Mineral Resources: Geology, Exploration, Economics and Environment

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Lecture – 01
Introduction

Welcome to this lecture series on mineral resources. Mineral resources are essential for the economic development of any country. Take the case of the developed countries like United States, Canada, Australia and so on, these countries the initial phase of their economic development largely was contributed by their mineral resources which they exploited for the development of their industry.

In the Indian context the scenario is not that very distinct as regards to the role of mineral resources in the initial phase of development of the economy. And still we lack resources of many of the important metals like the precious metals, base metals and critical metals for energy resources and we have to largely depend on import of these metals from other countries. So, there is a lead for the augmentation of the available mineral of the mineral resources and for better economic development and industrial growth.

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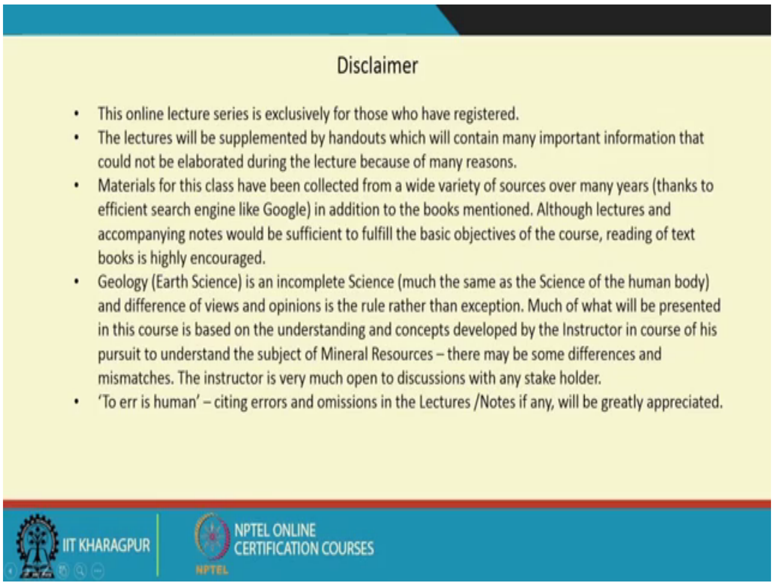

So, this course is essentially is a first level undergraduate level course, and it is taught in many universities and institutes by different course names as economic geology, ore geology. And in this course we will in this lecture series; it will be more conceptual, but not much not involving much of mathematics. What all little mathematics, we will have towards the later part only high school level mathematical knowledge and capabilities will be sufficient.

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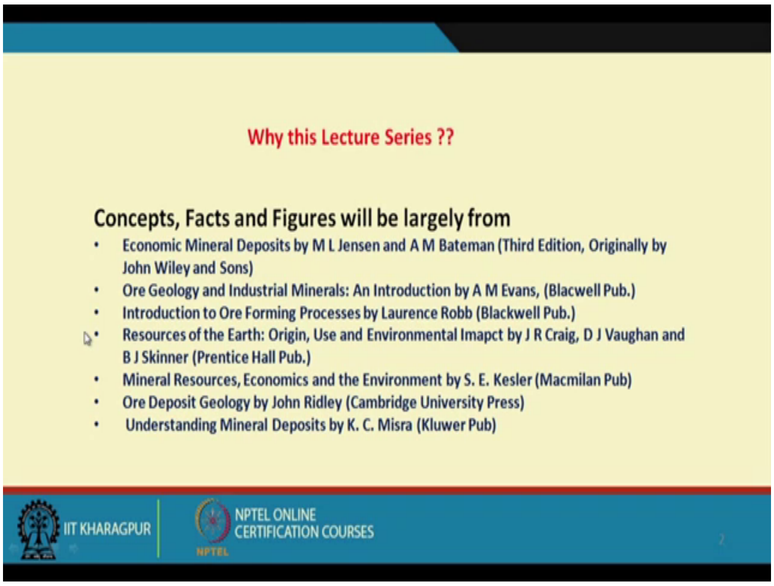

So, let us say brief idea. So, the concepts and facts figures that we will be discussed here; have been taken from available textbooks like the book by Jensen M L Jensen and Bateman, and by Anthony M Evans, Laurence Robb - Introduction to Ore Forming Process and the book by Craig Vaughan and Skinner Resources of the Earth. Mineral Resources Economics and Environment by Stephan Kessler, and Ore Deposited Geology by John Ridley, and Understanding Mineral Deposit by K. C. Misra. Although we will use various other resources and other materials and we will be indicating in the due course of the lecture series.

