**Mineral Resources: Geology, Exploration, Economics and Environment**

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**Lecture - 41**
**Mineral Exploration (Contd.)**

Welcome to today's lecture. We were discussing about the geochemical methods of prospecting, and we had some examples of the strategy for a sampling, which, and especially a reference to this well geochemical survey, and how the results are interpreted, results are presented in terms of geochemical anomaly map. And now, in the present situation there are many improvements, many different ideas that have come up to the geochemical prospecting.

Now there are ideas of sampling, in terms of the regional or the whole country scale, for preparation of regional geochemical anomaly maps, which can also be used, during the reconnaissance purpose. Such kind of anomaly maps have been produced, in large, in large scale, I mean already in process. And with objective of having them as reference material, even before an exploration program is planned, during the reconnaissance itself.

There are many different techniques like fluid inclusions, also can be used as, for, as a tool for mineral exploration. When there are certain processes like, boiling of the fluid or mixing of fluid sources, which come out from the fluid inclusion, micro thermometric data and their proper interpretation. And since these processes are responsible in formation of ore bodies and enrichment of ores in different situations, they can also be effectively utilised for that. We are not able to discuss them in details.

So today, we will start discussing on the geophysical methods of prospecting.

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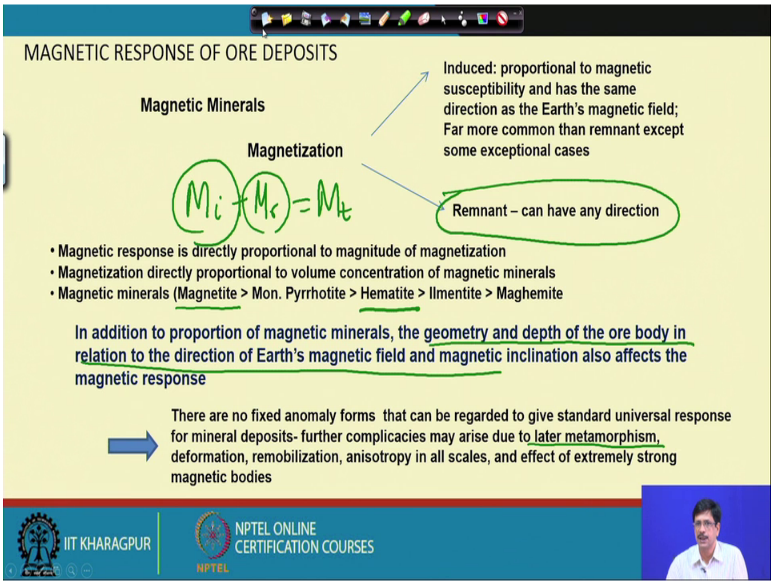


Before we start the discussion on geophysical methods of prospecting, let us remind, get reminded, as, about the fact that, we are not in a position, or we are not able to get into the details of the mathematical treatment of the detailed procedure of data reduction, in geophysical methods proper, but as geologists, we could always have some appreciation, some basic ideas, about the geophysical methods, which will be helpful for our general understanding and general guidance.

So, to begin with, let us first discuss about the magnetic methods of prospecting, and before we go to the, little bit of details of magnetic methods, and CNA case study. We know that this, any particular ore body, with brief we are planning to use a magnetic method, this magnetism, or this magnetic field, or whatever magnetism that is observed that is measurable in a particular rock, or any ore body, it is essentially divided into 2 parts, that is, or it is coming from 2 contributions, one is the induced part which is induced by the Earth's magnetic field, and that is how, it depends on how exactly the Earth's magnetic fields orientation, and the body that we are trying to measure, with relative orientation to the Earth's magnetic field.

And the other component comes from the remnant magnetism, which actually is the magnetism, that is, now, that is acquired by any magnetic material like a, ferromagnetic or a diamagnetic material, during the process of its formation, for crystalizing from a melt, as we see in case of the sea for basalt, which acquired the magnetism, and that magnetism of the polarity of the direction of the magnetic field is very much in accordance with the existing magnetic field of the earth. And, the most of the process that we do, the major, the magnetic anomalies, magnetic properties of this the rocks and ores, so this come from these 2 contributions, which will be essential, the contribution coming from induction, plus contribution coming from the remnant magnetism, and that is actually the total of magnetic field, that is, or total polarity that is developing in the particular material.

And essentially, for any particular body of a rock, or an ore, for its detectability by virtue of its magnetic property, it very much has to, it has to be the induction, in the induce part of the magnetic property, magnetization has to dominant because, this residual part, is, if the residual magnetism happens to be dominant, then it will be problematic for that particular body to show any magnetic signature.

So, the magnetic responses directly proportional to the magnitude of magnetization, and depends on the magnetic susceptibility. So, standard text books will always give the values of magnetic susceptibility of different minerals, and the rocks, accordingly their values will be available based on the dominant constituent minerals.

So, the magnetization is directly proportional to the volume of the concentration of this magnetic minerals, and the magnetic minerals are essentially the monoclinic Pyrrhotite fes, Magnetite, which will be the most dominant one, if any particular rock has a very high magnetic susceptibility, it could be, because of a high concentration or high proportion of magnetite, and then Hematite will be less, but it is gamma form which is Maghemite could be still having more Ferromagnetic characteristics, then Ilmentite and Maghemite which I just mentioned.

So, the magnetism or the magnetic field, that is or the perturbation of the magnetic anomaly that will be observable, identifiable, basically coming out of this. So, the addition to proportional magnetic minerals, the geometry and the depth of the ore body, in relation to the direction of the Earth’s magnetic field, is also an important criteria. And there are no fixed anomaly forms that can be regarded to give, substandard universal response to mineral deposits.

So, complications may arise, due to the, due to later metamorphism, deformation, remobilization. So, essentially what would be looking for is that, if there is, there is an ore body, and which has a high proportion of magnetic minerals like magnetite, or monoclinic Pyrrhotite. And some of the, in general some of the sulphide minerals will also have a higher magnetic susceptibility compare to common rock forming minerals, then we should be in a position to detect in the form of an anomaly, when you measure the magnetic property of the rocks which is surrounding.

