Welcome all. So today is lecture 12 of the module 3. So in today's lecture we are going to discuss about magnetic survey. When we started our lecture, I had insisted like depending upon different kind of structures, whether it is constructed on land mass, whether it is constructed offshore, whether it is related to like exploration for suitability of particular site for tunnels, even for mineral exploration or suitability or investigation of a particular site related to, adopted as a source of construction material, we have to go for different methods. Some of those methods are primarily based on detailed investigation, while some methods or before we go for detailed investigation, as I mentioned, like we have to collect information based on existing reports, published literature, and designed reports, if it is available for any kind of construction, which has been… which has been happened in the nearby areas, so that you can get more understanding about the site of interest and then possible challenges or difficulties, which were arisen during the construction of nearby structures. So… so that way you can be better prepared to phase any kind of challenge or difficulty and then you can be possibly ready with alternate options for construction as well as design modification and suitably you can also change your… your method of construction, which can be used, depending upon the kind of structures and depending upon what kind of soil is available, depending upon what kind of possible modifications are likely to be happening during later stage. So overall, it's going to be like, based on the existing literature, you can be better prepared for… to go ahead for your detailed investigation and followed by subsequent design and laying of the foundation or the suitability of a material for construction and that’s how you can also take reference to published literature or your designed consideration, whenever there is some legal issues also. You can always refer to… to the reports whether it is published by you based on detail investigation or the reports which are published based on the previous projects or maybe the reports, which are published as a part of mineral deposition study or may be sedimentology study or may be glacial deposits or may be related to seismic studies, which are generally covering larger area rather than side specific region specific studies. So those kinds of studies, because those are particularly intended to… to understand particular kind of characteristics of particular region or those can be state based or may be country based studies. So those studies are generally done because those are intended to be done for that particular purpose. So those studies are done with lot of details to be covered here. One among such studies on which you can before going for any kind of detailed investigation, you can often refer to such kind of surveys, particularly what we are going to study in today's glass is magnetic method or magnetic survey. So lot of places before you go for actual detailed investigation, you can always refer to magnetic survey methods or may be other methods, which we are going to discuss in coming classes, may be gravity methods, then electrical sounding, cross hose, sonic login methods, and other methods, which are going to give you a very broader spectrum of what kind of deposits or what is the characteristics of the medium available at a particular site, that site may be onshore or it can be offshore, it can be helitran, it can be like soil depositions, lot of soil depositions, sand dunes, everything is there. So depending upon your study area, and depending upon the objectives or the project type, for which you are going to go for detailed investigation, one can always refer to the kind of studies, like magnetic studies, because those kind of studies, though are… the objective of such studies are more to understand what are the geological processes, how the similar processes or depositions have been happening in terms of geological time scale, but overall it will also give you an understanding about what kind of deposits, what kind of mineral, what kind of soil, what kind of rocks, which are likely to be occurring at your site of interest. In addition these kinds of surveys also gives you an idea again on regional basis or may be country based surveys, or may be offshore, again covering a very larger area. This is also going to give you an idea about potential anomaly, like when we go for these kinds of surveys, we know like, when we go for gravity or magnetic surveys overall we know how much should be the value, because considering the overall geology or topography of the region. So if some characteristics of ground or subsurface features, which is leasing to some kind of anomaly or change in its average characteristics, that can also hamper or can provide additional strengthening to your particular foundation type for a particular kind of structures and same way depending upon the raw characteristics, you can also decide whether the particular kind of rock is suitable for a particular kind of construction purpose, it can be rock or it can be other fine aggregates as well. So in today's class, as I mentioned like what is the importance when we go for surveys, which are particularly targeted to understand different processes, which are primarily responsible for the current configuration of your study area or study region or maybe the inter-country as well. So those… those surveys are not in general intended for construction purposes, but it can be used as a preliminary investigation report in order to understand better about your study area, because as I highlighted like these surveys, generally people do for, relatively larger area, which will not be site specific or project specific area. Those are significantly larger area. So… but if, as I mentioned here, and again like if somebody is interested, you can always go for these kinds of surveys on smaller scales also. So magnetic survey, before going to that, I would like to start here like because many of the students, who have registered for this course may or may not have gone through in detail knowledge about earth configuration, tectonic plates, then carry of plate tectonics, continental different, all that. So for us, unless you have gone through this basic details, you will always consider that earth is, as though it looks from the surface, the same thing is there throughout the depth. But if you start analyzing, as done by different seismologist, geologist, in last century, people have understood, particularly based on the kind of ground motion or wave signature, you are getting during different processes, more prominently during seismic events, people have analyzed those data and try understanding what kind of possible medium is available beneath the earth, because nobody has directly gone into the earth till the core, but based on the ground motion signature, based upon wave characteristics, people have come to an understanding like that what kind of medium, both in terms of physical properties, both in terms of its mechanical compositions, people have tried to understand what kind of different layers are there? What are the characteristics of these layers? So in order to distinguish or in order to discuss about those layers further. This is typical photograph of our earth.

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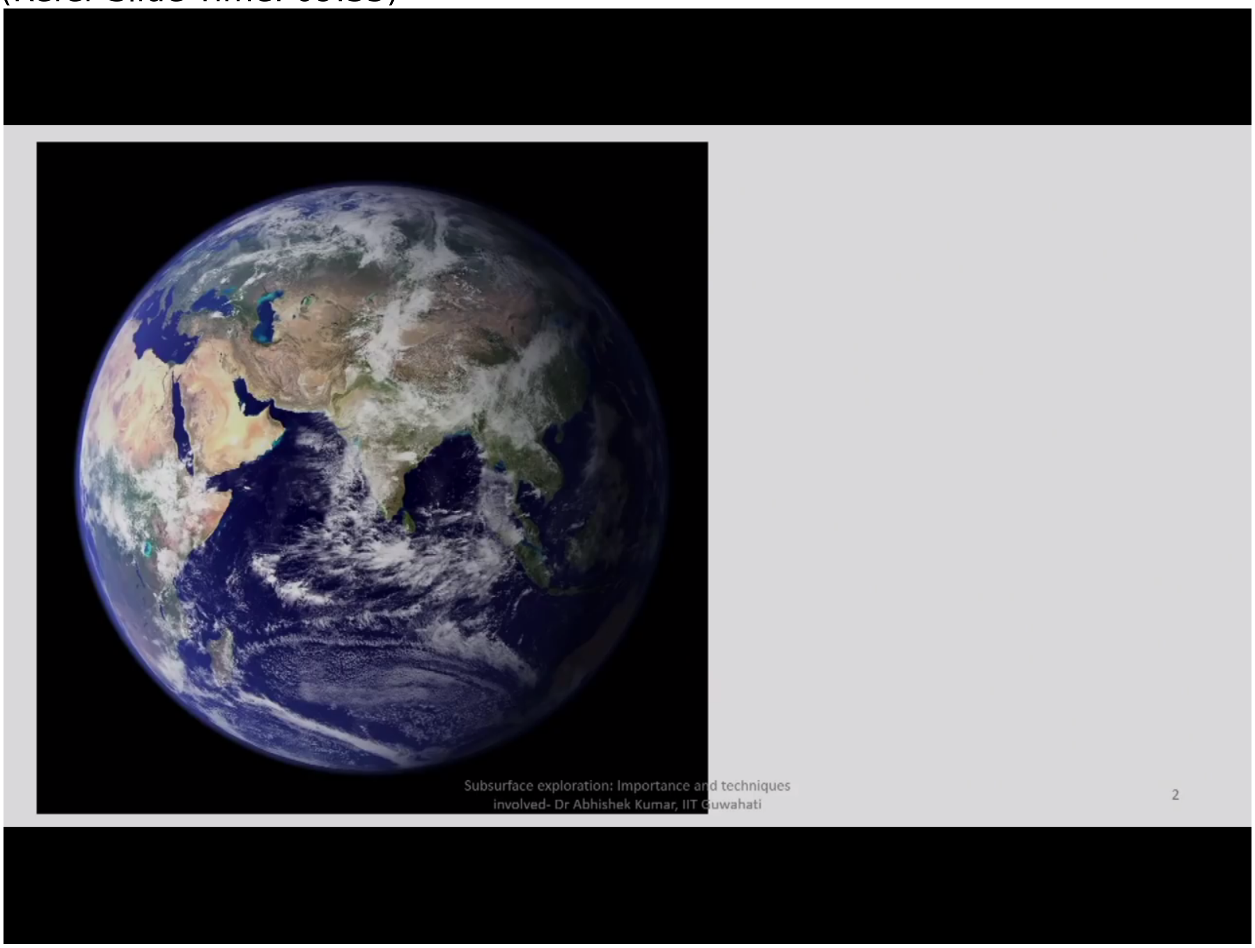

So I have just taken a wedge, slides of that. So in this photo it is not looking like particular wedge, which is… because its again, I want to represent on 2D plot like one kind of wedge. So actually it is a particular section, which is starting from the surface of the earth and trying to reach, so this part is actually reaching to the center. But as I am seeing from the side view, or the top, it may not reach directly to the center of the earth. Now so this is like a wedge, which has been taken from the surface, till the center. Now if you start analyzing this, if you consider, it's a homogenous medium, as you see from the surface, sometimes you see soil, sometimes you see rocks. But if you start analyzing or understanding different kinds of layer, which are possibly available at different-different depth, you may not see every time like soil, which you see on the ground surface is available throughout or rock,