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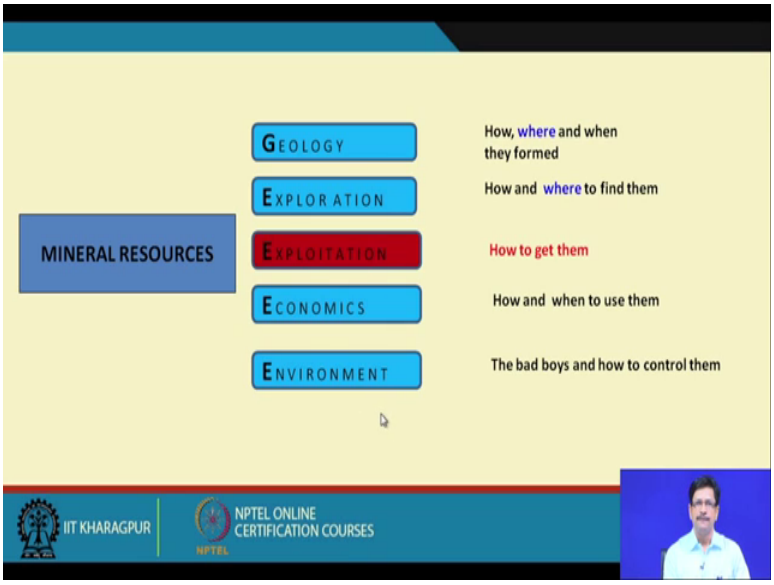

So, let us try to let us have an overview. So, this course is the objective of this course is to give an overview of the subject, and the very first aspect of mineral resources, it is the geology. So, it is the basically the science of mineral deposit formation and trying to answer very fundamental queries as to how these mineral resources form, where they formed, when they formed and trying to understand the rational behind availability or distribution of these mineral resources across different continents. And with once you we are equipped with the scientific knowledge about the mineral resources and their formation this can be very effectively utilized for exploration of this mineral resources in areas where they are not known to be existing as of now.

The another important aspect of mineral resources involves their exploitation use of technology and different methods, scientific methods for exploitation of these mineral resources once they discovered. Since, it does not follow the purview of geology this is rather the activities of the mining are done by the mining engineers. So, we will not be covering much from this aspect.

Then we will see these mineral resources are essentially economic commodities, we have to see how effective policies should be formulated for their exploitation in a sustainable manner. And we need to have, we need to formulate proper policies for their exploitation and to sustain for the future.

Mineral resources exploitation also does affect the environment in many ways starting from the time that they are being explored. And once they are discovered, the exploitation process the several downstream process and extraction of these metals and the various ways that the exploitation and the extraction process downstream industrial process involving the minerals metals, they affect the environment, the ecology.

And we have to see as to how such type of effects could be at least evaluated, and whether there are remedial measures which can be taken for the deleterious environmental impact and that also is the responsibility. So, these are the four aspects that we plan to cover in this lecture series.

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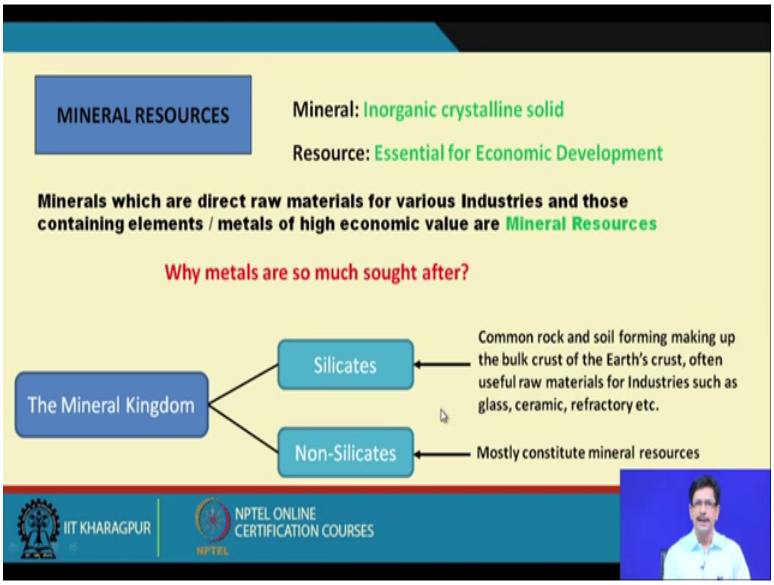

As we all know we can define minerals as inorganic crystalline solids. So, minerals could be they do occur in nature, but they can also be synthesized in laboratory. So, the missing of the term natural is intentional here, we can take them as inorganic crystalline solids, they are the minerals of different metals as we will see the classification. So, resource is an economic term this is essential for economic development as I have already discussed.

So, now we can say that minerals which are either direct raw materials from various industries we know what the industries are, (Refer Time: 07:27) industry, the infrastructure industry, the electrical and electronic industry, transportation industry, aviation industry, refractory fertilizer and so on and so forth. So, all industries either directly or indirectly, it depend on mineral resources as either the direct raw material for them or after the metals are extracted from the minerals, they are used in different industries. So, when these two are combined minerals with a direct raw materials for various industries, and those containing elements or metals of high economic value are our mineral resources which we will be discussing in this lecture series.