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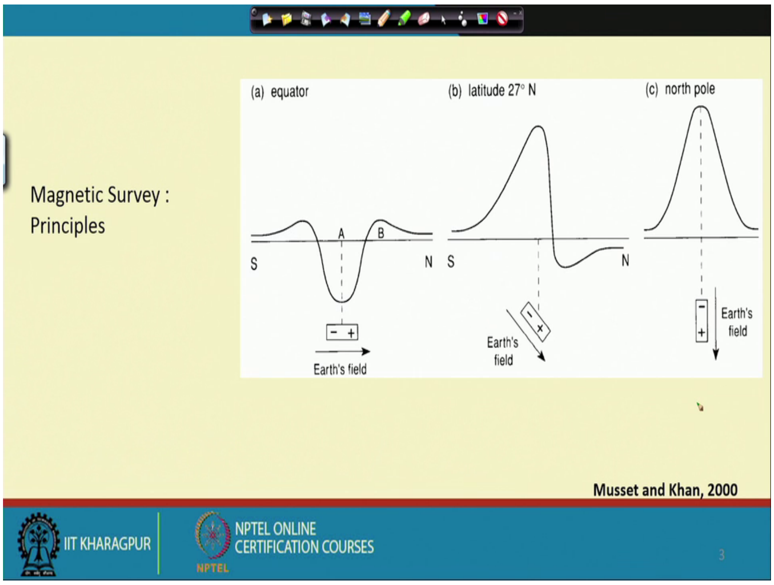


This is an example of a very simple example, which is taken from Musset and Khan 2000. So, here this Magnetic Survey, which is conducted, supposing that our ore body of the material that we are trying to do, trying to measure is a dipole, and it is oriented in respond in parallel to the Earth's field, and this is, the measurement is being done in the equator region.

And then we get a anomaly, which will be of this shape, if the same measurement is done at a latitude is 27 degree north, and in that, the Earth's field is, is a inclined oblique, then we get anomaly pattern which will be more asymmetrical over here. And this is the anomaly pattern, which will be getting in the north pole, because the Earth's magnetic field will be exactly vertical there.

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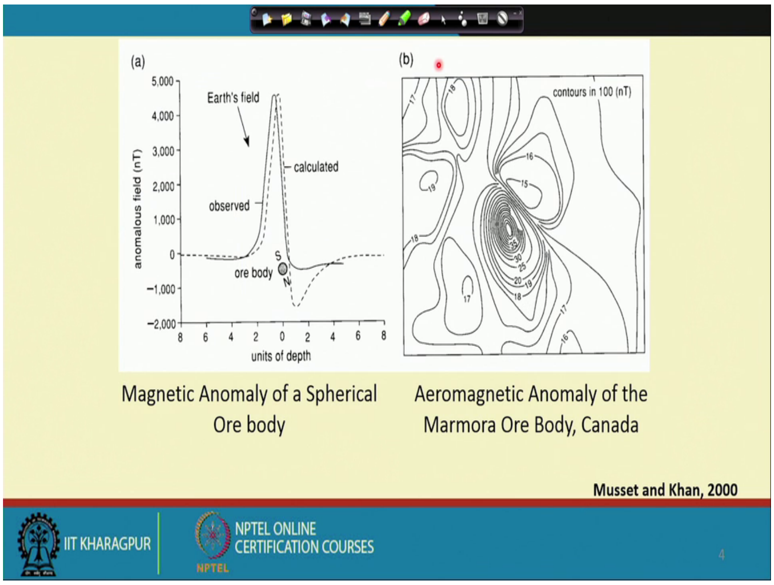


And the situation that can be imagine here, then what we measure essential is an anomalous field, which is measured in nanotesla unit, and this is an Ore body, where this dipole is oriented like this, north and south.

And, we can measure the field and the object in the calculated field, and it will give us an anomaly, when a locals, I mean, if there is an ore body which is in a subsurface, and sometimes such kind of measurements of the magnetic field can be carried out by, in an, in an air from an airborne magnetometer, these are done by some very well fabricated, well designed, magnetometer like, a proton precision magnetometer, where the, it can be airborne, and can make a survey, and the Magnetic anomaly could be plotted in the form of contours, the way it has been shown here, and this contour interval being 100nanotesla.

So, essentially what it shows here, that there is a body, there is a Magnetic anomaly, and it could be because of a body, which is present somewhere in the subsurface, exactly in this particular place where the magnetic anomaly is of the highest value.

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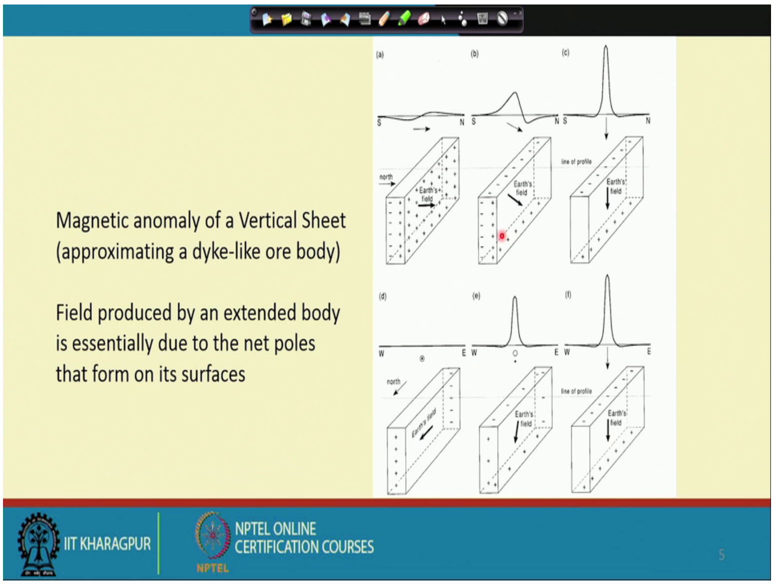


And the Magnetic anomaly, because have the ore bodies, can be always be approximated into different some simple shapes, for example previously we considered as spherical shape, and if the ore body happens to be a shape like a dyke.

