Mineral Resources: Geology, Exploration, Economics and Environment

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Lecture – 38
Mineral Exploration (Contd.)

Welcome to today's lecture. And we have been discussing about the mineral exploration methods going by the very trying to have the very preliminary idea, basic idea about the principles involved in using them for mineral exploration of different types of deposits. And we last week, we last class we just saw a very good example of how remote sensing technique can be useful for discovery of porphyry copper deposits, and similar situations there in many other types of deposits. Because of the fact that remote sensing technique also is the method which is first can be used to decipher the surface features.

So, any mineralization which is resulting in very conspicuous identifiable surface features say for example, lineaments can be better identified or better analyzed by looking at the satellite imageries. And if there are some specialized analysis of the digital image for extraction of lineament and features like Venice pattern sometimes the physiographic guide that we were discussing about in the context of geological exploration, (Refer Time: 01:36) channels or large scale shear zones even again manifested is large scale lineament.

And more importantly with better and better methodologies for perceive for processing of this digital image data, we would possibly in a position to discriminate the rock types to very minor test details. For example, depending on the spectral characteristics even a mafic rock from an intermediate rock with felsic rock also could be very well discriminated. And even many of the information important information about the lithology of the area could be obtained by settle by the image by the remote sensing technique. And they are very effectively utilized in producing more accurate, the dependable geological map then what was previously possible by conventional field exercise. They have been able to help a lot in this respect to fieldwork.

Although the fact remains that they need to be first checked with the ground observations of the field checking which are essential. But once it is done, for example if a particular area bearing hydrothermal alteration signatures, if it could be checked or could be cross

checked only once by physically examining a particular spot from where the satellite imagery of that area has been acquired then the similar features could always be extrapolated to other different areas which has been rather inaccessible or has not been possible to be mapped by conventional manual methods. So, remote sensing techniques in that way have come with a lot of advantages in supplementing to geological field work and especially when it comes to the utilization for mineral exploration.

So, today let us have a look on interesting exploration method which is utilized for exploration of diamond difference kimberlite. We all know that will be looking at we will be discussing coming back to the discussion of the discovery of the or exploration of diamond again, but we will see how our geological knowledge of, geological understanding on the formation of the kimberlite will help us in formulating or in designing an exploration program for diamond.

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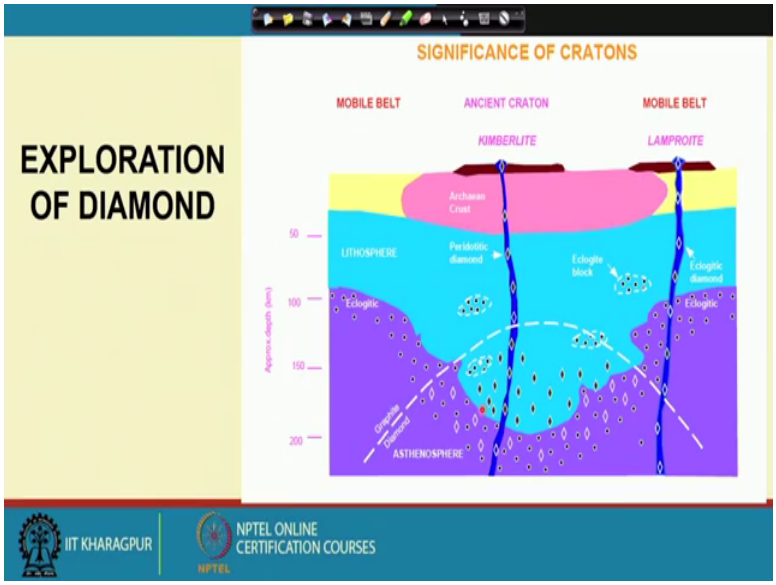

Here this feature we have seen before in different other type of diagram. This is the general this sketch I am giving the. So, this is the graphite diamond boundary so below which diamond is stable and above which diamond is not stable. And this shows the region from which the kimberlitic magma is generated and travels through to the mantle and the crust to be ultimately getting extruded on the surface to form the dikes they can be kimberlite or the lamproite type of dikes or to in have the tide trim. This represents a

thickened ancient craton and this depends a mobile belt where the crossed this thinner, similarly, here.

So, what we basically observe here that the kimberlite magma which is generated in the asthenosphere in depths ranges where the diamond is stable is most likely to take to incorporate or angles this diamond which are present already there in the diamond stability field. And carry them up in the form of the kimberlite which will be containing the diamond.