We all know why materials are so much sought after. The metals, for example the transition metals, the precious metals like gold, platinum of group metals, platinum, palladium, cadmium, iridium. And many of the metals like tin, titanium, vanadium and so on these metals have got very special properties, their electrical conductivity, thermal conductivity, malleability, ductility and so many other properties which make them very special and suited for many industries, many of our products for the modern technology. That is the reason why these metals are so much sought after. But also the non-metals, the non-metallic minerals are also equally important as we will be seeing them.

So, we can divide the mineral kingdom in broadly into two categories, the silicates. Silicates are the common rock forming minerals making up the bulk of the crust of the Earth's crust, often they are used as raw materials for industries such as the glass, ceramic, refractory industry. And they do they are constituted of the Si O 4 fundamental tetrahedral building blocks which combined in many different proportions to give the range of silicates as you have already studied in our elementary level courses. The nesosilicate, sorosilicate, iron silicate, phyllosilicate, tectosilicate and so on.

Some of the minerals like silica Si O 2 is a raw material for glass industry and many of the clays are raw material for ceramic industry. The alumina silicate, kainite silimanite and alusite are raw materials for the factory industry and so on. And we know that they are economically important even though they may not be as very economically valuable as the metals. The non-silicates they mostly constitute the mineral resources as we see them here.

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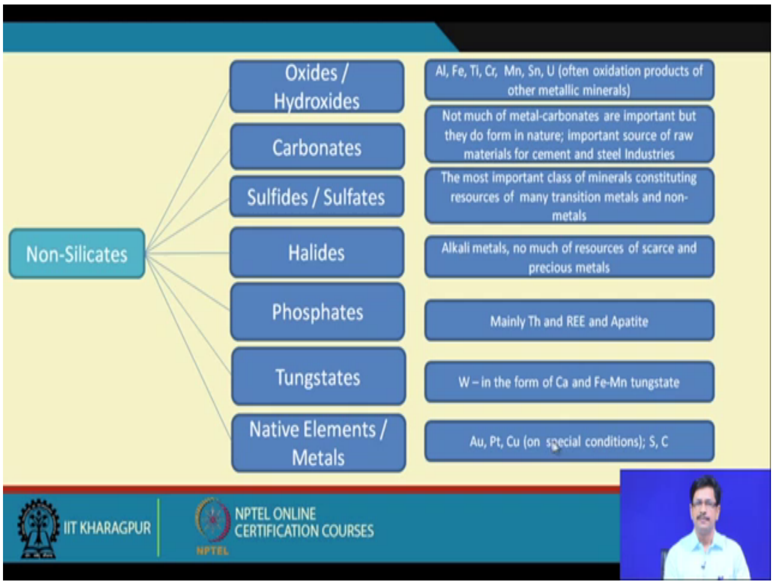

The oxides of the hydroxides metals like aluminium, iron, titanium, chromium, manganese, tin and uranium. And they are either the primary minerals forming in different environments or sometimes the product of oxidation of this kind of mineral bodies when they are exposed to the surface. And metals like aluminium, iron, titanium, the bulk of the ore minerals are the oxide minerals.

The carbonates no much of metal carbonates are important is mineral resources; but that it also sometimes the primary ore minerals get oxidized in the surface in the presence of carbon dioxide to give the carbonates. Some of them like the calcium carbonate which is an important with constitutes the limestone is an important raw material for cement industry.

The sulfides these constitute the most important class of the ore minerals, which we will see in a short while. Most of the transition metals and some of them other base metals, and the semi metals they do form their sulfide their minerals which are sulphides when they constitute the resource. The halides as we all know them the rock salt.

So, phosphates mainly thorium and the rare earth elements are available in the form of phosphates and apatite being one of the minerals which is an important material for our fertilizer industry. And we also do look for such kind of minerals. Tungstates, this whole a mineral for tungsten. And also the native metals for example, the global metals like gold and platinum, they do occur in their native form because and metals like copper also is available sometime in a stretiform under some special conditions. And as per the non metals are concerned sulfur which is an important resource for fertilizer, it will be less for many medicinal purposes. And carbon which is essentially where it is presented gemstones diamond. So, these are the some of the examples of native metals.

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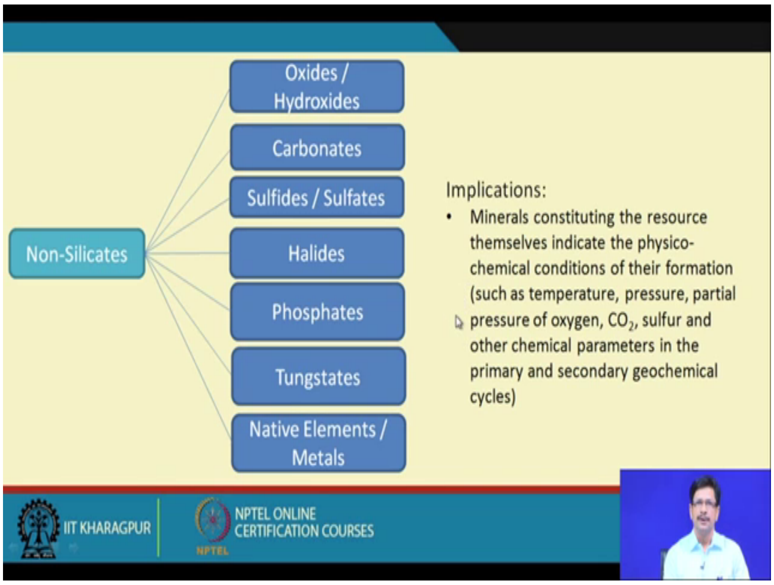

But this minerals their immediate implication that you can see from here is that whenever such kind of minerals are forming under any kind of an environment, they do indicate some of the physical chemical parameters of the environment that means, they are forming.