which you see again on the ground surface, may be available throughout the depth.
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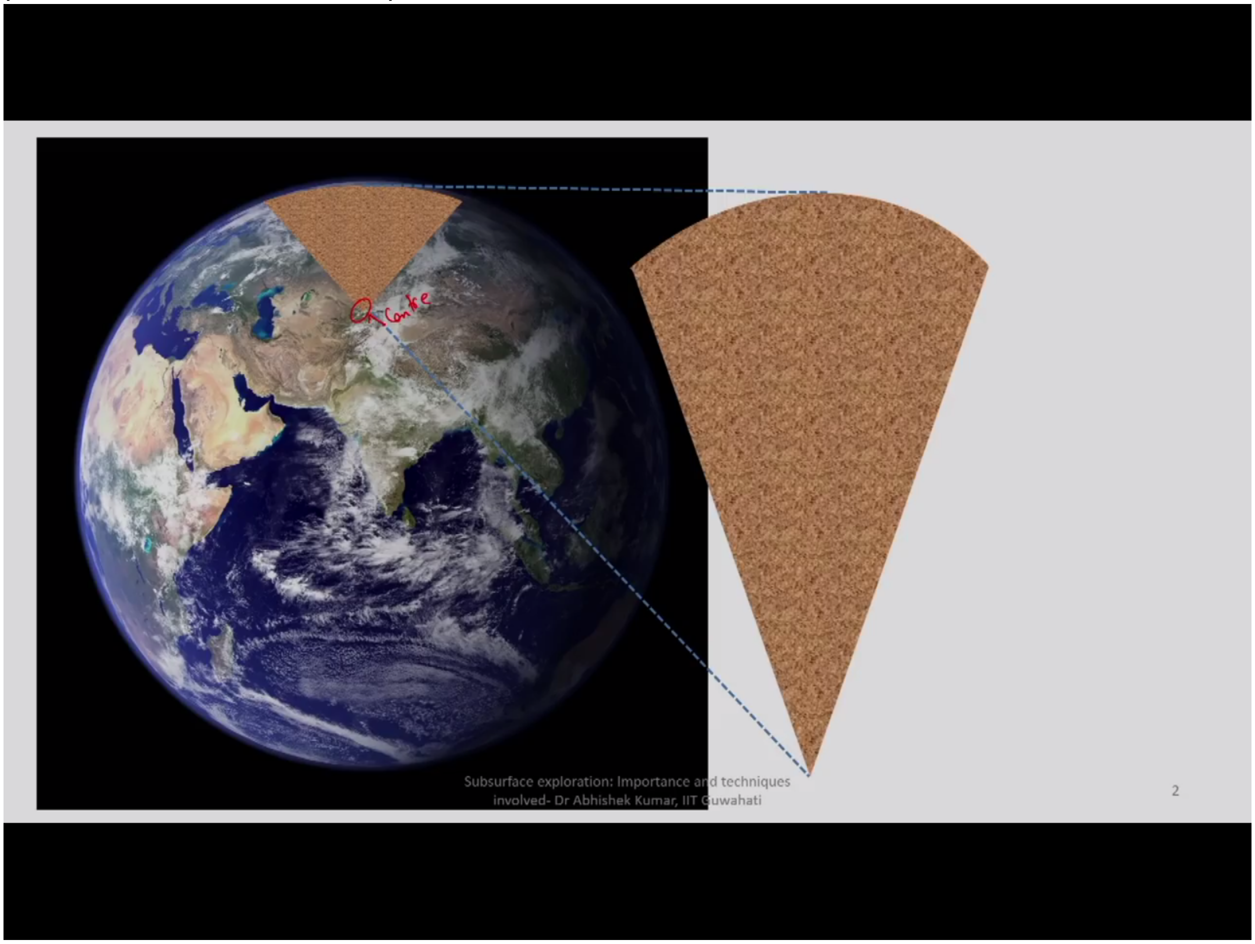

So like the different layers, which are available beneath the earth surface can be classified as, so you are having crust, which means like most of the... most of the soil deposits, maybe topographical features, geological features whatever, we are seeing on the earth surface, particularly on land mass that comes under oceanic crust, particularly features, and then over the crust you are having this soil deposits, which are again part of the crust. So oceanic crust, which is again, if you start from the ground surface, is available in the thickness of 5 to 8 km and mostly are basaltic in nature. Then again you are having continental crust, which are comparatively thicker and if you see the configuration, composition, it is mostly granitic in layer. The thickness again starts, so it is relatively thicker than your oceanic crust, it's in the range of 8 to 40 km. It is important to understand these different kinds of layers, because that will help you in understanding what kind of physical processes, which are governing the configuration, which are governing the forces which are surrounding us, and because of these forces we are able to, if you are able to utilize somehow the absolute or relative value of these forces, that will also give you an understanding about what kind of sub surface features are there. That’s why it is most important and that’s how I have started with different layers of the earth and its interpretation. So this is about the crust, that means the top most layer. So again you can see here this is the wedge, starting from the surface, where you are having all kinds of building, construction, bridges, tunnels, and all that thing. So it is located either on oceanic crust or continental crust and there you are having the center of the earth. So this is like earth center and then in between you are having different layers. So as I mentioned here crust different… depending upon the thickness, whether it is oceanic crust or continental crust, so again in the crust, the thickness of this layer can vary from 8 km, 5 km to as high as 40 km. Then you are having under the crust, you are having upper mantle, which is below the earth crust and extending up to 650 km. So from the lower most region of the crust, up till the depth of 650 km, it is… the layer is called as upper mantle. And again below upper mental, from 650 km to 2900 km, you are having lower mantle. And then again below the lower mantle, we know like core is there, but again depending upon the physical and chemical composition, the core is again divided into two parts, one is known as the outer course… outer core, which is extending from a depth of 2900 km till 5300 km, so this is outer core and then you are having inner core, which is solid in nature, extending from 5300 km depth and extending up to 6400 km, this is roughly the radius of the earth. So till the center of the earth, up till 5300 km high, I mean 1100 km height, that 11 km radius, solid kind of spherical medium, that is called as inner core. This is about the thickness sin which, if you start from the surface of the earth and if you reach the center of the earth, these are the different kinds of layer, which are existing. Now if you see in terms of temperature variation, on the ground surface during summer season, we see temperature as high as 40-42°C and same way in winters you can see again the temperature in negative side. So… but if you see the temperature variation with respect to the depth of the earth, you can see actually, near the surface it is 0 to 370°C start from the surface till the base of the crust. Then you see about mantle, collectively between upper and lower mantle, it is ranging from 3700°C to on an average 3700°C. So this is range is given is like on an average range, different literature you can find, plus/minus of this particular range, some deviation. Then again you go to outer core, so it is ranging from 4300°C and inner core as high as 7200°C. So now you can understand what kind of, I mean… though… though you see from the surface a very stable region, which is suitable for plant and animal as well as human habitation, but as you see, as you are going deeper and deeper, the temperature is increasing at a much faster rate, then whatever, we have… we have been seeing on the ground surface. Now again based on the discontinuity or based on drastic change in the medium characteristics, there are two discontinuities. So one is known as Mohorovicic discontinuity, which was named by the seismologist, who discovered this discontinuity between crust and mantle in 1909, this is called as Mohorovicic discontinuity and then you are having Gutenberg discontinuity, which is between the outer core and the lower mantle. So there… those two discontinuity means, the material shows drastic change in its physical characteristics or response to any kind of shocks, that’s how people came to know like this kind of discontinuity are available at that particular depth.

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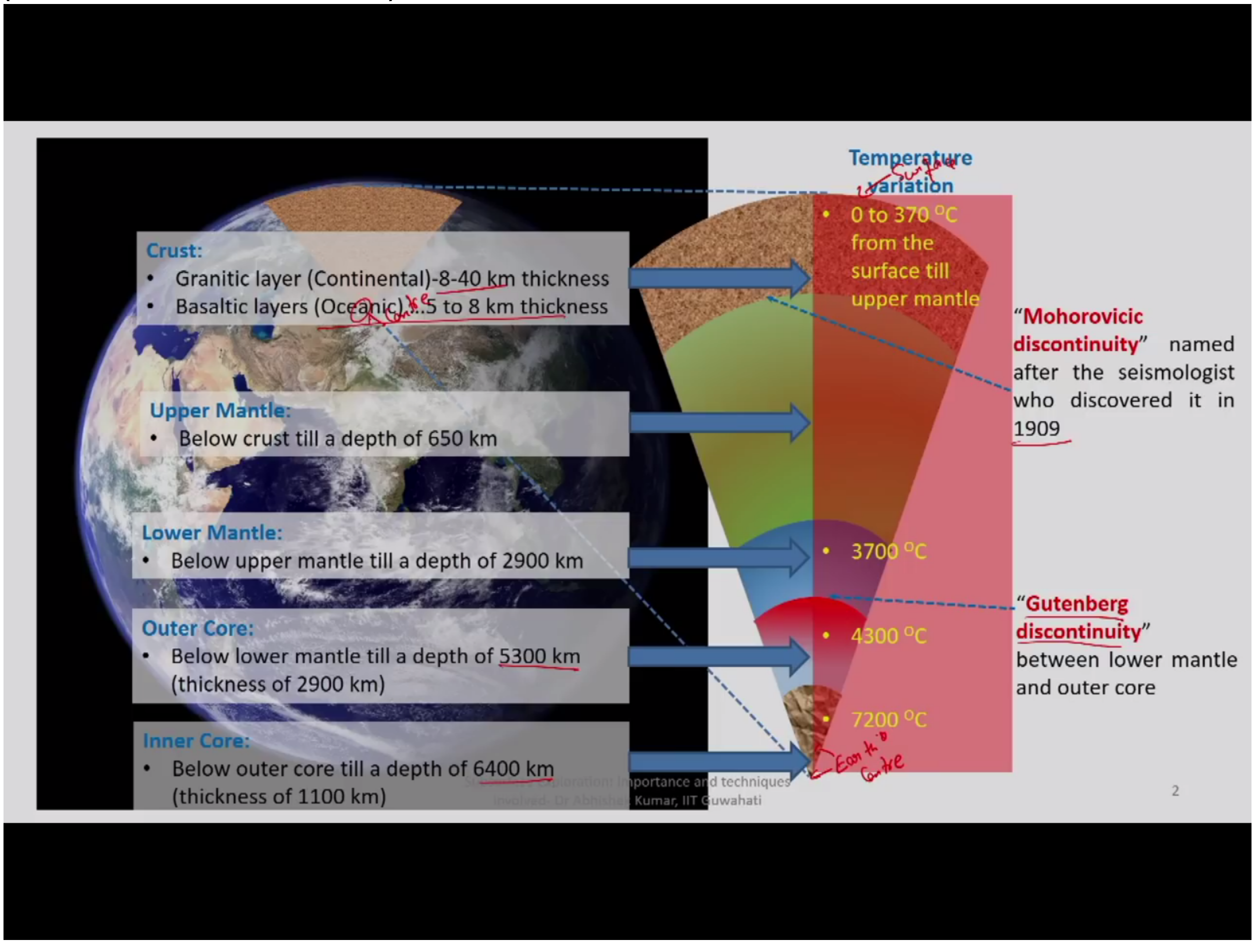