And here, they, it is a vertical sheet where it is a dyke like body, and this field which is produced by the extended body is essentially due the net poles that form on the, on its surfaces like the way it has been shown here. And if this happens to be at an angle to the, to the north, here this is, this is on the, this is on the equator, this in a place where it is oblique to the Earth's magnetic field, and here it is in the pole.

So, it could get different types of magnetic signature, for example, here this body is trending east to west, and here it is north south. So, in this case, a body which is trending north south, and parallel to the Earth's magnetic field, we are not getting any anomaly. So, what in a qualitative sense, what we get from these pictures is that, whenever we have any magnetic body which is console below the cover, we take measurements of the magnetic property, magnetic inclination, on a anywhere on the Earth's surface, we should be getting many different types of patterns.

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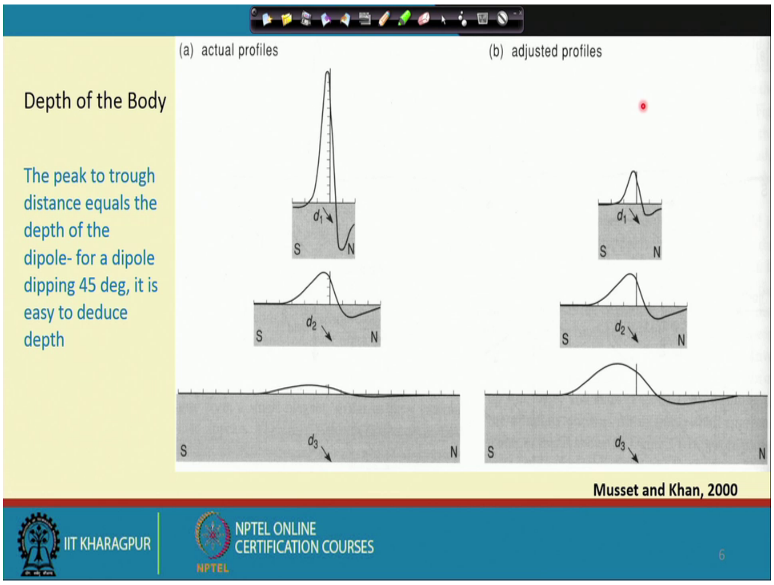


Even in this case, the pattern which may be of a very similar body like, it, like this here, may give different types of signals, and sometimes it also becomes important to know, what, how exactly the, where the body is, and what is the depth. Because one of the important parameters to measure is the Depth of the ore Body, these are very simple examples here, this is d 1 and d 2, there are 3 different Depths of the same Body being present, where this is the more surficial depth, d 1 is the least, then d 2 and d 3, we could see the nature of the magnetic anomaly.

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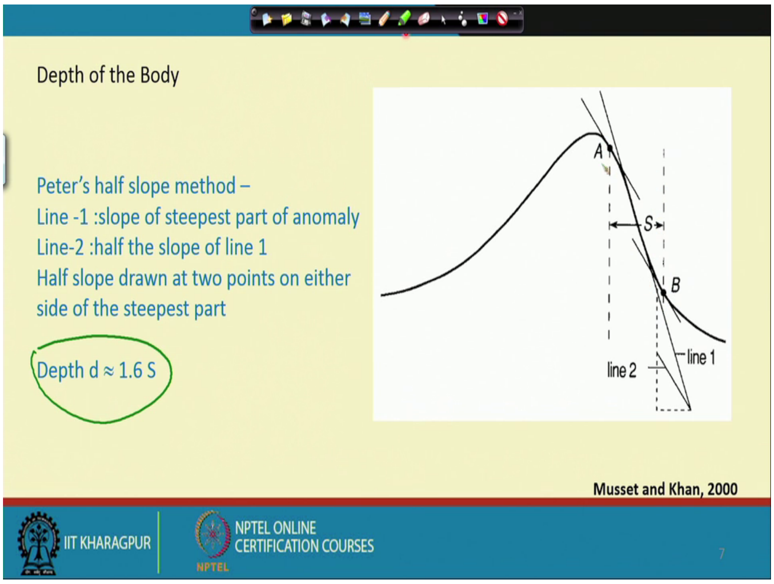

And this gives a very simple formula, very simple idea, as to how to calculate the depth of the ore body, say for example, which is containing the magnetic minerals, here this is the steepest part of the slope of the anomaly, that the curve that you are getting. So, if you draw a tangent here so, that becomes a line 1, and half of that tangent is line 2, and that half tangent line is drawn at points A and B, which are on the either side of the steepest part of the anomaly.

And it can be, there are very simple calculation procedure, very simple calculation scheme, of giving the depth at which the body could be there, Depth is equal to d is equal to 1.6 of S. So, the S being the distance between this these 2 lines, which are drawn from the half the slope points at point A and at point B.

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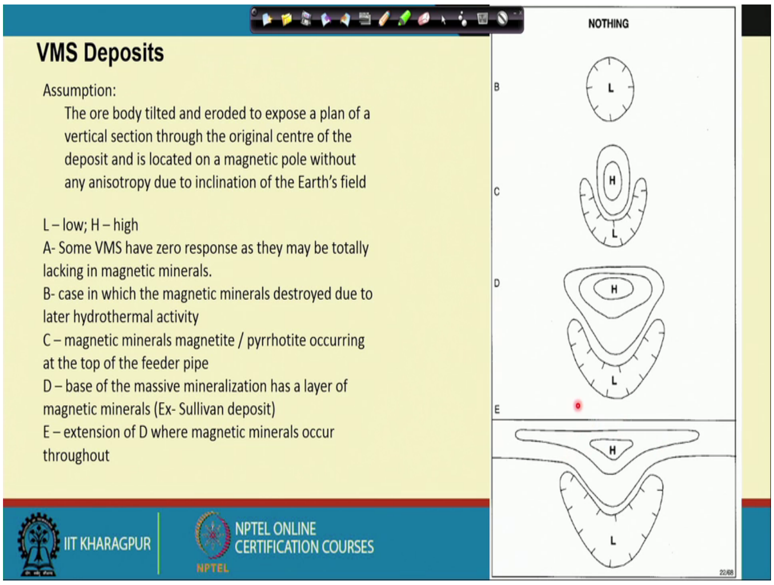


So, with that little bit of a idea about, how bodies behave, and their reflection in terms of the magnetic anomaly, on any of the anomaly pattern that we get, which, we, that tells us that, it all, it will depend a lot many factors, lot many deposition factors, its relationship with Earth's magnetic field, and the depth at which it is occurring and so many other parameters.

