Mineral Resources: Geology, Exploration, Economics and Environment
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Lecture - 06
Magmatic Processes

Welcome to today's lecture. In the last few introductory lectures we got ourselves introduced to the mineral deposits. We will take a very quick, brief recapitulation to the salient aspects of mineral deposits that we discussed.

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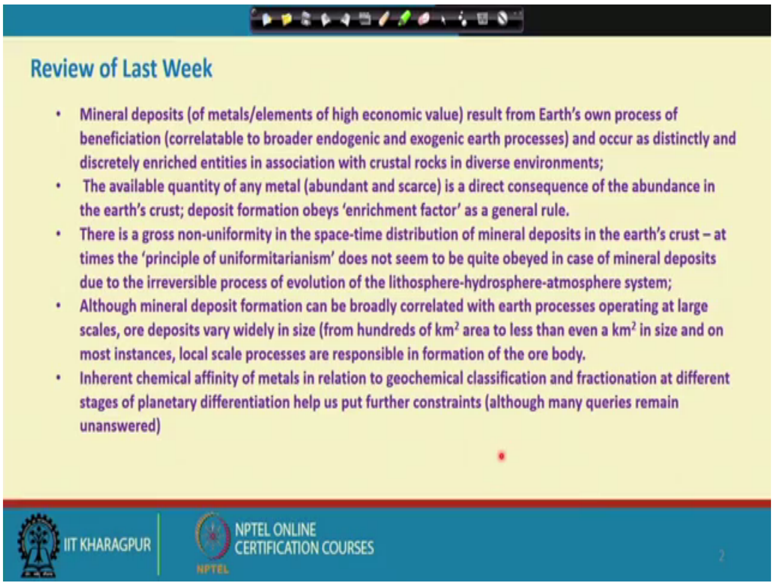

As we know that mineral deposits are the result from the earth's own manifestation processed and they are distinct, and they discrete and they parts where they, the part in which part in the earth's crust and occurred in association with common crustal rocks.

They can be called is anomalies in the earth's crust, because concentration of any metal of interest is higher than the surrounding, higher to the extent that they can be economically exploited and they occur distinctly in variable dimensions, sometimes an ore body can run for more than 100 kilometer in straight length, sometimes it may get terminated within a few hundred meters in straight length.

Similarly, in the depth and width dimension also, they are variable, and we see the whole spectrum of mineral deposits of many different metals and nonmetals in the upper continental crust. The available quantity of any metal of interest, as we have seen the very in millions of billions of tons, taking abundant metals like aluminum and iron, which the quantity vary in terms of billions of tons and scarce metals like the gold, platinum group of metals, rhenium.

They are only a few millions of tons or thousands of tons, and this can be explained as a fundamental control exerted by the abundance of these elements in the wall crust and in particular in the continental crust and they obey something which we call as an enrichment factor; that means, the minimum grade minimum, minimum value of the metal, minimum concentration of the metal which makes it an ore divided by the average crustal abundant something like clerk, we can find we can calculate a value and say that by how many times that particular metal has to be enriched to form an ore body in the crust.

We saw that there is a general non uniformity in distribution in space and time of this mineral deposits all across the continents, and they as far as the distribution in time is concerned, we do see some various and significant variations, going from the older era to the to the younger to the new era, and with the thing in mind that most of the continental crust are covered by rocks which are old to pick ambient rocks.

And thus we get the deposits from them which are also of that comparable age, and this ore deposits are a result of a very complex interplay of the lithosphere, hydrosphere, atmosphere system which has been evolving parallely with the evolution of the continental lithosphere and that is how we see variations in the nature of mineralization of different metals, or we take the different types, genetic types of different metals and the different genetic types of the same metals.

Mineral deposits are a result of operation of earth’s broad processes which are the endogenic and the exogenic process which we discussed. The endodontic process the energy being derived by the earth’s on heat engine, and the exogenic process have been mainly driven by the sun which are the surface operating process, and they can be somehow linked because as we discussed many of the surface operated process.

The weathering erosion process are much faster, where there are active continental uplift and active continental margin situations compared to parts of the continents where there has been mane 445 or there they 447 much of active called tectonism going on.

And although they are products of the earth's broad processes, the deposits vary in their size from hundreds of kilometer square area to even sometimes within just about a kilometer square in size. So, that leads us that make us believe that in addition to the broads, the processes which are operating on a broader scale larger scale. There are also some local scale controls which are exerted in actually giving rise to the enrichment process in many such cases.

And the different diverse mineral deposits occurring in their different minerologies, can be understood from the very basic nature of the metals of the elements, the geochemical classification, and the enrichment that took place in a in subsequent stages of fractionation of the of the planetary fraction has been such as the core, metal and the crust.

