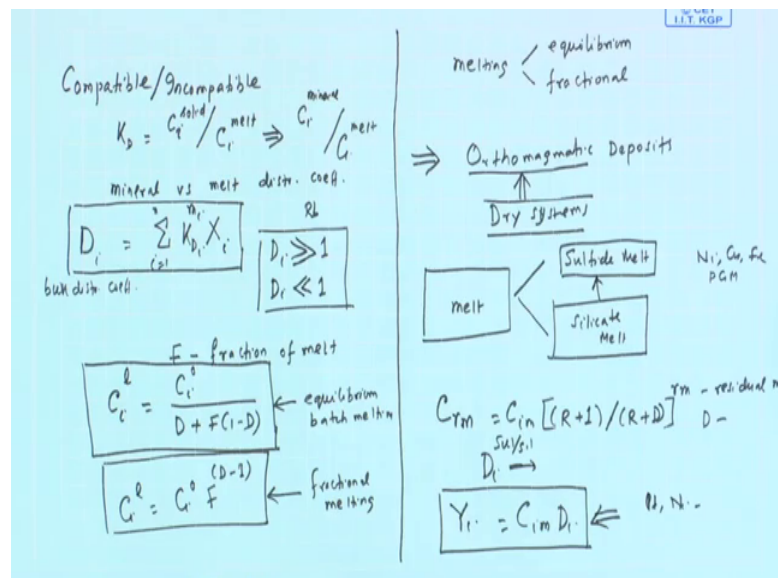**Mineral Resources: Geology, Exploration, Economics and Environment**
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Lecture – 07
Magmatic Processes (Contd.)

Welcome to today's lecture, we will continue with the discussion and just to recapitulate.

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We try to get ourselves introduced in a very simplistic way to understand the magmatic processes to what is melting, where melting takes place and what the consequences of such kind of a melting in relation to mineral deposit formation.

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And we define or we explain the metals or elements belonging to the broad categories are compatible and incompatible, we just like to express them in a little small quantitative way, as far as the compatible and the incompatible metals or the elements are concerned.

So, when is a compatible or incompatible, we generally look into a parameter which will be calling as a artisan coefficient or a distribution coefficient, as something like K D or small d of K D, that will be simply the concentration of an element i in solid divided by the concentration of that particular element i in the melt, which can be expressed as a time variously defined in many different.

So, we can use a term here K D as the when they solid melt. In other words our solids are the minerals because the elements were the metals it is their inherent characteristics that they get themselves accommodated in the lattice of the minerals. So, this distribution or the partition is essentially a fundamental control that is exerted by the minerals.

So, we always consider the concentration of any element in the C i in a mineral and concentration of that same element i in the melt, and we visualize them something as a mineral versus melt distribution coefficient or partition coefficient. To be brief if we want to define what a compatible or what an incompatible metal is, we will say that all these compatible. So, we will define a term as a D called as a bulk distribution coefficient for that particular element i, which is a bulk distribution coefficient. A bulk distribution

coefficient will be simply if we have minerals i is, we are representing an i varying from 1 to n.

So, if it is varying from i equals to 1 to n, then we could take it as a summation of the mineral versus melt distribution coefficient of this particular element in the mineral i and the void fraction of the particular mineral, which will give us values so; that means, if this if there is a rock in which there are 3 minerals which are present.

And these 3 minerals and take an element say for example, we take it take a trace element like say rubidium, and this mineral versus melt coefficient for rubidium for mineral 1 and mineral 2 and mineral 3 multiplied individual I mean individually by the void fraction of that mineral present in the rock, will give us a value which is called the poly distribution coefficient that is Di.

So, we will define that all those elements this bulk distribution coefficient which will be greater than 1 much much greater than 1 will be called as the compatible element compatible metals, and the Di less than 1 will be called as the incompatible metals. So, compatible metals will always get depleted in the melt, in the process of melting incompatible metals will always get enriched in the melt, in the process of melting and if the metal of our interest happens to be a incompatible metal, then all subsequent phases of melting will enrich it, and if it happens to be a compatible one then subsequent melting process will gradually deplete it and we know.

So, this is this kind of a simple and brief idea we can have which essentially will be the controlling factor that comes to consideration while considering the magmatic process. So, now, if we want to know that in any particular melting process, what will happen to the concentration of an element i? So, we; that means, if we have a parent rock in the parent rock the concentration of that particular metal of interest, has an initial concentration and the rock is undergoing melting.

If we say only the just a first step of melting then there is a parameter which we consider, that what is the fraction of melt that is generated this fraction of melt will be generated this fraction of melt will definitely be the controlling factor as to what is going to be the concentration of that particular metal in the in the melt which is forming.