Now one question, which… which always comes to my mind, our mind, like how did the earth become differentiated to different layers, like how you understand like earth is not a uniformly distributed landmass or medium density is not constant throughout. First of all the earth is at such a distance from the sun, that water can exist in all the three possible forms, like solid, liquid, as well as gas. Now if you see the density of water, on an average it is like 1 g/cc, density of most of the rocks, which are available in… at the earth surface, like you start with the soil 1.6, 1.7, 1.8 g/cc, then you take up some rock material, which may be 2.3, 2.4 g/cc and may benign some denser material, may be granitic origin, very dense rocks, most of those rocks are having density of 3 g/cc or may be less than that. Overall if you consider, considering the volume and considering the mass of the earth, the overall density of the earth is 5.5 g/cc. So collectively based on these two things you can get an idea that earth is not composed of the material which is available on the earth surface. Otherwise, there is no way you can have increase in the density from 3 to 5.5. So that indicates that earth interior, means as you are

going deeper and deeper into earth layer, the layers which are available at deeper depth consist of denser medium or increase in the densities. Then denser layers at those depths and lighter one at the surface and more denser at the center of the earth. So gravity is a driving force for such wide sedimentation of different layers over the ages.
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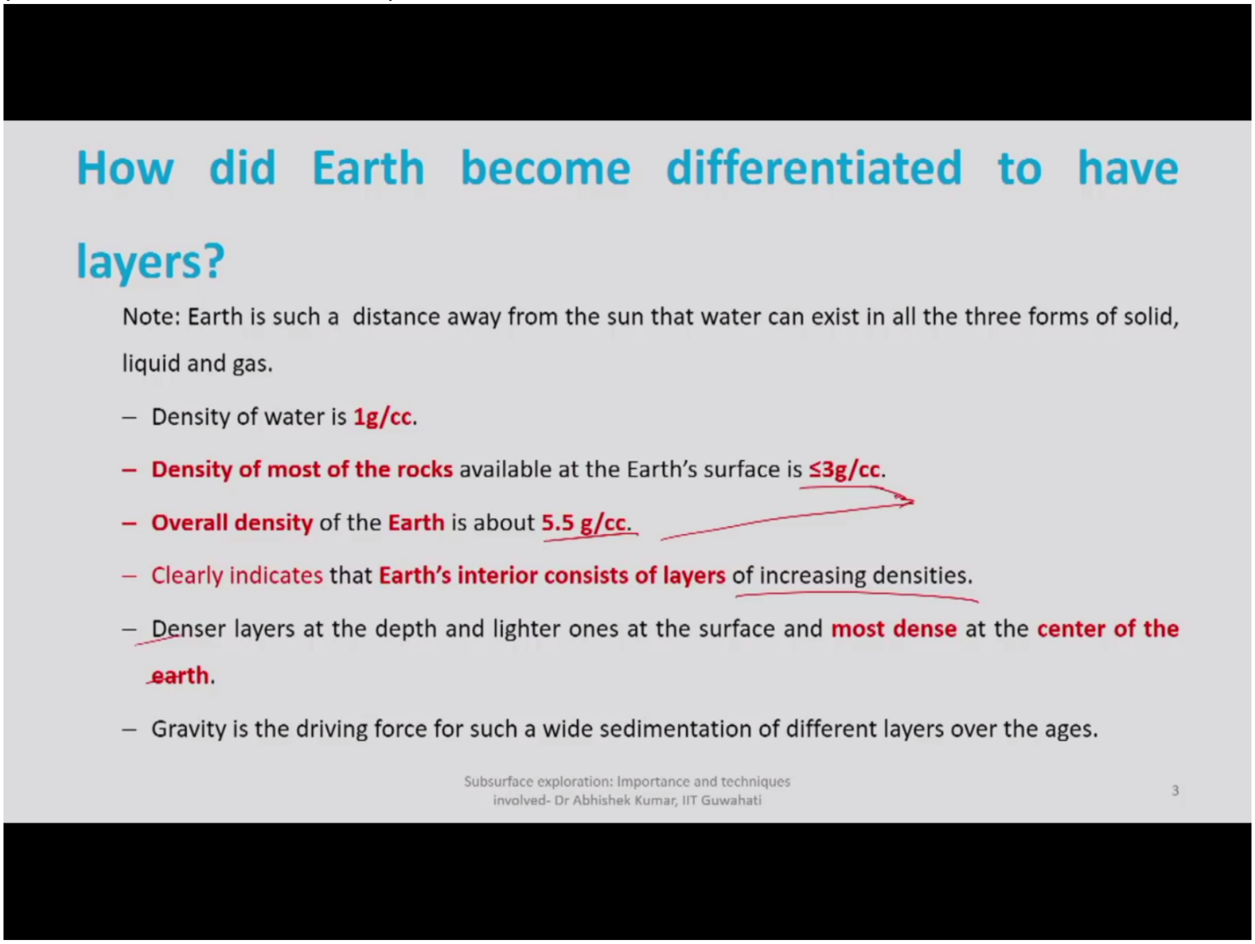

Now crust, as I discussed it is the topmost layer. So if you discuss about the crust, it can further be divided into continental crust as well as oceanic crust. So continental crust, it is much thicker, as I mentioned here 5… 4 to 80 km or so and… so it is much thicker and is composed of lands dense granitic layers of the order of 2.5 2.6g/cc and it is strongly deformable. It may also consist of planet's oldest rocks, some rocks, which are may be billions of years older. Then you are having oceanic crust, which are relatively thinner, on an average like thickness of oceanic crust is 8 km or close to that and is mostly composed of basaltic layers, while the continental crust mostly was in granitic layers. The overall density if you consider, the oceanic crust consists of 3g/cc and in comparison to continental crust, oceanic crust are really… relatively un deformable. The geological age is closed to 200 million years.
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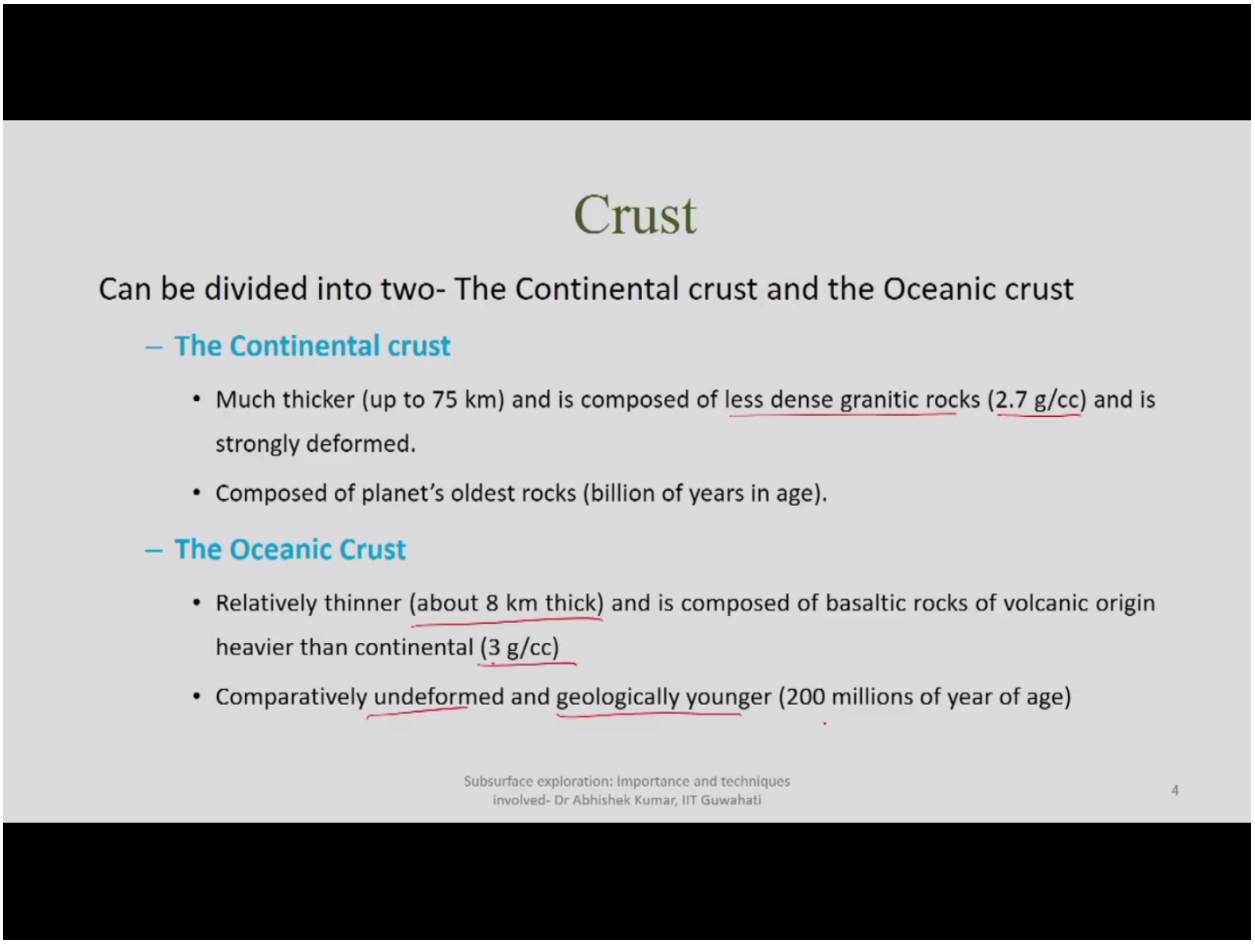

