Mineral Resources: Geology, Exploration, Economics and Environment

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Lecture - 05
Classification of Mineral Deposits

Welcome to the fifth lecture of the series on mineral resources. So, just to sum up, we we were discussing some very fundamental attributes of mineral deposits I would rather say because we are already knowing now that deposit is the term that we use for the entities which actually are the ones from which we recover the minerals where the source represents a generalized more qualitative term in totality.

In this lecture, we will try to build up the rational for classification of this mineral deposit and see what kind of a classification we could propose. Before that I would just like to continue quickly some of the points which we were discussing in the last class.

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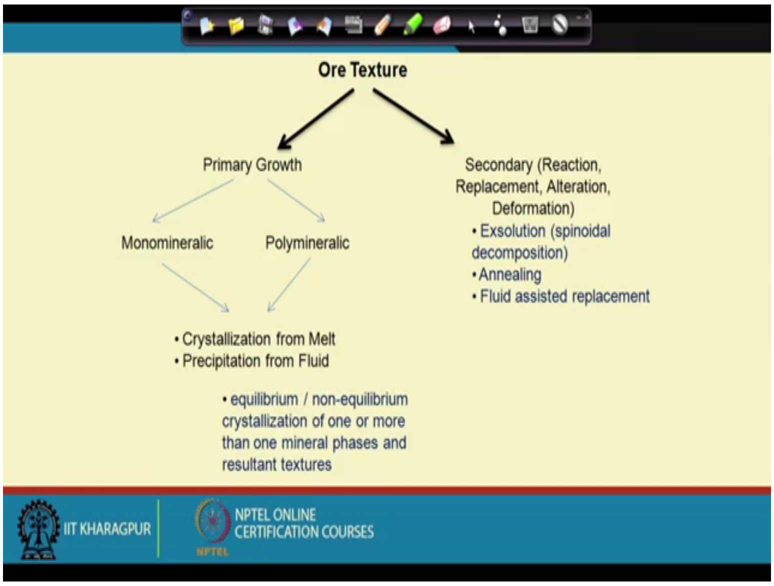

We were discussing about the mineralogy.

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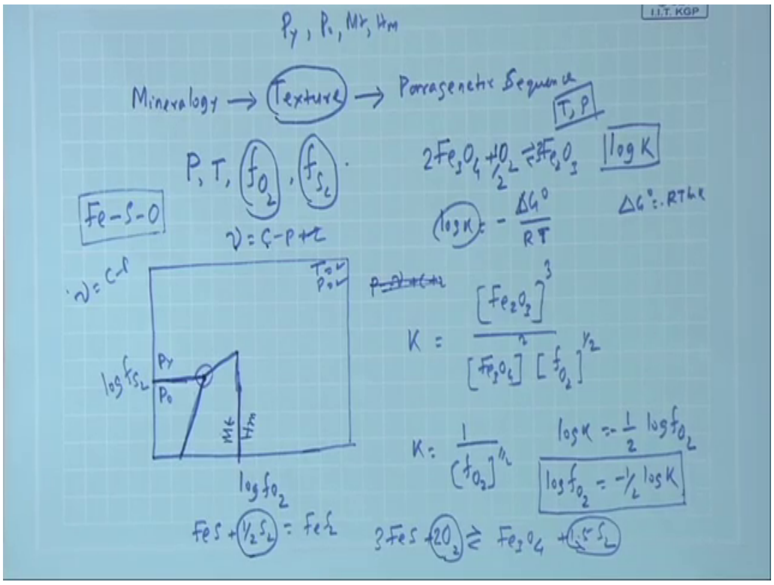

And we were essentially trying to understand the texture which basically can be defined as something as the inter growth of minerals more than one mineral in an ore sample of ore in the ore body.

So, from the texture, we were essentially trying to establish something called a paragenetic sequence and this paragenetic sequence when we study the texture, we are in a position to establish if there are the constituent minerals which are present in an ore; what is the time relationship and also from that we basically try to establish the assemblages or to be more precise; the equilibrium assemblages which you can see in that particular ore.

So, whether there are many such equilibrium assemblages which could be thought of in terms of the paragenetic sequence. Sometimes the paragenetic sequence can be divided into the primary stages and the secondary stage like the later alteration which are very important in context of ore bodies which we will see them later.

But what exactly we are trying to the information that we want because in the context of an ore body, we always would like to characterize the ore forming process in terms of the intensive parameters like pressure, temperature and the compositional variables. So, the compositional variables when our minerals are dominantly oxides and sulphides, we would be always be talking in terms of the fugacity of oxygen, fugacity of sulfur and so on.