So, with it, with that is background, we will, let us look at a case study of, what could be the magnetic response of a Volcanogenic Massive Sulphide deposit, if we measure the magnetic property of that particular area.

So, the assumption is that, the ore body tilted, and eroded, to expose a plan of a vertical section through the original centre of the deposit, and is located on a magnetic pole without any anisotropy, due to inclination of the Earth's field so, that is the assumption. Then the Volcanogenic Massive Sulphide deposit geometry that we have seen, if you could just imagine that it is a tilted, so that the feeder, the massive sulphide lengths, and the feeder the stop work, feeder pipe with it is alternation zone are all preserved, then we could think of, there are many such possibilities, which might packed with there.

First suppose that, the VMS in this context, the first one the A, is basically the response is 0, may be that it is so, happened that this particular VMS is lacking in all magnetic minerals. In case A, which is nothing, in case B we will get a magnetic low here. So, the case in which the magnetic minerals are destroyed, due to later hydrothermal activity for example, whatever magnetite was there has been destroyed, because of later hydrothermal activity, and they are converted to hematite or other kind of know less magnetic in nature, it could be a case, where it could be a situation like, see where that could be high, and surrounded by a zone which is low.

So, here the magnetic minerals like, Magnetite and Pyrrhotite, occurring at the top of the feeder pipe, and the lens is actually represented by this in the low. So, d could be at the base of a massive sulphide mineralize, mineralization, as a layer of magnetic minerals, for example, it is like Sullivan, or e is an extension of d, where magnetic minerals occur throughout so, giving this is high signature of.

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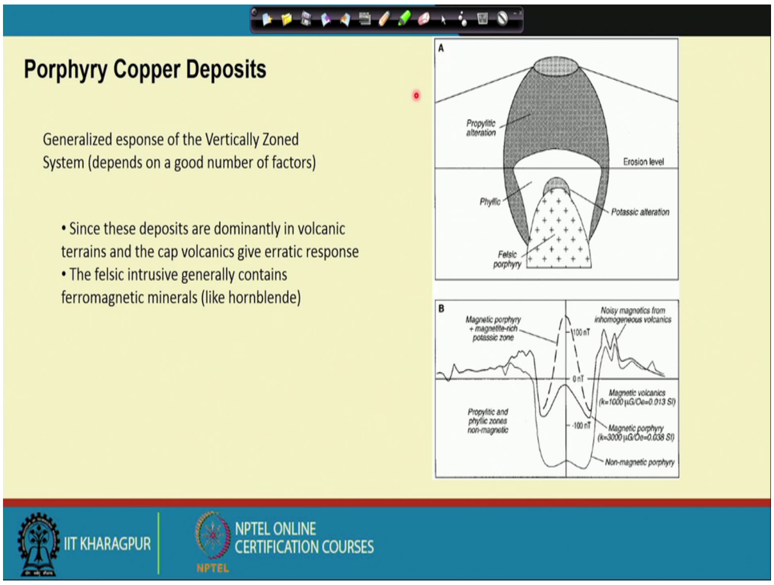


And let us say that, how a Porphyry Copper Deposit will be, will actually show up on a Magnetic anomaly, that is measured on a, on particular this area, where the ore bodies occurring.

Suppose this is the Porphyry Copper ore body, this Propylitic alternation zone, which is dominated by a, by chlorite and epitome, and this is the Potassic alternation zone, and here is the Felsic porphyry, there is a Phylic zone, and we know that the ore minerals will be accumulating over here. So, that would possibly 3 situations which might come up.

First one is the Magnetite porphyry plus magnetite rich Potassic zone, if this sometimes the Potassic zone is magnetite rich by breakdown of the, sorry, the oxidation of the Biotite to Potassic alternation plus magnetite assemblage, then this zone could become magnetite rich, and it will give you a positive magnetic anomaly is going up to 100nanotesla, for example, if we look at the second situation where, it might so, happen that the Magnetic porphyry, and is the Propylitic and the Phylic zones being non magnetic, and we can get situations, which is noisy, noise magnetic from inhomogeneous volcanics, which will be surrounding, and we can get different types of such magnetic signature, which is possible for a for the same Propylitic Deposit, where the 3 different situations is depicted.

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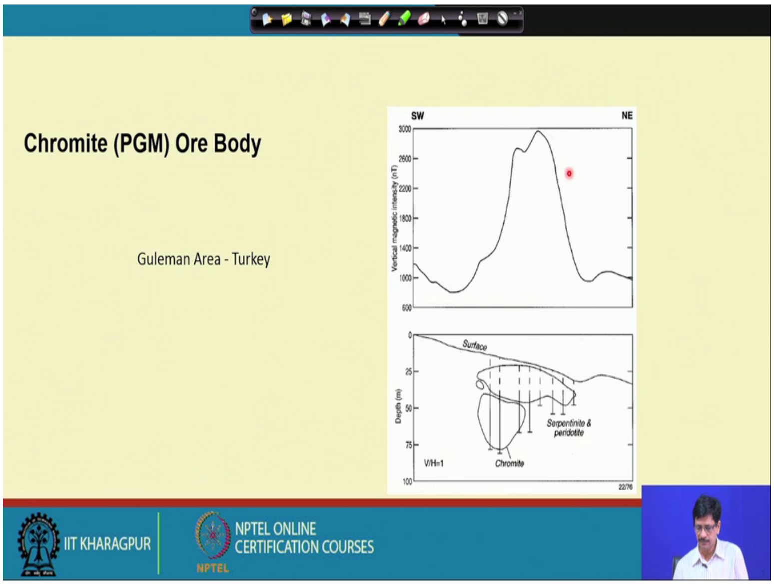


Say for example, there is a Chromite body, and it has been taken one example from of the deposits. So, here this Chromite Body is actually surrounded by a Serpentinite Peridotite on top, and it gives an anomaly which is not that very sharp, but still we could sense the higher magnetic susceptibility of the Chromite Body, compare to the Serpentinized murphy graph.

