Mineral Resources: Geology, Exploration, Economics and Environment

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Lecture – 09
Magmatic Processes (Contd.)

Welcome to today’s lecture, we had a brief look at the deposits, mineral deposits of a important metals like chromium, platinum group of metals nickel, associated with mafic ultramafic magmatism and we looked at the general characteristics the tectonic affiliation, the age distribution and got an overview basic idea about these deposits and as I explained that, there could be many ideas, many new ideas coming up because of many observational facts, many things which remain unexplained or many new experimental results coming, they can always be looked at a higher level.

But for this within this limitation of this particular lecture series, we looked at the general characteristics of these deposits, which are associated with mafic tetramafic magmatism. Now, we move on to an interesting class of a mineral deposit, which are associated with also ultramafic magmatism, but they generally are the rich sources of the gem, of the precious stone which is diamond. So, we will move on to the diamond deposits, which are associated with ultramafic rocks and the diamonds are generally are very, very specifically associated with the type of rock, which are the kimberlites. So, I have a look at them, the classification there we diamondiferous ultramafic rocks.

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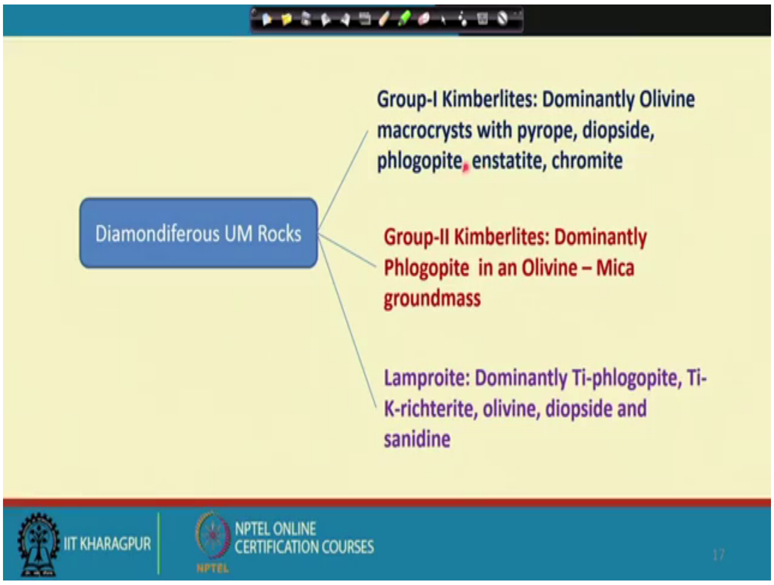

The diamondiferous ultramafic rocks, are generally can be classified into 3 groups, the group one kimberlites: Dominantly olivine macrocrysts with pyrope, diopside, phlogopite and enstatite and chromite. The group 2 kimberlites: Dominantly phlogopite in an olivine mica groundmass and the Lamproite is a Dominantly titanium berine phlogopite, titanium, potassium richterite and olivine, diopside and sanidine. So, essentially the ultramafic rocks, would be generated by the melting of mantle rocks, as we know, but these constitute a very special group of ultramafic rocks in having hydras mineral like phlogopite, which is a biotite and within them and that is how it makes them, to be a very special type of rock.

And also, the expression, because they do sometimes content diamond and the occurrence of diamond in these kimberlites, is very much in the form of a the very disseminated. Their concentration will be far low. About hardly a few carats in a ton of rock, a carat is 200 milligram and then, more importantly they do will have both the gem and the non-gem generated diamond. And the ones which are the gem variety and depending on the high carat value, there very precious to us, they are present in many of the older cratonic areas of the world.