For example, for the oxides to form, we need to have a environment where the oxidation states should be favourable or to have appropriate partial pressure of carbon dioxide to form the carbonates. And sometimes we find that these minerals as will be discussing the attribution of the mineral resources, mineralogy of the mineral resources constitute a very important aspect.

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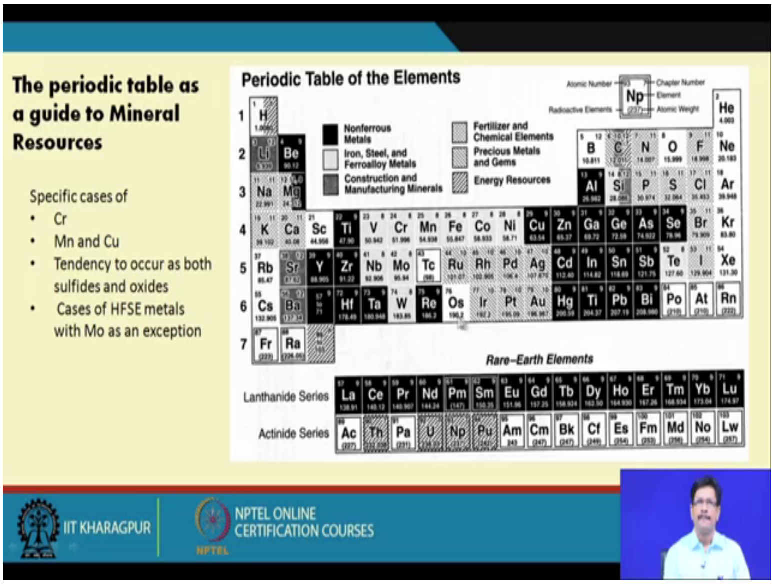

This is the one of the very fundamental contribution to science. This is a periodic table of elements, which guides us in understanding the many of the phenomena chemical phenomena anywhere. And since we are interested or the focus of our subject is mineral resources, information of this mineral deposits we can always get some insight by looking at the periodic classification of elements.

Here this periodic table has been taken from the book of Stefan Kessler, where you see did elements are differently shaded the non ferrous metals here the elements for fertilizer sodium, potassium, calcium, nitrogen of course, is coming from the atmosphere, phosphorus and sulphur. Here are the semi metals arsenic, antimony and bismuth, the metals like tin and lead, there are may be the tin and lead. This finest group of metal copper, silver, gold, the platinum group of metals, the transition metal and the rare-earth.

Some of some even though we can always go on studying it for very as much minute details as possible but to be brief say for example, a metal like chromium, it is very rigidly a rockers and only plus 3 oxidation state in the primary rock forming cycle, although plus 6 is also chromium also forms it plus 6 in different specific surface environment.

So, that series and this metal chromium occurs is very very restricted in its occurrence, in its type of because it forms only one ore mineral that is chromate, and it also does form a very restricted type of mineral resource.

Metals like a manganies occurs in a variable oxidation state from plus 2 to plus 7, but it generally is occurs if it is oxides and in mineral resources. It is a manganese oxides which is recovered is the ore mineral. Metals like iron has equal affinity for sulfur as well as oxygen. So, they do it occurs as pyrite so which is the major sulfide mineral of iron which is iron suflide pyrite. And also is oxide which constitute the major bulk of the ore.

The metals like zinc, cadmium, mercury, copper, and the semi metals this arsenic, antimony and bismuth are essentially they form their sulphides. Amongst the high field strength elements like titanium, vanadium, zirconia material hafnium tantalum they form the rock sites in exception to molybdenum which forms its sulphide.

And these rare the first series rare earth elemental lanthanides they are mostly deforming in the common rock forming minerals or as phosphate and the important resource of. They are very interesting allowing property for which they are very much sought after for the for improving the magnetic field magnetic properties of alloys they are very much used very much sought after.

And the classification like say for example, carbon is both a source for energy as for as well as precious gems as we know it occurs a diamond and so on. And the fertilizer industry, construction industry these elements which you can we can see from the classification here.