Now, as far as the diamond exploration is concerned it is also important to remember that if we go by the abundance of the concentration, even if we say that a kimberlite is diamond bearing, but then the diamond is present in very small quantity of the order of like about 5 or 10 carats per ton that is per 1000 kg of the rock, where carat is about 200 milligram. So, we know that they are almost like edge trace has the other train other precious metal like gold that we discussed before.

So, it is basically very difficult to physically find a diamond crystal all the time in the kimberlite pipe. So, then it becomes more important to know and since there are diamond bearing as well as diamond nonbearing kimberlites, it becomes very important to discriminate to have some criteria to distinguish them that which of the kimberlite are most likely to carry diamond and which are not. So, that whenever we encounter a kimberlite pipe in the field we can I have decide either to go for a expensive exploration efforts like drilling of the particular diamond kimberlite pipe or not to do it.

And as we know that even if it kimberlite contents kimberlite pipe has diamond only a very small proportion of it actually is the precious gem bearded diamond and rest of it is the non gem bearing diamond. Even not considering the gem or the non-gem bearing, we just have to see how we could go about or formulate the exploration of this precious stone.

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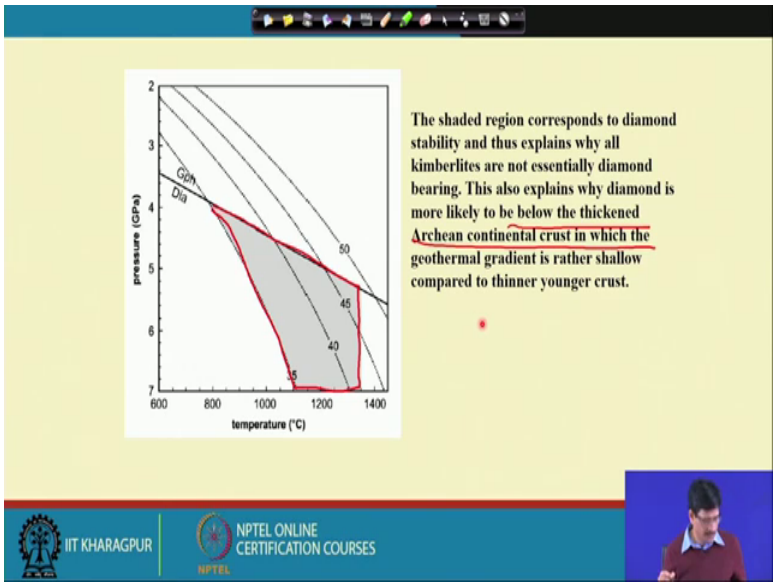

This is just to recall about the diamond window, this is the shaded part here. The shaded part here is the diamond window which explains the why we need to have a thickened continental crust where the geothermal gradients will be shallow and the temperature is high. And this defines when the graphite diamond stability line intersects this defines the diamond window. So, this condition of pressure in temperature is the diamond stability field. And if a particular kimberlite pipe has to be generate or kimberlitic magma either is will being generated or actually traversing passing through this particular diamond window is likely to be diamond difference. So, this explains why diamond is more likely to be to below the thickened Archean continental crust in which the geothermal gradient is rather shallow compared to the thinner crust.

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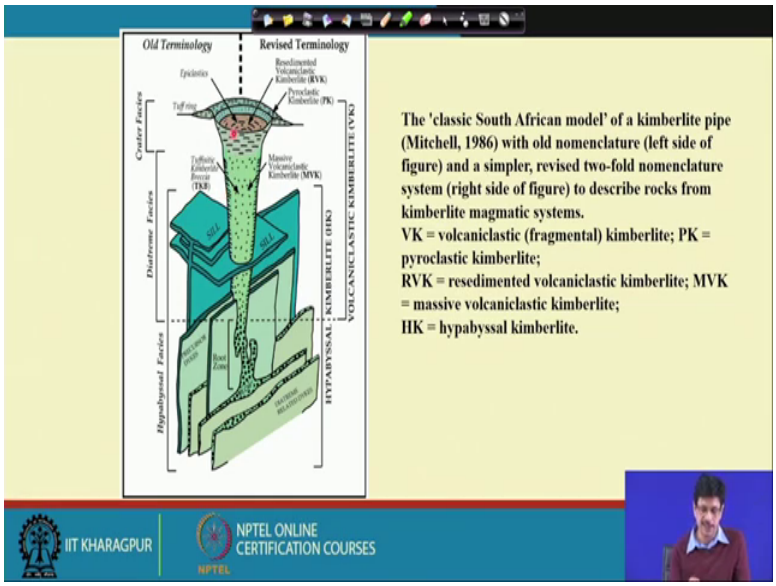

So, this gives the classic South African model of a kimberlite pipe with old terminology and the revised terminology. So, this we know that it is basically defined divided into the different phases with depth. The top part is essentially it was known as the crater facies or now it is being known as the volcaniclastic kimberlite or the VK, this is the pyroclastic kimberlite.