The this is the general expression which is already known, that if we want to find out the concentration of any particular element i in the liquid, that is in the melt which is forming that will be equal to the concentration of that particular element i divided by D plus F into 1 minus D, D we have already defined there is a bulk distribution coefficient this if the melting process and to be brief this melting process could be visualized in two ways.

It could either be an equilibrium type of melting or the batch melting, in which they melt that forms remains in equilibrium with the source rock before it gets separated out of the system, and the fractional melting means any incremental melt that is forming is no longer in equilibrium with the rock from which it is derived, and this formula is applicable to equilibrium melting or batch melting, and where the this expression is applicable for a fractional melting.

These two equations very fundamental equations give us the guidelines as to what will happen to different metals during the process of melting. All that is required for us that any metal of our interest which will be making which will be forming its mineral deposit by the process of magmatism has to first get enriched in the melt, and that enrichment process will be governed by the source rock composition.

The metal its compatibility incompatibility, and the fraction of melt that will be the first parameter the parameters that will be controlling the process and we can think of; that if such processes keep happening in different steps and different multiple phages, then the elemental concentration will vary which can be can be worked out.

So, with this much of a little background on the principles governing the magmatic process the enrichment of the metals, we now go on to look at the magmatic deposits and initially we will be only be considering those magmatic deposits, which you call as ortho magmatic deposits. I would basically put it in this way let in it will be firm it will be easier for us to first see the magmatic deposits, which are forming..

So, a magmatic deposits a melting is not just the end of it, after the rock melts the melt has to be collected in the form of a magma chamber anywhere within the crust, that magma chamber has to undergo crystallization, and the same crystallization process also will be controlling the concentration of this metal and depending on the crystallization process the way the parent magma is getting differentiated into its different members will

finally, we will that will be the factor, which will be responsible in giving rise to the deposit in terms of its richness, its size, its shape, its distribution and its exact this position in any of the magmatic deposits that we consider.

So, the orthomagmatic deposits are the ones which I would say that its rather we will consider the system as dry systems. Here the crystallization the of the magma will only be governed by the principles of the crystallization differentiation, just with the decrease in intensity parameters, without getting into the other compositional variables or the compositional or the influences exerted by volatiles, especially water and other volatile species. So, we will first consider those systems will be considered later we will first consider these systems which will call as the dry systems.

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Possible Scenarios of Magmatic Crystallization Processes
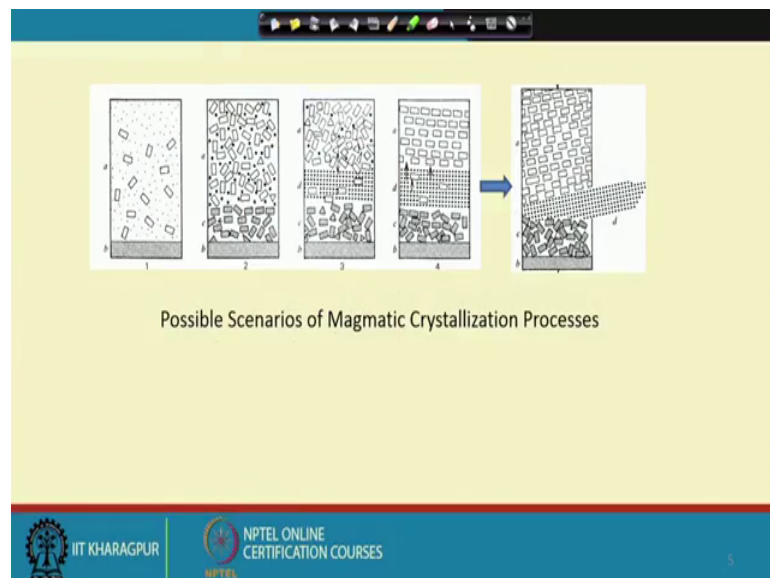
So, this diagram here is some of the very elements from some sketches we can explain the magmatic crystallization process very in a very simple way. So, this is a magma chamber here the first diagram it shows it is a kind of a chill margin at the base and this magma chamber, is just starting to crystallize and first is the liquids or any first mineral has reached the crystals have started to form. So, once the crystals have started to form they will be heavier, they will be their specific gravity is higher, and they will be settling to the bottom as shown in figure 2; this is one of the process.