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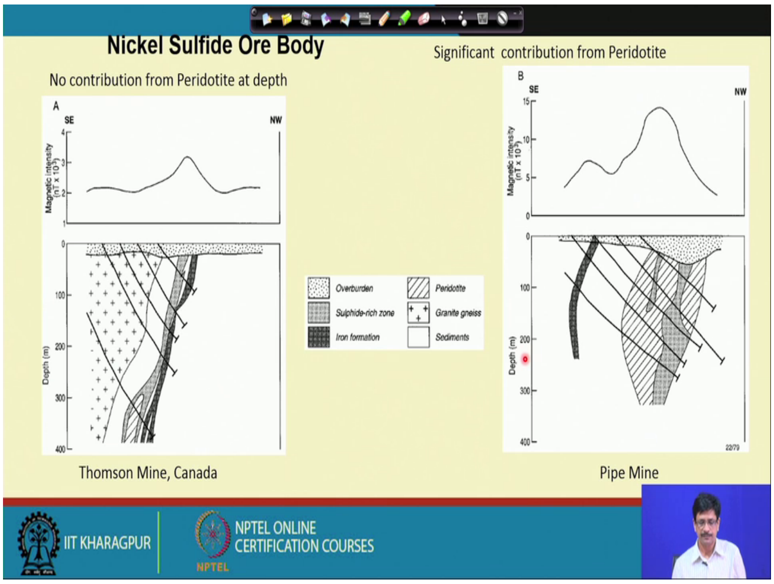


This is an example of a Nickel Sulphide Ore Body, where the, there is no contribution from the Peridotite depth.

Because, what is happened here is, this Peridotite occurs just as an, as a just an inclusion on this body of the Nickel Sulphide Ore. So, that is how it gives us a very prominent magnetic anomaly, going to the order of 4000nanotesla, but just if we have a situation where this sulphide body, this metal sulphide body, sulphide rich zone is included within the Peridotite, and also with some sediment on top of it, and this will give us an anomaly, which will be different from the one which is shown here.

So, they are, this illustrations, just hope that the anomaly pattern that we get in many different situations could be different, and it will always be interpretation, could always be very, I mean, depending on information coming from many other source to confirm the actual nature of the disposition of this ore body, and their relationship to the surrounding rocks, by which, in which case the anomalies could be reflected in many different ways.

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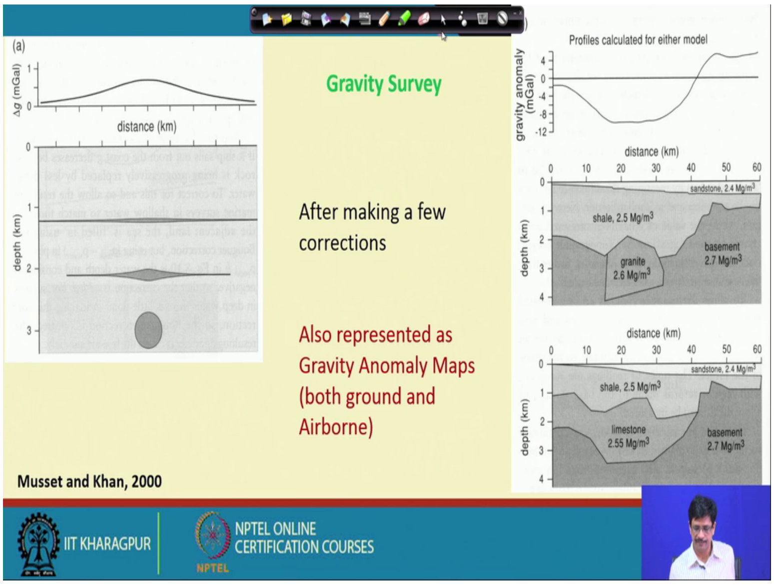


And just let us get some idea about the gravity methods, the way they replied, this is a very simple diagram here, showing that they serve the anomaly that we record here is, because of the presence of a, as a body, which has a much higher density correspond, compared to the surrounding, measured in terms of grams per cc or kg per meter cube, whichever will be more comfortable with a gram per cc kind of a value, which we know that, how the values range in crustal rocks.

And in many different situations the ores like, ultramafic ore, or a provide rich ore, or any other ore, which will have a very perceptible difference, in this, in the density with a surrounding.

For example, these 3, one which a spherical body, which is lying at the at a deeper part, or a lensoidal body, which is lying at little shallower, or just a flat lying kind of, which is lying just near to very surface, they all might give the similar type of a gravity anomaly in terms of the mill gal, that this gravity anomaly is produced. And this diagram also gives a very good idea that, the same the situation here, here there is a granite, which is about 2.6 mega gram per meter cube, 2600 kilogram per meter cube of rock, and where the basement is 2.7 mega gram per meter cube and a shale.

So, here the situation where a granite, a body of granite is enclosed within shale and basement, or here there is a limestone which is form a, which is basically occurring along with the basement and the same shale, we will give exactly the identical kind of a gravity signature, if we take the gravity measurement, the gravity anomaly. And what we are not exactly discussing here is that, the process is definitely very elaborate, and this data that taken by instruments like gravity meter, that we take in the field or in the airborne gravity meter, there the data required.

And they are subjected to a lot of corrections which are essential, before we can get the data on which the interpretation could be made, and such kind of gravity anomaly map could be plotted on the ground, and simple type of profile, or once the larger area is covered, then based on the gravity anomaly measured in terms of Milligal, it could be as similar gravity anomaly map, regional scale gravity anomaly map could be produced.