As we discussed during the when we were trying to understand the process by which the kimberlites form and the kimberlitic magma the moves through the cross to have tremendous velocity and creates explosive situation by heating up the groundwater which were within the shallow region of the crust. And they are extruded in the form of troops and the volcaniclastic which are deposited on the scrater. And later on they sometimes make depressions which also very prominent geomorphic feature and such kind of as we know that they occur in lot in more than one they will occur in large numbers as dikes forms. So, they will make some prominent geomorphic features which can be identifiable on the surface.

So, this is the hypabyssal kimberlite, this is the volcaniclastic kimberlite. This is the sill; this is the diatreme. So, this is the general morphology of a kimberlite and which the most interesting part would be there top part which is the crater facies or the volcaniclastic facies, where there could be pyroclastic materials, and sometimes there are resedimented volcaniclastic materials here.

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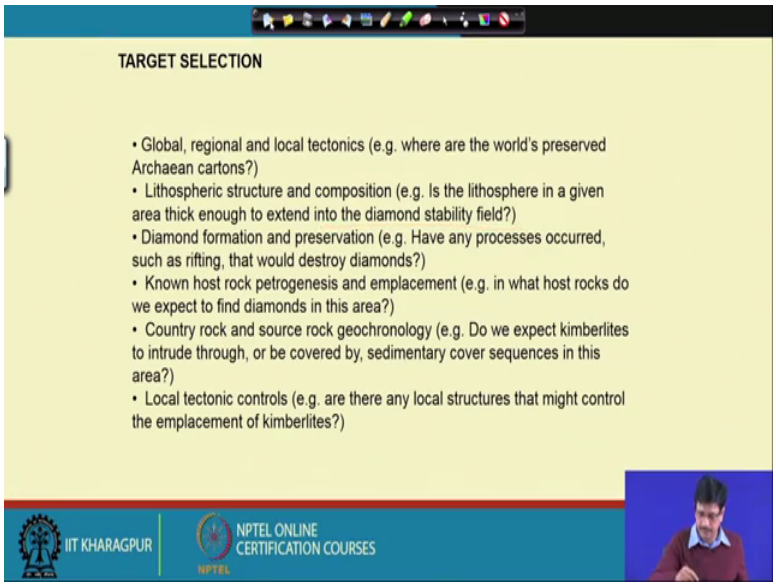

So, now if we want to select the target for exploration of diamond difference kimberlite, so we do have the global regional and the local tectonics at the back of our mind, where are the world's preserved Archaean cratons are there. The lithospheric structure and compositions is the lithosphere in a given area thick enough to extend into the diamond stability field. This we could always find out from our general geological idea about a particular craton. And the diamond formation the preservation, they have the process occur such as a rifting that would destroy diamonds.

So, they should this is the diamond the kimberlitic pipe where they stood it. This areas would have been not have been disturbed in or the tectonic and rifting activity later on. The known host rock petrogenesis and emplacement is, what host rocks do We expect to find diamonds in this area from the country rock and source from geochronology; that means, do we expect kimberlites to intrude through or be covered by sedimentary cover sequences in this area. Because if they are later covered by sediments, then the feature the surface features that we are talking about will not be conspicuous then there should be some other kind of techniques. And the local tectonic controls. So, these all these points together will help in our selection of the target. So, the overall geological setting the presence of such host rock and the later sedimentary cover, and the geochronology, because it is believed that they are present in rocks of older so which are known as the archons in the terminology of diamond exploration.