They give us the basic understanding to, for the behind the principles of ore mineral deposit formation. Although there may be some amount of queries, some queries which remained unanswered, because; for example, we know that during the core mantle fractionation most of the iron was partitioned into the core, at the same time we get huge quantity of iron as available finally, forming ore deposit on the in the continental crust.

So, that would lead us to believe that this fraction has in process was either incomplete or something else happened after the formation of the core, sometimes which is also talked about in the context of gold, gold being a siderophile element, is also supposed to have partition into the core, but we do get, the quantity of gold that we get in the form of deposits mineral deposits which might have been derived from the mantle, that led to the belief, led to the proposition of hypothesis such as the late veneer hypothesis by which the later materials which are created to form the earth, gave the necessary metals to form their mineral deposits.

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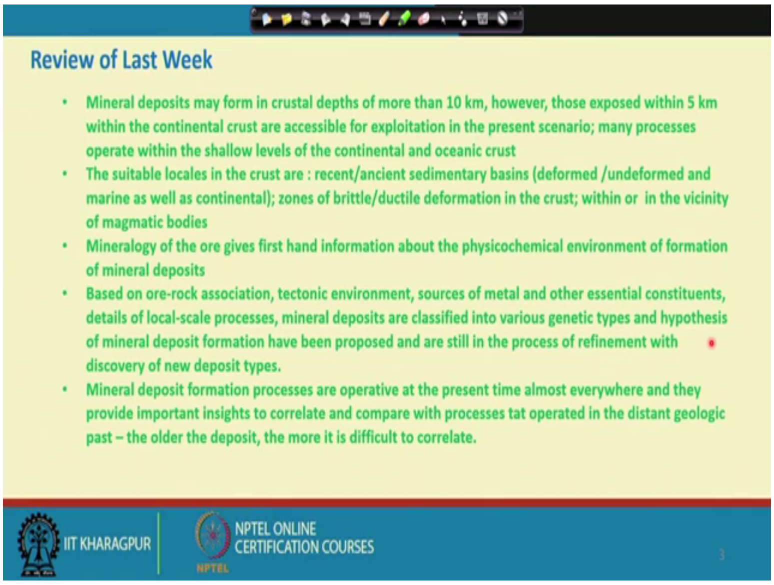

The deposits, the deposit forming processes operate within 10 to 15 kilometers up to a depth of 10 to 15 kilometers in the crust, but only when they are exposed within the top 5 kilometers with their accessible to us and we are able to recover them, we are able to economically exploit them, and there are surface operating processes within the top 5 kilometers of the earth's crust and the suitable locales in the earth's crust there could be a recent or ancient sedimentary basin, where the basin could be deformed or undeformed, could be a basin marine as well as continental derivation, which are the areas of the zones in which deposits and various metals or form to occur.

There are zones of brittle ductile deformations such as fall zones, sphere zones running for several hundreds of kilometers crustal scale features within or within in the vicinity of magnetic bodies. These are the important locales in which we see the mineral deposits.

In addition to that the surface operating process, the major rivers valleys, the present day ocean basins where there are mineral deposits active mineral deposit processes are in operation, which we looked at some few of the features such as the processes that the operating of the mid oceanic ridges and also in subduction zones. We also discussed that one of the important fundamental attribute of any ore body or mineral deposit, is the mineralogy, and this mineralogy gives us the firsthand information about the physicochemical environment or formation of mineral deposits. The physicochemical environment we defined by using various intensive and the intensive parameters; such as temperature, pressure and the compositional parameters; such as the fugacity of gaseous species such as oxygen and sulfur.

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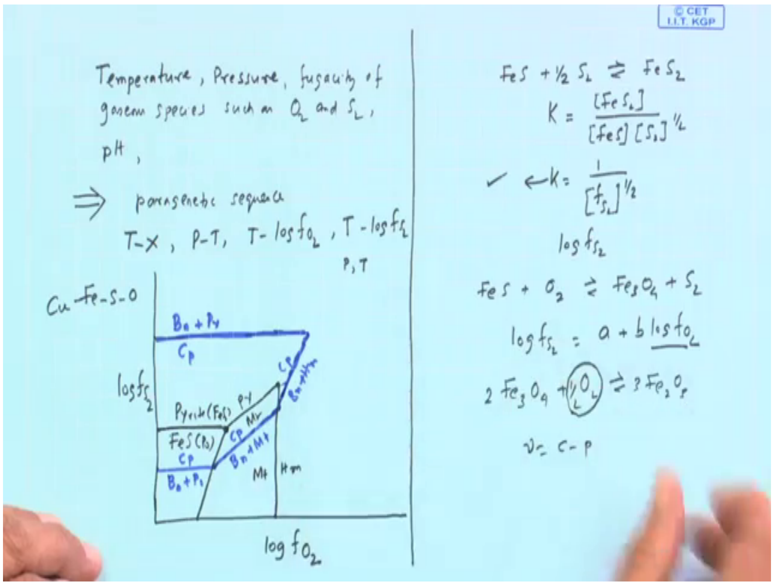