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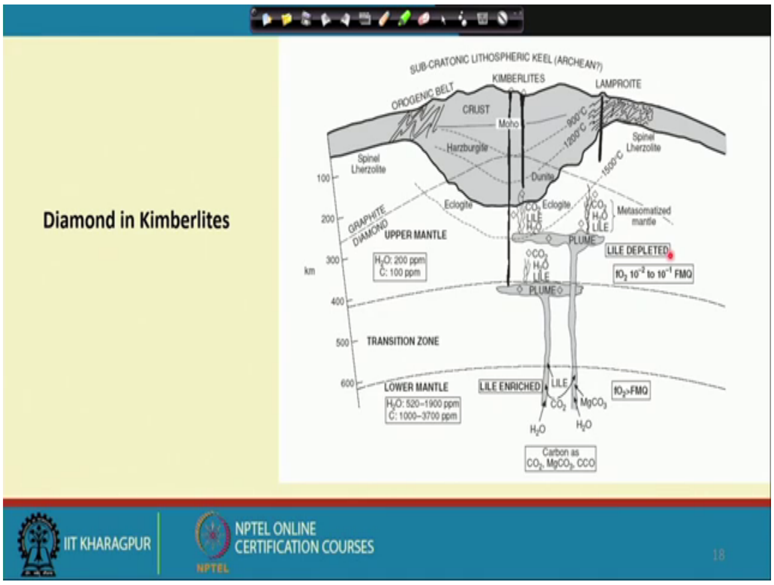

We just have a look at this diagram which gives us an idea, about the conditions in which the diamond might form. To note an important point here, the diamond crystals that we see within the kimberlite, are not a product of crystallization from the ultramafic melt, because a diamond as we know, is stable only at a very high-pressure temperature condition and we have seen phase diagrams like this will be graphite and diamond. So, generally diamond will always be stable at very, very high pressure condition the pressure temperature conditions and if the conditions changes the diamond can always get reversed to graphite.

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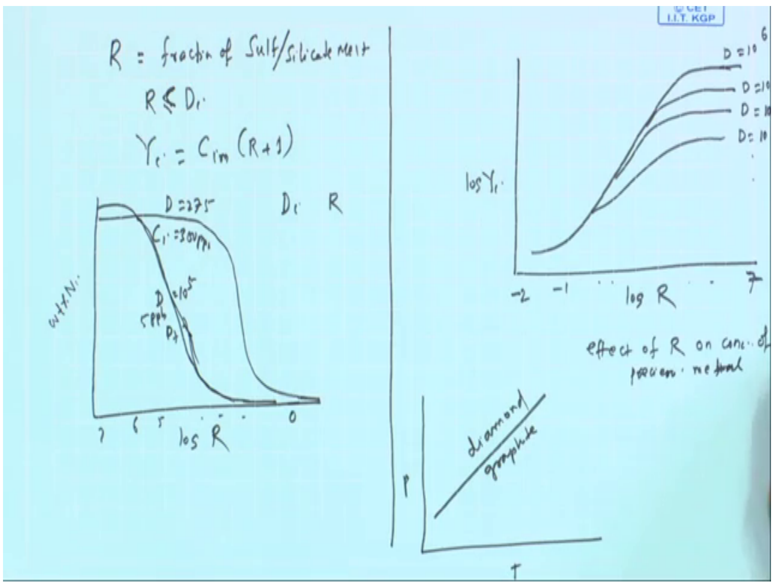

Now, this diagram essentially shows a very thickened part of the is a lithosphere, where a very thick continental crust is shown, with this deep with this gray color and the graphite diamond step the line, the curve is also shown, with respect to the isotherms 900 1200 1500 degree celsius and as you could see, the depth goes to as high as 600 kilometer, below the surface within the mantle, this is the part of the upper mantle and also, we see the eclogite stability field, this is the stability fielder peridotite the harzburgite and dunite. And from the diamond shape, we could see here that within this region, which is essentially a reduced part in the mantle in the lithosphere part of the semisphere.

Here, this is the actually the part in which the diamond is stable, because the zone below this is slightly more oxidized, with the carbon oxide layer and the fugacity of oxygen, which is shown here I could see that it is less it is much greater than the phyllite magnetite quartz buffer whereas, the oxidation state in this region of the a semisphere is 2 to is 10 to the power minus 2 to 10 to the power minus 1 or an FMQ, this phyllite magnetite quartz buffer almost like 1 to 2 orders magnitude less, in terms of the oxygen fugacity.

So, that essentially helps the carbon, to be present in the form of diamond in this particular region and this essentially the diamond instability field, below which the diamond is not stable, what is shown here in this black lines on the black thick lines, they represent the kimberlite in the form of pipes, which will be seeing in the short while now. So, they are forms in the form of dyke.