Now if you come to again mantle, so these properties, characteristics, people have understood based on ground signature against different kinds of disturbances created by the shockwaves and other sources. So the mantle, if we study about, it consists of, first of all it cover the core, which is the... the bottom most layer, around which the mantle is governing and then it is starting, as I mentioned, starting from 200... 2900 km thick. If you consider in terms of volume, it consists of... it constitutes almost 82% volume of the earth and 68% of earth mass. So now this gives you a clearly indication like the percentage share in terms of earth mass by the crust is significantly lesser and most of the earth mass, though the earth volume will be significantly larger at the crust level, but the earth mass will be significantly dominated by deeper layers. So the mantle, which is consist of 68% of earth mass and 82% of earth volume, because this is the most thick layer, which is among the three, so that's why it is consisting of 82% of earth volume. It is composed of rocks made from the compounds of silicates and oxygen, also concl... includes layer which are consisting of iron and magnesium in abundance, then fragments of mantle, like what happen like, as I mentioned like, the earth is composed of different-different layers, some layers depending upon the relative combination of temperature as well as over burden pressure, some, while some are in solid state and some are in semi solid state or viscous state, some are in molten state or liquid state. Because of the temperature variation, particularly in mantle. So the… the portion of the mantle which is in contact with the core will be having relatively lower temperature in comparison to the portion of the mantle which is in contact with the core. So because of this, a temperature variation between the crust as well as the core, generates a convection current in the mantle, so the material in the mantle, which is in contact with the core, will be, I mean, subjected to very high temperature, as a result of which it will become lighter. When it becomes lighter, it will start moving towards the crust or to the upper part of the mental. On the contrary, the matter, which was earlier in contact with the crust became now cooler in comparison to the rest of the medium and mantle. When it becomes cooler it becomes denser and it will start sinking. It starts sinking and it will come to the bottom. So thus rising and lowering of the material of the mantle because of… because it is subjected to very high temperature or subjected to subsequent cooling as it reach near to the crust, as a result of which there will be current, convection current in the mantle. Like this, it's like cooling of material or denser. So this is like your core interface and this is your crust interface and this is your mantle. So the material which is at this was subjected to 30… 370°C, here it was subjected to close to 3700°C. Mostly when we talk about convection current, we also… we talk like convection current, which are responsible for movement of different plates coming from the upper part of the mantle. So as a result of which, so whatever, I am telling, more specifically I can tell about upper mantle, you are having lower mantle also. Okay this is like the material is becoming cooler as well as it is becoming denser. When it comes here there will be increase in the temperature as well as, so it will be like material heating up, material heating up and becoming lighter. So when it is becoming lighter, the material will rise on to the surface between the crust and the upper mantle interface. So this… this is a continuous process, as a result of which this continuous process, what will happen, it exerts some kind of shear, some kind of stress at the interface, which is responsible for pushing this crust away from each other. So like, if some two kinds of convection currents are generating here, because… so there will be some kind of plate movement. So this part is moving away from each other, this part is moving away from each other, which is called as diversion plate boundary. Same way you can have the two plates like we know, like entire earth is divided into different kinds of plates. So at some position those plates are coming in contact with each other, where at some location those plates are coming… are going away from each other and in some location, there is relative motion between the plates. So there is no like moving towards each other or away from each other. It’s a relative motion, slight past each other. So this is particularly like diversion plate boundary. Same way you can have conversion plate boundary also. If the direction of convection current on either side of the plate boundary is of similar nature. Like both are pushing the plate towards each other. Now one important parameter, observation here. So I mentioned like, the mantle is composed mostly of silicates and as well as oxygen. It also includes iron and magnesium in abundance then fragments of mantle. So as a result of which, the fragments or the material, which is coming out on to the surface from this particularly diversion plate boundary. That's why we call it as diversion plate boundary as constructive boundaries also because new material from the lower layers are coming on to the surface, particular example is like volcanic eruption brings the material in the form of lava on to the surface. When it spreads on the surface it actually creates a new land mass. So that's why these are called as constructive plate boundaries also. So the fragments of the material from the mantle are brought to the surface through volcanic eruption, more common in diversion plate boundary. And then because of the pressure of overlying layers, it's density increases with dept from 3.2g/cc in the upper part of the mantle to 5 g/cc near the core. An important observation here, as I mentioned like mantle can be further divided into two parts like upper mantle and lower mantle. So then people have identified, like though the mantle is in semisolid state and exhibits the convection current to the plate boundary to occur, the plate tectonics theory, which talks about the continental drifts, how different continents are moving either towards each other or away from each other. So it is because of the driving force, which comes into existence, because of convection current, as I explained in the slide, in this particular figure, because of extreme change in the temperature, within the same material. However, the people have identified the decay of radioactive material in lower mantle used to generate lot of heat during archean age, that is almost 3800 to 2500 million years ago. However, presently the rate of decay is so less to drive plates through the convection. So that means, overall what I want to say here, like the mantle overall it is divided into upper mantle and lower mantle. While the convection current in upper mantle is responsible for pushing the plates or diving of the plates either away from each other or towards each other. There were processes happening in archean age, which is like 3800 to 2500 million years ago. During that time there were decays in the radioactive material, which were present in the lower part of the mantle, which were also contributing to the convection current responsible for movements of the plates. At present the rate of decay is so less that the resulting convection current is significantly lower such that it can contribute anything to the plate movement. So presently the rate of decay is less to drive plates through convection. So whatever, convection current has been generated at present in the lower mantle is not sufficient enough to cause any kind of driving or to control the driving of continental plates or oceanic plates. Thus presently the mantle is considered as in semi solid state and not causing convection current. This is particularly for lower mantle. So the lower mantle in comparison to upper mantle is in semisolid state and is not responsible for any kind of convection current and hence he is not contributing anything to plate movement. So Tackley in 2000 and Korenaga in 2006 also concluded this observation.

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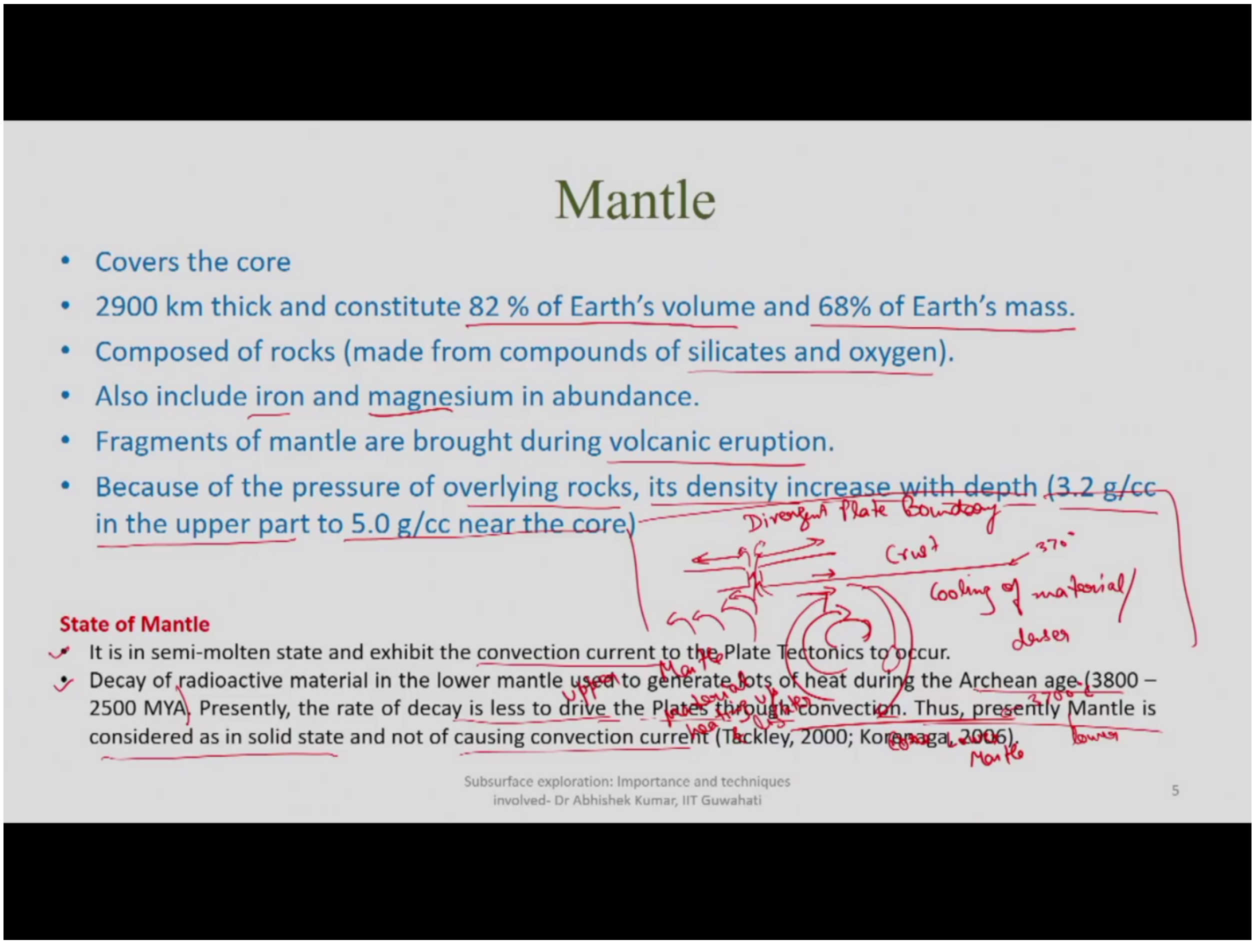

Then coming over to core. So core is extending in a diameter of almost 7000 km. You can consider. this is the diameter of the core, which is a solid, I mean, some part is solid. Sometimes it is again molten state. So density increases with depth in core. Average density is10.8g/cc. So you started with the density which is of typical material on the earth surface, starting with water, which is 1g/cc, then typical rock samples, which are in the range of 2.4-2.5 g/cc, then you move to mantle, where the average density is in the range of 5.2-5.3 g/cc, then you move to deeper layers further, where the average density is 10.8 g/cc. So the previous part, the earth volume in terms of mantle was 82%, here you see the earth volume is close to only 16%. However, so in case of mantle it is composed of 86% of earth volume and significantly larger portion of earth mass, here the earth volume is just 16%, but considering its very high density in comparison to the material which is available in the crust as well as mantle, the core is consisting of or contributing almost 32% of total mass of the earth. It is mainly composed of iron and nickel.

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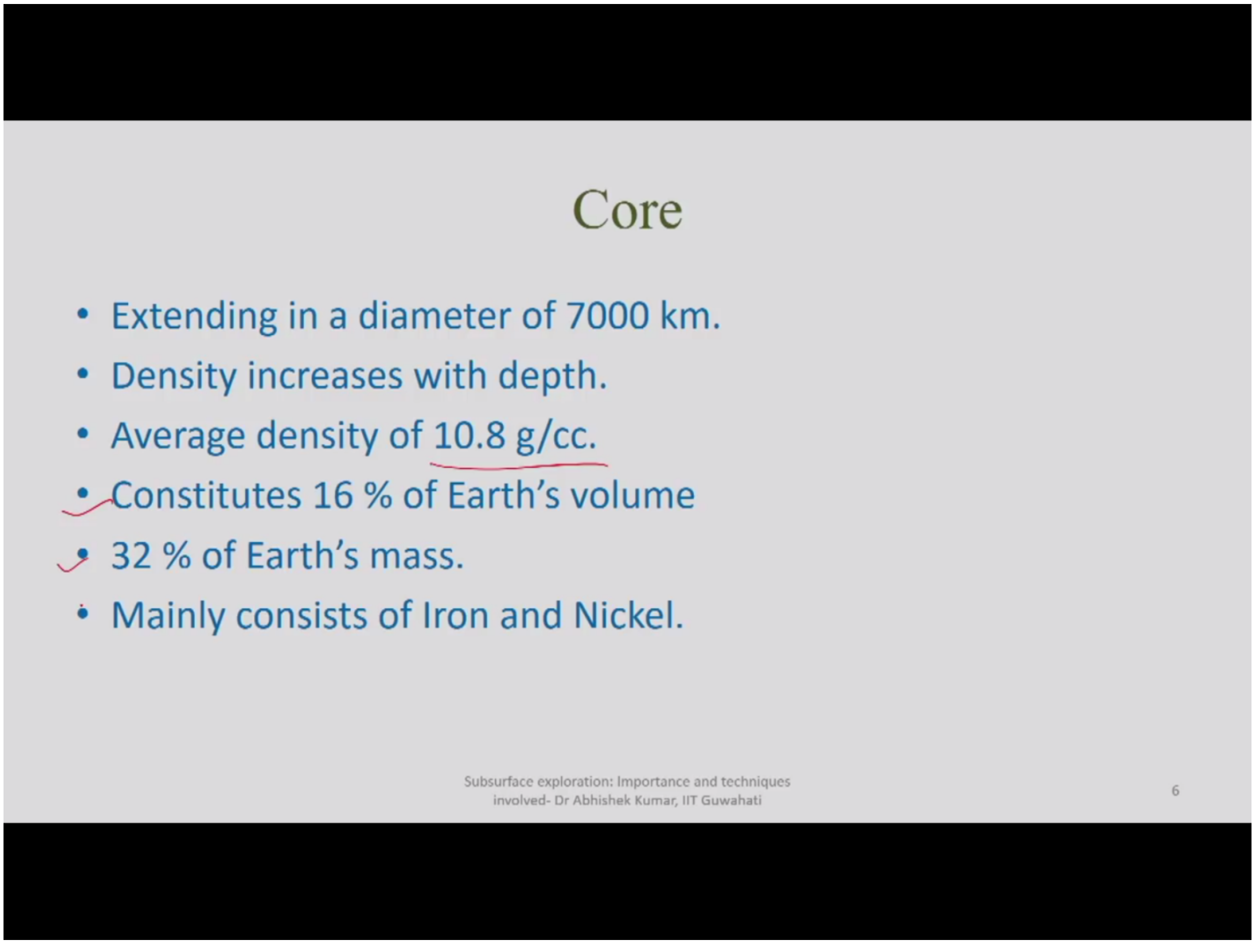

