Mineral Resources: Geology, Exploration, Economics and Environment

Prof. M. K. Panigrahi
Department of Geology and Geophysics
Indian Institute of Technology, Kharagpur

Lecture – 12
Sedimentary Processes and Resultant Deposits (Contd.)

Welcome to today's lecture. So far, we discussed about the sedimentary process as a ore farming process, are taking the chemogeneic sedimentary process into consideration. We had a brief overview of the bended iron formation and the associated manganese deposits older in the old cratonic blocks and old cratonic deposits, almost in the late archean to almost late protruding time; and we also got ourselves reminded that as far as the iron deposits are concerned, there are no modern analogue available or these deposits never formed after 800 million years or so, there is never been any such concentration of iron deposits comparable to what we see them in the precambrian.

So, the origin of these deposits remain pretty conjectural in many of the cases. So now, we move on to the process which will again be a exogenic process given by the energy being provided by the sun. But they are pretty efficient processes; ours own beneficiation mechanism and let us first discuss the deposits which result from the process, which we broadly call as mechanical concentration.

Mechanical concentration essentially means their surface operating process by agents such as water, air. The water could either be river, a fluvial cycle or could be the sea waves, where it say or it could be air. So, I will be restricting myself for this discussion to the fluvial cycle and a river being the main agent of this process, and resulting in the deposits which of mechanical concentration deposits and which are broadly known as the placer deposits.

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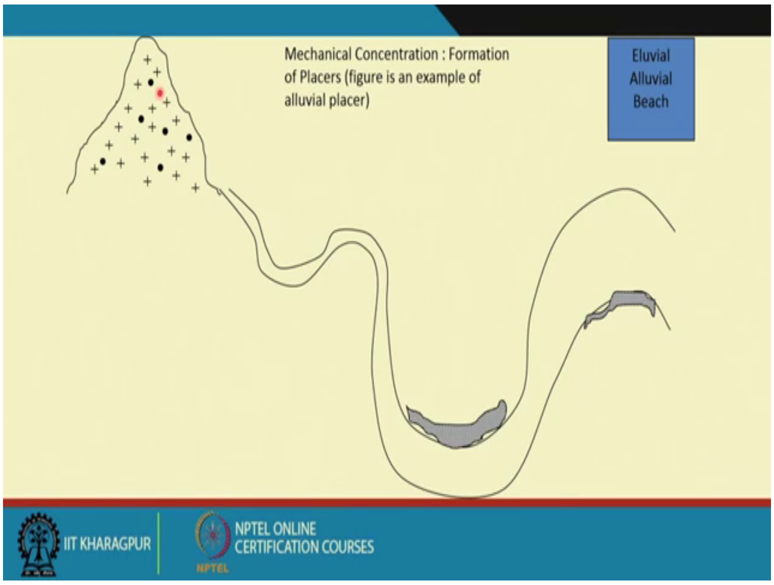

We can see the diagram, there is a carton where I have drawn just for your understanding. Let us take an example, here is a disposed rock, present in a hill somewhere in the continent, in the continental parts and let us say the weight is shown, it is a granite and this granite is shown by these black circles. It will be exhorted and theirs size, they are representing some mineral. Let us say it could be a cassiterite like a steam oxide or could be a uraninite, UO2 or could be free metal like gold, which is there in this rock mass and the rest of the constituent of the rock are the normal silicate like quartz, feldspar, mica, etc.

And this particular mass of hill is being subjected to active weathering, maybe it could be the weathering which causes just mechanical weathering which could be just depositing some sediments on the foot hill, where we call them the alluvial sediments, which just very close proximity to the hill, on the foot hill region and this area is also being dissected by this is indicating a river.

And in this region it is indicating the infinite stage or the juvenile stage of the river, where they are rejective transportation hardly and a deposition is taking place and this represents the mature stage of the river; where it is meandering and this is a very common knowledge in any textbook depicting physical process, physical geology, where the river cycle is shown and these are, we all know that the velocity of the water in this kind of meanders is maximum on the outer one then the inner one.

So, they do deposit situations like this, which will be pointed by deposits. And here what will happen is that these minerals like cassiterite, which is SNO2 or any other like a uraninite or could be gold which will have at least 3 or 4 times or the more than that specific gravity of the normal silicate minerals, over here and these areas where these sediments are deposited, will be enriched with respect to the materials which are higher in specific gravity and that is how we get there. And all these places which are there are places called alluvial deposit places.

So, what we get here is essentially, it is not that we get the particular mineral of interest as a pure form all lying like to be taken out, but this kind of situations or when we see them it is a very very simple situation, which is being depicted here it is actually not just that mineral of interest, it is also mixed up with the other detrital particles of the common rock, like a quartz, or any other mineral and that is how, but only that this mineral of interest which is of a higher specific gravity, has a higher concentration in this region in the placer deposit.

So, we need to possibly be worthwhile to understand what exactly happens; that means, you would essentially be looking into the mechanism of this. The hydrodynamic condition in which the detrital particle will be transported by a river channel and what the conditions would be, that will lead, that will result in a deposition of these particles and then we will see some examples, some classic examples of such kind of a places which is resulting from this fluvial process.