So, essentially these terms are the nothing, but the corrected partial pressure. If at this point of time, we are not getting into the fundamentals of thermodynamics to define or to explain; what this term is. For the time being if we think that these are compositional parameters representing because at the partial pressure corrected partial pressure of oxygen sulfur or sometimes even carbon dioxide as we saw in the last lecture.

So, it is essential for us to characterize the ore forming process with respect to these intensive variables. So, that we can interpret in terms of what was the broad physical process that was responsible information of this zone deposit? So, how it could be retrieved from the mineralogy? I will give you a very very small example here.

Suppose, we have a mineral which is magnetite and we also do have a mineral which is hematite, I know that this magnetite where iron is present in both plus 2 and plus 3 form whereas, in hematite, the iron is present only in plus 3 form so; that means, it tells me that going from magnetite to hematite it the partial pressure of oxygen has to be increase or the oxidation state has to be increased. So, what I do? I will just add oxygen to it even though oxygen may not be available as free oxygen the way I am representing it, but I can represent the reaction in such a way that I can use this oxygen as an operator here and so, I will put 2 here and 3 here. So, 8 plus 2; 10. So, this is 9. So, I can make it half half O2.

So, this is something like magnetite plus half oxygen giving rise to hematite. So, if this is a reaction, then this reaction will have a equilibrium constant as log K corresponding to a particular temperature and pressure. I am not getting into any deep any more details into it as to because we all know that when we put this log K will be equal to minus del G 0 by r t. So, del G 0 is equal to minus RT l n k.

So, log K is coming from this del G 0, if we do not want to get into the details of this exercise. So, this is the free energy change. This is the gas constant. This is temperature in Kelvin. So, we get a log K value for this particular reaction and now this reaction if I write the log K will be the Fe 2 o 3 raised to the power 3 divided by Fe 3 o 4 raised to the power 2 into fugacity of oxygen or I can write partial pressure of oxygen based to the power half.

So, we know that this is the K, we know that this is a mineral solid mineral whose activity or the concentration the activity is one concentration is 1 and this is also concentration is 1. So, here K becomes one by fugacity of oxygen raised to the power half and if we take the log K. Log K will be is equal to half minus half log f o 2.

So, if we take a diagram like this where we put log f o 2 then; that means, here log f o 2 will be equal to minus half log K and I will get a single value. So, suppose in the in the in that case if I draw a line somewhere here this is the point this is the line which will be dividing magnetite which I will represent is magnetite here and this is hematite is hematite here. So, here this is temperature is fixed and pressure is also fixed.

Similarly, suppose I take a reaction suppose I have in this particular mineral assemblies also I do have pyrite and pyrrhotite magnetite and hematite . So, now, suppose I have got pyrrhotite and pyrite. So, the reaction pyrrhotite is Fe s. So, I will write Fe s plus half s 2 is equal to Fe s 2 for this reaction, since exactly following the procedure that I have followed here where the solid activity r one and it is actually reduced as a fugacity of the gaseous species this also will be able will be reduced to only the fugacity of the sulfur based on the log K value that I have got at the particular temperature and pressure and I can draw it also as a line which will be here on this axis, it is log of fugacity of sulfur.

And suppose I have got pyrrhotite Fe s and I will add oxygen and this will give me Fe 3 o 4. So, this is 3 and this is 2 and I will get 1.5 s 2 here. So, this reaction is one where oxygen and sulfur both are involved. So, if I write the log K of the reaction which we can elaborate through our some of the exercise which will be I may be giving you that this particular reaction. Since it both involves oxygen and sulfur, I can always put them into a straight line equation where log fugacity of sulfur will be a function of the log fugacity of oxygen and I can get these the corresponding points and get this boundary.

Similarly, I can also get the similar reaction written for pyrite and magnetite and you can get this boundary and also, already I have explained how the magnetic hematite boundary will be plot. So, here what basically we get here is that suppose in a situation in our mineralogy we are getting pyrrhotite magnetite and hematite and then we know that with this principles we could think of that whether our para genesis is actually is in correspondence with these principles or not.

So, here I can represent that this is a chemical system where it belongs to Fe s and o is a 3 component system in this 3 component system where temperature and pressure are fixed where the 2 compositional variables are fugacity of sulfur; that means, sulfur and oxygen.

So, any point which will be called as an invariant point there I must have if I if I put mu is equal to c minus p plus 2. So, here the number of components are 3 and if I put an invariant point where nu is equal to 0, then this will become the number of phases will become 0, this is minus 3 plus 2. So, minus is. So, the number of phases will be 3. So, p is equal to nu minus nu plus c. So, nu is 0. So, c plus 2.