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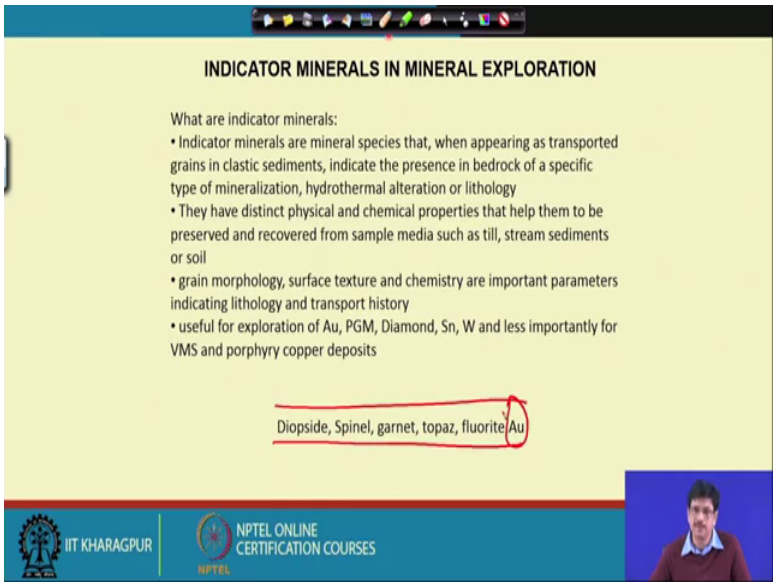

So, we will come to a discuss which will be a very interesting situation corresponding to diamond exploration. We know that the diamond itself in the form of either a gem or a non-gem type diamond crystals, either very well preserved or to have undergone some amount of resorption during the process of their upward migration through the crust. There in any case is going to be very scarce and it is very difficult that one will be encountering a diamond crystal normally in a kimberlitic material kimberlite.

But this kimberlites minerals which are other abundant minerals like the chrome, spinel, the pyroxenes, the chromate even our garnet more importantly garnets, topaz. So, these minerals which are also which are abundant in the kimberlite are the ones which will be available which will be abundant and more importantly these are the minerals which will survive the normal process of erosion if the kimberlite pipe is in an area, where it is expose is actively being subjected to the weathering and for the erosion process and which is more likely when the area which is very well dissected by streams by rivers.

So, here we use a method which is largely known by a name is indicator mineral exploration which by using a very simple geological principle. So, by using so instead of diamond some other mineral which will be representing for diamond and which will be we call them as indicator mineral or indicating the presence of diamond in that particular host rock. So, the indicator minerals by their the property has to be such that they have to

retain their characteristics without getting chemically altered or destroyed in the secondary weathering cycle.

So, the indicator minerals are so this kind of indicator mineral are applicable to not only to diamond, but other deposits as well like in gold, in platinum group of metal deposits, but for in case of diamond, it is very widely used. So, these minerals diopside, the spinel, chrome bearing spinel, the garnet, topaz, fluorite, so this could be the indicator mineral of course, gold itself could be indicator minerals when it is a gold deposit. So, the indicator minerals are mineral species that when appearing as transported grains in clastic sediments, indicate the presence of the bedrock of a specific type of mineralization.

They have distinct physical and chemical properties that help them to be preserved that as I just mentioned. The grain morphology, surface texture and chemistry are the important parameters indicating the lithology and transport history. Because the grain morphology would be very much an indication from the kind of rock from which they derived. So, these indicators mine what we what we are calling them as indicator minerals, they are likely to be dispersed in the area where the kimberlite pipes which are exposed the undergoing active erosion and mostly in the obvious places will be the streams in the form of the stream sediments.

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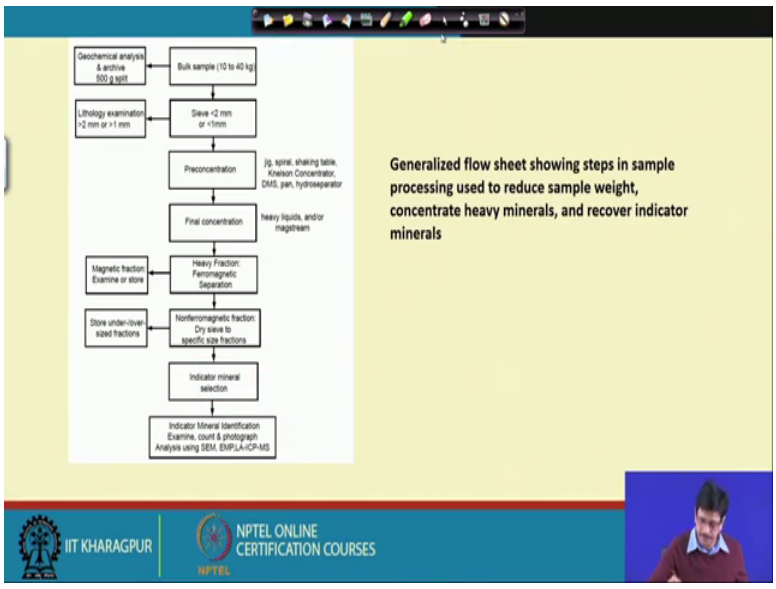