So, they move through that they just include through, the melts are generated here and the melts migrate through the crust and in the form of dykes or pipes rather and they are exposed on the surface, and these are the kimberlitic melt or the kimberlite the melt, which is generated within these layers when they move up, they are very likely to catch or they have these diamonds at the quarter fragments and can carry them or transport them, to the within the crust which we find them.

So, there are many studies which is done on them, this diamond is found out to be older than the kimberlite and there are many evidence which are there, to suggest that the diamond which is present in this kimberlite pipe and not actually product of crystallization from the kimberlitic melt, a kimberlitic melt definitely has some it generally comes from a carbon di oxide rich part of the mantle.

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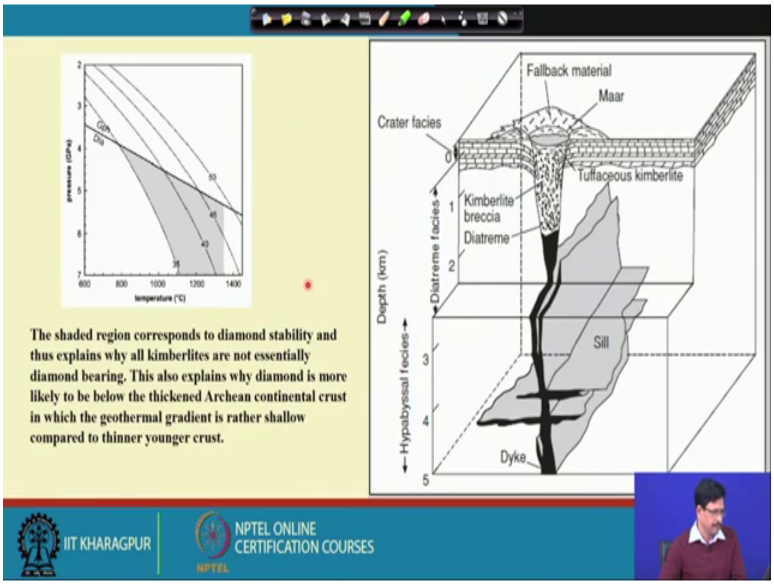

This diagram shows, something here which is the gray part, which is known as the diamond window and that correlates with what exactly we just have seen in the diagram, where we require a thickened part of the lithosphere, where the isotherm because the geotherm, should be shallow. Like the this these dotted series are blotter lines over here, at the geotherm in the in the lithosphere continental, geotherm the lithosphere this geotherm which is pretty shallow, which is about 35 degrees per kilometer will be only possible, when we have a much thicker crust above compared to the areas where the crust is thinner, where the geothermal gradient is supposed to be much steeper.

So, this is the diamond graphite stability field, on the pressure temperature diagonal and the intersection of the pressure temperature this diamond stability field, with this the geotherm shown on this 3 these 4 series of lines, this grey part is only the labeled as a diamond window, this the areas or the region in which diamond is stable and this is a typical morphology, typical shape of a diamond bearing kimberlite, which is the this part is known as the diatreme and this is the kimberlite bricks here and then it is extruded at the surface here.

It is very interesting situation because, sometimes we call these is a representing something like a phreatomagmatic process here, because when this diamond bearing kimberlite, is including through the crust, it could always heat up the groundwater. So, here, the depth is through shown in terms of a kilometer, this is 0 this is up to 2-kilometer depth is the top surface of the dyke of the kimberlite pipe, which is has a base in the form of the seal and is pretty interesting and complicated, in the subsurface structure.

And the more interesting fact is, at this such kind of kimberlite pipe they are occurring in groups or in terms of in the form of swarms, many such dykes occurring in any particular part in the crust and this heated water, actually causes the rocks to fragment and the. So, that is why, the breccia kind of a zone is very common to many of the kimberlites and they are, extruded at the surface which fall with material and the alteration there are some later sediments, which are also deposited here some tuffaceous or some kind of material, these are the these sediments also get fragmented and they fall back on this material, they do represent very interesting geomafic features as well.