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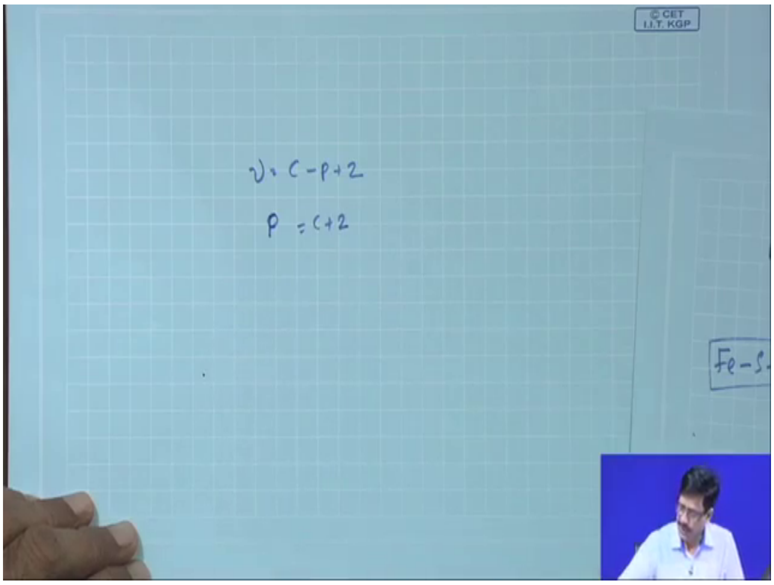

So, here since we have since we have pressure and temperature both fixed. So, number of components. So, here actually it quit reduces to the goldsmiths mineralogical phase rule where nu is equal to c minus p. So, in an invariant point where nu is equal to 0 the number of components will become number of phases. So, here in this particular invariant point we can get pyrrhotite pyrite and magnetite all 3 which will be coexisting with each other is an equilibrium pair

So, now basically what I am trying to explain is that mineralogy constitutes the 4 most important fundamental attribute of an ode of an ore where the compositional variables like the fugacity and of sulfur and oxygen could be constrained and if we go on increasing the number of components; for example, in case of iron sulfur oxygen we had copper or go on adding any many other components. So, we will be ending up with the phase relationship amongst them where we can we will be able to interpret the different assemblages in terms of the physicochemical parameters which is important to us.

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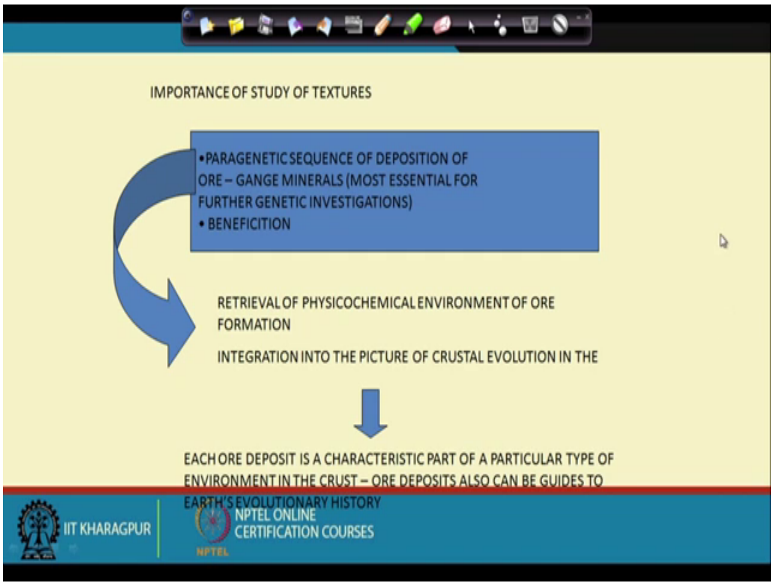

And this texture study is that we draw the para genetic sequence of deposition and it is not only helpful for our interpretation in terms of the origin or the processes understanding the process of by which the ore has formed it also helps us in the beneficiation process by looking at the inter growth of the ore minerals retrieval of physicochemical environment of ore formation and integration into the picture of crustal evolution.

So, basically what we try to do? The information of the intensive and the variables compositional variables that we retrieve from the from study of the mineral para genetics we along with the intensive parameters like pressure and temperature, we integrate them and then try to formulate the or try to understand the physicochemical environment and which the ore deposit form.