Now it is divided, the core itself is further divided into two parts, one is called as the outer core and another is called as inner core. So outer core, which is extending between 2900 km depth to 5100 km depth, then alloy of iron nickel having temperature ranging from 4000 to 5000°C in liquid form and which is again causing some kind of convection current. You see, like the top surface is subjected to somewhere like 3500°C and at the bottom your are having as high as 5000°C as a result of which there is convection current in the outer core as well, which is also... again is in molten state, composed of different alloys of iron and nickel. It is also responsible for earth's magnetic field, which we are going to discuss in coming slide, due to its high density and constant motion as well as metallic properties. It also cause shift in magnetic poles, which again we are going to discuss further in detail. So inner core, again as you travel further inside the earth, you will come to know, there is inner core also, which is extending from 5100 km and continuing till 6400 km, that means you reach exactly at the center of the earth. So that is like, the solid core mostly composed of iron, having temperature of 5000-7000°C as high as on the surface of the sun. Even though the temperature is so high, like in the range of 5000, 6000, 7000°C, but still the core because of overburden pressure of different layers, which is equivalent to the density of that material, multiplied by the thickness of that particular layer, plus density of superior… I mean, the material which is above outer core, then mantle, multiplied by the thickness of each layer, so that you can get an idea, how much enormous pressure is subjected to the inner core, as a result of which, though the temperature is very high, the overburden pressure keeps the material in solid state and does not allow it to melt. So the material, which is subjected to so much high temperature, but also subjected to so much high pressure because of outer layer, mantle, and crust, it is not able to melt and that's how the inner core is in solid state unlike outer core.

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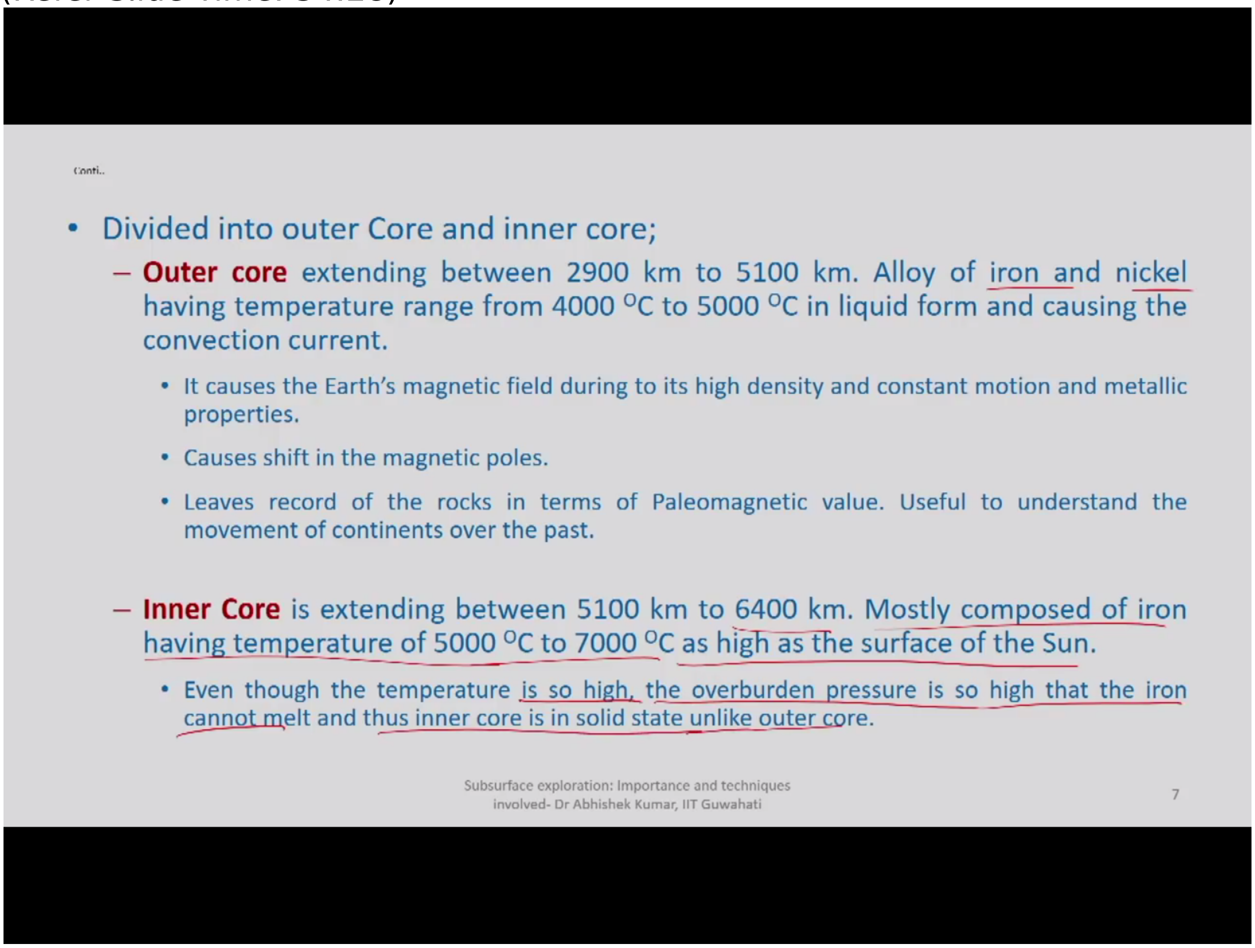

Now the overall purpose of getting introduced to different layers of earth is like, as a part of magnetic survey we are interested to understand the magnetic properties, but before going for understanding magnetic properties, it is equally important to understand why these magnetic properties come into picture, why the characteristics of the material in terms of its magnetic characteristics is coming into picture. So as I mentioned, because of the convection current, which is primarily due to temperature gradient in the upper mantle, it is causing some kind of convection current responsible for plate movements in different-different directions. Parallel because of this plate movement the material from the upper mantle also reaches to the ground surface, create new landmass. Same way. If you go to convection… subduction plate boundaries, the one layer might be subducting under the other layer, that is called as some kind of consumption of land mass. So that is happening parallelly, as a result of which some places you are having creation of landmass and some places you are having consumption of landmass. Now overall what I wanted to say here, like the core. So you are having core like, outer core, which is again in molten state, composed of iron and nickel and again very much similar to your upper mental, it is also subjected to some kind of temperature gradient, like the bottom most part of outer core is having temperature of may be 6000°C and top most is in the range of 3000-3500°C as a result of which again there will be some kind of temperature gradient between the upper part of the outer core and the lower part of the outer core. As a result of which, again there will be some kind of convection currents in the outer core. Now above the outer core there is semi molten… semi solid lower mantle and below it, it is solid core. So as a result of this convection current, what happen, it again starts some kind of shear stresses or some force, which is responsible for pushing the core, the solid core as a result of which again the solids… the solid core is actually… is in continuous motion. So considering the presence of iron, now you are having some material, which is actually solid, which is iron, which is having like magnetic characteristics, you are actually rotating that material, so as a result of which there will be generation of electric current. So some material which is having magnetic property, if you rotate, very much similar to generation of electricity, so there will be some kind of magnetic, electric current. And then once you are having electric current, perpendicular to that there will be magnetic current also, if… if there is some kind of dipole characteristic of the medium. So considering the presence of iron at a high temperature in solid core and as a result of convection current generated due to temperature variation in the outer care, drives the inner core. So the inner core, which is a solid wall of iron is actually in continuous motion because of convection current as a result of which the inner core rotates just like a dynamo, resulting in the generation of electric current. So in the inner core you are having electric current and further because of its magnetic properties, again there will be magnetic current coming into picture, which you actually see in terms of magnetic north and south pole. So for magnetic force to exist, there should be a dipole very much similar to a magnet. So if you see a magnet and if you bring any material, which is kind of reactive to this magnet, like which gets orient to magnetic north and south pole, it should have some kind of dipole characteristics. The… so even our earth is consist of dipole characteristics. You are having a magnetic north and magnetic south. So you are having… because… because of different layers, temperature variation. It is like convection current is coming into picture at different layers, whether it is upper mantle, whether it is outer core. Upper mantle is responsible for movement of the different plates across the globe, whereas the convection current in the outer core is responsible for movement of, rotation of solid inner core, which is responsible for generation of electric current and subsequently the magnetic field, which can be indicated by the presence of magnetic north and magnetic south pole. The present inclination of axis joining the magnetic north and south pole is almost 11° with respect to geographic north and south pole. So one is like purely vertical and other is like magnetic north. So it's at… the… the two axis are by difference of 11° inclination.