The important chemical parameter in an aqueous environment is the activity of the hydrogen ion there is the ph, the concentration or the activities of the various anionic and cationic species, all that even including the metals which form their mineral deposits. and what is the systematic study of a mineral deposit, the first, very first information is obtained from the minerals that are the constitute the ore body, and from the mineral by systematic study of the minerals under the microscope studying their inter growth.

The textural relationship between them, the parageneous or the paragenetic sequence is decipher and just giving an example, let us say that we have a, and we use this parametric sequence to explain the different, the intensive and the extensive variables and sometimes we plot them in different types of phase diagrams; such as the temperature and composition diagram, pressure temperature diagram, temperature versus log f o 2 diagram or temperature versus log F S 2 diagrams and so on, to interpret the environmental parameters.

Just to give an example. We can consider some isothermal isobaric conditions P and T fixed, and we can; for example, we just look at take a simple example of a system in the Fe S and O system, there we can, this is the, this is pyrrhotite FeS this is pyrite FeS 2, this is magnetite, hematite and in this FeS O system we can write the reactions between pyrite and pyrrhotite. For example we can write a reaction of pyrrhotite plus half S 2 giving rise to pyrite, in which we can have this when we write the equilibrium constant K, we put it in this way.

By convention we take the thermodynamic concentration or the activity of the solid species is equal to 1. So, K reduces to 1 by and in when it becomes a gaseous species like sulphur, we explicit the activity the thermodynamic concentration or the activity is expressed as fugacity which is the corrected partial pressure for the gas.

So, we will put it as F S 2 to the power half and this equilibrium constant at a this, this pressure and temperature is known from which we can calculate that, what will be the value of log FS 2 corresponding to the pirate and pyrrhotite boundary, and we can plot it here and then we can construct similar diagrams, similar reactions such as pyrite plus oxygen giving rise to magnetite plus sulphur.

We can balance this equation and then in that case the log K. Here the log K will be depending on both oxygen and sulphur and we can find the relationship of log FS 2 will be equal to something like a plus b into log FO 2 and for a range of log of FO 2 value, we can plot the calculate value of log FS 2, and then plot here, and similarly can draw the boundary between pyrrhotite and magnetic, similarly for magnetite and hematite, we can write Fe 3 O 4 plus oxygen Fe 2 O 3, this will be 2 and this is 3 half.

So, here only variable is the oxygen. So, fugacity of oxygen can be taken and this boundary between magnetic and hematite can be plotted now. So, this becomes a phase diagram isothermal isobaric phase diagram of in an FESO system and if its an isothermal isobaric. So, we know that nu is equal to C minus P nu is the degree of freedom and C is the number of components in the number of phases.

So, for an invariant point like this is an invariant point this is an invariant point and on these invariant points we get the three minerals; like pyrite, pyrrhotite and magnetite to be coexisting. These will be the univariant lines on which two phases will be coexisting. For example, this is a stability, this is the boundary for pyrite and magnetite and these fields will remain as the bivariant fields, where only one phase will be stable; for example, pyrrhotite.

Now, if we extend this particular system including a species, another species is copper, then it is going to give us the stability field of other minerals like chalcopyrite bornite, just for example, this becomes a boundary for bornite plus hematite given rise to chalcopyrite, this is a boundary bornite plus magnetite giving rise to chalcopyrite.

So, here we define a stability field of chalcopyrite, and in this cases when copper is included is one of the components, these bivariant fields will become phases where the areas, where two phases will coexist instead of one, and similarly we can define the invariant points is number, number of components becoming 4. So, number of phases also will be become will be 4 on this kind of invariant points, and we can interpret the variation depending on the, what mineral paragenic sequence you can establish.

For example, if we get dominantly a pyrite magnetite mineralogic giving rise to hematite, we can always think in terms of increasing FO 2 and FS 2 condition in this environment, and similarly we can use these diagrams, this kind of reaction relationship, using standard state thermodynamic data to retrieve the environmental parameters. So, this is one example, we can extend it to any number of components including the species; like potassium, silicon and iron.

