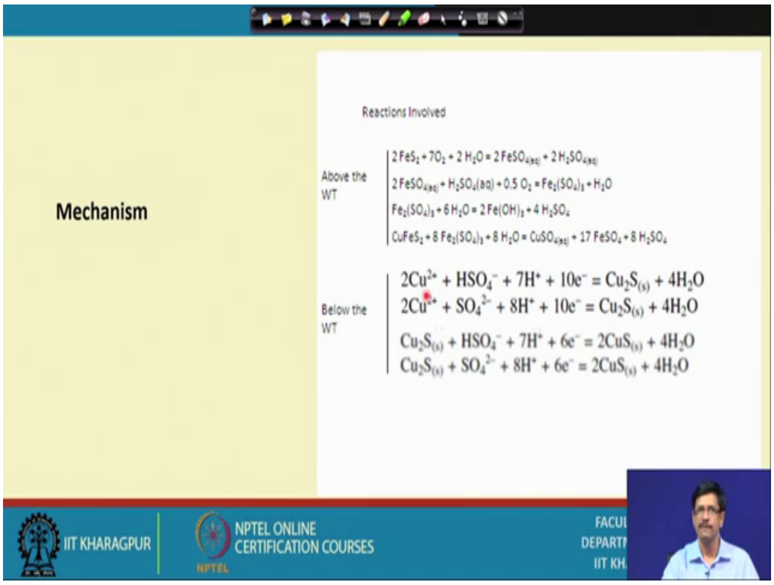

Mechanism

Reactions Involved

Above the WT

$2FeS_2 + 7O_2 + 2H_2O = 2FeSO_{4(aq)} + 2H_2SO_{4(aq)}$

$2FeSO_{4(aq)} + H_2SO_4(aq) + 0.5\,O_2 = Fe_2(SO_4)_3 + H_2O$

$Fe_2(SO_4)_3 + 6H_2O = 2Fe(OH)_3 + 4H_2SO_4$

$CuFeS_2 + 8Fe_2(SO_4)_3 + 8H_2O = CuSO_{4(aq)} + 17FeSO_4 + 8H_2SO_4$

Below the WT

$2Cu^{2+} + HSO_4^{-} + 7H^{+} + 10e^{-} = Cu_2S_{(s)} + 4H_2O$

$2Cu^{2+} + SO_4^{2-} + 8H^{+} + 10e^{-} = Cu_2S_{(s)} + 4H_2O$

$Cu_2S_{(s)} + HSO_4^{-} + 7H^{+} + 6e^{-} = 2CuS_{(s)} + 4H_2O$

$Cu_2S_{(s)} + SO_4^{2-} + 8H^{+} + 6e^{-} = 2CuS_{(s)} + 4H_2O$

Let us look at the mechanism the way it works in form of the reaction. So, here we could see what exactly we discussed the reaction is pyrite, plus oxygen, plus water is giving rise to a ferrous sulphate which is soluble aqueous and generation of H 2 SO 4 this aqueous chain reaction where the FeSO 4 is again acted upon by sulphuric acid to form ferric sulphate.

This ferric sulphate gets oxidized the iron is getting oxidized to form the FuH3 which actually is the part of that iron hat or the gossan which we just stated again releasing H 2 SO 4. So, that is how the amount of the s is released is high and the system becomes far more acidic, and if you look at if it act acts upon the mineral like chalcopyrite over here, then it forms the soluble copper sulphide, copper sulphate and similar reactions also could be written if we find when the zinc iron sulphide is sphalerite or it would have been a led sulphide.

So, it dissolves the metal in the form of copper sulphate and then so these are the reactions which take place in above the water table and below the water table, the reactions that take place is that this copper iron which is being transported through the fluid is get it may gets reduced to Cu 2 S, that is the chalcocite or even CuS. So, these reactions are responsible or these 2 sets of reactions they operate on the above the water table and below the water table and explains the formation of the super gene sulphide enrichment.

