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

Lecture - 04
Mineral Deposits in Time, Attributes of Mineral Deposits and Theories of Mineral Deposits

Welcome to the 4th lecture of the series on material resources, just to have a small recapitulation. In the last class, we were trying to rationalize the temporal distribution of mineral deposits and in that we discussed the spectrum which gave the different mineral deposit types they are basically called as a genetic types. And they are occurrence in different time periods and trying to find out what exactly they tell us. I would like to just go back to what we discussed just one small well couple of points which I would like you to just again note.

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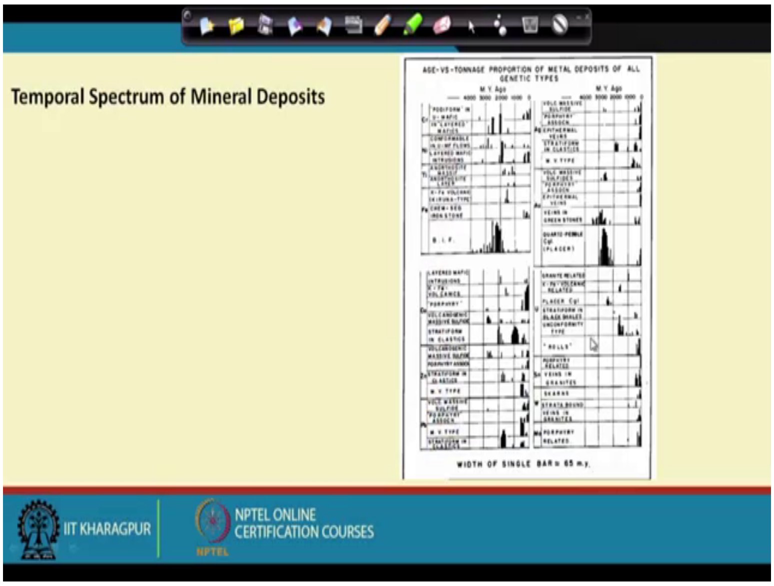

In addition to, what we discussed about the relationship or the discussed about the correlated the occurrences or formation of these mineral deposits, to the irreversible evolution of the hydrosphere atmosphere in terms of the oxidation state of the atmosphere.

In addition to that, just some of the quick look we can have. Say for example, a deposit of lead which ever deposit type you could consider just as copper forms different genetic types and so as lead, in volcanogenic massive sulphide, in sediments and so on. But, you see that glade deposits there are no deposits which are older than about 1800 million years. Similarly, if you look at metals like 10 tungsten and molybdenum, they do their deposits also. If we consider them that that is exactly what is real then these deposits also formed only in the later part of the geologic history mostly Mesozoic of post Mesozoic these also need to be explained.

One immediate or run a very quick correlation which you could make here, if you remember we were discussing about something called the enrichment factor or the general crustal abundance of metals against the quantity that is available in terms of mineral deposits. We also will also discussed about something called enrichment factor; that means, the number of times are the order of magnitude by which one particular metal or an element has to be enriched 2 form it is mineral deposits. And we observed that metals like teen tungsten molybdenum they do have a very, very high value of the enrichment factor and so as lead.

So, without getting much into the intricacies at least we can make one inference quick inference here, that formation of deposits of scarce metals like molybdenum tungsten tin which have got, who have a very high enrichment factor value of the order of 40000 16000 or so; that means, it definitely took time or it needed several cycles of such enrichment through normal rock forming or rock recycling processes, to form their deposits. And there are many such small many such observations we could to make on this temporal spectrum, but these are some of the quick ones which we may we will be discussing them in details which we when we go to the individual genetic types.

So, the present lecture is mostly here we are going to discuss about the attributes of the mineral deposits and try to give a general framework on basically on what several theories of ore deposit formation is based. As I have said before this course is the first level course, where we do not have much scope to delve much deeper into the subject of what we call as ore genesis or the origin and evolution of the ore deposits. But, what will we only look at the in a very brief and conceptual manner we do not getting much in the details of it.