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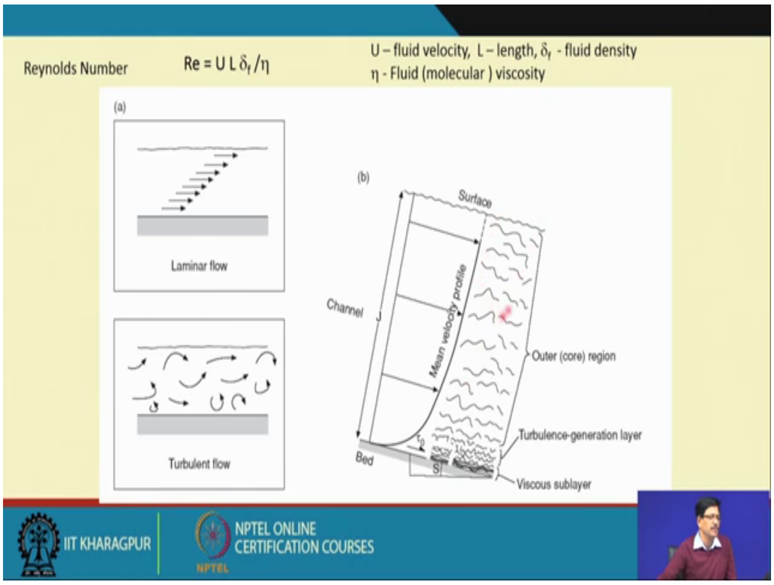

So, here there are some very fundamental illustrations which are here. This is how the flow can be described. The flow velocity increases as we move up in the y, in the z direction and the to flow could either be a laminar flow or turbulent flow depending on a a parameter which is a Reynold number, which is given by, not getting to the much of the renovation of this because it is out of the scope of this discussion, but they depend on very fundamental parameter like fluid velocity, the length, the fluid density and the viscosity of the fluid and this is a situation.

So, the situation could be anything between a turbulent and lamina, where, if we look at this section of the river channel, we see that this is the bend of the river and this is the immediate layer which is adjoining the bend is the viscous sublayer, where there is a drag, that is the experienced by the water and there is a threshold shear stress, and this is the region in which the flow will be different.

Then here the flow is basically the turbulent generation layer and as we move up, the turbulence decreases and approaches towards something like a infrared exactly laminar, but much less of the turbulence. And this is the outer core region. So, most of the transportation of the river system will be taking place, where as we go up in the river section, it will be if particle sizes will be finer and finer, they will be in suspension.

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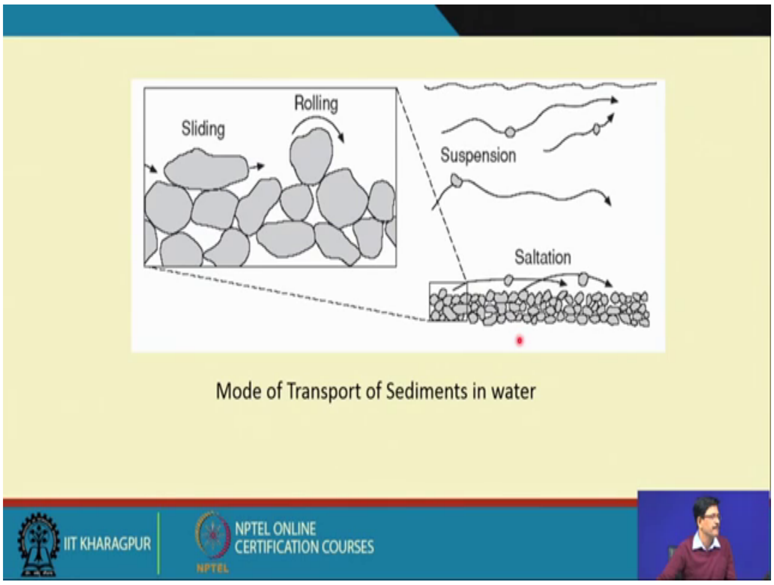

Just see them here, the process can be visualized in this way, there the closest to the river bed. These are the coastal particle, which are transported by a series of jumps on the saltation and a process where they could be sliding, they could be rolling and because, we are primarily interested in looking at that, we have different minerals of different sizes, shapes, specific gravity and how, and what conditions we can get the get them consented, deposited in a way that will lead to or we can see that what basically happens when this kind of process take place and how the deposition takes place.

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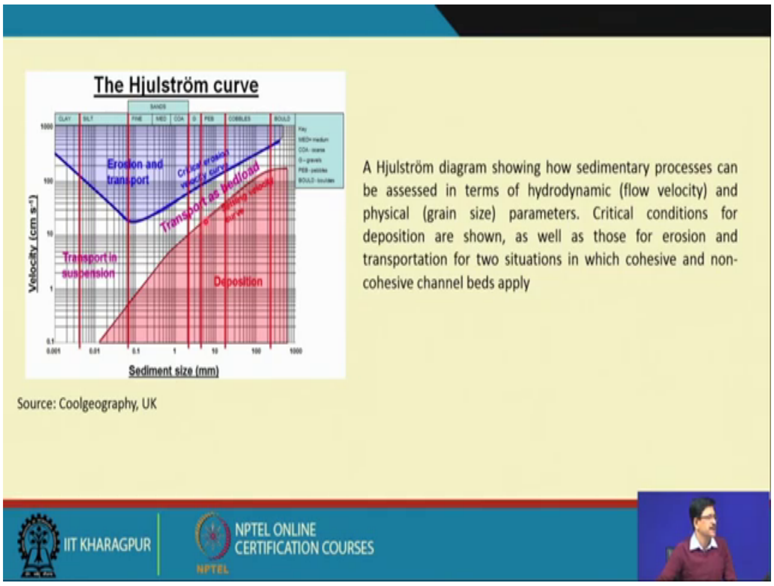