Now, what could be basically be told about such a situation? That we get diamond in them, if we the diamond is sourced from a very great depth and it traverses through several 100s of kilometers on it is way up, and then the and encounters lower pressure temperature conditions, then it is very likely that the diamond would get converted to graphite in this process, and we would not be having any ground diamond available within this kimberlite. So, it does not happen. So, that led us too many to believe, these kind of a kimberlite pipes, actually move up very fast within the earth's crust, sometimes the movement of can be as fast as 70 meters per second, kind of rate which should be which is calculator, visualized for the rate of a ascent or the rate of propagation of such kind of kimberlite pipes.

And. So, we will. So, this is how the situation with this kimberlite of the diamond deposits, these deposits are plentily available in many of the cratonic blocks, including the older cratons, in India, in Canada in, Australia the many of the famous diamond fields are there, like the Ekati diamond field in Canada, the Argyll diamond field in Australia and they are very each sources of diamond. We will get back to this again, when we discuss about exploration for diamond.

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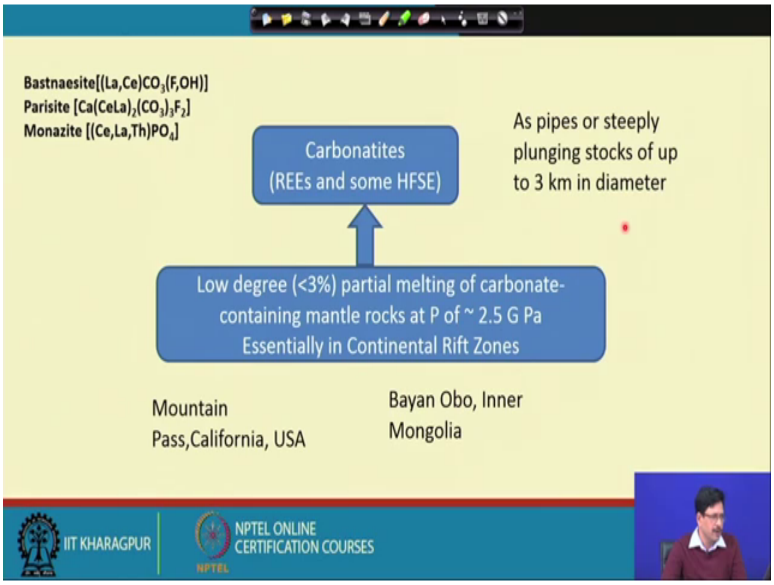

Now, we move on to another class of a deposits which has to be of course, included in this particular category, that we are discussing when we discuss about the mafic automafic clocks and they are the Carbonatites, they had a very special type of a magma, but they represent a very special type of magma, a magma which is essentially being carbonate melt and they give rise to rocks, which are carbonates with calcite and dolomite and they also do occur, as pipes steeply plunging stalks up to 3 kilometer in diameter and these Carbonatites, who they occur in many parts of the world one of the 2 important occurrences, that we could cite is the Mountain pass, in California united states and the Bayan Obo deposit, in inner Mongolia, which is one of the major resources.

So, this Carbonatites the their economical is very, very significant, the content very high concentrations of the metals, which are the light wear earth elements and the high field strength elements, the light wear earth elements are the lanthanum, samarium neodymium, gadolinium etc, with some of the high field strength elements also and like some of the minerals, the content the carbonate minerals, carbonate and the phosphate minerals, is the Bastnaesite is a lanthanum, cerium, carbonate with chlorine and hydrogen this in the hydroxyl site, parisite with calcium, cerium, lanthanum and carbonate monazite, which we all know it is a phosphate of thorium, one of the major minerals of thorium. So, they come from these Carbonatites.

The Carbonatites, generally are a result of very low degree of a passive, melting of a mantle rocks where the mantle rocks is rich in carbon dioxide, by some process and the rocks melt at about 2.5 gigapascal, corresponding to a 90 kilometer depth and such kind of Carbonatites and such kind of a generation of this kind of Carbonatite melt is usually expected, where we have a continental rift zones, like their presence in some of the prominent reef zones, only has given this idea.