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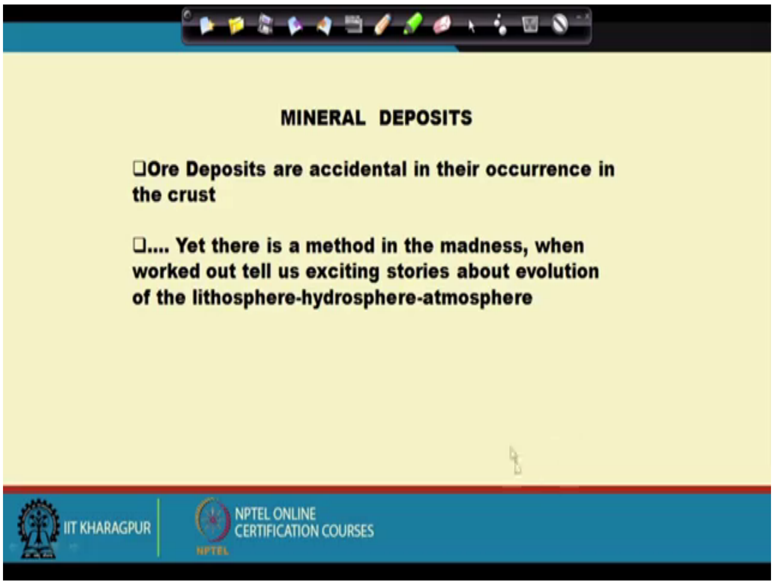

So, let us first try to see their attributes of this mineral deposits is what they are. First thing is that, which would look a little strange, but ore deposits are accidental in their occurrence in the crust. Why I say accidental? Because in the previous.

Lecture we saw and we also were quite convinced that, the quantity of any metal present in it is deposit is not actually in accordance with the equivalence or the similarity in the geological terrain. Across the continents of the world, if we get one deposit in a particular type of say for example, we will go to a granitic terrain in one particular continent we get a deposit of say molybdenum, but that same situation where we go to another continent to a similar drop same similar granitic terrain we may not get that deposit of molybdenum. A very simple way to reconcile it is that the deposit formation definitely requires a certain processes to have operated in a proper in a oh.

In the sequence proper in a in the required sequence and to have operator to the optimal level that will only give us give the result in the mineral deposit formation. And as of now, we have not been able to a very precisely quantitatively understand these processes to put them in a deterministic manner that yes, if we have such and such geological situation we would expect to such a such and such mineral deposit to form. Even though, we definitely attempt to make these signs as exact as it be, but as it stands today, we are far of we are far from it.

So, there is a there is a element of chance, which is there which is that is the reason why we can also sometime use some probabilistic or stochastic model to predict the formation of these deposits. Where, it will be a semi empirical mixed with science and observation together, but then we also say that here there is a method in the madness. So, when the mineral deposit formation looks like random or mad, but yet there is a method in the madness when worked out tells us exciting stories about evolution of the lithosphere hydrosphere and atmosphere.

We have just seen the formation of the iron deposits, older iron deposits, formation of uranium deposits; formation of certain deposits in much later in the geology, history could be rationalized. So, there exists a parallelism between the formation of mineral deposits of different types and the evolution of the crust continental crust from the very beginning the oldest to the present day. Ore deposits are distinct geological.

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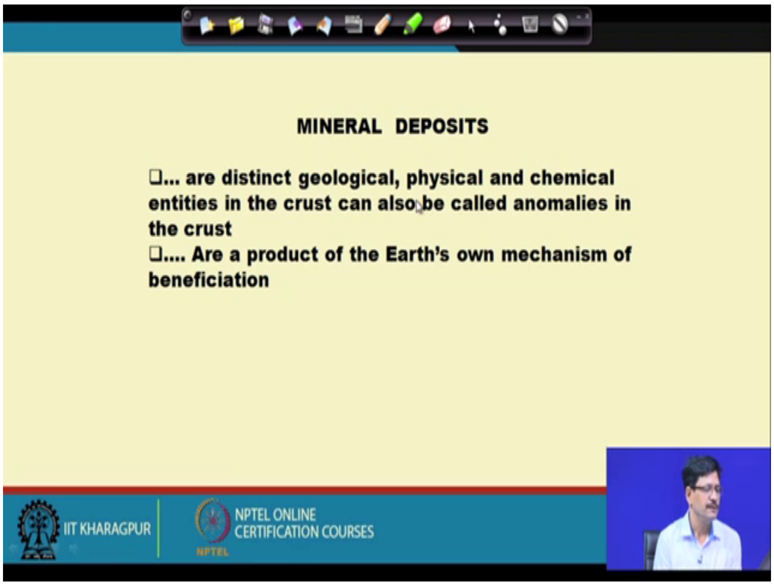