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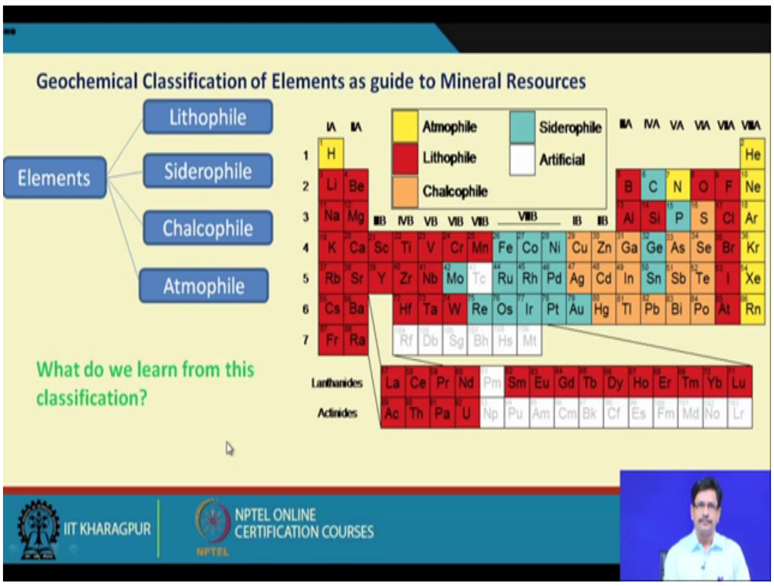

Elements of the periodic table in context of mineral resources, also a geo chemically classified to lihophile, siderophile, chalcophile and atmophile. A lithophile elements are they generally have the tendency to get enriched in the earth crust on formation in the rock forming silicates. They do constitute many of the larger and lithophile elements like lithium, potassium, rubidium, cesium and so on. The siderophile metals are the ones which have the maximum they have the affinity for iron, which is marked over here in blue there the siderophile elements.

The implication is that during the fractionation of the palk earth to core and mantle when the most of the iron and nickel went to the core many of these hidden file elements like the platinum group of metals and gold also were partitioned or fractionated into the earth’s core and that is how their availability in the mantle was greatly reduced. And as shown in the previous figure from the periodic table you could see the chalcophile metals.

So, they are these are the ones which occur as the sulphide minerals and recovered as from nature in the form of their sulfides. Atmophiles are the noble gases which we do not consider them in the present scenario. So, these geochemical classification of elements help us in getting before first hand information about the mineral resources, what type of minerals to expect and what kind of geological environment.

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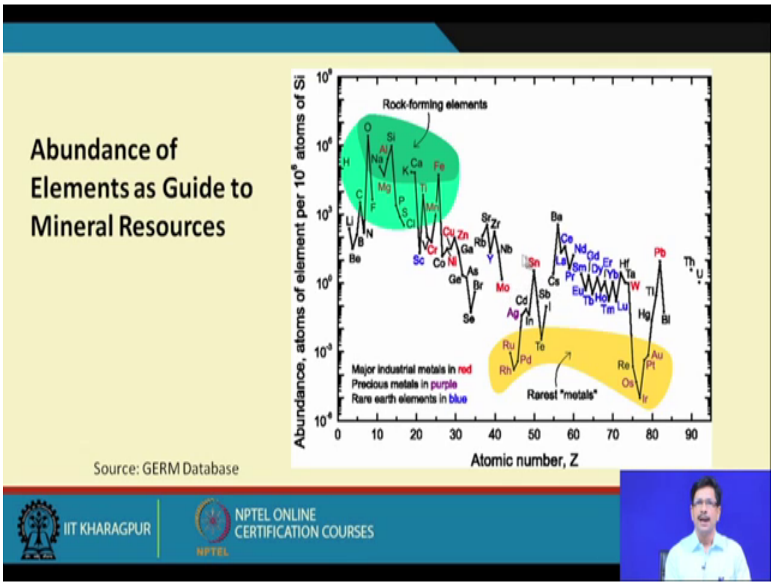

This diagram has been taken from the geochemical earth reference model database. Here of the x-axis the abundance the atomic number are plotted from one to just above 90 up to uranium. And on the y-axis, the abundance of these elements in reference to silicon power 10 to the power 6 atoms of silicon have been plotted. This the zigzag pattern in the abundance of these metals is a very fundamental principle that odd number atomic odd atomic number elements and less abundance than the even the atomic number elements.

And the ones which are the most abundant elements the rock forming elements are shown over here. The rarest metals ruthenium, rhodium, palladium, gold, platinum as we saw in the previous diagram are the rarest minerals. The blue ones are the rare earth metals which are ever which occurring much stress amount compared to the other metals and (Refer Time: 21:22) on log scale.