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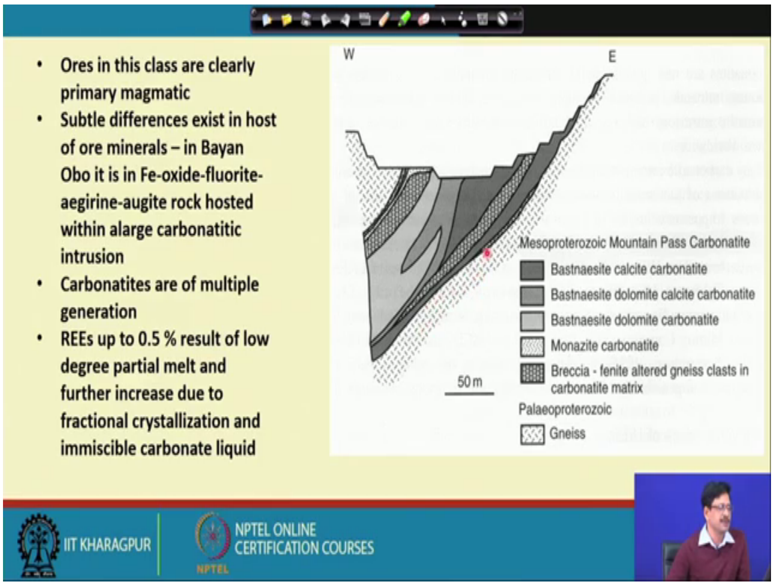

This diagram this figure is actually, represent in the mountain pass deposit where you could see that, it is one of the large-scale ore from this particular deposited is the mountain pass deposit.

Within the (Refer Time: 15:50) country rock, what they generally observable is? That they do have multiple generations of such, Carbonatite bodies present in them and there are different, they can be differentiated into like Monazite Carbonatite, Bastnaesite dolomite carbonotite, Bastnaesite dolomite calcite Carbonatite, Bastnaesite calcite carbonate..

So, these they do represent multiple episodes of injection, of the generation of this kind of this carbonatitic body, and interesting is that that the ores in this particular class, are clearly primary magmatic, they crystallized from the magma and their certain differences there in the host ore minerals. In by although it is an iron oxide fluorite arginine all their type of rock, hosted within the larger Carbonatite intrusion, and a Carbonatites are of multiple generation, and rear earth element concentration up to 0.5 percent.

The way the metal rocks melt in low degree of partial melting, of about 3 percent this can have a cabonatitic melt, which could be could have about 0.5 percent the total rare earth element concentration, and when we get them in the deposit, they get further enrich to almost going up to few percent. So, that must be there must be some kind of a differences, in fertilization differentiation process, which is responsible in making these or further enrichment of this rare earth element in them.

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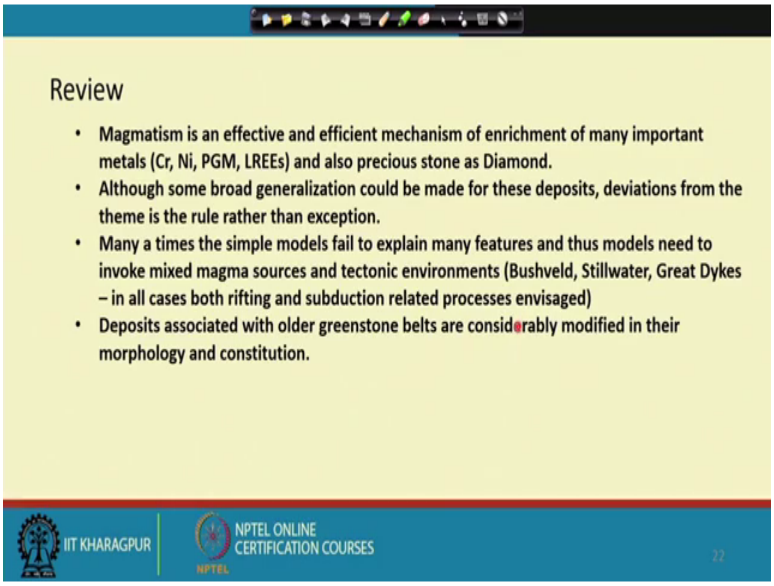

So, that brings us to the close of our discussion on deposits, which are resulting out of the direct orthomagmatic processes, although in situations like what we just discussed in a Carbonatite, it cannot be essentially called as a fully dry magma, because in even in case of a kimberlite, which is which can also be cannot be also be called as a dry magma in the strict sense. Because, the presence of many hydrous minerals and what we have seen in case of the Carbonatite also, there are mineral phases which have a fluorine and hydroxyl, as in their in the mineral in the crystal sides, to make up some of the points.