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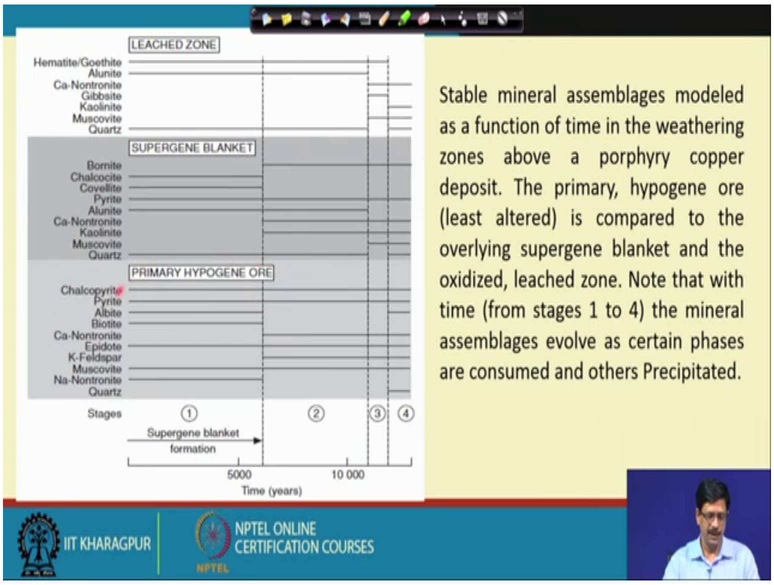

Stable mineral assemblages modeled as a function of time in the weathering zones above a porphyry copper deposit. The primary, hypogene ore (least altered) is compared to the overlying supergene blanket and the oxidized, leached zone. Note that with time (from stages 1 to 4) the mineral assemblages evolve as certain phases are consumed and others Precipitated.

And the here the it is just an example or just a schematic presentation of the situation miner logically, is the primary of the hypo gene ore as we call them chalcopyrite pyrite and it can have the silicates like Aj albeit, biotite, Epidaurus phosphor and so on; in this primary ore and in the supergene blanket we can have bornites, chalcocite, covellite, pyrite and some of the alteration mineral like alunite which is a potassium aluminium sulphate mineral and some clays and so on. And the least zone which we labelled essentially as the iron hat or the gossan with they have hematite goethite and sometimes even some gibbsite or kainite type of clay.

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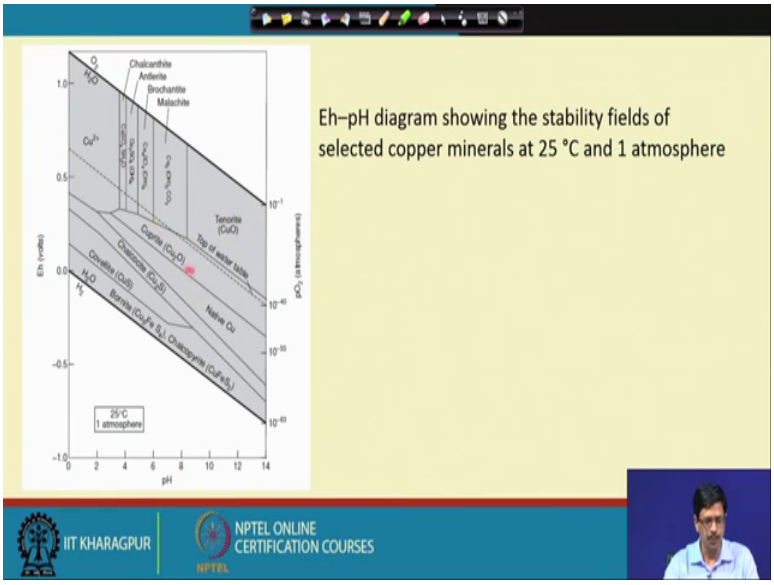

Eh–pH diagram showing the stability fields of selected copper minerals at 25 °C and 1 atmosphere

So, the situation also can be explained the mechanism by the help of EhpH diagram, where the appropriate reactions could be written. So, these are the stability field as you could see this is copper 2 plus, this is these are some of the silicates and the sulphate Brochenthite ancleirite, chalchenrite and this is the field of malachite, which is copper carbonate hydrated copper carbonate this is the one of the oxide forms of copper the distanite, this is the other form of oxide of copper cuprite and as you could see here the Eh is increasing from cupite to tenorite and what is more important to observe here that in such a situation, we also do get native copper.

There are many deposits sulphide deposits including the ones irrespective of their genetic affinitive in genetic affiliation, whatever sulphide body in the form that we presented is a cartoon in the previous figure.