So, this is a generalized flow sheet showing the steps in the sample processing used to reduce sample weight, concentrate heavy minerals and recover the indicator minerals. So, the stream sediments in any area that is being first of all by our reconnaissance survey and the way we have defined that how we are going to choose a target, area for exploration of diamond. And if we happen to recovering the stream sediments in bulk quantities, then these indicator minerals somehow have to be recovered or have to be concentrated and by virtue of their physical properties and then to be examined what exactly they are indicating.

So, the bulk samples about 10 to 40 kg recovered generally this is for the geochemical analysis and archive. So, they are the size ranges generally within less than 2 millimeter or 1 millimeter. And then they are pre concentrated and the final concentration by using heavy liquid and other kind of media. Heavy fraction, ferromagnetic separation and in the non-ferromagnetic fraction, and by that time we are basically we are able to if there happened to be the heavy minerals like the chrome spinels or the chromite or sometimes other heavy minerals, so by this process of their enrichment, we are finally, able to recover this indicator mineral. And this indicator mineral are subjected to the study where we need to identify them, examine them, and then more importantly we are going to analyze them chemically.

So, these indicator minerals one of them, which will be considering here. So, through this elaborate process after the separation, we are going to study them to extract the information that exactly what we are looking for. To pinpoint whether a particular kimberlite pipe which from which these indicator minerals are derived. Of course, our main objective is to find out how to look at that kimberlite, but before that, we can do this exercise to have some idea that whether the indicator mineral that is coming from that source is coming from a kimberlite which is likely to be diamond bearing or not.

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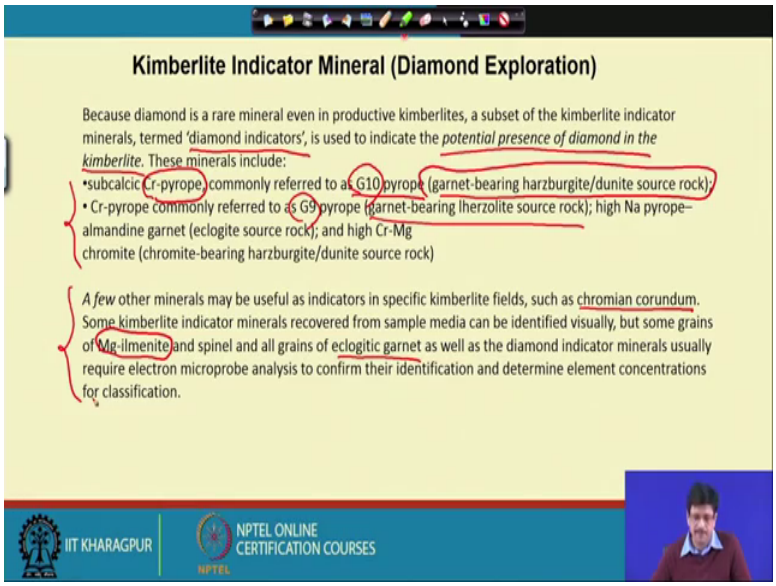

So, this is a say thing that we are using is a subset of indicator mineral which are the termed as the diamond indicators or the potential presence of diamond in the kimberlite. These minerals, these are the minerals for these are the diamond indicators, because diamond is rare. So, the sub calcic chrome chromium bearing pyrope of this carnot, this is one very important one, this is commonly referred to as the G 10 pyrope garnet. So, the garnet so this actually has come from a garnet-bearing harzburgite to dunite type of source rock from the lower metal and this is popularly known as this chrome bearing pyrope is the G 10 pyrope. And this chrome bearing pyrope commonly refer to the G 9 pyrope is coming from a garnet-bearing lherzolite source rock; and high sodium pyrope almandine garnet and high chromium magnesium chromite.

So, there are two different types of garnets which are discriminated based on the composition to G 9 and G 10 which we will see what their characteristic is. Sometimes you can also get chromian corundum as specific kimberlite fields, sometimes magnesium bearing ilmenite. We also get spinel and grains of eclogitic garnet as well as these are also the diamond indicator minerals. And essentially now this is leading to something which is a very routinely adopted analytical method for mineral analysis for phase petrological work. This method has come out to a very important method, because we of course, have to analyze this grain, so these mineral grains by using some micron analytic techniques.