So, generally whenever we are discussing about these deposits, it is the age distribution, the tectonic settings, which becomes the important attributes of these deposits. In the ultramafic complexes, we have seen that any simple interpretation on the on the tectonic setup, that or the tectonic control of this mineralization does not seem to be very straight forward, which is true, for cases that we have already discussed and even in case of the like, the platinum group of metal enrich we under the sulfide faces, they are all controlled by processes, which all sometimes seem to be pretty hybrid and not exactly a very simple sequence of crystallization evolution, that is expected in any crystallizing magma chamber, controlled by many factors like magma mixing etc, coming in.

So, magnetism is ineffective and what we have to sum up, we have seen that magnetism is an effective and an efficient mechanism of enrichment of many important metals, and also precious stone is diamond, which we can go on to even calculate, by using simple governing equations, taking the distribution coefficient of a metals, between Silicate melt and solid or a Silicate melt in the sulfide melt, and can understand the basics of the young to make an appreciation, as to why such kind of enrichment takes place.

Although some broad generalization could be made, for these deposits deviation from the theme is a rule rather than the exception, because as we have seen in many such cases, we always see observations which are starting from the very, situation in the chromate deposits, many times the simple models fail to explain many features and thus models need to be involve, for mixing of magma sources tectonic environment, mix tectonic environment like, both lifting and the subduction type and deposits which are associated with older greenstone belts, are considerably modified, of the in the very beginning what we discussed that, we do see present day ore forming processes in many well defined tectonic zones, in the lithosphere as expressed in the seafloor or in many of the continental interiors, as if zones and so on.

The older ones, like we see an edge distribution they go all the magmatic deposits that, we have discussed so far bearing a 1 or 2 of them, most of them are in the old Precambrian terrains, where they have undergone multiple phases of deformation, metamorphism, remobilization of the ore body. So, thus making things a little bit more complicated, for explaining all those deposit formation through very simple process of magnetic differences in revolution. So, we had a brief overview of, a mineral deposits which result from the magmatic process, and we have restricted ourselves in the beginning, to the orthomagmatic process and magma which are essentially to start with basaltic composition and a dry.

And the mineral deposit formation, in a broad sense could be explained by the process of the magmatic differentiation, which involves crystallization to give rise to a different members, in a basaltic magma and also the extradition of a of a magmatic sulfide component, which selectively enriches many of the important metals, like the like nickel and the platinum group of metals.

So, with this now, we conclude the discussion on the magmatic deposits, the orthomagmatic deposits and we move on to discuss the another important process, which is the sedimentary process and we see that, how we can discuss? Or how the sedimentary process the in terms of it is efficiency? How they are important in formation of the mineral deposits?

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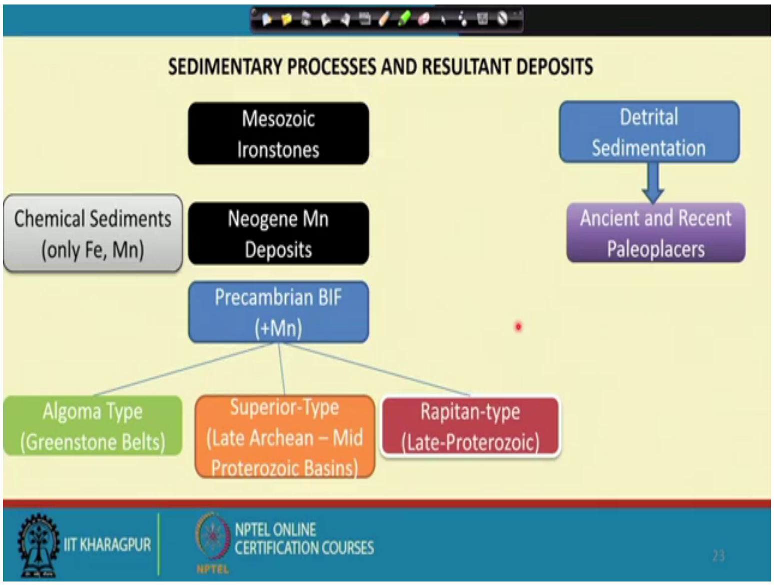