So, this is a very fundamental diagram. This Hjulstrom curve, basically shows how sedimentary processes can be assisted in terms of hydrodynamic flow. So, this on the X-axis, you have the sediment size going from clay to bolder size as, you know the size ranges of them about less than 0.001 of a millimeter to the clay size and going to 1,000 millimeter to the bolder size and we get the intermediate sizes. So, we are seeing 3 regions dominantly, this region which is marked by pink, is the dominant domain of deposition and this deposition actually is depending on the increasing particle size. So, even higher the particle size, here they can even deposit, being the deposited velocity is high.

And it is pretty well understandable that there is erosion and transport. This is a critical value, for the critical curve, for is critical conditions, for the deposition here and this is the dominantly a transportation in suspension. So, this region actually shows the transport is the bed load, they said it. So, this corresponds to the vertical section. Here, is the region in which the particle size is less. So, there will be the mostly going is suspension, here the particle size are larger, they will be going is bed load, and this is the critical erosion velocity curve. So, this gives us some fundamental idea about the control that is exerted by the flow conditions.

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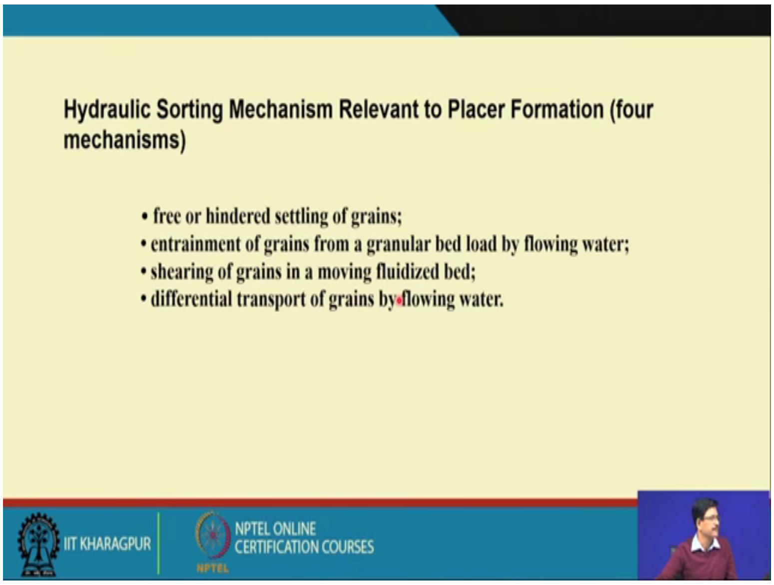

So, what essentially we will be looking at is the sorting mechanism, that how because sometimes we will see that in a placer deposit of a, say gold, we see quartz, gold and maybe sometimes, some other mineral being deposited or into deposited together constituting the placer deposit, and we know that they vary in their specific gravity, their sizes. Then we will see whether how, under what conditions.

So, essentially there are 4 such mechanisms for the deposition or the hydro hydraulic sorting mechanism. They are relevant to placer formation. You could either have a free or hindered settling of the grains, we could have entertainment of grains, when the grain will be moved from its rest position, it will start moving from the granular bed load, by flowing water, shearing of grains in a moving fluidized bed, or differential transform. This could be the 4 possible mechanisms.

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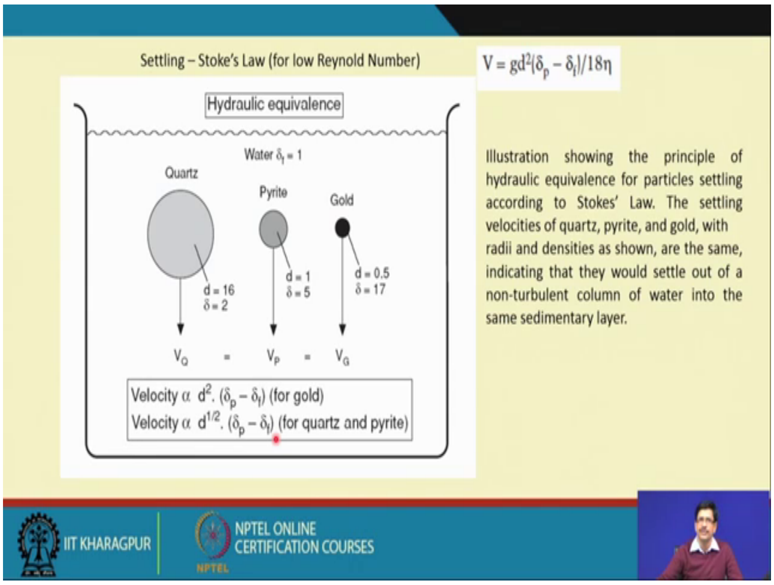

And let us see the first one. Here, is the case of settling for which, we can take help of very simple relations that is, there which is stokesian relationship, which involves the switch, the searched into the gravity, the particle diameter, the difference in the density between the particle and the fluid.