Physical and chemical entities in the crust and can also be called as anomalies in the crust. I will just try to explain what I mean by that. So, an ore body or an ore deposit we have define an ore deposit essentially has something which is called an ore body. Which is a which is an entity having a definite shape, size I mean length, breadth and thickness in the associated with the crustal rock.

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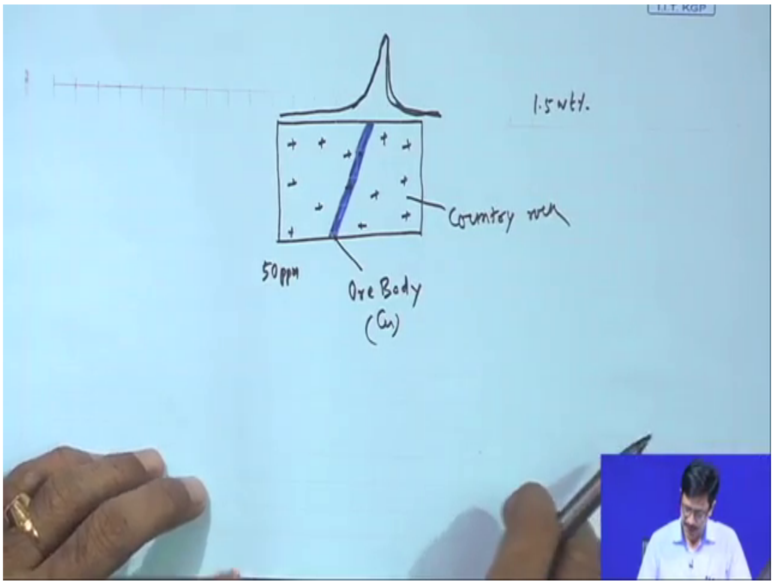

let us think of that we have a situation where, this is a normal crustal rock. Now, in this crustal normal crustal rock, let us say that there is a whatever maybe it is shape and size, we will we will look at them more closely when we look at the morphologies of different suppose this is an this happens to be an ore body. As it will be fine, this is the common crustal rock let us say that this is a ore body of copper. So, what is basically meant as an anomaly? Or a so this definitely is a distinct physical entity which is identifiable in a domain with respect to the surrounding rock. Which basically we call as the country rock. So, what is meant by an anomaly? Is that the concentration of this particular metal such as copper.

Has a value which is a threshold value or a plural value of say 50 p generally whatever it is let me let me say it is 50 ppm anywhere, anywhere within this rock I will get wherever I analyze I will get a value of say 50 ppm or maybe within a little bit of an uncertainty. The moment I am taking a sample from this particular part, this is going to give me a much higher concentration set say 1.5 weight percent and if I just try to plot, you take different points and then try to plot I will get something like this.

So, that means, the concentration of the metal is going to be maximum whenever I am going to measure the concentration from this. This actually is my ore body, so that is why they that the distinct physical chemical entities. They can be their shape, size and depth extension could be estimated by using various methods. And so, that is how I can explain and then this ore body. Say for example, this is a common rock and this is an ore. So now, there could be lots of questions which could be put here. When they when did this old body came into come into existence? And how it came into existence that many so many questions?