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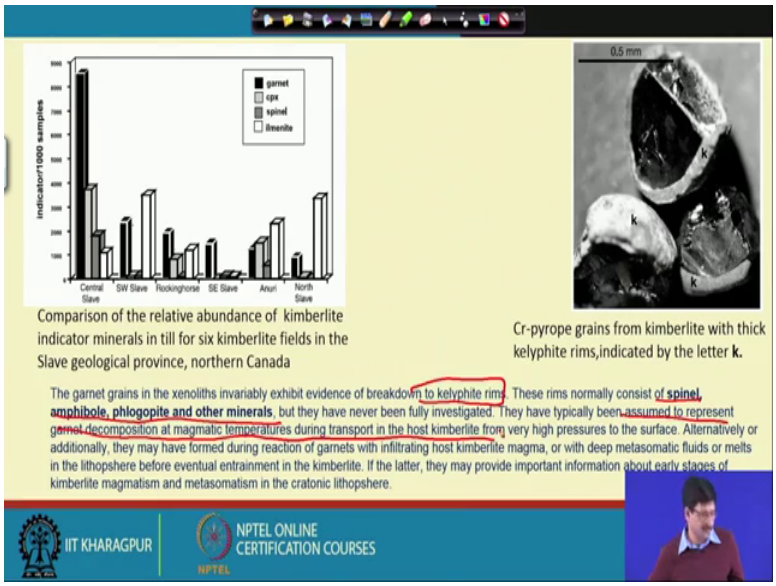

So, here are some of the features which are important. So, here it actually gives a comparison of the relative abundance of kimberlite indicator minerals from the six deep kimberlite fields in one of these diamond field from Canada. So, the dark one is for garnet, this a garnet, and this is for clinopyroxene, this is spinal and this is ilmenite. These are from the different provinces. And we see that in some of the provinces this garnet dominates. And this is one of the interesting features here in the chrome bearing pyrope grains that comes from the kimberlite with they sometimes they are observed to have a very thick kelyphite rim on this garnet.

Now, this kelyphite rim is not quite very well understood, but the possibilities that this garnet grains in these generalists invariably they exhibit the evidence of breakdown. These are essential evidence of breaking down to kelyphite rims. These rims consists of spinel, amphibole phlogopite and other minerals. And they are assumed to represent the garnet decomposition at a magnetic temperature during transport of the host kimberlite from a very high pressure to the surface, so that means, whenever we see this kind of chrome bearing pyrope grains and we see this kelyphite rims that give us the indication that they were actually coming from great depths. And they represent decomposition of the garnet in a magnetic pressure temperature condition. And these are also taken as very characteristic feature and that is observed in the during the root examination after they recovered as indicator minerals.

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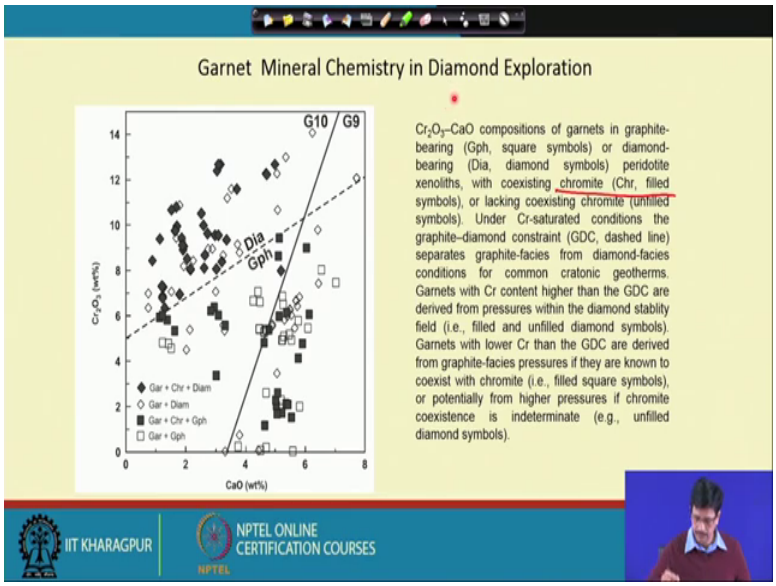

So, this is the conclusive, this is the diagram which is actually is the most important and gives us the conclusive idea. So, this is a plot. These shows that there are lots of such garnet grains which are recovered from the stream sediments through the process that is described and the garnet grains are analyzed. So, this analysis is now plotted on a Cr 2 O 3 versus chromic or chromic oxide versus calcium oxide weight percent plot. We get the electron probe micro analyzer the details of which I am not going. This is a very standard micro analytical technique analysis of minerals giving the major oxides in weight percent and also sometimes elements occurring in trace amount in several tens of ppms. So, this when the so here on this concern on this diagram the diamond versus graphite boundary also plotted.