So, that is written by del p and the del f and rho is the viscosity. So, this illustration; here what it is actually showing is something which is called a hydraulic equivalence; where quartz of a larger diameter, pyrite of an intermediate diameter and gold of the smallest diameter, where the diameter is 0.5. Here, its 1, its 16 and their density here is, quartz is 2, the pyrite is 5 and the gold is 17 and then we find that this velocity of quartz is VQ and the velocity of pyrite is VP and VG.

It might if allowed a condition of laminar flow or allowed the condition of unhindered settling then these three possibly would settle with the same settling velocity and would possibly explain that why these 3 would be together in a placer deposit. And here, we see that the settling velocity is being the expressed as the square relationship with the diameter, but then this you know is far from what exactly happens in nature,there are three reasons.

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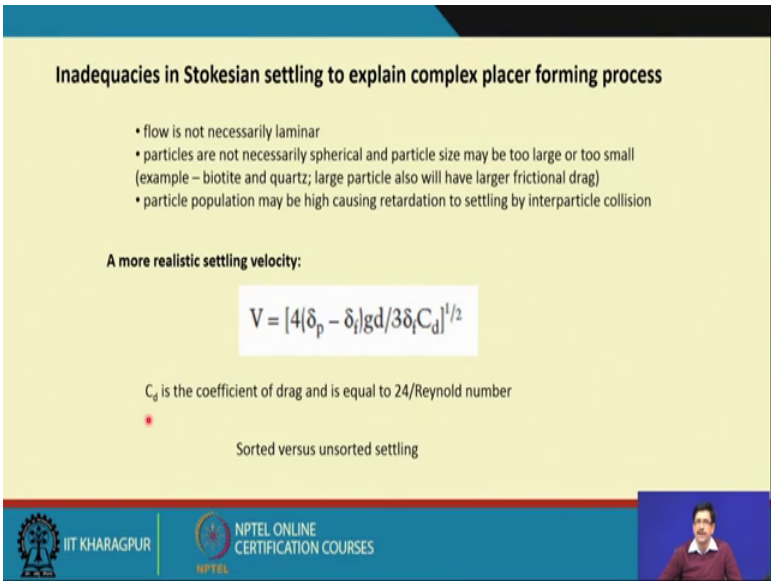

Firstly, that the flow is not laminar and the particles are not necessarily sphere, the particle's size may be too large or too small. So, for example, a biotite and a quartz; large particles also have larger frictional drag, which is not being taken into consideration in the stokesian settling velocity and it could be turbulent condition. So, looking at this, more realistic relationship which was given, which again we would not be deriving here, but we could just see here that instead of having a square relationship with d actually it is, having a square root relationship.

Where CD is the coefficient of drag and is equal to 24 times the Reynolds number. So, that possibly would more correspond to a situation where, this kind of basic assumptions of highlighted the particle and here other the situation is that, when the particle density is more, then there will be interference of into the inter particular interferences and simple laws would not hold a simple square laws will not hold and the more realistic velocity would be given by a square root relationship rather than a square relationship.

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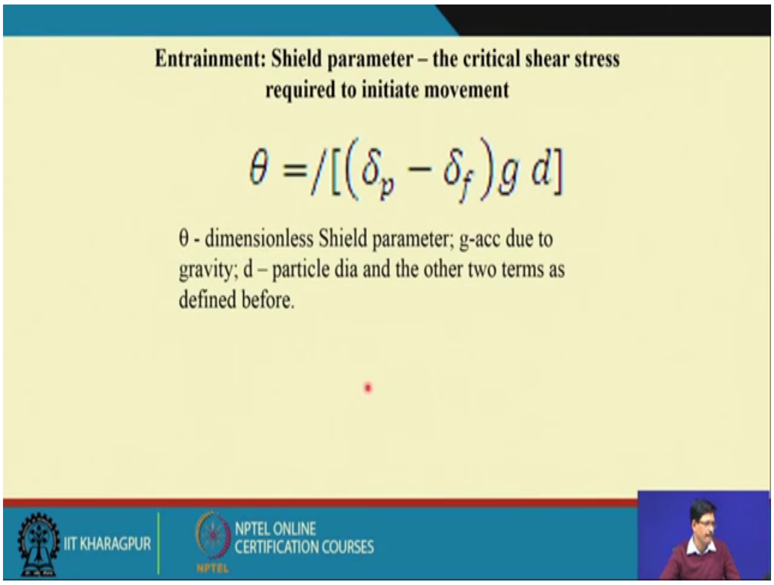

So here, that is all about the settling. So now, the other mechanism is the entrainment; that means, that here a parameter, which is called the shield parameter is defined as, the critical shear stress required to initiate the movement.” So, that is the shield parameter represented as theta, the g is the acceleration due to gravity and d is the particle diameter, and the 2 terms the del p and the del f where, is defined before there is density of the particle and the density of the medium there is water.