And can also find out the stability filled with silicates and can explain the assemblages in which ore minerals also occur along with the silicate minerals, and the reconstruction of the physicochemical environment becomes even more precise with those kind of by, by increasing the number of components which will be more close to the situation in nature.

So, based on the rock or association, tectonic environment sources of metal and other essential constituents and the working out the details of the local scale processes; mineral deposits are classified into various genetic types, and there are many hypotheses of the mineral deposit formation that have been proposed, and such hypotheses are still in the process of refinement, because discovery of new type of deposits, observation of new types of features which were not seen before or the extensions were not available, because of some limitations.

So, and if we now from here, if we go into the looking into the different types of deposits, that form in different types of as a result of different type of processes, we see that the amount of information getting into the minutes details of such deposits will become dauntingly vast, and it will be this, this scope of this lecture series will not allow to go into the much finer details of this, but we will present a broad overview of the many types of deposits which result from the broader processes, and so that we just get a basic understanding of them in terms of the process, in terms of the deposit characteristics and look at what are the working hypothesis or working, or the understanding of their origin and the violation of the deposits.

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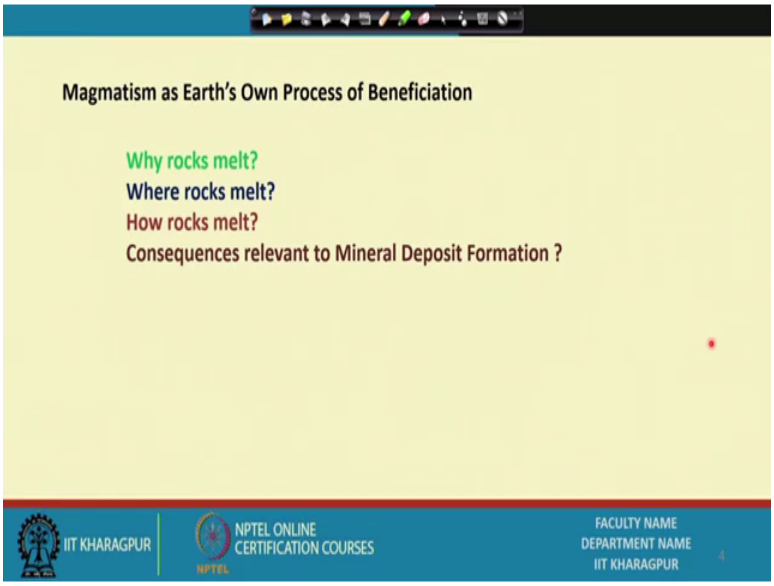

So, from here we will go to discuss the very first major of the most well one of the processes that operates in the earth's crust and they are in the lithosphere and also in the deeper parts of the earth into their lithosphere. And we look at as how we look at magnetism, as we define their mineral deposit forming processes is earths own mechanism of beneficiation.

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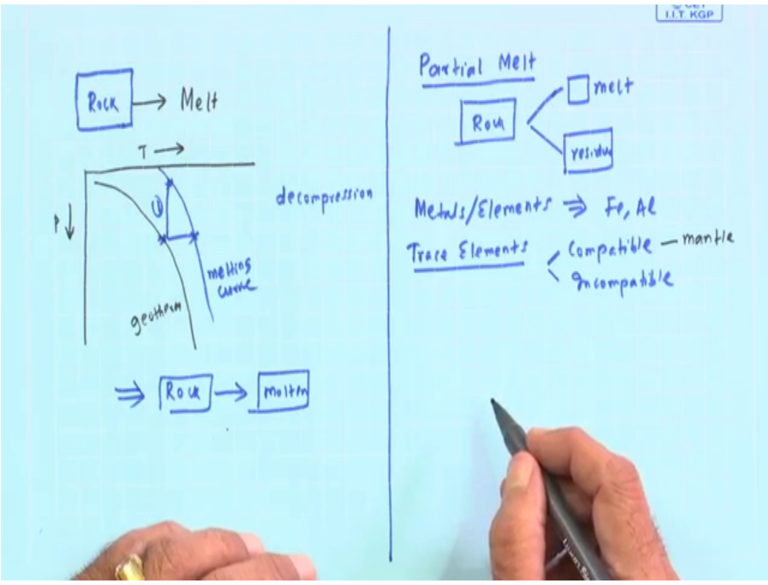

So, we will see how magmatism is a process or how effective or how efficient magmatism as earths own beneficiation mechanism. Now, to understand magmatic processes, we have to answer some of the basic queries, even though it may be very common knowledge when we start studying this geology at an elementary level. So, the first question is the why rocks melt? Rocks will melt well this is a rock.