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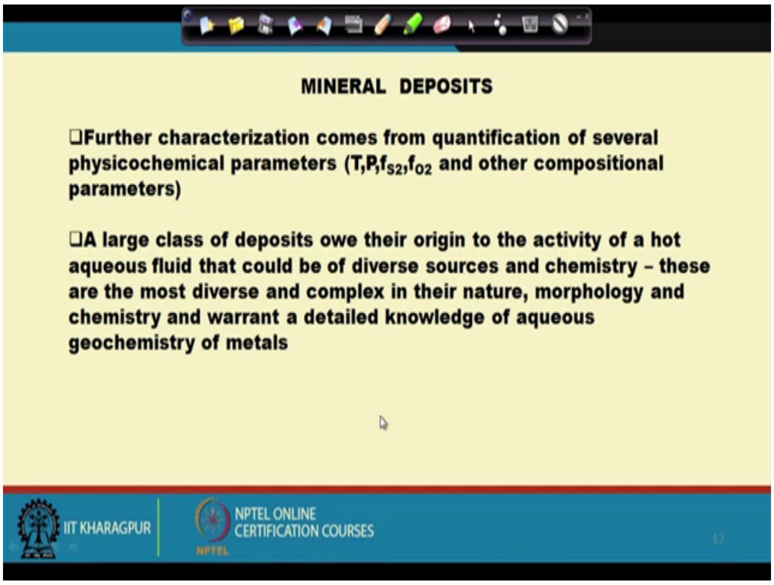

And a large class of deposit owe their; so, we understand by further we characterization comes from quantification of several physicochemical parameters like temperature pressure fugacity of sulfur oxygen and other compressional parameters; a large class of deposits owe their origin to the activity of a hot aqueous fluid that could be a diverse source which we will be discussing in the part of this lecture series will be devoted to hydrothermal deposits.

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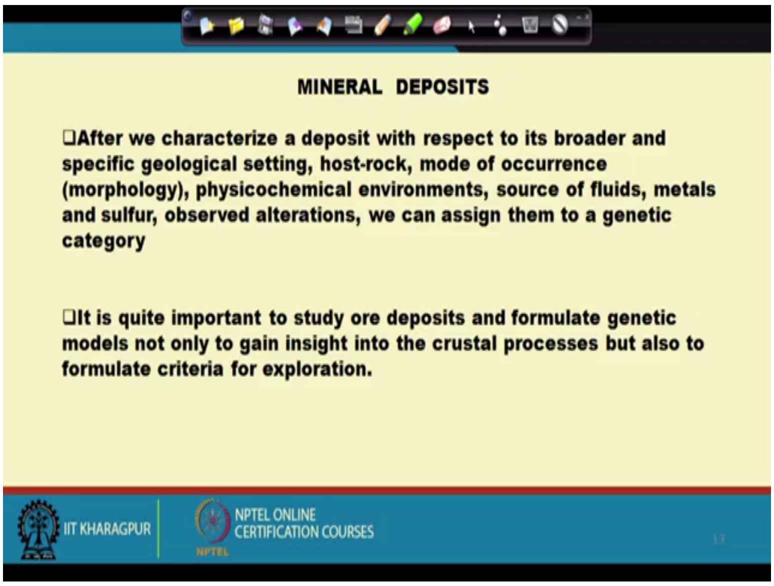

And after we characterized this deposit with respect to its broader specific geological setting host, rock mode of occurrence morphology which is a very important attribute of ore deposits physicochemical environment the source because if basic questions that we pose whenever there is a mineral deposit in terms of its origin that where from the metal has come where from other constituents like sulfur where from it has come.

So, these are the basic queries that we address its quite important to study ore deposits and formulate the genetic models it is just not only for academic purpose, but also that as we from the very beginning, we have stated the basic objective of this course that the scientific knowledge, the knowledge base that we generate, that you acquire and that we rationalize on the formation of the mineral deposits we utilize the knowledge for the exploration of these deposits in areas where such deposits are not known to be existing.

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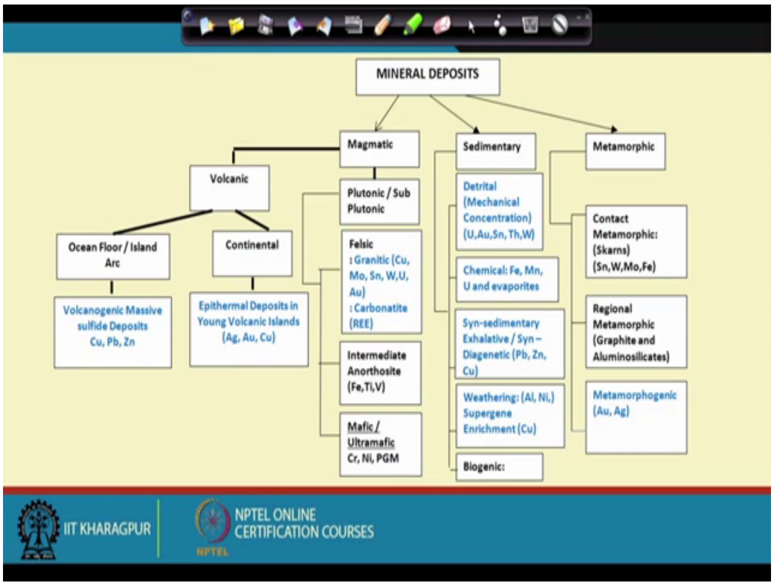

So, at this point of time suppose that we have some idea about the mineral deposits in terms of the broader processes endogenic and exogenic processes that give rise to mineral deposit formation.