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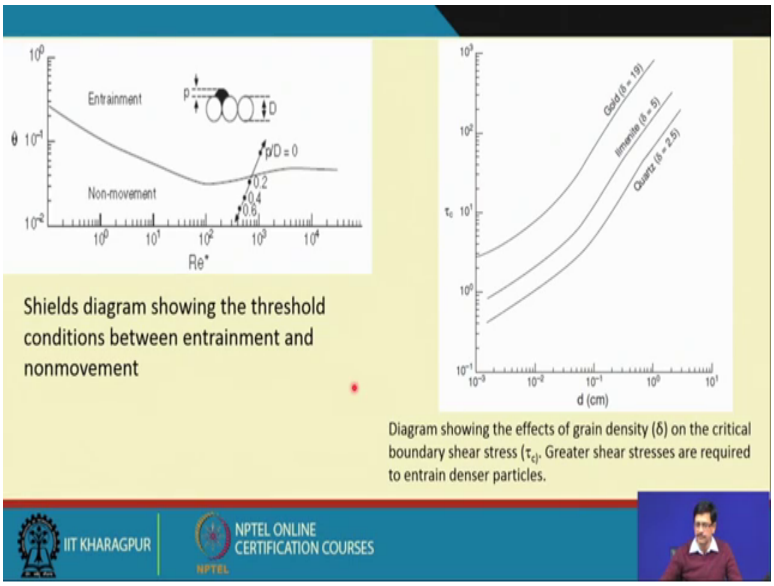

So, if we look at this the diagram on the left explains us what exactly happens. So, if we take the shield parameter then, it is on a logarithmic scale. Here, 0 10 to the minus 2 to minus 1 and 0 and can be defined at region over here, here the particle will be entrained and each shear that the shield parameter which is coming out of the expression that we showed just before, as falling is lower in its value then there will be no movement. It is essentially, we have to see that at what condition a particle has to move from its position of waste, will be taken by the transporting medium, and this shows the threshold conditions, it will be entrainment and the non movement.

So, this is essentially the parameter that is p and d. So, here this p by d is 0 and the p by d value point 2.0. The more the p, the greater the chances of its entrainment. So, that is how it will go to and more values of threshold of the shield parameter and then this diagram shows, this is the critical shear, the shear stress that is required for the entrainment and it pretty much depends on the density of the particle. So, when gold is around 19 and ilmenite is 5, quartz is 2.5 and we see that the critical shear stresses more and this is the diameter; more is the diameter, more is the shear stress and more is the density, more is the shear stress is required who get the particle entrained in any flow condition.

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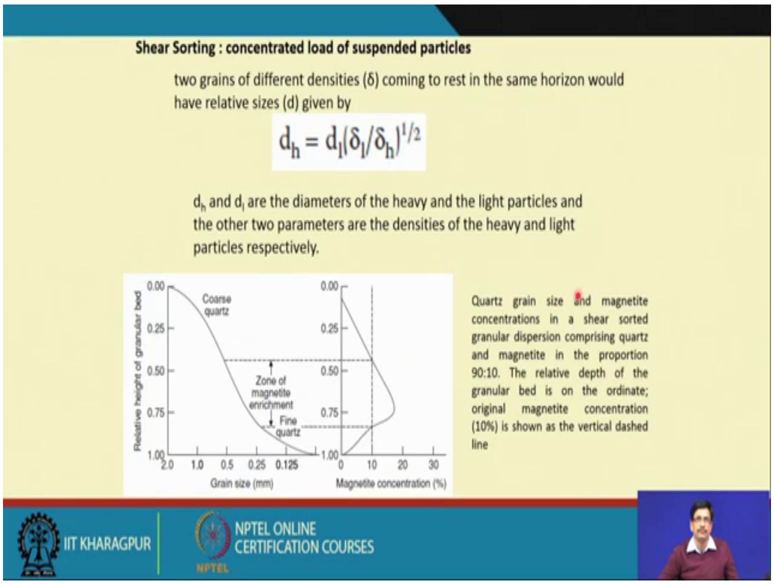

And then the shear sorting is just to impress upon the fact that sometimes, we do see say, we start with compress a for example, in this, the diagram that is shown here. So, the starting is essentially is a function of the 2 different densities. That is where we defined before the lighter particle and the heavier particle. So, the shear sorting is always will be in terms of the relative values of the densities of the particles.

So, here is the lighter l is for lighter and h is for heavy, in the two grains of different densities coming to rest in the same horizon would have the relative sizes d. So, d of the heavy particle and the d of the lighter particle will be related in this expression where the dh and dl are the diameters of the heavy and the light particles and the other two parameters the del parameters which you have defined before.

So, what is interesting to see here is that suppose, we start with a material where the there it is constituted of quartz and magnetite. Quartz and magnetite are of different contrasting density and suppose we have started with a material where, quartz and magnetite are in a proportion of 90 is to 10. So, if we bring out such conditions, here the relative height of the granular of this bed in any bed where the they have been transported if you see the height here, so, there will be a zone in which at a particular height within this column, there will be a zone in which, there will be an increase in the magnetite proportion.

So, it is shown here the magnetite concentration in percentage, this line represents the original percentage of 10 percentage of magnetite, we can have in the sediment even as high as exactly double of 42 was originally by this process of this shear sorting.