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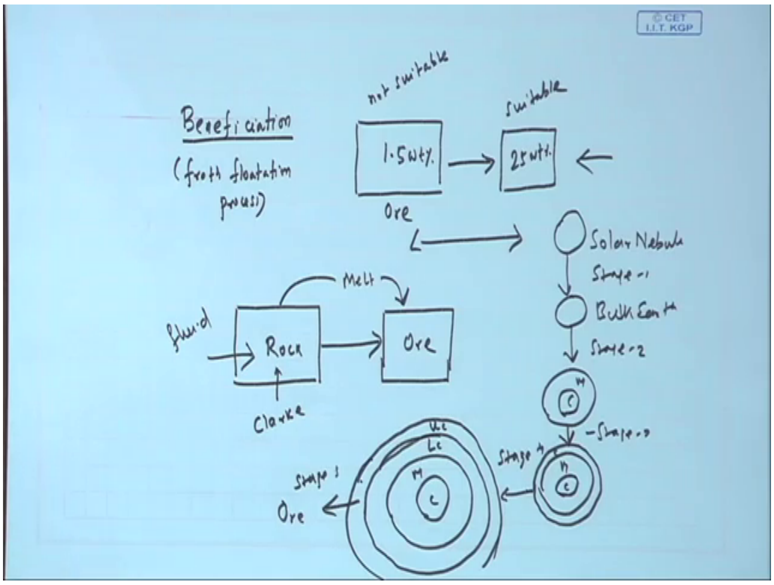

So, the next point which I made here is as a as the attributes of mineral deposit is that they are a product of the earths own mechanism of beneficiation. You all understand what beneficiation is, you all have studied in your school. One of the process of beneficiation which you all would have studied is the froth, froth flotation process. In this froth flotation process suppose I have a an ore, of a metal say copper where, the percentage is 1.5 weight percent this particular ore containing 1.5 weight percent of copper is not suitable to be taken into a processing plant or to taken into a plant where the ore could be subjected to some kind of a pyro metallurgical process such as a smelting to get the copper.

Now, what is needed is that this particular material has to has to be improved in terms of it is copper content to at least say 25 weight percent. Only when it becomes a material which is 25 weight percent is a concentration of the metal. Then only, it becomes suitable as per the present a technology to be taken into a smelter for extraction of the metal.

Now, so, then we need to have a process for increasing the metal content from this ore of 1.5 to 25 weight percent. Then that is the process which we all know that we crush in the in a primary, secondary, tertiary crusher take it to a make a slurry and then make a froth and use the surface property of the, because this is very much dependent on what the presence of this metal in what form in which mineral.

So, that minerals surface property is taken can help of and then the process is designed in such a way, if the if the if the mineral can be made in to be an arrophilic substance where they can be attached to bubbles and those kind of bubbles can be formed by using a frother and the rest of the process is well known to you. So, this is a process where we are designing a processing plant. It is main mad a artificial process of beneficiation.

So, similarly, whenever there is an so, if we say that the in nature essentially the process is actually rock to ore. The way we have defined the rock, where the concentration of the metal is somewhere the threshold which is the Clarke and then this particular rock is has to be enriched to form the ore. That is how that is what is our enrichment process so, that is how that is why we say that, this process which can be obtained by a very by a single step of enrichment or could be a multiple stage of enrichment. That is all done by the nature by the earths own whatever the endogenic and the exogamic processes that we have discussed have actually come into play to convert from a normal rock to a to an ore.

And that normal rock could be anywhere could be every there in the mantle, could be there in the lower crust, could be there in the upper crust, could be there on the surface. And where all the processes that we will be gradually discussing like in a short value we will be going for the to see the classification. All these processes either one of them or more than one of them in combination could have acted to convert this particular rock to an ore. So, talk of magmatism, magnetism is efficient in certain circumstances to convert from a rock to ore; that means, through a melting process.

Let us talk about weathering or erosion process it is also capable. Let us talk about. So, here would it be that either I could melt this rock and get the product where the concentration of a particular metal could be more. I could act I could make a make this rock acted upon by a fluid from where, the essentially the with valuable metal content could be dissolved out and could be deposited in the form of where they could be enriched and will satisfy, the criteria to be called as an ore or I could differentially leach out. Suppose, if this is a rock and this contents certain metal in the form of this mineral. And where I will be able to get rid of the all the constituents which are not necessary to me and can get it in the form of enriched form which I can converse. And also, all these it could be a melting, it could be a at external fluid on that, it could be a process of weathering erosion and transportation, it will be either one or a combination of one of them which will act upon to convert a normal crustal rock to an ore.