So, now then we will use that to classify the mineral deposits. So, here is a is a one scheme one such scheme for classification of the mineral deposits since we know that the 3 broad processes the exogenic and the exogenic and endogenic together could be like a magmatic process sedimentary process metamorphic process and this magnetic process could be divided into 2 volcanic and the plutonic because we know that these are somehow different in the mode in which they operate. So, the plutonic or the sub plutonic process or the volcanic process; the platonic process might give rise to rocks of diverse composition felsic intermediate and mafic.

The felsic rocks generally at the granitic rocks or the carbonatite the granitic rock will encompass the range from granite to monzonite quartz diorite or diorite type of composition and generally we observed that mineral deposits of copper molybdenum tin tungsten uranium and gold they are associated with these felsic intrusives sub plutonic sub plutonic kind of process. There can be intermediate composition rocks which give rise to the iron titanium vanadium oxide deposit and they give rise to a very important class of deposits which are the chromium nickel and platinum group metals which are associated with ultramafic magmatism.

And in the sedimentary, we have a classification broad classification of the sedimentary environment in the detrital and chemical. So, in the detrital; the deposits that we discussed about the uranium quartz pebble conglomerate or the pressure type gold deposits they will come under this category the detrital mechanical concentration we have uranium gold tin thorium and tungsten deposits we generally are found in this environment result of detrital sedimentation process.

We have chemical sedimentation which we have seen the large class the banded iron formation and also manganese and uranium they do result from the chemical process the chemical sedimentation in response to change in the physicochemical environment from transportation to deposition as we saw uranium being transported only the plus 6 stays state and being deposited when the condition is reduced to plus 4 and so on.

We could also add up a little bit up to the sedimentary environment because some process which could also go on along with the deposition of sedimentary rocks in a basin which we call them broadly the syn sedimentary exhalative or the syn diagenetic or people used to or they are popularly we are known as a z x syn sedimentary exhalative deposit or syn diagenetic quite a good amount of the base metal resources lead and zinc come from these deposits and the weathering related deposits mostly aluminum and nickel and enrichment process which happens on the surface operative process purely exogenic in nature nearby the kind of beneficiation earth’s own beneficiation mechanism that we discussed our weathering process which give rise to also some times that these weathering process.

They do not give rise to the primary mineral deposit, but they can enrich an existing deposit to a higher concentration which we will discuss them in the later part and biogenic and the metamorphic, we see that either it could be a contact metamorphic or contact metasomatic type of process which give rise to the skarns deposit which a very rich sources of tungsten molybdenum tin and iron even there are golds also with their very generally named called by the name skarns.

Regional metamorphism we all know that is because of the materials which are produced there is no much of metallic mineral deposits that known to be resulting directly from the process of metamorphism, but graphite alumina silicate minerals like kyanite sillimanite andalusite, they do result from this process and under the metamorphic group, we can all we could also include something the process which would be metamorpho genic rather truly metamorphic something in addition to metamorphism also takes place, they are exemplified by most of the gold deposits occurring in older geological terrains, we will look at their characteristic in more details.

And under the volcanic category we can have a volcanism that is taking place on the ocean floor or the island arc or within the continents. So, the ocean floor island arc we have seen examples of them like giving rise to the volcanogenic massive sulfide deposits which are comparable to the present day mineralization process which are observed on the mid oceanic ridge systems and are also believed to have older analogues like the example which I gave in case of the Noranda deposit in Cubek or cypress deposit copper deposit they are all volcanogenic massive sulfate deposits.

And in the continent where there are volcanism there are rich mineralization of gold silver and base metals and if you look at the tectonic map, you could delineate something which is labeled as the pacific ring of fire in the pacific ring of fire all along we get volcanic islands and in those volcanic islands like the Indonesian island Papua; New Guinea Lihir island and the Japanese island arc.

So, we see that there are some very rich mineralization of base metal and the precious metal they go by the name as the volcano associated epithermal deposit because their near surface process. So, this is one scheme of classification this is definitely not very complete you could possibly add a few more of them, but conforming to the broad framework of the classification scheme that we are adopting here mainly a process based.