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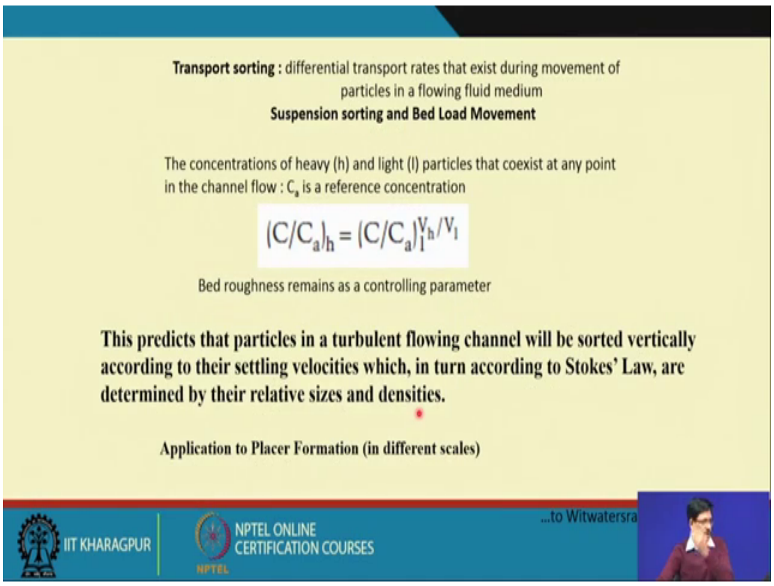

And then, the transport sorting that is the last mechanism for the hydraulic sorting mechanisms. So, differential transport rates that existed in movement of particles in a flowing fluid medium, the suspension sorting and bed load movement this concentration. This is again here, the heavy and the liquid particles are taken into consideration and they are coexisting at any point in the channel flow. Here, the Ca is the reference concentration and it can be shown by this kind of a relationship where, h is for the heavy and the l is for the light particle and the v is for the velocity of the heavy particle and velocity of the light particle.

So, this predicts that particles in a turbulent flowing channel, will be sorted vertically along their settling velocities, according to the settling velocities which in turn, according to the stokes law are determined by the relative sizes and densities. So, here it says, when stokes law only talks about the relative sizes, it is also according to this transport sorting, the velocities at which these particles are moving, is also a parameter which decides whether there will be deposition and there will be sorting.

So now, you can see how this helps or how this kind of thing we can correlate to the process of placer formation. It requires a little bit of a more of final details on exactly the process of sedimentation, that is taking place when exactly a cross bedding is forming with the 4 set laminar and the where in a flowing water system. So, that requires a little bit more of perspectives and more of understanding on the details of a sedimentation process which, I am not going to discuss in detail here.

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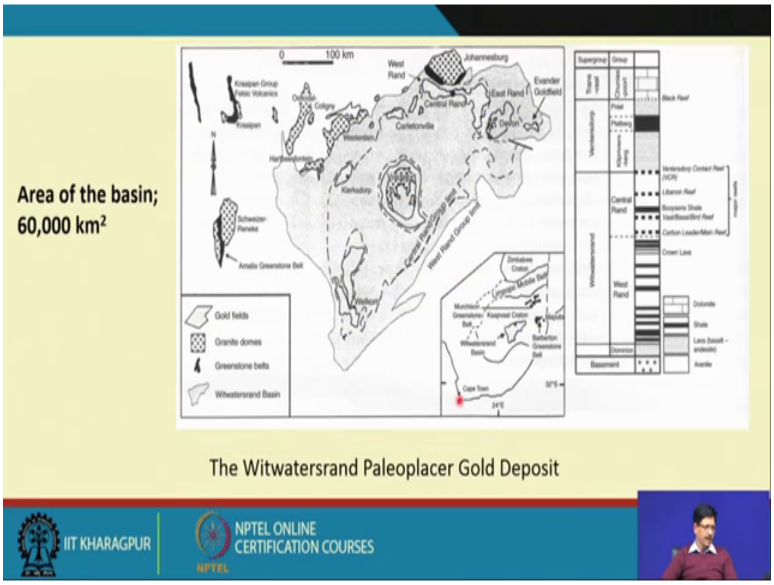

And, but the fact is that these processes are manifested. A manifest, in starting from very small scale to very large scale, means if we are examining a particular sedimentary horizon with the sedimentary features, that we see, the cross beddings this where, we know that the there will these things have come up because of the velocity differences in minus scales and the transporting characteristics.

So, you should be able to see situations in which the particle enrichment and the sorting of these particles and fraction of the behavior particles that will be there, in any particular domain can be correlated and we see that it comes. So, whenever you look at paleoplacer deposit, we should be able to deceptive through to look that how, such small domains or the local scale are very micro scale and which meant have given rise to such huge accumulations in the form of a big placer deposit, and what we have in front of us here is, the famous Witwatersrand Basin, paleoplacer gold deposit in South Africa, is one of the major paleo deposits. It is one of the major deposits, it is an old deposit, it is in archaean. It has given a huge and good amount of gold production over the past time.

And this diagram, which is taken from the book of John Ridley, is the plan of the Witwatersrand Basin. So, this basin, this part, which is the Witwatersrand Basin, with the central Witwatersrand group is about 60,000 kilometers squares. Possibly, It is difficult to find any present day analog of such kind of huge fluvial system in operation and what we see here, is that, this is the, what is shown here, those small places here marked like this, these are the individual deposits of gold fields. There are about 6 or 7 such gold fields in this entire basin.