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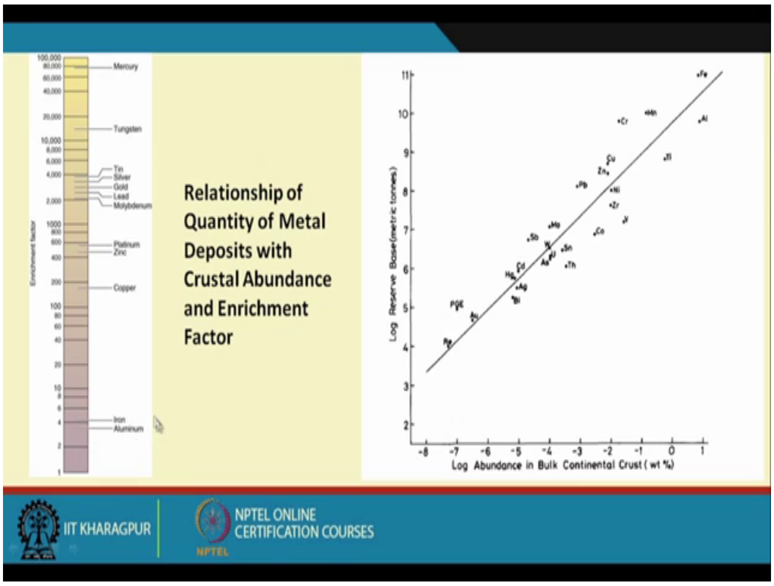

Now, as far as the mineral resources are concerned, the fundamental questions that we ask that in what quantity we actually get them. And if and this diagram here is it shows the relationship on the x-axis, we will have the log abundance on the bulk earth continental sorry bulk continental crust.

Where the order of about 9 order of magnitude variation means 10 to the power of minus 8 to nearly 10 where you could see the abundant metals like aluminium and iron having abundance is almost is 8 percent 5 to 6 percent in the continental crust. And on the y-axis, the quantity of these petals available as mineral resources in terms of metric tons and 1 ton is 1000 kg are plotted here that is also on the log scale. We also see that they vary all most of the in beyond the similar about 8 or 9 orders of magnitude in the quantity of these metals talking from very scarce metal like uranium to going up to aluminium and iron which are available in billions of tons of such mineral such resources taken all together. They are occurring in the earth.

So, we do this diagram gives us a first very first insight that the total quantity of any particular metal that is available as a resource is has some kind of a relationship direct relationship with their abundance in the continental crust. And the diagram onto my left is a vertical scale where a term that is written here is enrichment factor which is mentioned here. And the element the metals of interest are plotted on this or are shown on this vertical scale starting 1 to 100000.

We see abundant metals like aluminium and iron have enrichment factor values which are less than 10, we can say the less than 1 order of magnitude. What is it tell us, it tells us that an abundant metal like aluminium and iron does not only needs to be very little enriched to give its to be available as resource which you can exploit. And it is very scarce metal like mercury, whose crustal abundance is of the order of 10 to the power of minus 5 in weight percent. It require almost about 80,000 or more enrichment, but I mean times of 80,000 the more time times enriched so that it will be available to us in the form of a resource.

It does give us some few more insights that the processes so that means, if we when will be looking at the different earth processes that is what we basically try to correlate here, they all the earth processes to formation of mineral deposits. Then we see that the this scarce metals like mercury possibly we would be needing multiple steps or multiple stages of enrichment so as to reach to a level where we can call them a resource and the metals in between form. They do also are tell us at least at the first end that these metals we will definitely take longer time to be available as resources in the earth.

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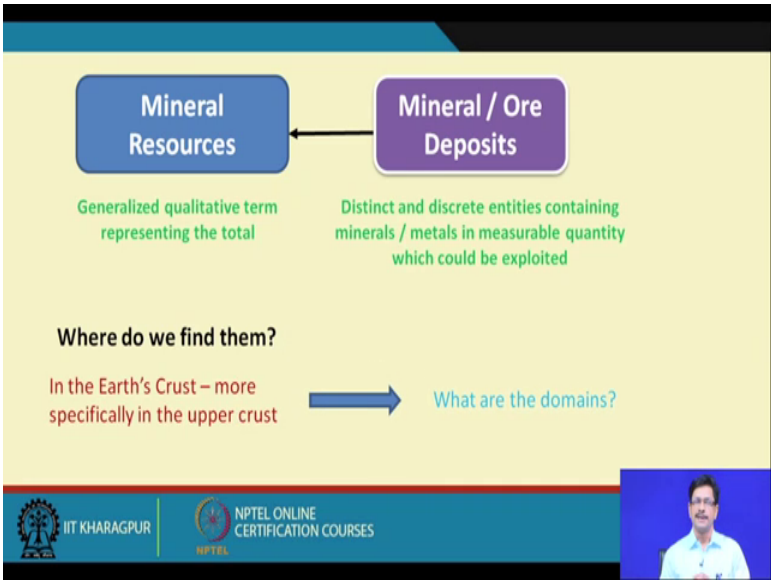

Now, let me tell you that when we use the word resource it is a putt generalize qualitative term giving representing the total for any particular metal or a mineral. What actually it comprises is the mineral or the ore deposit. These are discrete entities present that we see them and measurable in the quantity. They do satisfy some quality and quantity parameter. And the question is that where actually do we find them. So, the answer is that we find them in the earth's crust or to be more specific in the upper crust.