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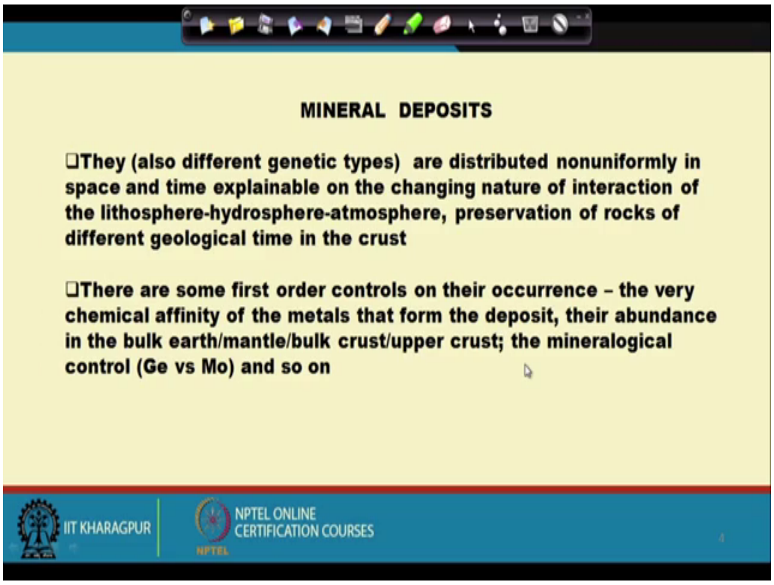

So, ore deposits are distributed non-Uniformly in space in time explainable on the changing nature of interaction of the lithosphere, hydrosphere, atmosphere. Preservation of rocks of different geological time in the crust, which you have just justified that the ore deposit formation can be visualized as a complex process or interaction of the lithosphere, hydrosphere and atmosphere.

They are they cannot be kept isolated from each other in at least in relation to the formation of ore deposits of different types. And we also have just seen that, whatever quantity of the metals that we have we as see as our endowment of the total endowment of the continental crust. With respect to, consider any metal any abundant metal or scarce metal then they definitely are the amount that is left after any kind of a self-destruction process or what we get is of is actually the ones which are preserved.

And there are some first order controls on their occurrence they very chemical affinity of the metal the form of the deposit their abundance in the bulk earth mental bulk crust upper crust and even neurological control. This we discussed in the very first introductory course that, the total quantity of the metal that is available to us is essentially controlled by the crustal abundance. What we what we see something is present in the crust today or in any ore body.

We can always go back and see what is the ultimate source. Although, we can just really crudely say that well the ultimate source is basically first it starts with the solar nebula, then the formation of the bulk earth. From the bulk earth, we had separation into core and mantle core and mantle. And once the core is separated out it does not it is not involved in the process.

Which is in which is of interest to us as far as the ore deposit formation is concerned. So, then we will have a mantle and the continental crust formation. So, this is the stage 1, this is stage 2, this is stage 3. And then from this. So now, this is the core this is the mantle and this is the this part is the crust and this again goes to core mantle core mantle and this could be the lower crust and upper crust took in always. So, this is the lower, crust this is the upper crust. So, ore deposit so this could be a stage 4 and from stage 4 we do get the ores. So, that it our stage 5 so at each step there is some enrichment that is taken place.

Whatever the elements they are getting fractionated between the solar level and the bulk earth, elements are metals are getting fractionated during the core mantle formation. For example, any of the metals which are siderophile in their tendency, they have an affinity for iron we will likes platinum group of metal gold they will go into the core and not be available in that much quantity to form ore. Then during the crust and mantle fractionation most of the elements which are lithophile, they will be enriched in the crust. And then the lower crust and upper crust structure nation will further take place and whatever we get, as ore deposits are further enrichment process from the upper crust.

So, they could be they can happen in just 1 stage of enrichment or multiple stages of enrichment. Depending on what is the abundance of that particular metal in the in the upper crust and what is the enrichment factor that it will require? And also, we discussed that the availability of any particular metal in the quantity that we have them is essentially controlled by fundamental parameters like whether they are present in their discrete mineral phase or not. Because, it will be sometimes it will be easier if that particular metal is present in it is discrete mineral phase, it will be easy for us to extract it separate it out and get the metal out of it or use the mineral if it is can be used directly for as a raw material.