And this basin is surrounded by, there are some granite domes and the black part is a greenstone belts, which will be discussing, are which what they are actually as producers are gold when we come to the topics on hydrothermal deposits, but for the time being it will be worthwhile to note and this basin which has been one of the major resources from gold and uranium both, is in proximity to some such occurrences of gold deposits in the close vicinity and this basin has very rich pockets or these deposits of gold total about some 6 or 7 in this entire basin.

And what we could possibly look at here, is the column which shows the Witwatersrand group of rocks, the wasterand and the simplerand. They do contain the gold accumulations in the form of what is basically written as these reefs, then will they are termed as reefs. They essentially conglomerate horizons where, there has been enrichment of gold, uranium which some amount of pyrite and into intervening shales, which are given here in black color, these are the horizons which are shown are this.

So, there are many reefs. Here, is one. This one, is the dashed black line 1 2 3 4 and these reefs this (Refer Time: 25:39) containing gold occurs about three kilometers above the base of the basin and this is the basement which is shown here, and we only concentrated on the group of this Witwatersrand block because the later one, even you see, the famous already found ground which is essentially a metered they say, impact character and

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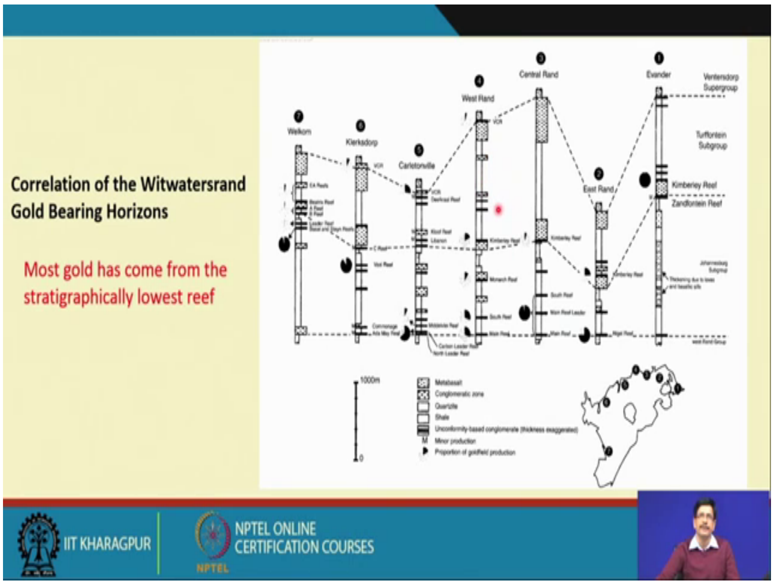

What is very interesting here in the Witwatersrand is, that those 6 or 7 this places where we saw the gold deposits accumulation, they are little bit correlatable, the reefs are very much correlatable in a basin scale as in as its been shown here. These are the reefs, the gold bearing reefs, which can be very well correlated and what is shown in terms of the pie circles here with part blackened is essentially showing the proportion of gold till production.

So, you could see that almost all just about just, but one although almost all have reactions in the gold producing horizons here, and so, the gold, most of the gold has come from the stratigraphically lowest reefs, which are here and this is the main reef. This is the south reef, these are the stratigraphically lowest reefs and the upper reefs are not that very well continent which can be shown here.

Like here, very little of gold is coming and, but the lower ones give the maximum amount of gold, and as I mentioned that they are an just pure gold, that they contain gold and uranium with pyrite and quartz and the (Refer Time:27:21) horizons are essentially are from the bodies of quartz, which might have been exposed in the anywhere in the nearby areas that we saw.

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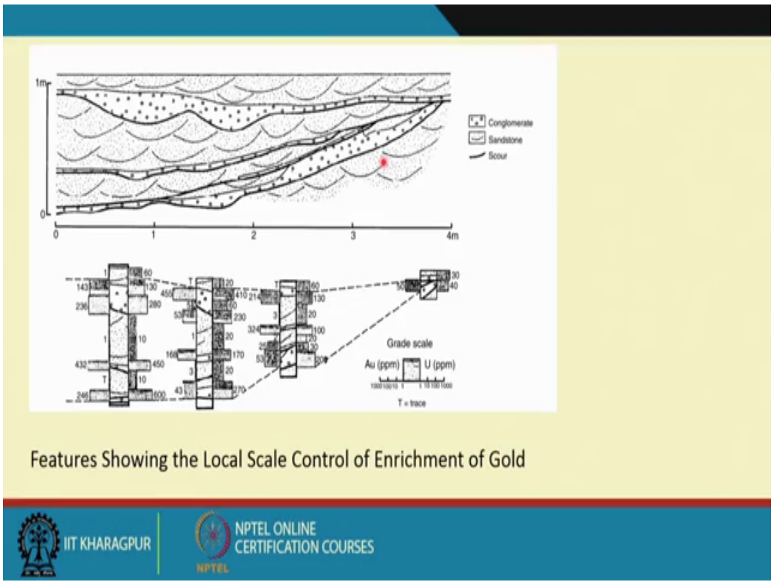

So, while discussing about the manifestoes of the mechanisms, starting mechanism that we just saw from the very small scale to large scales, this diagram shows that these are the source where we get the dominantly the sand deposits and these are the intervening conglomerate which are essentially the gold bearing reefs and we see, that there are series of search and there these are conglomerate reefs gold bearing reefs.