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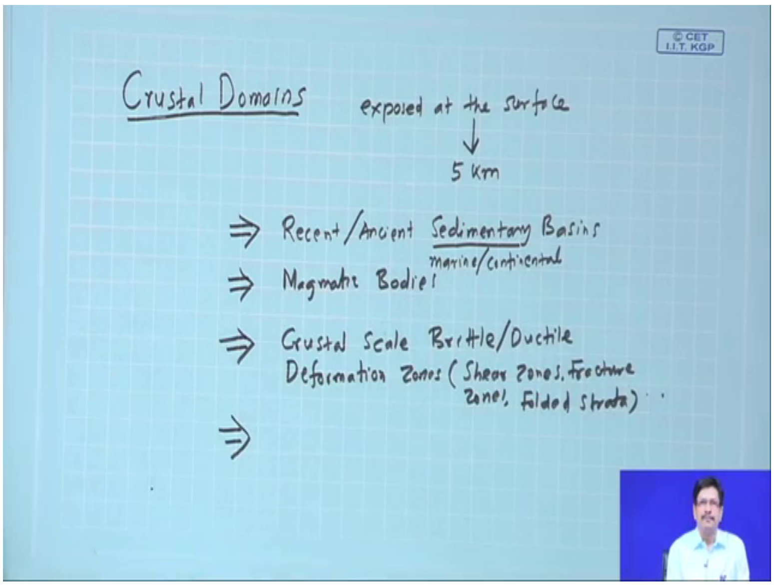

So, what are the crustal domains in which we these ore deposits of the this mineral resources they occur in the crust more specifically in the upper continental crust either exposed on the surface or even going to depths as high as 5 kilometre. Quickly we can see; what are the different crustal domains that we can expect to see such mineral deposits occurring.

They will be occurring in recent or ancient sedimentary basins, they may be occurring in associated with magnetic bodies, subsurface into as the magnetic bodies in crustal scale brittle ductile deformation zones, it could be crustal scale as well as local scale deformation zones such as shear zones, fracture zones, folded strata and so on. And these sedimentary basin also could be the marine sedimentary basins or the trivial and so on. So, we will see them the whole spectrum in the due course of this lecture.

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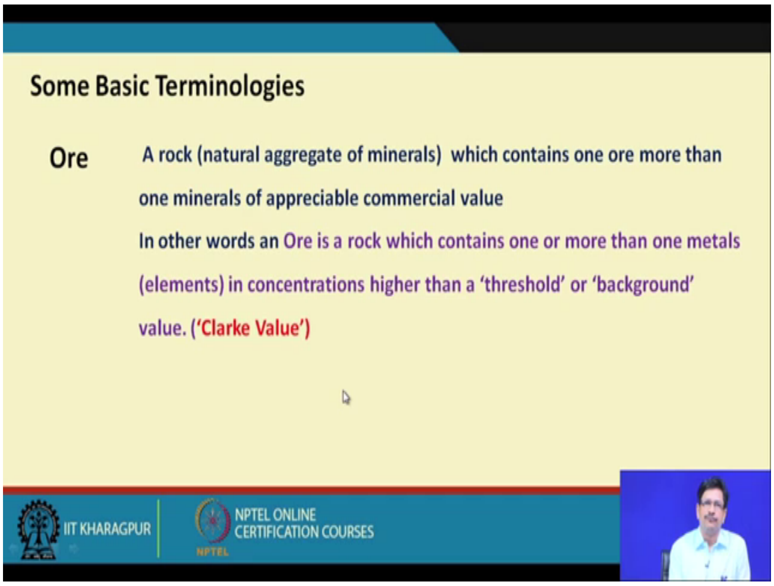

And let us try to look at some of the basic terminologies. What you mean by this mineral deposits that we are talking about is essentially constituting of some entity which you can call as an ore. So, we defined ore as a natural aggregate. Ore essentially a rock it constitutes of natural aggregate of minerals. And the only speciality is that in the ore there is the concentration of either one or more than one element is above a threshold or a background value which is called as a Clarke Value after the famous geochemist FW Clarke. It is kind of an average value concentration in there in the crustal rocks.

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So, these are examples of ore. This is taken from the iron ore, this one photographs from the Hamersley Basin in Australia where I could see the darker bands constituting of hematite and the lighter band with the red bands are the (Refer Time: 29:58) silicon on a chart. And in this we all know that this black this grey band which is the iron oxide is the material for interest and we call the if that is the ore mineral then the part which we would like to discard is the gangue mineral. This is as Hamersley.

This is a specimen of ore from Malanjkhand copper deposit in central India where you could see these as the sulfide minerals of copper in a matrix of quartz. And here the quartz is the gangue mineral and these are the ore minerals. And if for in order for this material to be qualify to be called as an ore, here we know that this concentration of metals like copper has to be above a certain value. Say for example, at least of a 0.45 percent of copper to be for this material to be called as an ore.