And the diamond field is here and the G 10, G 9 boundary on the compositional characteristic or their relative presence of chromium oxide versus calcium oxide that means the ones which are more calci is the G 9 more garnets. And the ones which are following here as the G 10 garnet. And when this G 10 garnet falling in the diamond stability field are the kimberlites which are likely to be diamond bearing. So, here this solid square represent garnet plus chromite plus graphite, and the solid diamond represent the garnet plus chromite plus diamond. So, this gives us a very conclusive idea. So, these are the entire areas in which it will be graphite will be stable here along with garnet and chroma chromite, and this field will be the field for diamond stability.

So, Cr 2 O 3 CaO composition and garnets and graphite bearing or diamond bearing peridotites generalist with coexisting with chromite, or lacking coexistence of chromite here it is its own. So, this dashed line is the graphite diamond constraint this dash line as I already described diamond is stable, but this or this represents the compositional field in which the granite is coming from is diamond stability field. So, this is a very interesting case in which a geological method is being utilized for exploration of precious gem like diamond. We will again be coming back to look at the case history of discovery of diametric for a kimberlite using other methods, for example, any kind of any geophysical method or geochemical or other geological methods.

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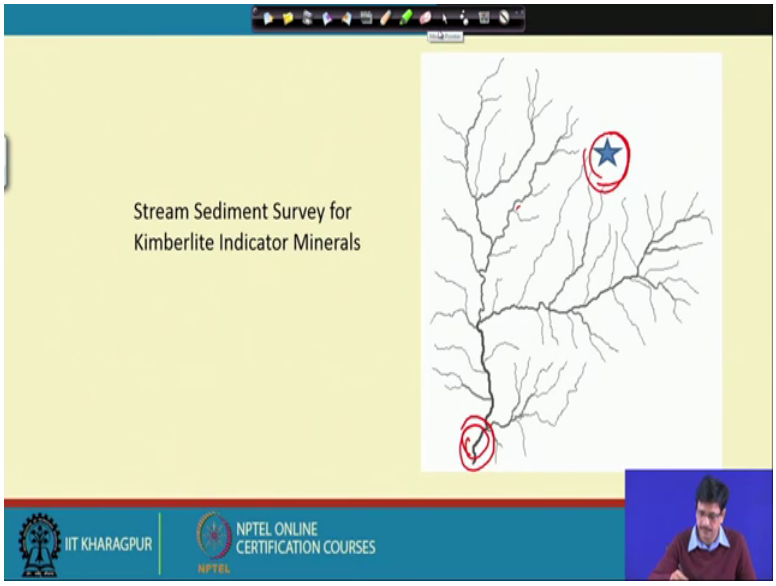

This is just a schematic; this is a sketch just to show us what exactly happens in a stream sediment survey. So, if we think that this is the hidden kimberlite body here, the simple hidden kimberlite body. So, this is an area which is basically dissected by a pattern of drainage in this. And as we all know that these are this smallest one are the first order streams. The first order streams join to give to give rise to the second order streams, and then the second order stream joined to give the higher order stream. So, any stream sediment survey will be depending on will be taking the stream sediments.

So, for example, the highest order stream over here if the diamond difference kimberlite is being actively eroded from this particular point then the streams which are coming and joining and forming the highest order stream here. The sediment will be containing the

kimberlite indicator mineral, but then the position of the kimberlite has to be traced out by a very systematic thorough survey of the stream sediments and to finally, to able to locate at a particular look at the position where it is located.