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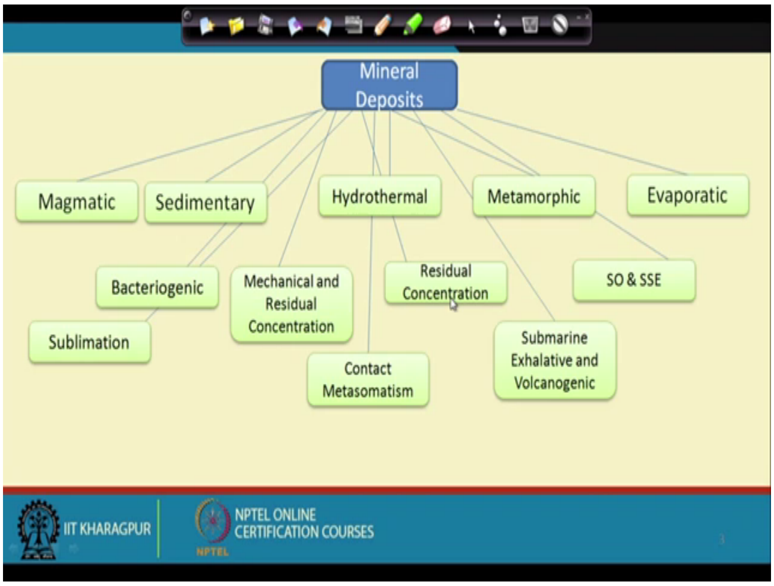

If you look at the textbooks like I refer to book of Jensen and Bateman, they are the classification scheme is far more wider it also takes into consideration some very rare type, but sometimes important deposit which is resulting from the process of sublimation we all know sublimation this is deposition from vapor.

So, this generally, we see some deposits of sulfur as well as some very low volatile metals like mercury arsenic and antimony, they are occurring, there mineral deposits they occur in hot spring kind of situation where this process could be broadly categorized a sublimation in addition to the one which followed is our previous scheme magmatic sedimentary hydrothermal metamorphic.

And sometimes evaporation process also is becomes important in given rise to some specific mineral resources. For example, gypsum which is a mineral for our cement industry and so, this only comes from the evaporate belts which result by the evaporation of seawater in landlocked basins and here it is this because the name is a little bit long this is super gene oxidation and secondary sulphide enrichment.

So, this is essentially a process by which preexisting ore deposits become enriched that is how the name supergene sulfide enrichment is proposed and they are controlled by the exogenous process because the surface weathering process is controlled by the precipitation the surface water and which is by it acquires it chemistry in relation to the rocks and the soil and of course, one thing we should remember that the exogenous process is very important because it forms soil and soil is very very important for us as a resource because many things depend on it.

And residual concentration which we have already discussed as a mechanism by which deposits can form good example is the bauxite deposits occurring in many many of the continents mechanical and residual concentration is already we have seen where the our detrital sedimentation process and contact metasomatism skarn. So, this is a scheme that was that was followed in textbooks like Alan Bateman and Jensen where the deposits are described.

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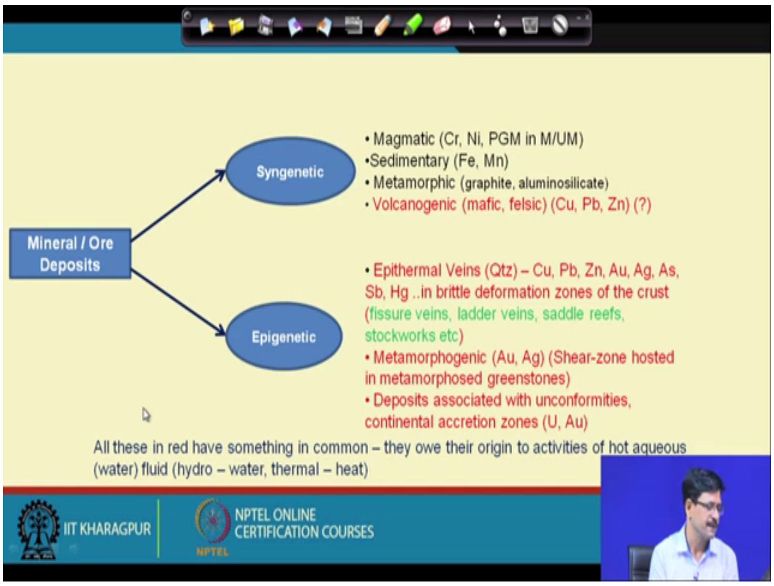

But our course of lecture will not be exactly following this, but will be followed the broader process that we have in the literature of mineral deposits, there are many ways also to classify them in more genetic term genesis what you mean by the origin the processes involved in the origin.