If the conditions are such the appropriate pH and the Eh conditions are such, we also can have formation one native copper as we see them and the oxides and they generally are within the oxidation zone, because we could see the pH stability of these oxide minerals like tenorite or native copper or cuprite, generally will happen when the pH is much higher. So, the situation where the country rock is able to neutralize the acidity generated by the process of a pyrite oxidation, then the copper of the primary ore and d zones may not be able to be disserved that efficiently, some amount of copper will be left behind in the oxidation zone to form the minerals like tenorite and cuprite and some native copper as well.

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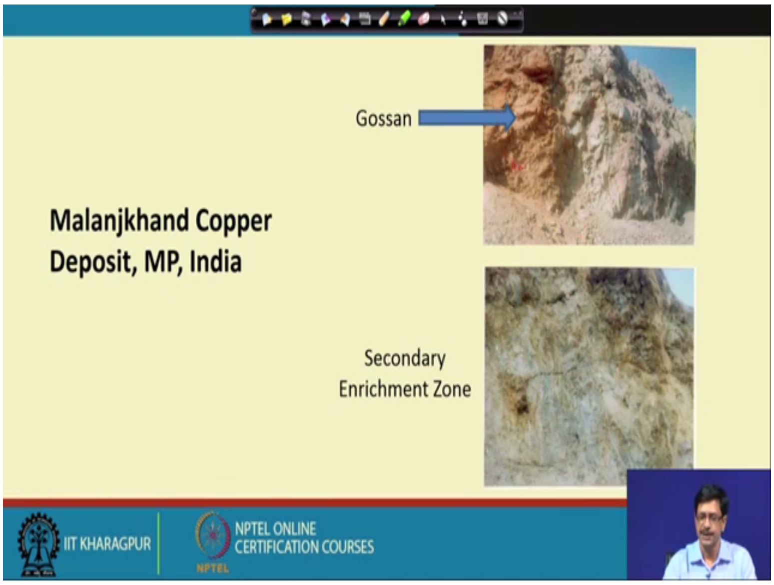

Malanjkhand Copper Deposit, MP, India

This is just to show you an example; this is a famous malanjkhand copper mine in central India, dills of which we will discuss when we will be taking of the Indian mineral deposits. Just to show as an example, this is the altered weather drannit at the top this is the ore body which is exposed on the surface and is converted to a entire mass which is enriched with limonite or this is exactly where the Gossan which looks like.

Just below the gossan here we see that this is the oh this is the zone, which is secondary enrichment zone and the chalcocite and covellite ores minerals have a very typical black colour and they give such kind of an appearance and sometimes these zones are also called as the sooty ore body in the mining geological terms, and if one goes further down then the primary ore body is encountered. So, in such kind of an ore body almost like for a vertical height of almost 20 30 meters, and for 30 40 meters, such kind of zone generally is observed below the super gene, below the super oxidation zone, which is characterized by the presence of this gossan.

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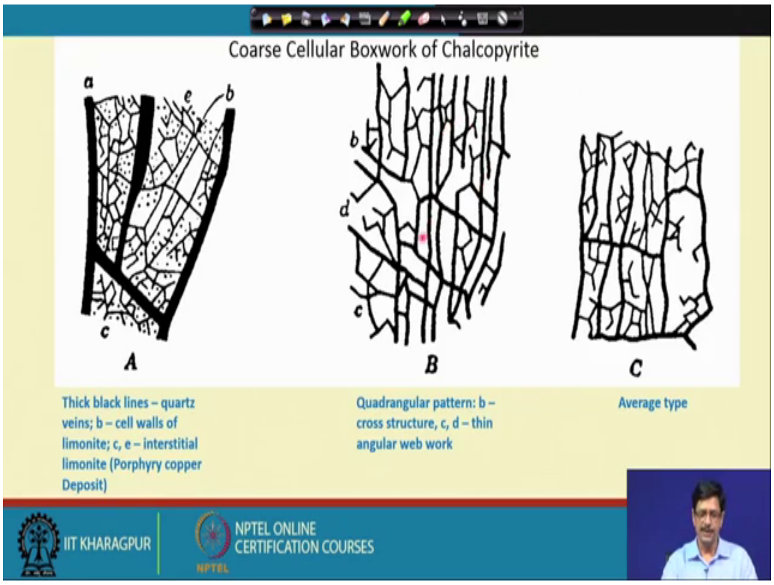

Coarse Cellular Boxwork of Chalcopyrite

Thick black lines – quartz veins; b – cell walls of limonite; c, e – interstitial limonite (Porphyry copper Deposit)

Quadrangular pattern: b – cross structure, c, d – thin angular web work

Average type

So, this gossans actually as we will be discussing sometime later when we take up exploration topics, they are very interesting. First of all when such an ore body is undergoing super gene oxidation on the surface, and is a clear cut indication that there must be a secondary enrichment down below and more importantly a presence of an ore body in the subsurface and that is what exactly we are looking for.