So, this ore when we call that an ore comes from something which is an entity within occurring in the association with common rocks in the crust which is an ore body this is an example of the ore body of copper from Malanjkhand copper mine in Central India. Where you see it is a rich mineralization of copper sulphide copper iron sulphide chalcopyrite mineralization in this ore body. So, the ore body it needs to be present in a required diamonds and length baton width and. So, that it gives us certain point certain quantity of the metal for that to be feasible to be recovered by utilize by using our process different scientific methods for extraction of a recovery or this particular metal.

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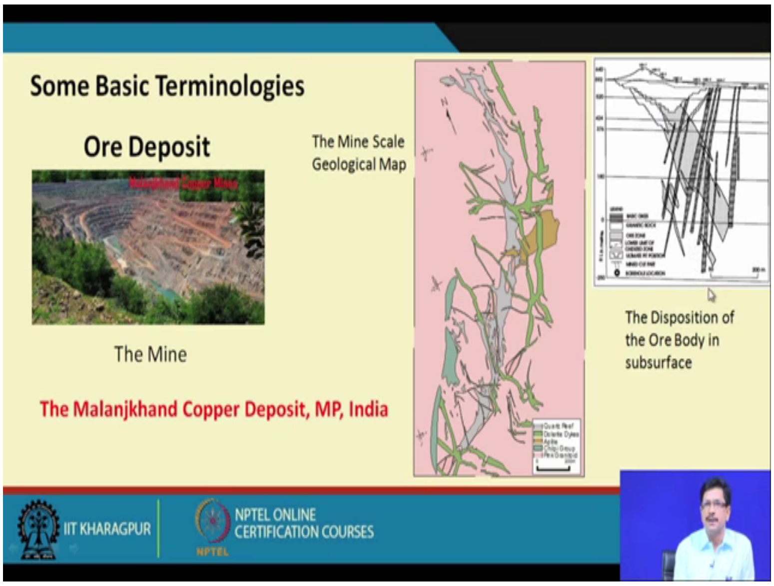

So, this is the example. So, when we see this is a typical look of a mine where an ore body is being exploited. This is taken from the Malanjkhand mine. And if we want to represent the ore body in space we can only do it on a geological map. So, it is very very important that if we want to understand the ore deposit formation processes, we do have to look at their maps at all scales.

This is a mine scale geological map where the ore body which is basically the copper rich ore body extending for a length of almost like 1.8 to 2 kilometer in surrounding rocks in association. As I told you that they occur in association with common crustal rocks this is what is an example of a mine in scale geological map. If we take a subsurface section of this ore body we do we do see that it does extend to depths that is what exactly what I mentioned that this occurrence, they do sometimes they do either do they are exposed or they do extend to a great depth in the subsurface variable depths.

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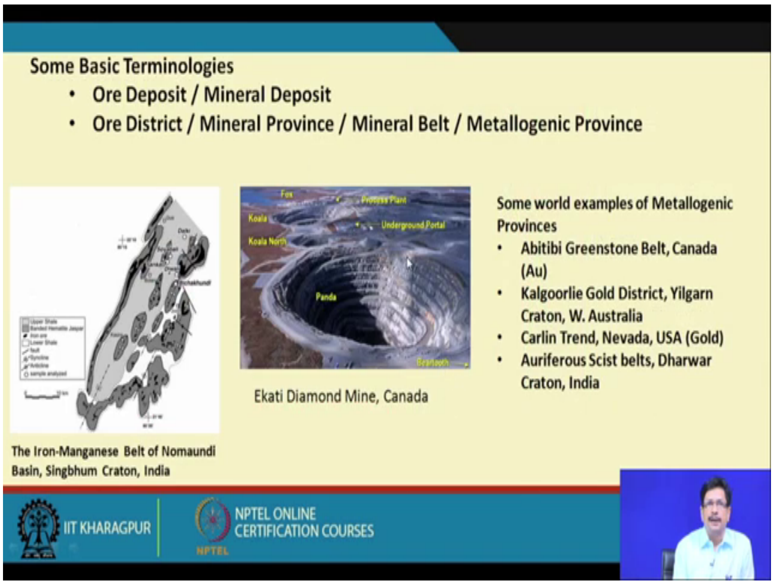

And when such ore deposit they can either occur independently in one geological terrain or there could be lots of such deposit occurring together this one example this is from the Nomaundi Basin in Singbhum Craton. In this particular basin itself we get a good number of localities where the iron ore is being mined. In addition to that, there are many manganese the local it is where the manganese ore is also been mined. This is an example where and the this is an example of a place where there are several such ore bodies can occur in a small area of just about a square kilometre, which is coming from the Ekati diamond mine in Canada.

And several such in those cases we call them as ore district or mineral province or mineral belt or mettallogenic province. There are many such examples of such kind of mineral belt mettallogenic province, the classic examples come from the Abitibi Greenstone Belt in Canada, Kalgoorlie Gold District, Yilgarn, Craton in West Australia, Carlin Trend in Neveda, United States of America where it is a very rich zone producing gold ores and the gold bearing Scist belt in Dharwar craton. These are some of the examples of the mettallogenic province or mineral belts. So, we will continue discussing about these mineral resources in the subsequent classes.

Thank you.