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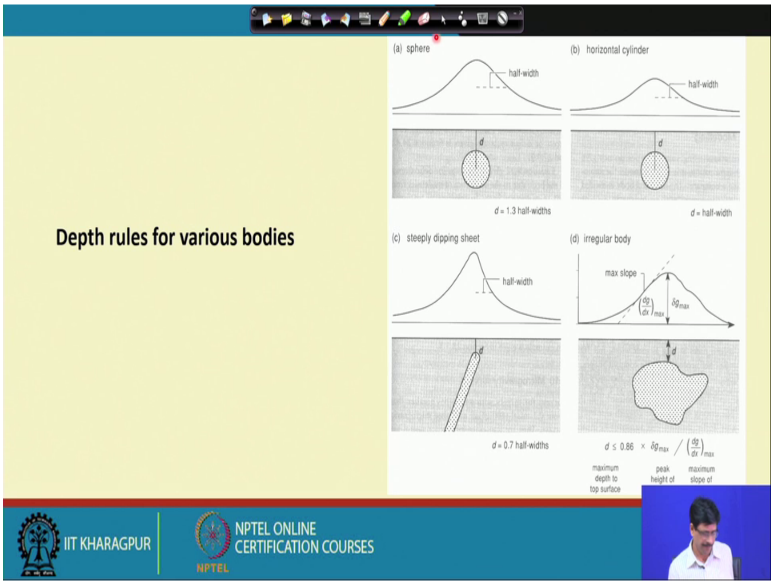


And here, the depth rule also is applies, here for example, if it is depending on, what is the kind of shape of the body that we presume, if it is a spherical shape then, so this peak essentially, we can always take the peak at a half height, and the half width at half height.

So, this is the width at half height, and here, it could be simple formula like, the depth at which depth to the centre essentially lies, this just about 1.3 into the half width. In this case, it is just, just the half width, and in the case like this, where it is a dyke like body that we are showing here, if we presume that the ore body, which is in a higher density compared to the surrounding, is having a, is has a shape of a dyke, then here the depth to which the dyke could be occurring is 0.7 of half width.

And here it is interesting that, if we consider any irregular shaped body which is more likely the case in nature, there the depth is usually found out by the slope, that is the change in the gravity anomaly, this, this slope on this side, with distance dg by dx is multiplied by the del g max, that is the maximum anomaly that we are getting here. So, that will be less than or equal to 0. 86 into this dell g max divided by the slope that we get as the dell g by dell x.

And in most of the cases, when we will be seeing the case studies also, that, this always will be give us some very basic idea, for discussing application of a magnetic method, or a gravity method, for a exploration of any particular ore body, and looking at the case history.

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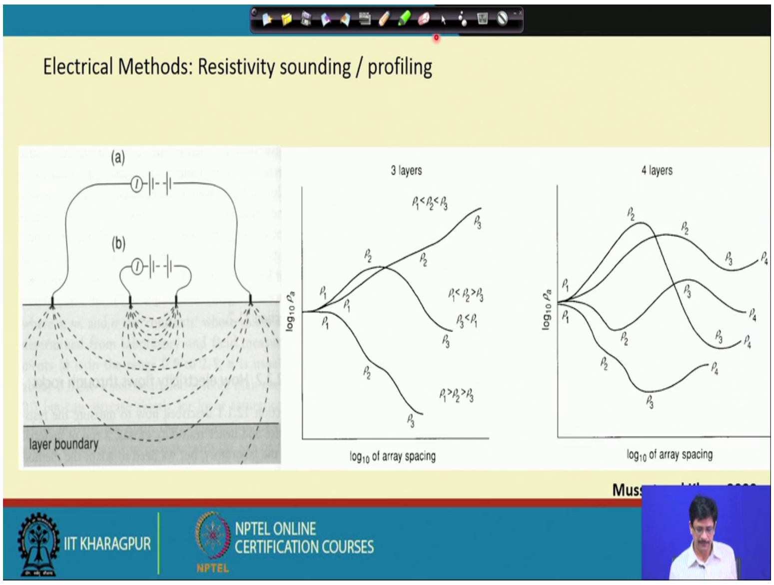


There is an Electrical Method, as we all know that, this electrical method more applicable for.

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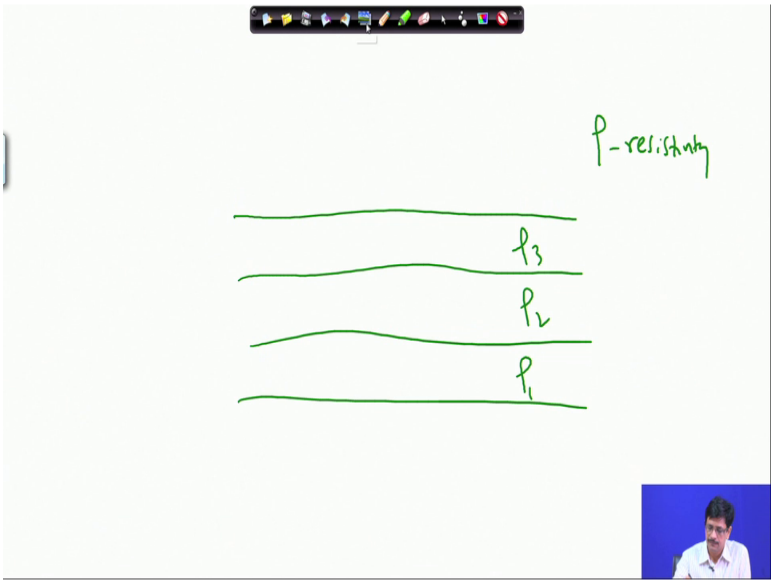


For example, most of the, most of the cases we have situations like, there are crustal metre, they rocks different types of rocks, the rocks could be of different hydro, I mean their porosity, permeability, characteristics, could be different, their what, their different types of water wearing horizons, they could be dry rocks, or could be fluid field rocks.