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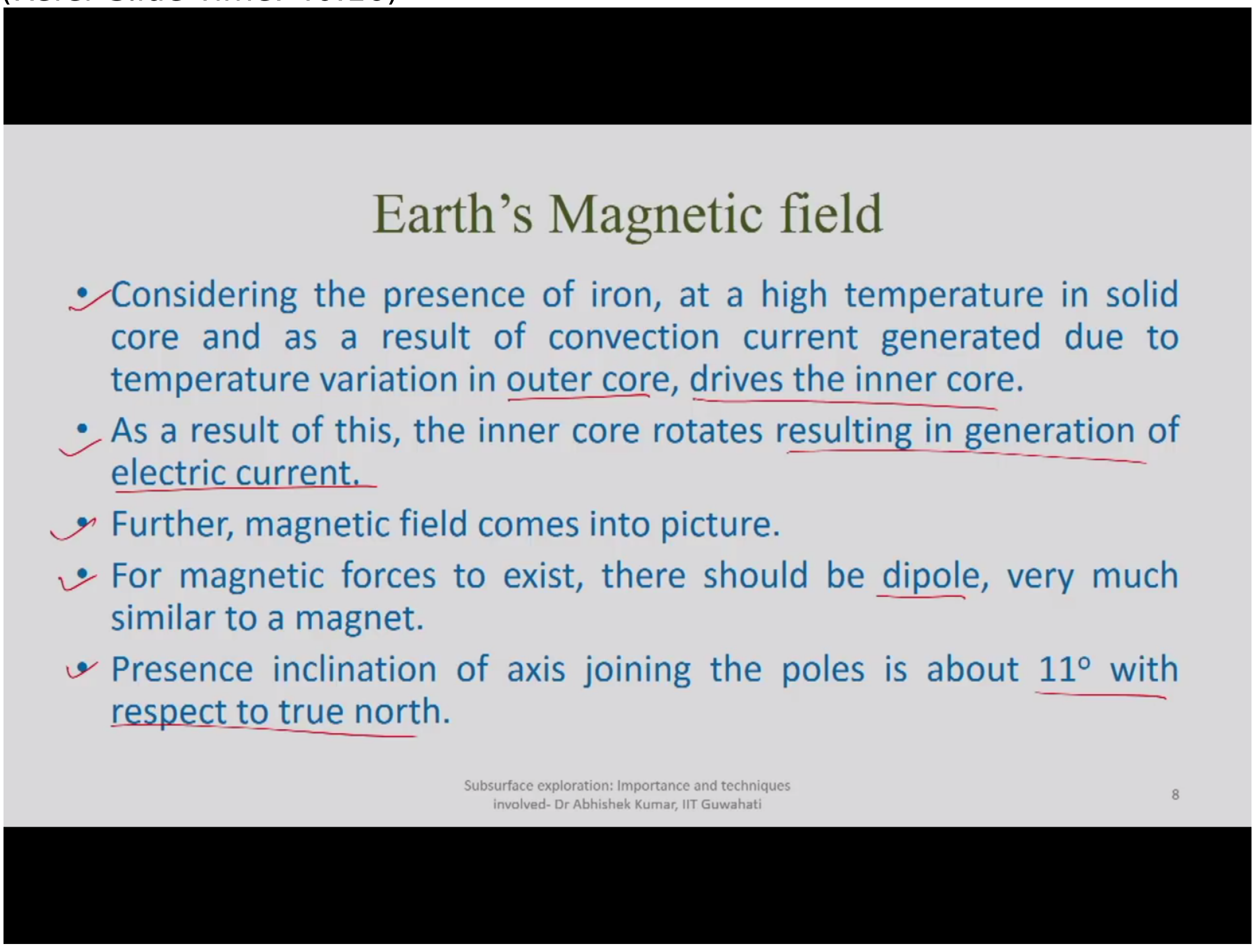

Now change in polarity, this is one important parameter. Whatever, current configuration of magnetic north and magnetic south pole we see, it's not a constant configuration. Rather it keeps on changing in every several 1000 years, which is also called as geomagnetic reversal. The present configuration of magnetic poles keep changing. So the period in which such change occurs is defined as Chrons. So every time there is some change, that period is called as Chrons, one Chrons, two Chrons, and at times people have named also these Chrons, as can be found in the literature. So while normal polarity, normal polarity means whatever configuration we are seeing at present with respect to magnetic north and magnetic south pole, if in the past also the same configuration was there, that is known as normal polarity, indicates the present configuration of the magnetic poles. Reverse polarity, if it has happened in the past, it is responsible… it is indication of the… the present magnetic north was magnetic south and present magnetic south was magnetic north, in some particular period in terms of geological time scale. So far as per study by Leonardo et al., 2014, it has been found like so far, this change in magnetic poles or reversal in magnetic configuration or geomagnetic reversal, whatever, we say, so far 183 times such kind of reversal has happened in the last 83 million years. So this has been found in very interesting story in 2014. Again as per Byrd in 2018, every kind of reversal configuration lasts for almost 200 years, like the south becomes north and north becomes south, so that lasts for almost 200, 250, 220 years and then it will come to its normal polarity. A complete reversal again as I mentioned like this Chrons often are nomenclature, so a complete reversal known as Laschamp event occurred almost 41000 years ago, so almost 41000 years ago, there was complete reversal in the present configuration. So the present magnetic force direction also became reverse, that can be understood. So overall what I meant to say, the.... Because of convection current, there is magnetic force again depending upon the direction probably of core rotation. This magnetic force or magnetic pole configuration also keeps on changing.

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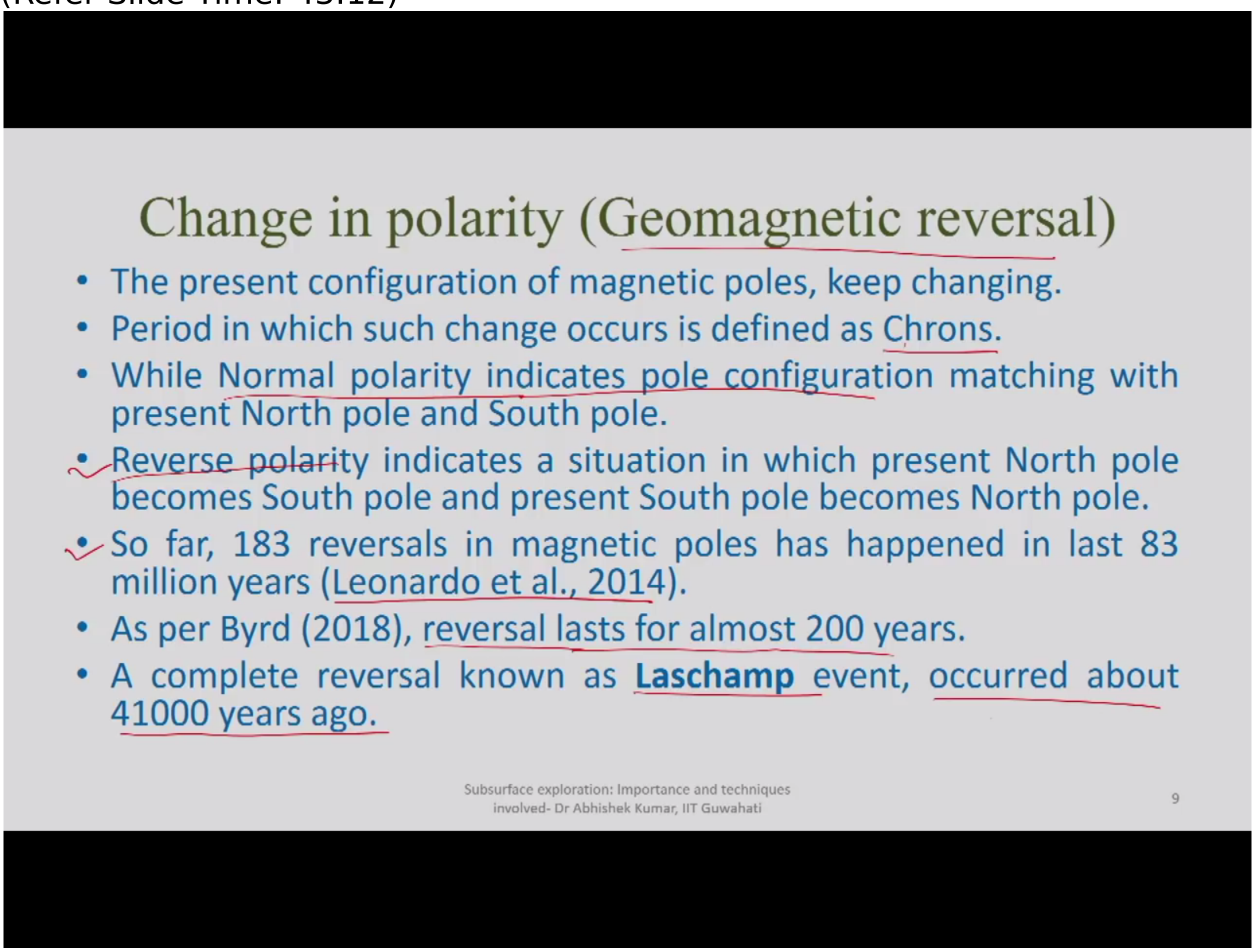

In early part, now how people understood, like this, about this reversal in the magnetic pole configuration. So in the early part of 20th Century, geologist reported like they were trying to understand the… the raw characteristics, which have been primarily volcanic deposits and they understood like the magnetic characteristics of two rocks in similar region were showing reverse orientation, like by some rocks, because the rocks which are primarily coming from mantle, as I mentioned consisting of iron and magnesium, because of its magnetic characters often what happened when these rocks come in on to the surface, so the magnetic minerals get orient in terms… in the direction of present magnetic north and south pole or the magnetic south configuration, north-south configuration at that time, these minerals came on to the surface and getting cooled. So it's like, if any deposition, which has happened in the Laschamp event will have mineral orientation reverse in comparison to the mineral orientation at the same location, which is happening at present. So it keeps on happening, depending, because deposition is again a continuous process, magnetic pole reversal is also happening though in geological time scale, but it is also a continuous process like at present whatever, is the configuration, may not be there, maybe several 1000 years back. So if you see, if you compare the… the mineral which are deposited at present and the mineral, which are deposited may be at the same diversion plate boundary several 1000 years ago may show completely a different characteristics in terms of its magnetic orientation and magnetic characteristics. So while some rocks inclined, when people started analyzing the volcanic rocks available in that particular region, they started analyzing like while some rock indicate magnetic deposition, matching with the present configuration of the magnetic poles, other show a complete reverse field. So reverse field in terms of magnetic configuration, which is indicated by deposited magnetic minerals is an indication, like the time when these deposits were cooled or came on to the surface, the direction of magnetic north and magnetic south was not as same as it is today. So that gives you an indication just by understanding the magnetic characteristics of minerals or rocks containing those minerals in a larger area, like the… the magnetic characteristic of the poles or the magnetic configuration of the poles have undergone any kind of possible change or reversal and if same thing you keep on changing at subsequent interval, you can understand this reversal is a continuous process. So based on the dating method, it was found in the rocks, which were showing reverse magnetic field belong to Pleistocene age. Like we know in… in terms of geological time scale, where there are different eras, like Cenozoic era, which is starting from today till 66 million years ago, then you are having Mesozoic era, which is from 66 million years to 252 million years ago, and then Paleozoic era, which is like 252 million years ago to 541 million years ago, and so on and so forth. So depending upon different time scale, the configuration of magnetic mineral may be matching with the present configuration or as subjected to any kind of reversal in the magnetic pole configuration. So it was found like, the minerals, some minerals are there, which primarily has been deposited