So, a particular class of deposit are known by the term is syngenetic syn generally stands for same time as the formation of the rock in which they are occurring. So, syngenetic essentially means that the mineral that the ore body and the rocks in which the ore body is occurring they formed at the same time not only the same time, but with the same process.

So, this is how the syngenetic process where your magnetic deposits giving rise to chromium nickel platinum group of metals and in the mafic ultramafic rocks they very unambiguously belong to this syngenetic category where the rock the ore itself is a product of the magnetic process magnetic crystallization process.

Similarly, the iron which we see in the form of the banded iron formation and also the manganese in sedimentary horizon different sedimentary basins, they are also syngenetic they do form the part of the sedimentation process itself kemogenic metamorphic and the volcanogenic massive sulfide deposits which we saw them which form on the ocean floor, we can also categorize them as syngenetic although the in terms of the time, but in terms of the process because it requires a little bit more than exactly the sea floor basalt which is coming on the mid ocean ridges to give rise to this deposit.

So, the ones which come is epigenetic; epi stands for the term that they some anything that is not related in time. So, it is something later or something different. So, epigenetic means the mineral deposit came into existence anytime later then the time at which the rocks associated rocks form examples are many rather the number of mineral deposits which come under the category of epigenetic are much more than the ones which come under the sea genetic this epithermal veins means I am still there are words like the epithermal is still being used they generally represent the near surface processes at last class of such deposits give rise to copper lead zinc and precious metals.

They are present in the brittle deformation zone in the crust as we discussed in our introductory lecture and the metamorphogenic gold which we just discussed that in the prime along with the metamorphism there is something in addition that happens which will see what the addition thing is in shear zone hosted atom situations where there are crustal scale deformation in the form of shear zones or faults and deposits associated with the unconformity because they also were unconformities where the locals which are more favorable for formation of certain deposits which will be later than the time at which the host rocks form.

So, these deposits which were representing a epigenetic all these in red have one thing in common that they owe their origin to the activities of hot aqueous fluid that is water is which will be one of the major topics that we will be covering the hydrothermal deposits because the number of such deposits is are too numerous compared to deposits which form from direct magnetic process or any direct sedimentary process. So, involvement of a fluid which is there in the crust is very important information of the ore deposits.

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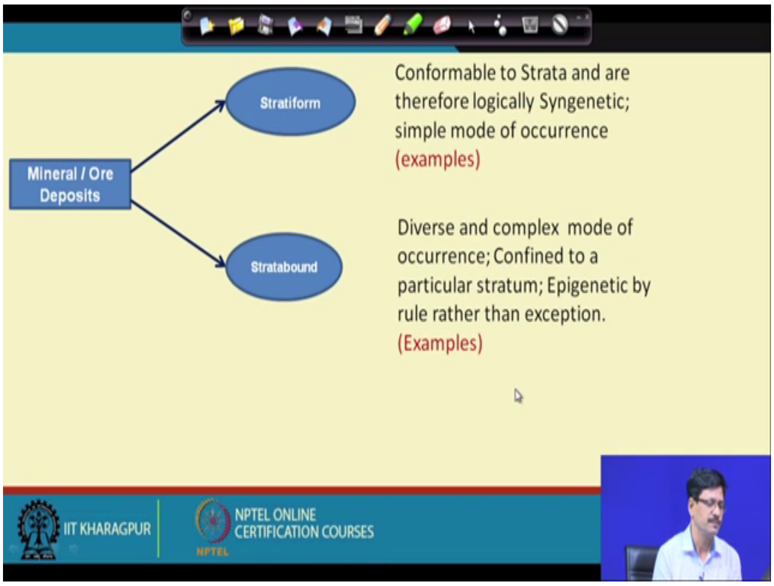

So, sometimes we also do classify ore deposits based on their morphology into strata form and start a bound stratiform; the term is pretty straight forward that they are very much conformable to the strata in which they are occurring the examples are the pendulum formations or the chromate layers in ultramafic rocks its basically by this term comes from the morphology; the exact form in which they are occurring the terms stratabound.

So, these are the stratiform will always be syngenetic by default whereas, the stratabound deposits are diverse pretty complex mode of occurrence, but they are generally object we have confined to some particular stratum in a sequence say for example, if we have a sequence of sandstone shale limestone and is included by felsic magnetic rock, we will find or we generally find that the deposit which forms will be very much confined to the limestone horizon.