And compared to a situation where the metal remains is in trace quantity in common rock. And that becomes difficult for that particular metal to be extracted out. The very good example here is the germanium and molybdenum. Germanium and molybdenum have near identical abundance in the crust, but the total amount of molybdenum available to us in the form of deposit is far more then the total amount that is available to us for germanium. Because, germanium is a lithophile element and remains in their lattices of the silicate minerals. Whereas, molybdenum is a chalcophile element forms it is sulfide will be readily and that is how we can recover them in larger quantity whenever it forms an ore body.

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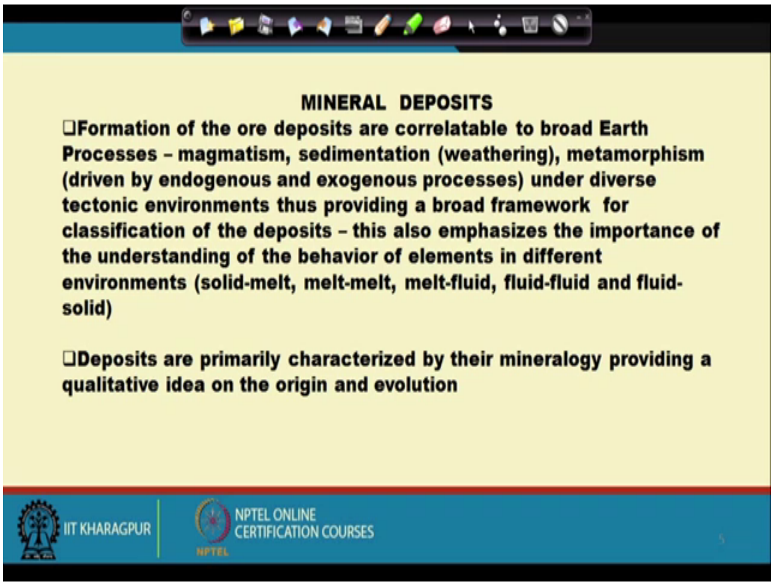

So, we have seen that the ore deposit formation. That coralable correlatable to broad earth processes magnetism, sedimentation, metamorphism driven by the endogenous and exogenous processes under divers tectonic environments. So, tectonism is always the operative force and under diverse tectonic environments, that is providing a broad framework for classification of ore deposits. We will see the how we can classify them, this also emphasizes the importance of the understanding of the behaviour of elements in different environments.

So, we can always think of the formation of a mineral deposit of any particular metal, coming out of the processes which can be very well defined in the domains. For example, if we are talking about magnetism then it is a domain of solid and melt interaction.

So, any of the metal or element to be enriched their behaviour will be depending on the energetics on their fractionation in a solid melt system, it could be a situation it will be melt. Means one of the melt component can get fractionated out from a parent melt and if that also involves fractionation or enrichment of any of the particular metal or metals that becomes a process. It could be a melt and fluid it could be fluid melt and fluid situation we will see, it could be fluid fluid that could be fluid and solid. And deposits are primarily characterized by their mineralogy. So, mineralogy is a very essential attribute of any mineral deposit.

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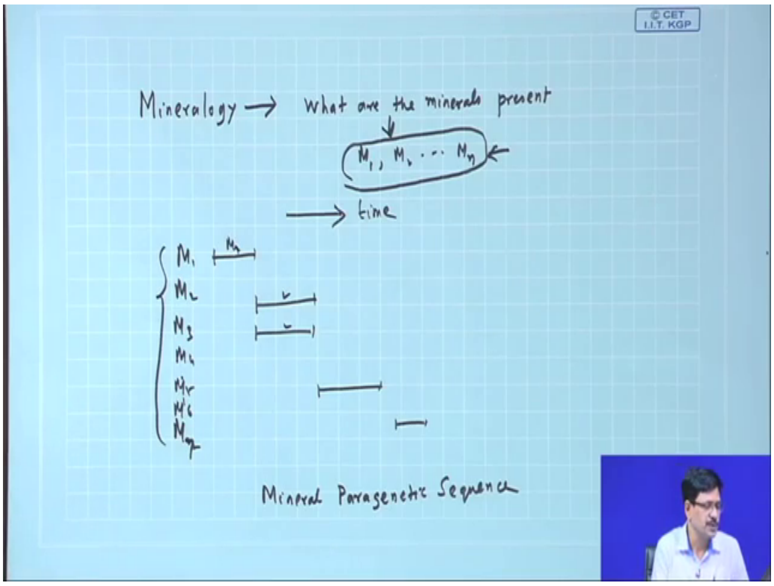