during the present magnetic pole configuration, while other minerals may be at certain distance from the... this sample, were deposited again in some may be, different geological time scale, preferable where the configuration of magnetic mineral was completely different. So Pleistocene age, which is ranging from 2.5 million years to 0.12 million years ago.
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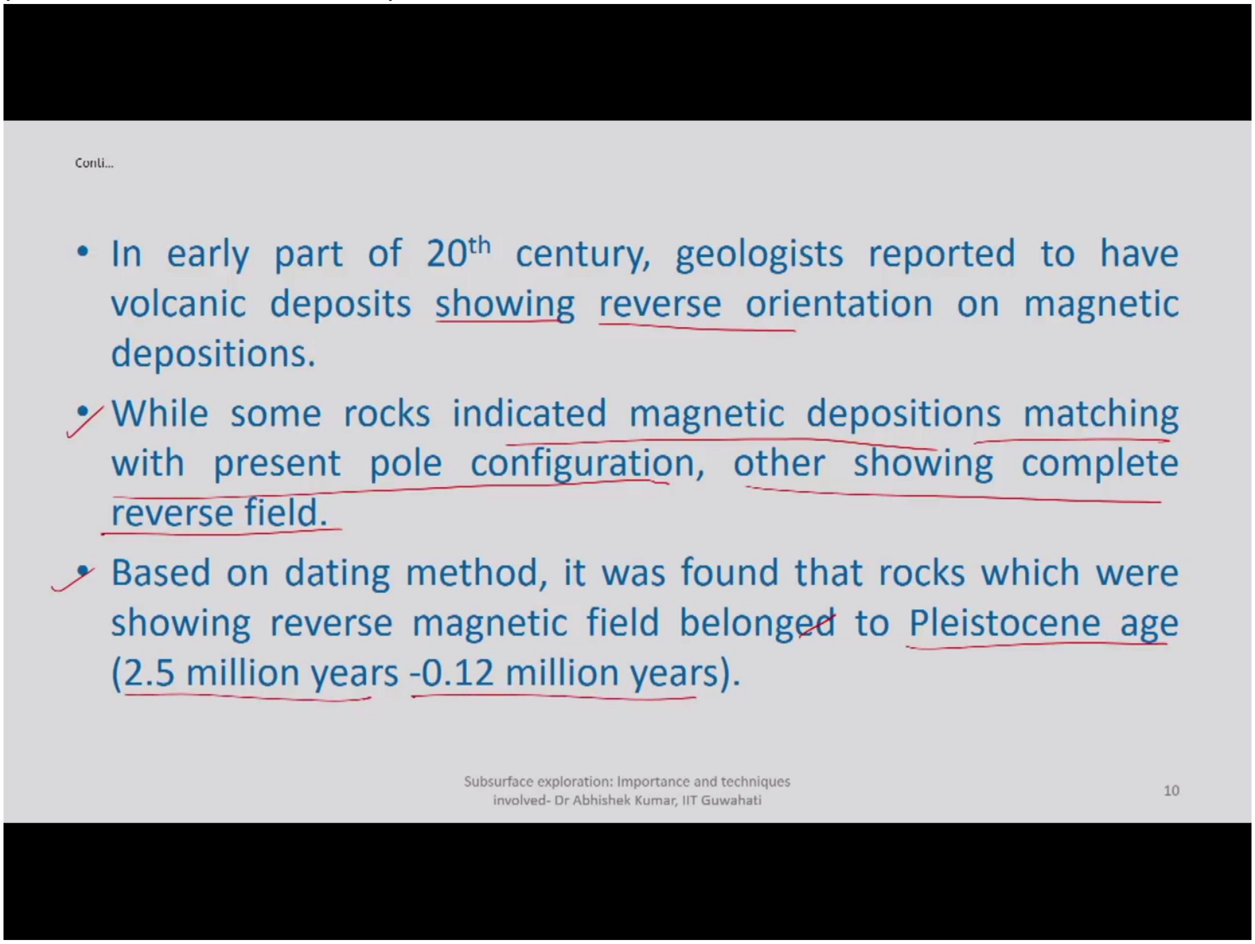

Now important observation, now we understood so far like one is like rotation happening at the core responsible finally for the magnetic field. Second is, because of this magnetic field, whatever, material coming out from the upper mantle on to the crust is also getting oriented. So that means, if at the plate boundaries mainly the diversion plate boundary, new material from the mantle comes on to the surface and get deposited. So it's a continuous process. The material is coming on to the surface as far as the volcanoes are active, material is coming on to the surface, it is getting deposited, it is getting cooled, this way new surface is formed, it may be at one place or may be other places, so this process is happening all across the globe, wherever volcanoes are there particularly active. Then you are having molten material, which is coming on to the surface, having magnetic minerals. The minerals which are having, which are attracted towards magnetic north and south poles are also contained or are composed in this rocks or may be molten material, which is coming on to the surface. So these materials or mineral at the time of deposition and subsequent cooling, these minerals, just like you take a magnet and subject it to free, I mean just free hanging from a thread, it will orient to its… to magnetic north and south pole, considering present configuration. Same mineral or same mineral characteristic, if it is there in particular material, which is coming from the mantle and getting deposited on to the surface, so all those minerals, which are contained in this molten material will also oriented themselves to the magnetic north and south pole, which is available at that particular location and that particular geological time scale. So this way, magnetic rock preserve, this is most important thing like, it is actually preserving. So whenever in geological time scale, the rock came on to the surface, getting densified or cool. It actually preserved in terms of orientation of magnetic minerals or in terms of its magnetic characteristic, it actually preserve, what was the characteristic of the medium, what was the characteristic of magnetic pole configuration at the time it had happened. So later stage if you bring out that material you can get an idea about what was not only the age of that resemble, but also what was the configuration of magnetic and north and south pole at the time when it was deposited. So it actually preserved the characteristics of pole configuration into that.

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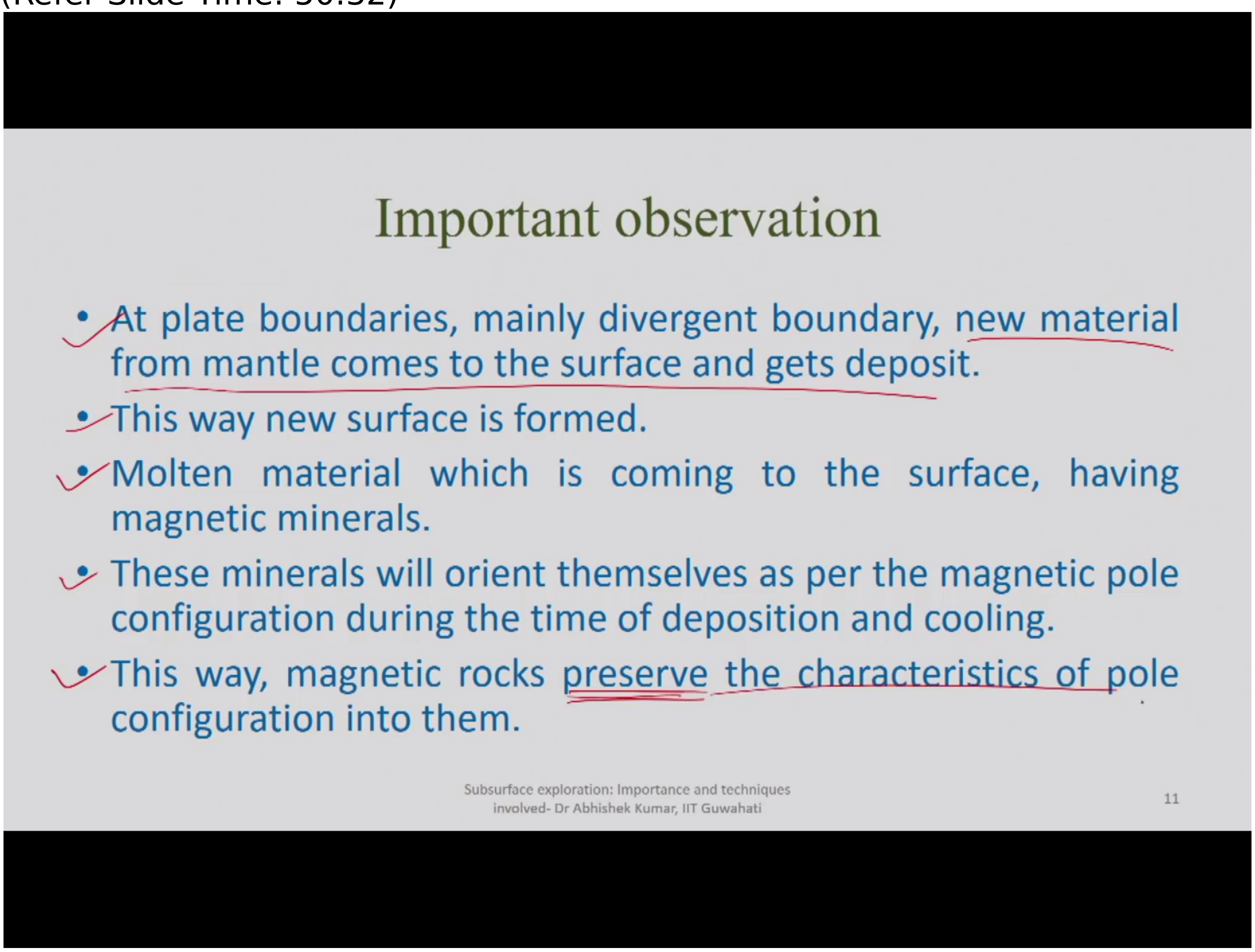

So at the diversion plate boundary, the deposition of material is a continuous process. Like the material keeps on depositing, which means that just at the plate boundary, the deposition characteristic will be matching with the present configuration. However, because the plate boundary itself is moving, so there might be material, which has been deposited today, but after may several 100s or 1000 of years ago, the same material, which is deposited today, will be at certain instance away from the plate boundary. Now if you observe this thing over a long distance away from the plate boundary, you can see the matter which has been deposited at different-different geological time scale, because of this, the matter, which is coming from the mantle. Now as you are near to the surface, which is particularly the deposition oriented in present configuration of mineral, the material which has been deposited and cooled may be several 1000 years ago, which may be… may be several km away from the plate boundary will have some configuration, which is indication of magnetic pole configuration at the time of deposition. So based on the age of deposition, mineral orientation, the configuration of magnetic polarities in the geological time scale can be assessed. So this one important, like however, away from the plate boundary, depending upon the rate of deposition, because that also depends upon the rate at which the diversion plate boundary is moving away from each other and the configuration of poles, the material even at the same plate boundary as you are going away from the plate boundary, different material may show different characteristics in terms of its magnetic properties.