So, we conclude that there must be something some chemical relationship between the one particular stratum in the sequence to the formation of the ore body and that is they are mostly epigenetic rather than very few exceptions.

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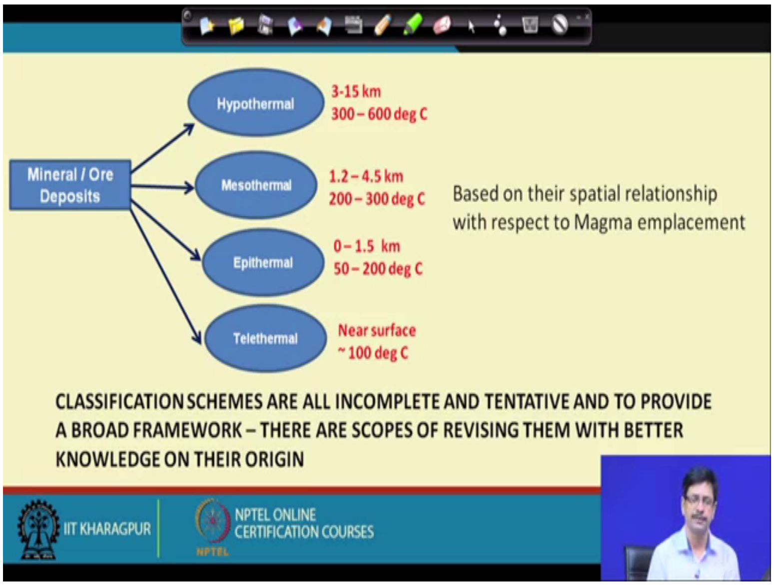

Previously the ore deposits were also classified into hypothermal, mesothermal epithermal and telethermal. These are all basically based on their special relationship to a magma because the previously they belief was that all the deposits that we see are actually result from magma.

So, the deposits were classified based on the specially relation to the magma the hypothermal were the deepest ones 3 to 15 kilometers and the highest temperature 300 to 600 degree centigrade mesothermal being 1.2 to 4.5 kilometer epithermal is more surficial where the temperature also is much less telethermal was only those deposits which were specially far more away or distantly from the intrusive body of the magnetic body which is supposed to be responsible in giving rise to the mineral deposit.

So, what we generally see is this classification schemes are all incomplete and tentative and they, but they just provide a broad framework on which we can base our theories about genesis and there are scopes still there to revise the deposits in the classification scheme and also there are instances in which a deposit which is earlier classified into one particular category later on because of its because the changes are the difference in the attributes that is observed later on could also be classified differently than what it was done originally.

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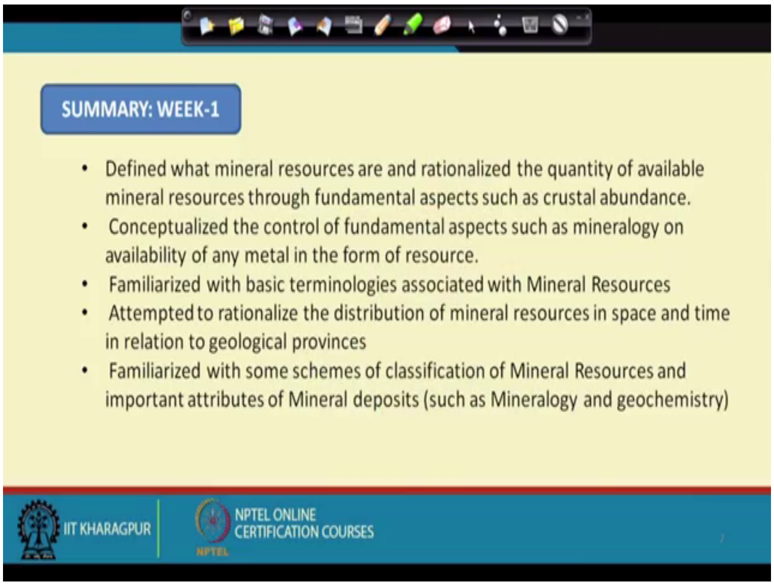

So, in summarizing other weeks; so, we have defined what mineral resources is conceptualized the control that is exerted at in their occurrence in the quantity and quality we familiarize ourselves with basic terminologies ore body ore mineral province mineral belt we attempted to rationalize the distribution of mineral resources in space and time.

And we tried to when we saw how these mineral deposits, I mean what we gained by studying these mineral deposits hypothesize them understand their origin and then propose a classification scheme and so this is basically providing us a broad fundamental insight to these ore deposits to continue looking at them in greater details and to although will be very limited in the understanding the ore genesis and then we will see them till other all other aspects in due course.

Thank you.