So, they will be differing in the resistivity, which is, we can put as rho 1, as rho 2, and rho 3, and this is what we are basically putting, this rho is the resistivity. And as we will seeing here, the most, the Electrical Method will only be considering the one, which is the resistivity sounding, or the resistivity profiling, which is mostly used.

And as I just showed that, most of these cases for situations like, detecting water wearing horizons for groundwater survey, this kind of arrangement, this kind of device is used where there is, there are current electrodes, and potential electrodes. And when the current is applied, the potential differences measured. And there are different types of configurations like, the distance between the potential electrode, and the current electrode, either they could remain as, one is fixed and, one, the other one to be moving, or the all 4 could be moving apart, it moving away from each other, and that is by allowing the current to flow dip to different deeper region of the different layers.

And we get, when we plot the logarithmic log, log scale on the logarithmic of log of the resistivity, apparent resistivity, versus the log of array spacing, we get different types of curves, from which we interpreting in terms of different layers of different resistivity, that is there below the surface.

So, this kind of resistivity sounding, a very widely, or very regularly, applied for the exploration of ground water, which are essentially the layers, more or less to be, to be horizontal or to parallel, with the earth surface, and such kind of situations, and here also just for the sake of understanding, we know that what we are measuring, here is the apparent resistivity, because it is not. Since it is a heterogeneous material, consisting of different types of mineral grains in a rock matrix, or water, or sometimes even the water will be of different salinity, which will vary in their electrical conductivity, and that is how changing the resistivity.

So, what is measured essentially is a apparent resistivity, and that apparent resistivity is, when it is plotted with the log of the array spacing, and this kind of. So, there are, these are very standard procedures, which are available to interpretation of this graphs, in terms of water wearing horizons, and there are much more developed computer course also, this is available which does the job for us.

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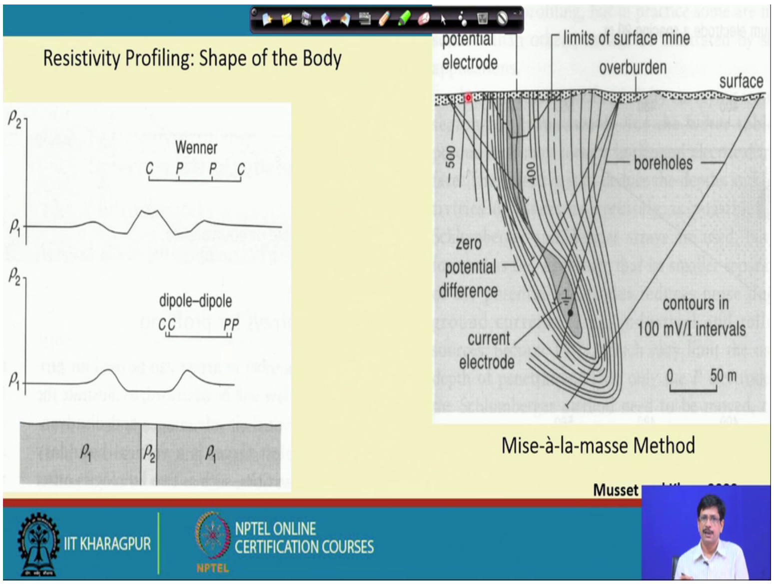


But essentially the situation is that, the ore bodies which are of our interest, will very, in majority of the cases will not be like, in very rare exceptional cases, where there are very static form, and very confirmable to the sedimentary strata, or and such kind of a situation, where they are occurring, but in most other cases like in n types of deposits, or bodies which oblique to the sedimentary strata, or a later on their tilted, or deformed, and their present, in shape which will be more be depicted by the situation, which is here like, this is rho 1, and rho 1, and our body of interest is something which is like rho 2 over here.

So there, it is, it becomes more challenging, and becomes it definitely requires a little bit more of elaborate procedure to actually identify, and here our object is not just to detect the presence of the lower resist, lower resistive, or higher conducting body, which is an ore body, but also we need to, need to know the shape, approximate shape in which, this particular ore body is occurring under depth. Because, that will be the most crucial aspect of our survey, because what we intend to do finally, is to reconstruct the shape of ore body in the subsurface.

So, there is a method, which generally is applied in many of the case histories of discovery of mineral deposits, by use of electrical method, which is encountered.

This is known as a, Mise-`a-la-masse Method, in which instead of the electrodes, the current, and the potential electrodes, moving or being moved away from each other in regular intervals, what is done here, that the potential electrode is fixed, on the, on one of the points corresponding to the exposure, or wherever we detect that, their such kind of an for example, by geochemical survey, or any other method, we get to know that, the, there is an ore body, which is below this particular point.

So, it could place our potential electrode there, and through series of drill holes, we, this current electrodes are also inserted, and the resistivity profiling is done, in a way, and these are the lines which are representing the lines of equal resistivity, and that is how the shape of the ore body, shape of the ore body could be very much well approximated by such kind of method, which is known as a Mise-`a-la-masse Method, which a, application of this will be seeing in an one of our case studies.

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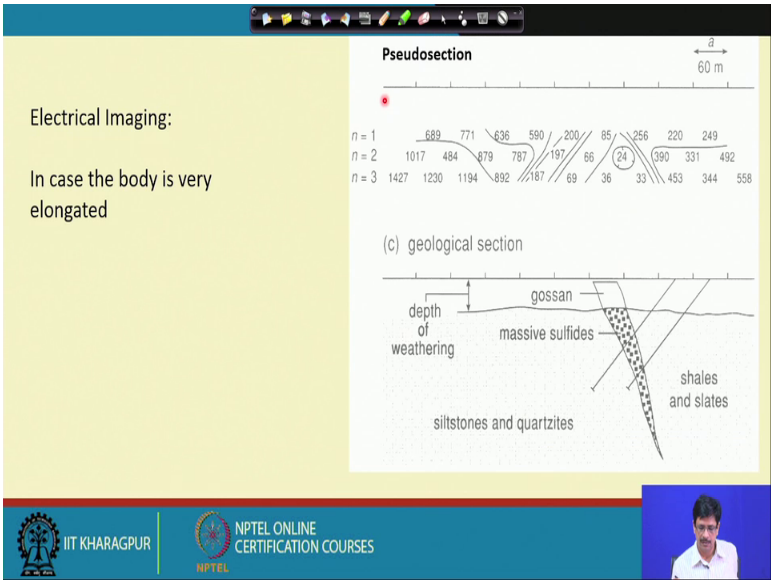