So, if this happens to be a mineral of our interest, then in this simple differentiation process we will get a layer which will actually reach in that particular metal, and we can

get them in the form of an ore body concentrated a enriched to a certain level, in which we can use it as a take it as an ore and exploit it. In a situation like this where it is shown that in the differentiation process, in addition to also giving rise to the early form crystal could also be could also give rise to a melt of a different composition, that composition is supposed to have been soluble or have remained dissolved within the parent melt at a high percentage temperature condition, going from 2 to 3.

We visualized that the temperature pressure conditions have decreased and that is how the separate liquid has exalt out of the crystallizing parent magma. And if they are also have this this particular liquid if it also segregates into a layer, then also it will be a able to give us an ore body if it happens to be enriching any of the metal of our interest.

And this situation depicts a condition in which the magma chamber is actually crystallizing under the influence of some external stress condition, and at a certain stage if this magma chamber is kind of compressed, then this residual or this liquid which got segregated out of the process can get squeezed out, and we can get a an ore body which is away from the main body of the magma, and where there are so many such examples which exist.

So, these are the possible scenarios of magmatic crystallization process. Essentially it could be a crystallization differentiation giving rise to different members we have seen, if we are having to start with a with a magma of basaltic composition that magma will if it is allowed to crystallize in a condition. Where it is not tectonically much disturbed, then it will start to differentiate giving rise to the members going from the most ultramafic members, and gradually decreasing in the graphic index and giving rise to the intermediate and compositions gradually as we go up.

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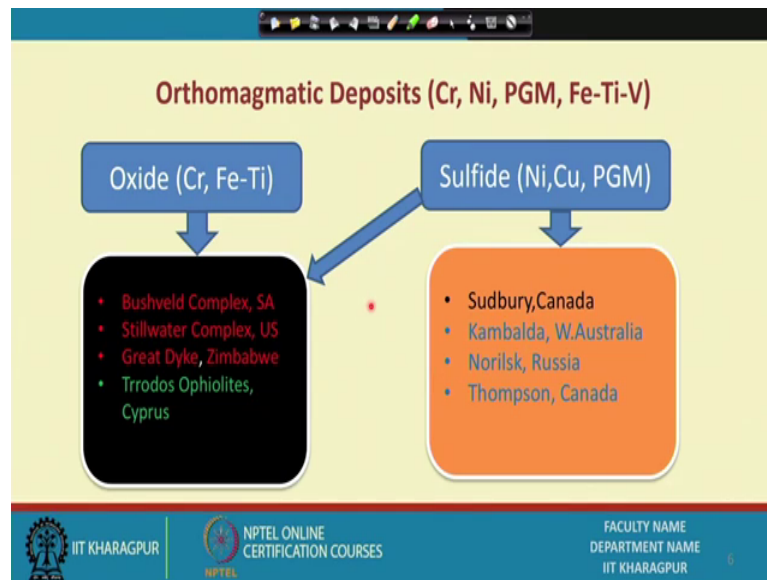
So, for with this little bit of background information, let us go to look at the deposits which are they we are dealing with the orthomagmatic process. So, we will call them as the orthomagmatic deposits. So, such deposits generally we find of chromium, nickel, platinum group of metal, iron, titanium and vanadium, rarely some other elements could also metals could also be associated like tellurium or selenium etcetera, but in much trace quantity. We can take this orthomagmatic deposits in a broad sense almost like classifying them into feces, I can call them as feces in the same way we define.

So, I can classify them to belong into one is in dominantly oxide feces, where we get the deposits of chromium iron and titanium. So, the examples are Bushveld complex in South Africa Stillwater complex in Montana in US, the Great Dyke of Zimbabwe and the Trrodos Ophiolites, Cyprus. So, the ones which are in red are the old deposits belonging to the precambrian and the one in green is young deposit post Mesozoic in the alpine.

Himalayan and in there essentially the ophiolites trrodos ophiolites in Cyprus and these are essentially the ultramafic complexes the Bushveld complex in South Africa Stillwater in Montana, and the Great Dyke in Zimbabwe and these three deposits contribute the bulk of chromium and as we will just see and then we do have just we just as we saw in the diagram, which we are discussing before.

A Magma originally a homogeneous magma which also contained lot of sulfur in it acquired from the source from where the rock, rock melt a mental source would always contribute some sulfur.

So, that magma could always get differentiated or split up into a sulfide liquid, and a silicate liquid the sulfide liquid fraction could be small and in during this process what happens is, there are partitioning of metals because the sulfides will essentially will be acquiring those metals which will be essentially Chalco Foil in their affinity and the metals or non Chalco Foil metals will be remaining in the residual silicate melt, we could possibly look at their relationship very quickly as to what exactly happens.