So, the first and foremost as we all we all being geologists the very first and foremost attribute of a mineral deposit of an ore body to a very specific or the mineral or the mineralogy. So, mineralogy we is essentially we are understand what are the minerals which are present there. In the introductory course lecture, we saw the we all know the middle kingdoms division into silicates and non-silicates. This non-silicates are all oxides sulfides carbonates and so on. So, what is essentially required? Is that we must identify what is the mineral that is present in an ore body.

Mineral 1, mineral 2 and so on mineral n, because this gives us this gives us a the first hand information because minerals as we stated earlier a mineral occur a metal which is occurring in it is oxide form, a sulfide form of sulfate or carbonate or. So, this this is very much controlled by the by chemistry by the physical chemical environment in which the whole body is forming. So, understanding the mineral is or getting the minerals is very important.

We do have laboratory methods to we are all very familiar with seeing thin sections of rocks and identifying minerals. Some of the basic difference between the minerals which occur in silicates and minerals of some of the metals which either occur is oxides or sulphides, which generally opaque to ordinary light they are also studied by making some sections from them and they are studied under incident light and the first and foremost exercise that in the any study of an ore deposit is to characterize the ore deposit in terms of mineralogy.

So, what exactly briefly we can see we can discuss them in greater details later. Suppose, there are there is an ore body, where there is there are minerals M1, M2, M3 and so on up to Mn. Now, what generally is required for us to understand is that whether how and when these minerals formed whether they formed as the mineral assemblages in different points of time. And if so, then whether it is possible to work them out. So, this is the first step that we follow there to understand, something called the paragenetic sequence.

Suppose there are M4 and M5 M6 and M7 there are 7 minerals that I am finding in an ore body in an ore sample of ore. So, here I could represented it in terms of a qualitative sense in time, not in absolute sense, but in qualitative sense and relative sense early late and so on. And I can represent them in situations like this and say for example, M1 was here, M2 it was here, M3 was here. So, by looking at the neutral intergrowth I could just show you some of the quick yeah.

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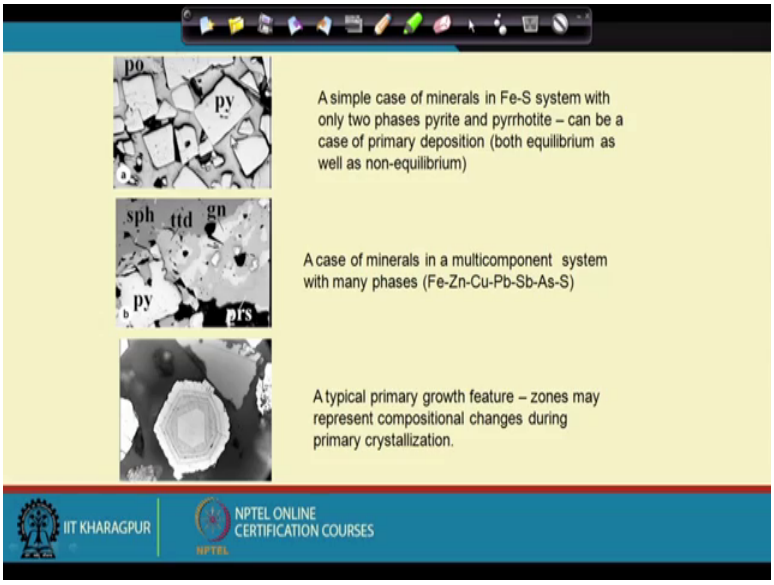

So, this these are some of the photographs, photomicrographs that we have that is that are that I could show you here. Here, it is an example where you see that this is py is for pyrite this is for pyrrhotite is Fe-S.

Pyrrhotite is also argon sulfide this is what essentially could be thought of as a mineral assembling here we are seen that are the 2 minerals. In this case, we find there are more than 2 minerals this is pyrite, this is spalaride, this is tectohydrade galena, these are forming a mineral this was what exactly we mean by an assemblage.