So, we move on to sedimentary process, and the resultant deposits. In the classification scheme that we proposed in the beginning, we broadly divided the sedimentary deposits into 2 classes, the deposits resulting from process of plastic sedimentation; that means, the erosion and transportation of a fragments of rock in form of plastic sediments, and a deposition in the depositional basins, which could be a marine basin or could be a continent in a intercontinental basin or somewhere in the continental margin.

And then, the other class which are the chemogenic sediments or the chemical sediments, and we will first take up to begin with, the deposits which are resulting from the chemical process, chemical sedimentation and within this, we have a very important class of deposits of metal, important metal which is iron and manganese both of them are abundant metals. So, the major source of iron and manganese in the present day, come from this type of a ore deposits, which is arising out of the chemogenic sediments, in ancient later came to early proterozoic sedimentary basins, distributed in many parts of the world like the Superior province in Canada, the quadrilateral peripheral in Brazil, the transfer super group in South Africa.

The (Refer Time: 22:45) iron ore craton in India, the there are other sedimentary basins, like the in the central India and the bus craton and one the most important and the most the reach one is the Hamersley basin in Western Australia. So, these are the examples, in which we get prolific development of this kind of a iron formations, in these basins which constitute the majority of the bulk, of the iron low resources of the world.

A little less significant in this class, are the iron stones which form mostly in the Mesozoic time, we will not be considering them in details, because they are not the sources of iron, they are mostly used for different other purposes and then the Neogene manganese deposits, which are mostly in the in and around the black sea region in Ukraine, they give they also constitute a major manganese resonant land-based manganese resource of the world.

So, we will first take up the Precambrian banded iron formation of the BIF, to begin with when we are saying, it is banded iron formation, it does not represent any stratigraphic unit, as we know them formation, but it is actually used for denoting a type of rock, which we basically name, is banded iron formation and such kind of banded iron information deposits, say a invariably associated with also occurrences of manganese along with them.

As we come to this Precambrian iron, form iron deposits the branded iron foundations, we can classify them to 3 broad categories the Algoma type, the Superior type and the Rapitan type, the Algoma type they are associated with the old greenstone belts and they are the oldest, allowing to middle to Late Archaean, the Superior type which are mostly object they come from the type area in the Lake Superior region in Canada and there the Late Archaean to Mid Proterozoic Basins and the Rapitan type, all switched from the Rapitan basin in Canada, they are the Late Proterozoic or the youngest amongst the banded iron information in the series.

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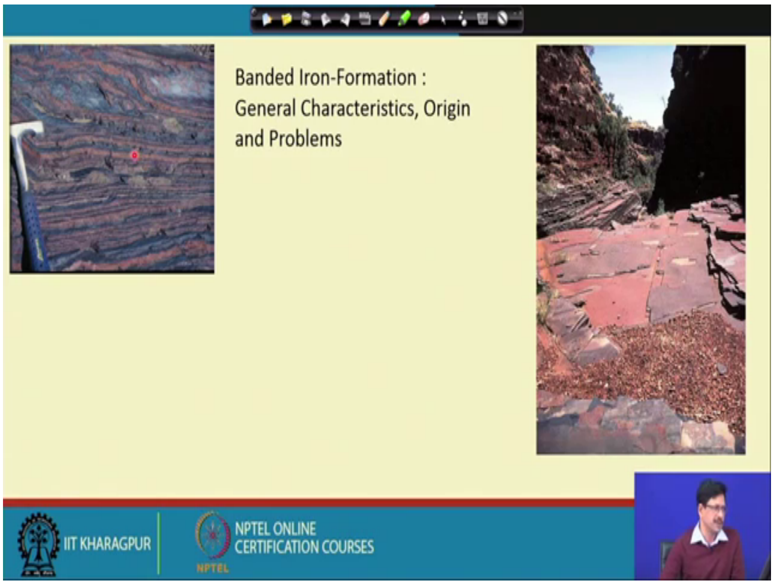