So, when we have a original melt a silicic melt which is getting splitted up into a sulfide rich or sulfide melt, and the residual silicate melt then there will be partitioning of many of the metals for example, our Chalco Foil metals like nickel, copper and also iron and more importantly the platinum group of metals will always tend to be enriched in the sulfide melt that is separating out of it.

So, here we define so, here the fractionation will also follow similar kind of partitioning behavior between the silicate melt and the sulfide melt, with the situation might be that where, silicate minerals the early forming silicate minerals are fractionating. And also the silicate the sulfide melt fractionating in that case it becomes a situation where the trace metals will be the enrichment in the residual melt, the fractionating melt, the residual silicate melt will be governed by a by the contributing factors coming from the crystallizing silicate minerals like olivine and the separating sulfide melt.

So, if we only consider the case of where only a sulfide melt is crystalline is separating out of the current sulphur and silicate melt, then we can express it as something like the concentration of any element in the residual melt, which will be basically rm; rm is the residual melt will be equal to the concentration in the initial melt im, R plus 1 divided by R plus D where D will also be a factor D is a which is analogous to a distribution coefficient and here we will consider the d as a something which is a partition bulk partition coefficient or the because here its only a sulfide melt and a silicate melt, a partition coefficient between a sulfide melt versus silicate melt.

And we can express that the concentration of any of the melt in the sulfide liquid, will be Yi will be equal to C im into D i which will be very simple relationship, concentration of

any of the element in the sulfide in the sulfide melt will be the initial concentration of that and the distribution coefficient of that particular metal. So, we can get the fractionation of the elements like platinum, nickel etcetera between the sulfide and the silicate melt.

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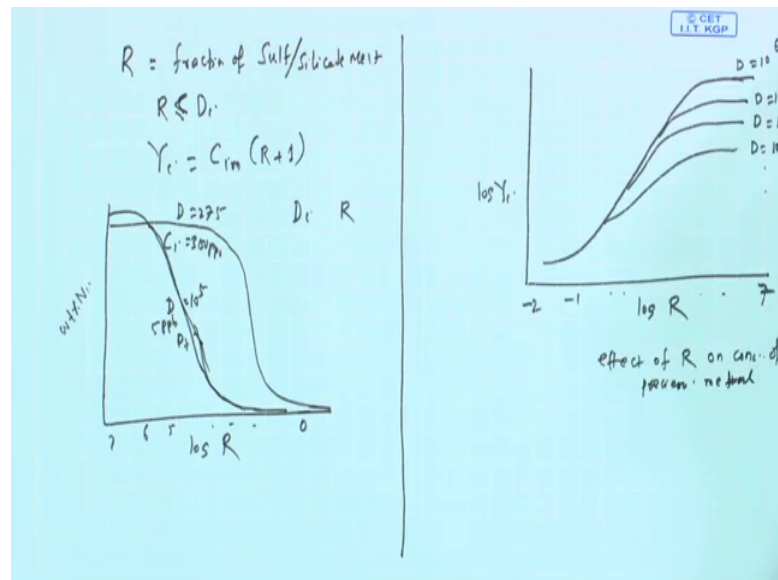
And if we consider the situation where we have defined the ratio R as something which is the fraction of sulfide melt to silicate melt, if R becomes much less than the Di they said by distribution coefficient of that metal, we reduce the relationship to concentration initial concentration into R plus 1.

And we can see the variation in concentration, let us say for example, if we plot as log R here, going from 7, 6, 5, up to 0, and here we put weight percent say taken, but taken metal like nickel, weight percent nickel. Then we can see that their concentration profile are varying depending on their value of the Di.

So, this will be the profile of a metal like whose distribution coefficient would be something around 275, and its initial concentration say is around 300 ppm. This will be for a metal whose distribution coefficient will very high of the order of this say for example, this will be for a case like platinum, here the distribution coefficient value would be very high of the order of 10 to the power 5, and the initial concentration would be something like only 5 ppb.

So, what is what I mean using this fundamental relationship that we have shown, we can see that the concentration of any of the metal is will increase very exponentially when the fraction of the silicate melt is just increasing a little bit of the sulfide to silicate melt, and will essentially be governed by the parameters.

So, as the distribution coefficient the R and the initial concentration of the particular metal in the original melt to start with they will they will all be having very small concentration and their concentration will go up with increasing in R here it is shown for the weight percent of nickel.

And similarly we can see log R versus log of Yi, here it is going from minus 2 minus 1 up to 6 7. So, this will be for a situation like D is 10 to the power of 6 for D is 10 to the power of 5, D is 10 to the power of 4, D 10 to the power of 3 and so on. So, this is the effect of R on the concentration of the precious metal. So, with this so, we again look at this deposits.