And situations corresponding to these are something, which is a little improved method, and it is something, which is called as an Electrical Imaging, in case the body is very elongated, like the one which is shown here, and some such situations very very common, even a situation which could be (Refer Time: 29:59) pipe, or it could be a brachiating hole wearing zone, or it could be a deep seated fracture, filled with quartzite kind of mineralization, like (Refer Time: 30:09) kind of mineralization, which we have discussed.

So, here the profiling is done on regular intervals, in 2 dimensions over the entire area, and what is reconstructed is something like a pseudo section, and these values representing the different value resistivity value regions, and from which this kind of geological section could be reconstructed.

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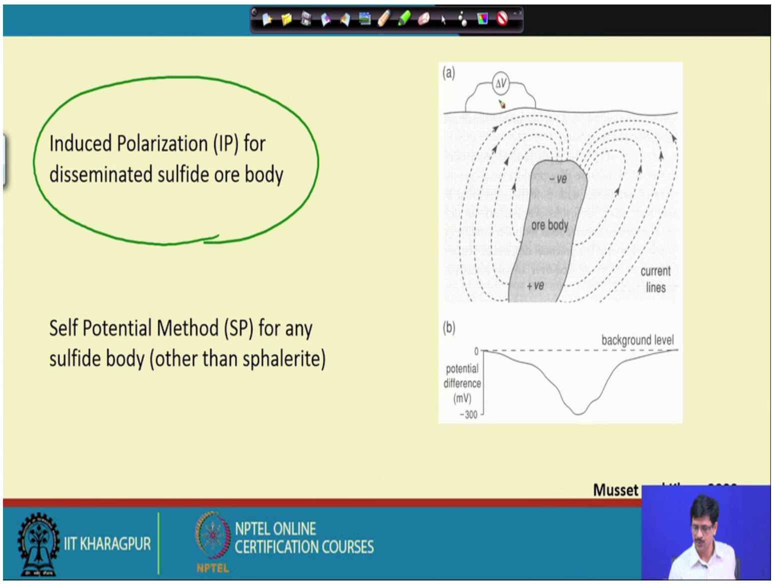


So, the other type of electrical methods, it is to regularly use for detection of the sulphide mineral body, in the Induced Polarisation method, which is use for disseminated sulphide body, because Induced Polarisation takes the a help of the principle that, if I applying, it is more like a, like the same way that the resistivity method by which we are applying, we apply current to flow through the surface, when the current applies then there is, there is generation of this, the creation of polarity within the mineral sulphide conducting minerals, the only exception to the this polarize.

And then if we stop full flowing of the current, then there are some residual potential which remains there, and which gradually decays, and that is measured, and that is the induce, Induced Polarisation method which is mostly apply to situations, where there are disseminated type of ore body, but situations like this, where we have a, we have an ore body, which is a concentrated like a like a vein or any kind of a situation like even a acid sulphide vein, where the concentration of the ore minerals are high. So, here we use methods which are called the Self Potential method.

In this method, there is nothing, when no more current is flown through the surface, it is just that itself, behaves like a polarity is developed, in the different part of ore body as shown here, as a negative and positive side, and current flows through this, from a close circuit, and that current could be measured by using a, but the potential difference could be measured by using a volt meter.

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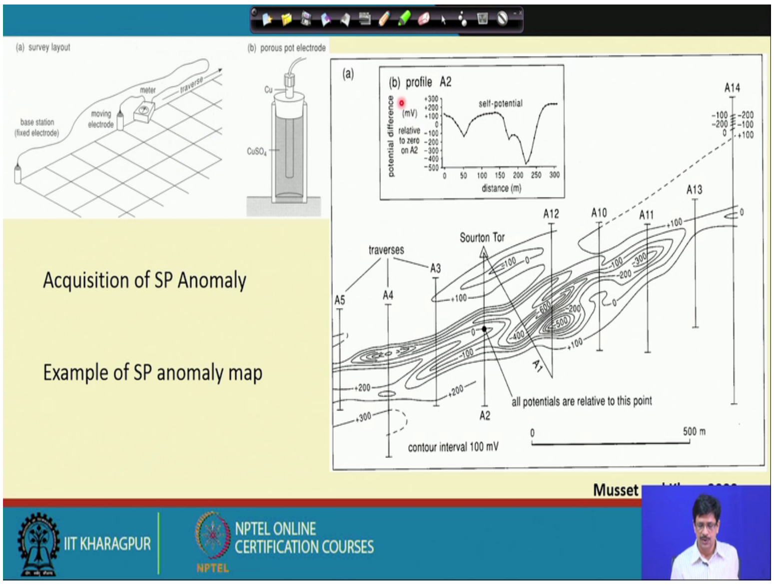


And, so this gives an idea. So, this is how the self potential methods always done, just one needs only a moving electrode, and the device to measure the potential. And this Self Potential that is the data, that is acquired can also be plotted, in the form of contours, and this is one example taken from one of the deposits, this is a, this is an SP anomaly map, which can be prepared, and by that, we can always pin point the higher anomalous zone as shown here, in negative value. So, this will be indicating the presence of the sulphide ore body.

So, we will continue with our discussion of some of the case studies, where the methods that we have discussed like the geochemical method, the sampling, and the production of or the generation of the geochemical anomaly map, are looking to the series of geophysical methods like a magnetic method, or an gravity method, or an electrical methods like resistivity.

So, this one some of the case studies, we can see, how this combined use of all these methods, result in discovery of mineral deposits. We will continue our discussion.

Thank you.