As far as the banded iron formations are concerned, they are definitely very, very interesting class of deposits, iron being one of the abundant metals and also as we saw before, they do from their deposits are huge in quantity, billions of tons this photograph is from Hamersley Basin, where you could see such type of a iron ore is occurring almost like, constituting the entire hill and some such occurrences are very common in many parts of the world including, the iron ore craton in India. So, and this is a extruded scale photograph of the typical banded iron formation. So, we call them, the term banded iron formation has come from the very appearance, in which there are iron rich and Silica rich layers which are present in the ore.

When you could see from the photograph of taken from Hamersley Basin, or even on these exposures can photograph. So, this is one of the curiosities, so far as this deposites are concerned. So, this banded iron formation, they mainly they are the BIF.

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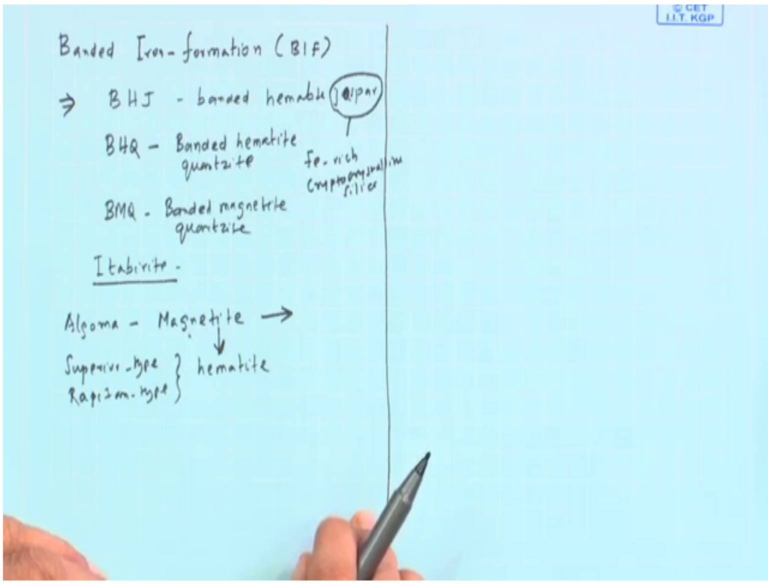

So, they occur in Archean and Proterozoic sedimentary basins, in many parts of the world as I just mentioned, and they constitute of the very many different types of mostly where they are named in different parts, the way there way they occurred in this kind of bandwidth forms, they are known as the BHJ or the in the form of banded hematite jasper.

The jasper is basically the iron rich Cryptocrystalline Silica, they are present in the form of BHQ as banded hematite quartzite, they could be as BMQ quartzite they are named in different they are called by different names, in different parts of the world for example, they are called Itabirite in Brazil and the area of quadrilateral peripheral that is just mentioned, what we see the dominant mineralogy, in most of the cases whether it is a Algoma type the mineralogy is dominated by mostly, Magnetite and in the Superior type and Rapitan type, the mineralogy is dominated by Hematite, maybe it has to it basically because, of the fact that the with increasing oxidations the Superior type in the Rapitan type, by the time they formed the partial crystals of oxygen in the atmosphere was quite higher compared to the time, during which these Algomatite was formed.

And this Algoma type, which formed mostly as a part of the these green stone, where we get a very great sequence of the volcano sedimentary sequence starting with very mafic high MgO, which Comatides to he give rise to the Tholeiitic basalts and the Chemogenic sediments, Clastic sediments and the bimodal volcanism and so on. So, many of these members of this the blower member, of these green stones they are associated with this magnetite mineralization, in the form of this banded iron formation.

So, we will discuss about this banded iron formation, their characteristics, the possible origin and many of their characteristics in the next class.

Thank you very much.