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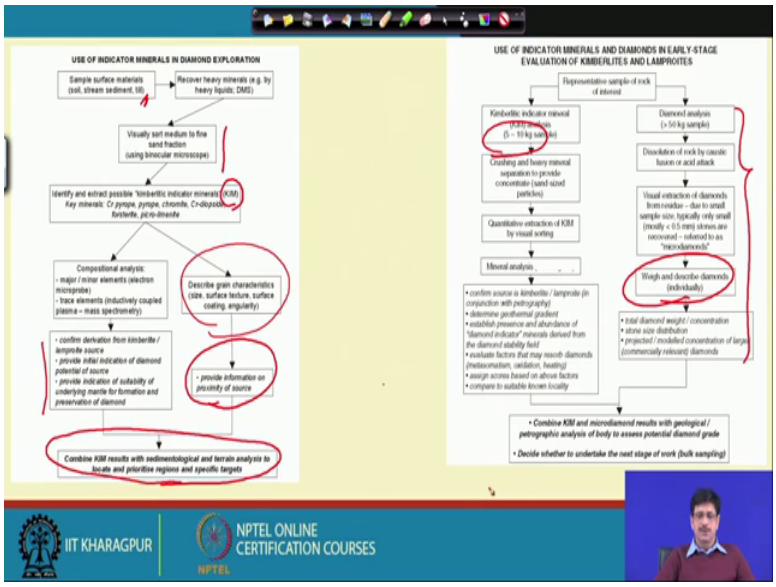

So, this gives us the summary of the thing that the use of the indicator mineral in diamond exploration. So, here the sample surface materials, soil, stream, sediment or sometimes it could be the teal also which are which come from the glacial areas glaciated areas. So, normally they could come suppose if we talk about exploration in a situation where the kimberlite pipes have to be detected in areas like a like Bastar craton or in Dharwar craton when we show them. So, this kind of steam sediment survey could be carried out the sample surface materials a soil stream sediments recovery of the heavy minerals by the method that we described before. Visually sort medium to fine a sand fraction, and then identify and extract the possible kimberlite indicator minerals. These key kimberlite indicator minerals such as the chromium pyrope, chromite, or chrome diopside, forturite sometimes and even pico ilmenite.

Do their composition and analysis, the major mineral element electron microprobe trace elements, and describe the grain characteristics, the size, surface texture, surface coating. It is just not only the composition that we is always will be the deciding factor even sometimes the grain characteristics also have to be well documented for that. And then this gives a confirmed derivation from the kimberlite or lamproetic source. They provide

the initial indication for diamond potential of this of the area; and also provide indication of suitability of underlying mantle for formation and preservation of diamond. And here this while the composition gives us the idea about that this garnet is coming from a kimberlite which is most likely to have been diamond bearing have come from a mantle source where the diamond was stable. But that will essentially not give us an idea about how far the source could be from where it was recovered. So, these characteristics like the grain characteristic, size, surface texture, and texture etcetera will give us the information on the proximity to the source.

So, this combined kimberlite indicator mineral results with sediment logical and terrain analysis to look at and prioritize the regions of specific target. So, in this we also put our hierarchy into order. So, if these are going on for the target detection, then finally, when we are zeroing in and able to find out that where exactly the source kimberlite is. And then it will be easier for us to locate it like the previous diagram which I showed with respect to a hypothetical area which is detected by a network of rivers or streams from which we can draw the stream sediments.

So, it is basically the indicator minerals and diamonds in the early stage of evolution. This representative sample of the rock kimberlitic indicator minerals, their separation, mineral analysis they, confirm the source and here the dam it is actually this part even if we get the diamond, so we can do the diamond analysis. For which so depending on if we are only looking for the diamond kimberlitic indicator minerals then the amount of sample that will be choosing will be less will be of the order of 5 to 10 kg.

But if we want to really even recover in terms of the diamond crystal then we have to get even more than 50 or 50 kg or above 100 kgs of the rock cross them and then carefully separate out and get the diamond. Then visual extraction of diamonds from residue and the way and describe the diamond individually this part is only when we are interested in a. So, by after the after we get the indication of a diamond bearing kimberlite, then the next step is that we have to assess that what quality of diamond this particular kimberlite and or this basically the commercial evaluation part.

The total diamond with refraction concentration then this stone size distribution and this model concentration and now this combined is altogether. And then decide whether to undertake the next stage of war that is the bulk sampling and whether to go for even

further assessment of the quality quantity parameters and do the I mean whether that particular kimberlite pipe has to be worked as a mine for diamond or not. So, that is a brief discussion or brief story about how diamond exploration can be carried out by using the simple exercise, but very important which finally tells us about the very important result in terms of exploring for a diamond difference kimberlite. So, we will continue discussing with other cased histories.

Thank you very much.