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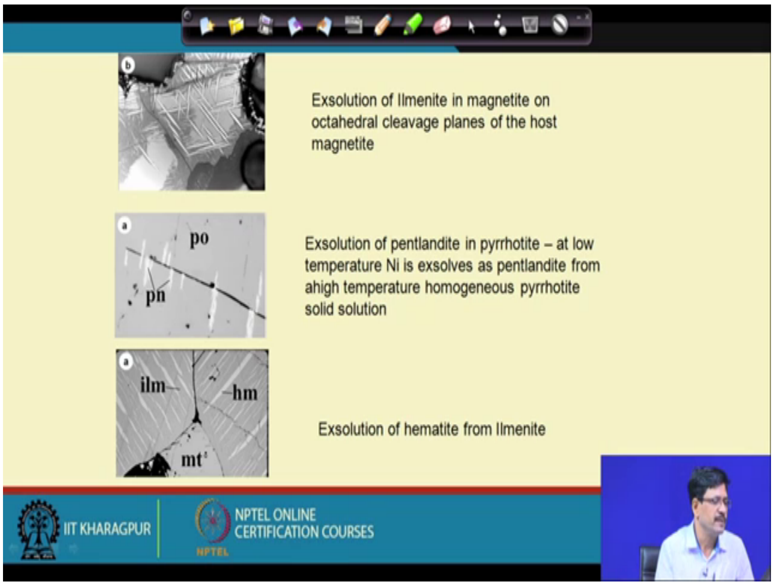

And by looking at this kind of photograph, this kind of images, you see that if here there are 2 minerals which are present, this is quite different from the situation which is depicted here. This is this is a this is a penotide and the pentlandite which is nickel sulfide and this is iron sulphide. In this case, it is the these needles are essentially of ilmenite within the main bulk of the material which is magnetite. So, even though we will we exactly are not going to understand what they are, but it is very easy to see that these inter mutual intergrowth of these minerals depicted in these 3 or 4 diagrams are different. They represent certain different processes.

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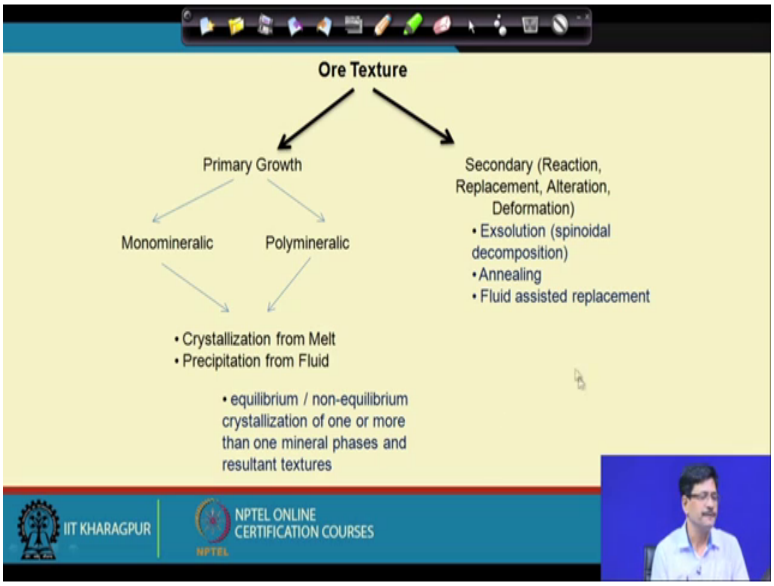

So, these different processes can be essentially thought of, if we say that we are trying to understand the ore texture. Then, this ore texture could result from a primary growth of these minerals together.

They could be monomineralic or they could be polymineralic they could crystallize from a melt or precipitation from fluid. There could be secondary reaction the replacement reaction relation, replacement, alteration, deformation, exsolution, annealing and fluid assisted replacement and so on and so forth. So, these are all the processes that we can think of in that that are interpretable by studying the ore minerals. When there when more than one ore minerals are present, we can see from there the way they are intergrown with each other. And so, we will continue discussing in the next lecture.

Thank you for today, we will continue in the next lecture.