So, these metals which we are considering then if they are the Chalco Foil metals like nickel copper and platinum group of metal, they will be enriched in a sulfide melt that is exhaled that exhausts out of a parent silicate melt, the parent silicate melt is essentially a mafic melt of basaltic composition in general examples. So, these are the ones which will be weighing their origin to a solution of the of a sulfidic melt from the parent silicate melt, parent basaltic melt will give rise to the deposits which will be rich in this nickel copper and platinum group of metals.

The examples are the Sudbury deposit in Canada, Kambalda deposit in Western Australia, the Norilsk deposit in Russia and the Thompson mine in Canada, other than this this Norilsk deposit in Russia, this Sudbury deposit Kambalda and Thompson Canada are old deposits and the reason why they are shown somebody else in black because it actually constitutes it to be a very very special type of deposit, which will be discussing and the Kambalda deposit and the Thompson deposit they are associated with older Wringstoarents (Refer Time: 27:10) and the Norilsk deposit is with tolly etic flood basalt.

Now, the interesting situation is where is that, we can always take these deposits as a whole and so, the that possibly would justify that why we consider them to be this oxide of the sulfide faces that when we see deposits we see the Bushveld complex or the

stillwater complex or the great dyke of Zimbabwe, these systems also do have a significant fraction in the sulfides the significant, sulfide fraction and also they do provide the bulk of the resources of platinum group of metals and nickel and copper what basically it looks like to be generally true is that the. So, that is why the they are shown as a common arrow here from the.

So, the oxide species and the sulfide also both being present in the Bushveld type complex, but the reverse is not generally true that no much of oxide in the form oxides of chromium; in the form of the oxide phase is actually obtained from any of these deposits, which are primarily or dominantly the sulfide feces way, and they dominantly they are the resources constitute that this was for nickel copper and platinum of the world.

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Geological Map of the Bushveld Complex

Typical Chromite Ore Body with rhythmic layers
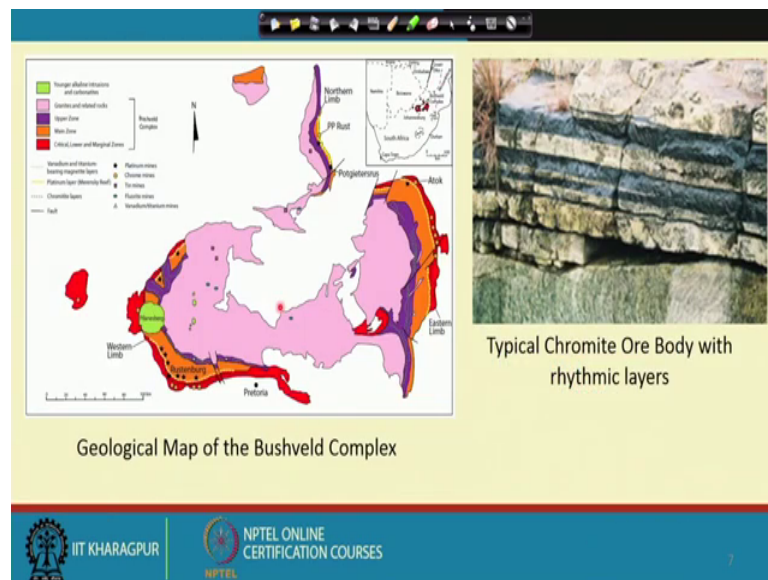
And with this as I have all as I have repeatedly told that if we want to understand mineral deposit formation, the best way to do is that to look at the maps in all possible scales. Here we could see that geological map of the Bushveld complex they can has an example and on the right, we have a typical Bushveld chromite ore where these black bands are chromite Cr 2 FeO and there as you could see they are almost forming like strata and repeated strata repeated layers or repetitive layers of this chromite, which form the ore in Bushveld complex and if you look at the Bushveld complex very carefully.

So, this is the western part, this is the eastern and this is the northern and they are separated by huge benedict propene, and in this you could see this part in the red and

orange and blue are essentially the ultramafic complex. So, this is the western limb, this is the eastern limb and this is a northern limb and you could see here that in the western limb the black dotted lines are essentially the chromite reaps, and the yellow dotted yellow line the discontinuous dotted line which is shown here is the platinum reaps.

And the top of it and the blue are the ones the region or the part of the complex, which essentially is the vanadium ferrous and titanium ferrous magnetite giving the good constituting a good resource of titanium and vanadium in the oxide species of the complex. And the here the, it is a very interesting complex, and we will get into detailed of the anatomy of this complex in the will continue discussing in the next class so.

Thank you.