So, these serve is very good indicators geological indicators for exploration; that means, the process of finding out new old bodies are finding out new bodies in areas where they are not known to be occurring and these limonitic cap which is the gossan, the gossan zone usually is there in the area of the ore body has a considerably fractured that is how the fluid could populate to the fracture zone and they do display various types of forms which are known as the limonite box work, the gossans which is basically they have call as the box work in mining geological term. Here are the 3 examples which is shown here the first one is the typical box work which is produced from a chalcopyrite ore.

These thick lines are the veins of coarse because they are essentially the present in the coarse veins and mineralized coarse veins. So, these are the rest of these are the original coarse veins in which the minerals, the primary sulphide minerals has been leached out and have been left behind by the interstitial limonite. So, this c e and b are all the interest is a limonite and is has come from typical type of it copper deposit, which are known as the power fury copper deposit, which we will be discussing a later on, and this pattern has come up from a quadrangular pattern where there is some cross structure and thing angular wave work. So, these are actually the indications that what kind of an ore body could be expected below, whether it is a chalcopyrite reach ore body ore similarly We see that this is the kind of box work which is created, if there are sphalerite reach ore body.

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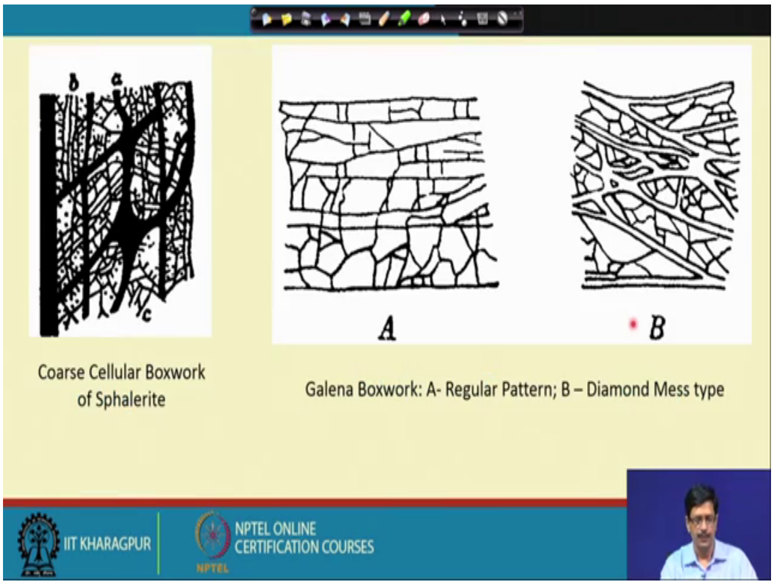

Coarse Cellular Boxwork of Sphalerite

Galena Boxwork: A- Regular Pattern; B – Diamond Mess type

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Because, spalerite by virtue of it is morphology, it is crystal habit and the way it forms in the fractured spaces in the deposit. After the sphalerite is leached out the zinc is leached out by the; I said that is generated on the surface and these are again filled up by the limonite, this gives a look of a course cellular box work in sphalerite. This box work is a typical pattern which is coming out of galena reach ore and here is a regular pattern this is a diamond base type pattern.

So, these processes which we have discussed the surface operating processes, the mechanical concentration, the residual concentration, and this super gene sulphide enrichment are essentially very efficient processes in giving rise to ore deposits, as well as getting the already existing deposit enriched to high grade values.

So, they are even as important as the primary or forming processes, primary ore forming processes when they form the ore body, we are what we have observed in the secondary or the surface operated ore processes have always upgraded or improved or further enriched the ore body which essentially is could be traced back to processes of for the very enrichment process, which we see fundamentally as ore forming process. So, we will be continuing our discussion through other deposit types.

Thank you.