They are occupying exactly a position just above a nonconformity and so; that means, which indicates that there has been many series of such of reworking of the several stages of such erosion and deposition in this basin, that has gone in and that might have possibly work in getting the gold further and further enriched to give rise to this rich gold occurrences, where the gold will go to even the reefs, are generally what we see here is about 5 to 2 meter 5 centimeter taken 2 meter in their thickness.

And the grade goes decreases down reef and belts are generally conglomerate or sandstone and what is observed here is the thinner the bands are, the richer they are involved and this gives a gives idea about the relative uranium and gold concentrations in these reefs. The grey part shown by uranium and the lighter part shown by gold.

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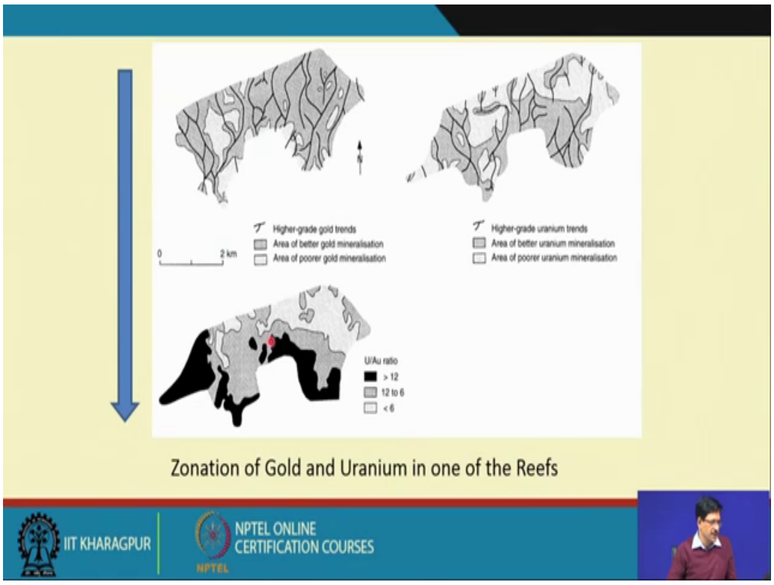

So, where you could see that the uranium and gold proportions vary which can be shown here and how the processes the manifest in local in, here you could see then these are representing the anastomosing graded pattern of the basin and the slop is actually from north to south and is very well correlated, if you look at here, this, the uranium and uranium by gold ratio.

So, in this diagram we can see that these represent the area where there a better gold mineralization and the areas here, we see, the better uranium mineralization if you could them together into look as if from north to south the northern part is more rich in gold, and the southern part is more rich in uranium and actually shows that I mean there has been some efficient sorting mechanism that is taken place.

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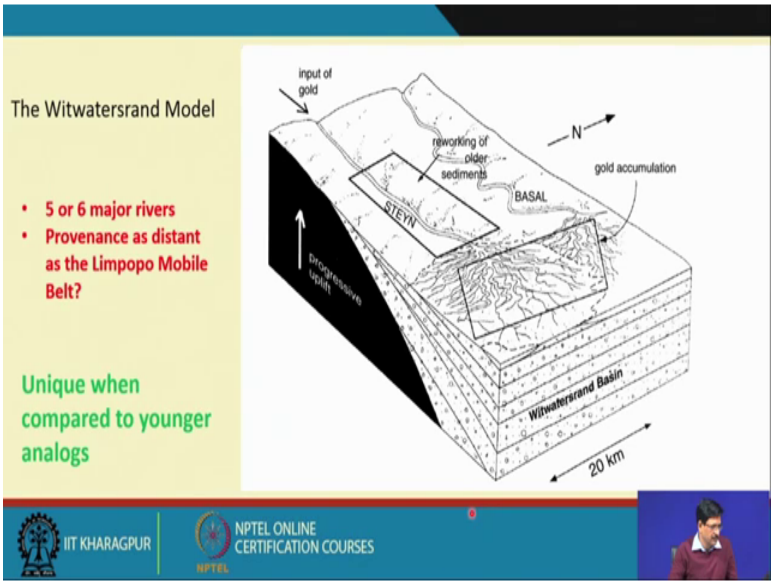

And this is an interesting situation, the interpretation of the Witwatersrand belt basin which is interpreted to be a result of some 5 or 6 major rivers and this particular sequence of the sedimentation almost goes to 6 to 7 kilometers in thickness and one would wonder, that how such thick centimeters you took place and that is why, it was visualized that there has been progressive uplift on the provenance area, during the deposit during the formation of the basin this prevalence could be as distained has could be the Limpopo belt which is about 250-300 kilometers and this diagram gives a very good idea.

So, this is the vertical section and this is the Witwatersrand basin, which this is a picture the depicts the situation resulting from the work of five or six major rivers during that time and we still do not see any such present day comparable situations in which such large river systems in it work and whether any such kind of represent they deposit forming process is actually operating or not.

So, thank you very much we will continue with the sedimentary process in the next class,

Thank you.