This rock could be anywhere, could be in the in the middle of the crust, in the shallower level of the crust, deeper in the middle, deeper part of the crust or in the upper mantle and depending on that the rock is a different composition. So, this rock has to melt.

So, the melting process if we want to, if we would like to see it very fundamentally, then we can crudely define situations like this, this is temperature, this is pressure. So, it would indicate or it would, it represents we are going deeper and higher and higher temperature we are encompassing, and something like we can define crudlision.

Suppose this is the geotherm, the increase in temperature with depth as we go to the deeper part of the crust, and something if I just draw a crude curves over here, which could be the melting curve. We know that rocks will remain solid on the given pressure and temperature condition, and anything that to the right of this curve will make the rock melt, or the rock is, present is stable solid on this part of the.

So, that there are many ways in which this solid rock would melt; number one is that we would increase the temperature, take it to the right or we can say that the conditions corresponding to intersection of this melting curve with the geothermal make the rock melt. If you are somewhere anywhere here, we could either go up to a situation like this or like or this.

So; that means, if we are following this something a path like this one; that means, we are decreasing the pressure, and we are essentially creating something called a decompression which happens in the, when the asthenosphere rises and the mid oceanic ridges, they give rise to the rock of the mostly a peridotitic type of mental rock which melts, because the pressure is released, because of this decompression with the rise of the convection cell as we go then.

We could possibly add some more extra heat from somewhere, and make the rock melt. There could be many other possibilities, but the situation is that we are able to melt a solid rock giving rise to a molten material, and then let us think about. So, here rock melt, rock would be melting anywhere in that any intermediate depth in the crust in the mantle, and there are many zones, we will see melting taking place in subduction zones melting taking place in mid oceanic regions, melting taking place in mid continental rift zones and so on.

And when the rocks melt anywhere in this region; that we have defined when the rocks are melting so, the melt how we describe this melting process. We have describe this melting process as something we called as partial melt, means when we melt a rock, it actually, it gives rise to a small fraction depending on, it gives rise to a fraction of melt and it leaves behind a solid residue; that is why we call a partial melt.

So, all melting processes within the earth's into the essentially partial melt, partial melting, and depending on the parent rock composition, we get the melt which are of different composition which can be explained, on the basis of the mineralogy of the source rock and the temperature and pressure conditions are melting and there has been all work done in understanding the melting behavior or different types of rocks and different types of conditions.

Sometimes when we are discussing this kind of melting process, sometimes we find that the solidus, which basically the melting curve that we are drawing here, sometimes the solidus moves towards in the left if there is fluid present in the rock, which happens in many situations which we will not be discussing in detail here.

But what will be more relevant to us here, is to discuss is to what is the consequences of this melting process that is relevant to mineral deposit formation, because the mineral deposit formation we are concerned about the metals elements. We will not consider the metals which are the abundant metals; like iron and aluminum. They are present in most rocks that we are considering, the content iron and aluminum is there major element and then what happens to this major element during the process of melting will not consider in detail, but we know that there will be, they melt that forms will also be acquiring this major element depending on their characteristics.

We will be considering about metals which are present in trace amount. So, these trace elements could be anything, could be our transition elements (Refer Time: 27:54) from the chulk of this siderophile element like the precious gold, platinum, group metals, could be the base metals copper, zinc, could be silver, gold, could be the high field shrink element and so on. So, we will have to see what happens to these elements when there is a partial melting process.

So, in this method, in these terminologies we distinguish these elements trace elements or during the process of melting. Essentially we need to if we consider magnetism or melting as a process of benefices and own beneficiation in converting a common rock, to a rock, to an ore, where the concentration of elementary interest is elevated or is increased to a level that makes it, made qualifies it to be called as an ore and to be exploited, then this is essentially has to be looked at as an enrichment process.

So, in this we can divide these trace elements into two broad categories, they are the compatible and the incompatible elements or metals. The compatible, or an incompatible terminology is always coined with respect to, when we understand compatible, means which a mental compatible or mental incompatible. Or in other words we can also put it in this way, that all those elements, all those metals which during the process of melting have the tendency to remain back or stay back in the solid residue, we will call them as compatible metals or elements, and their concentration in the melt which is resulted in this melting process will be lower than what it was in the parent source material, which melted.

And conversely all the metals who are incompatible, always have the tendency to get themselves enriched in the melt it is generated, and their concentrations will always be higher in the melt, compared to what the concentration was, in the parent rock or the source rock which melted. So, we will continue discussing on the magnetic process.

Thank you very much.