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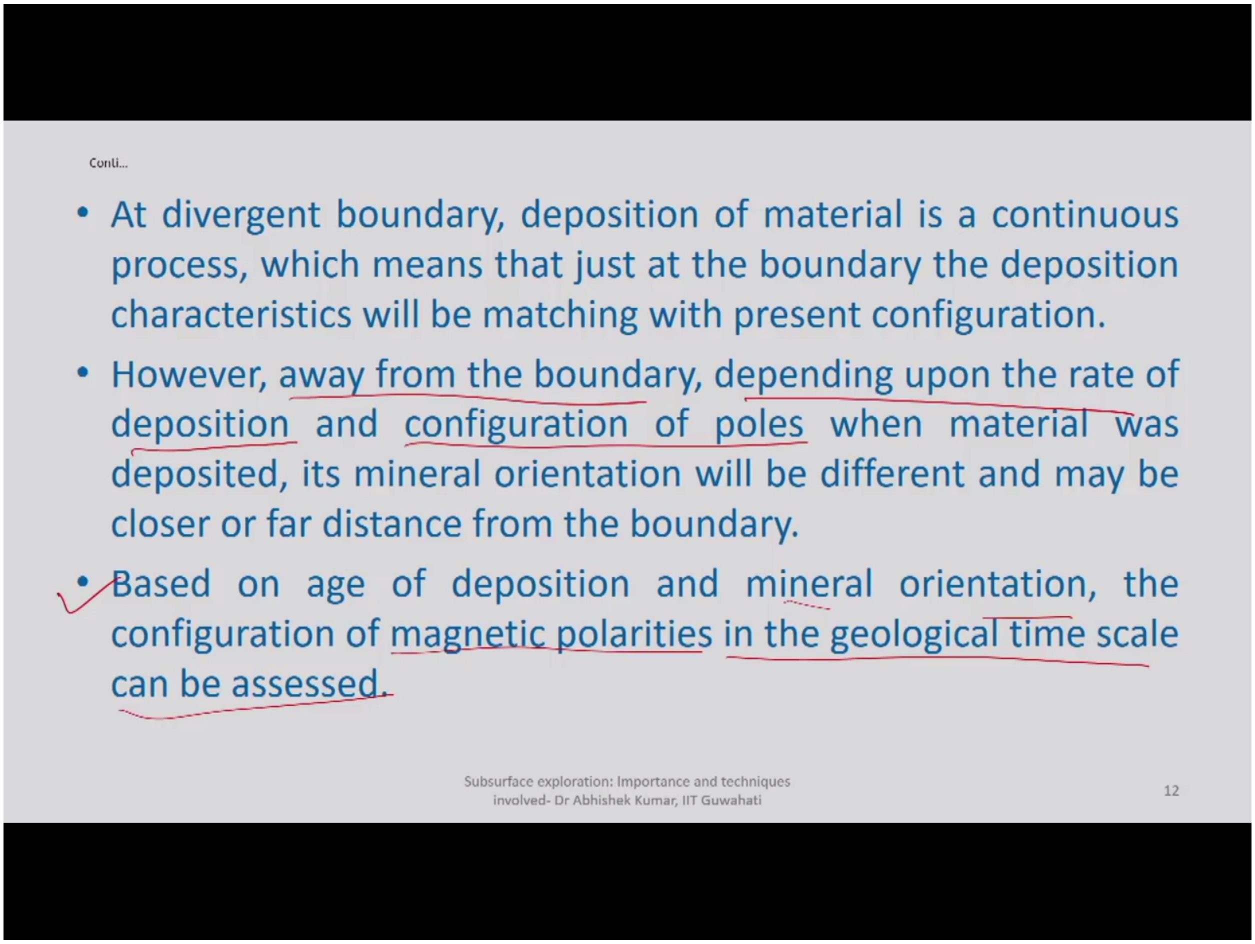

Now what I wanted to show here it's like, if it is a diversion plate boundary, what will happen here. So this is like plate 1, this is like plate 2, and because of this material will come on to the surface because of confection current. So this is going in this direction, this is going in this direction, material will come on to the surface and getting deposited. Now this is also moving, this is also moving, so what will happen at time 1, material will be deposited here, followed by subsequent movement of the plate, so what will happen at time T2, the same material which was deposited at time T1, will reach this particular location, similarly here also it will reach this particular location at time T2. Again at the present configuration, which is like T knot, some other material will be deposited here, so I am telling here deposit 1 and deposit 2, deposit 2 reach to its position because of movement of diversion plate. So if you take this particular material, it will… it may show a different configuration or reverse polarity, because it was deposited when the configuration of magnetic poles were different. Again this one is may be normal polarity. Now if you see here there is continuous deposition of material throughout. So if you take this thing in plan, you will have something like this, so you will have some material like this. So it's like may be normal polarity, reverse polarity, normal polarity, reverse polarity, depending upon what is the duration for which normal polarity existed and what was the rate of divergence at that particular geological time scale, I mean that particular plate boundary. So same way you can understand. Now, so this is going to under... give you an idea about what is, on an average what is the average magnetic property of subsurface medium of medium. This is the overall understanding why magnetic field come into picture. How these magnetic properties are getting stored in the depositions. So these are basically the depositions of rocks containing magnetic mineral.

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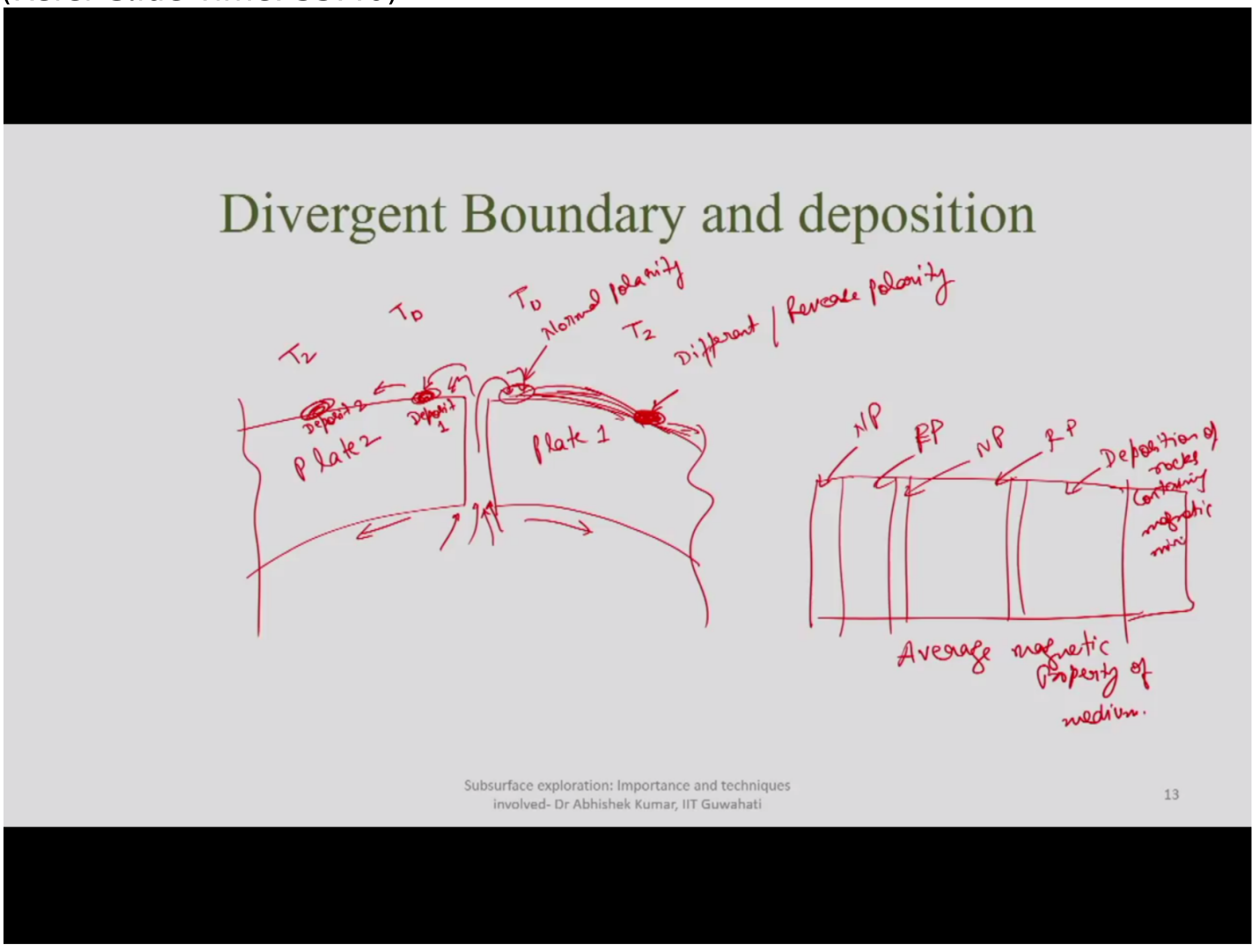

Now we are interested in magnetic survey 1 is like, you... as a part of geologist, sedimentologist, you can understand what is the magnetic characteristic of the medium on an average, depending upon when it was subjected to which kind of magnetic pole configuration and other thing is like. So based on the deposition and configuration, you have on an average the medium characteristic in terms of its magnetic properties. What will happen? Depending upon the characteristics of diversion plate boundary, the mineral deposition in addition should be indicative of average magnetic properties. The mineral which has been deposited under same pool configuration will show almost same type of magnetic properties or to be constant or on an average, not significantly varying. Now what will happen in case of small magnets, when it comes in contact with earth's magnetic field.

So you are having additional material which is also susceptible or which is also showing some influence by the earth magnetic field, whether it is increasing the magnetic property at that particular location or decreasing the property as a result of which there will be additional change in the magnetic force at that particular location. So this material, what is contributing to some change in the existing magnetic property or some change in magnetic property with reference to average magnetic property is actually the material you are trying to understand in terms of magnetic anomaly, which is possibly indication of subsurface material characteristics. So the presence of material such as ore deposits, unconformity, buried objects, voids, which are responsible for some change in the magnetic characteristics, with referral to or with respect to average magnetic characteristic in the surrounding region, this is possible indication of magnetic anomaly. So if you are able to detect this magnetic anomaly, that means on an average some magnetic property should be there, but if you go to the site, it is possibly indicating you different value, slightly different value. So this slightly different value may be possibly indication of some change in the subsurface medium, because of additional material present or reduction in the material, which is present in this particular location, may be because of discontinuity void or may be because of buried object, which are actually exerting additional property to the magnetic forces, which are available at the particular site of interest. So which can cause change in the magnetic characteristics in comparison to average characteristics in comparison to average characteristics. Remember there is a part of subsurface exploration program. So we are interested to understand the subsurface property. So any property which is dominated by magnetic characteristic, possibly like over deposit, unconformity , or voids like, due to some reason, particular deposited mineral has been washed away or, it is not there, so void in that particular sense. Like the magnetic property in a very smaller area, confined area is not matching with the surrounding area, possibly indication of void or unconformity or some kind of material which is not the… is not parent in nature or buried object again influencing the magnetic property. So it's actually causing some kind of anomaly to your magnetic properties.
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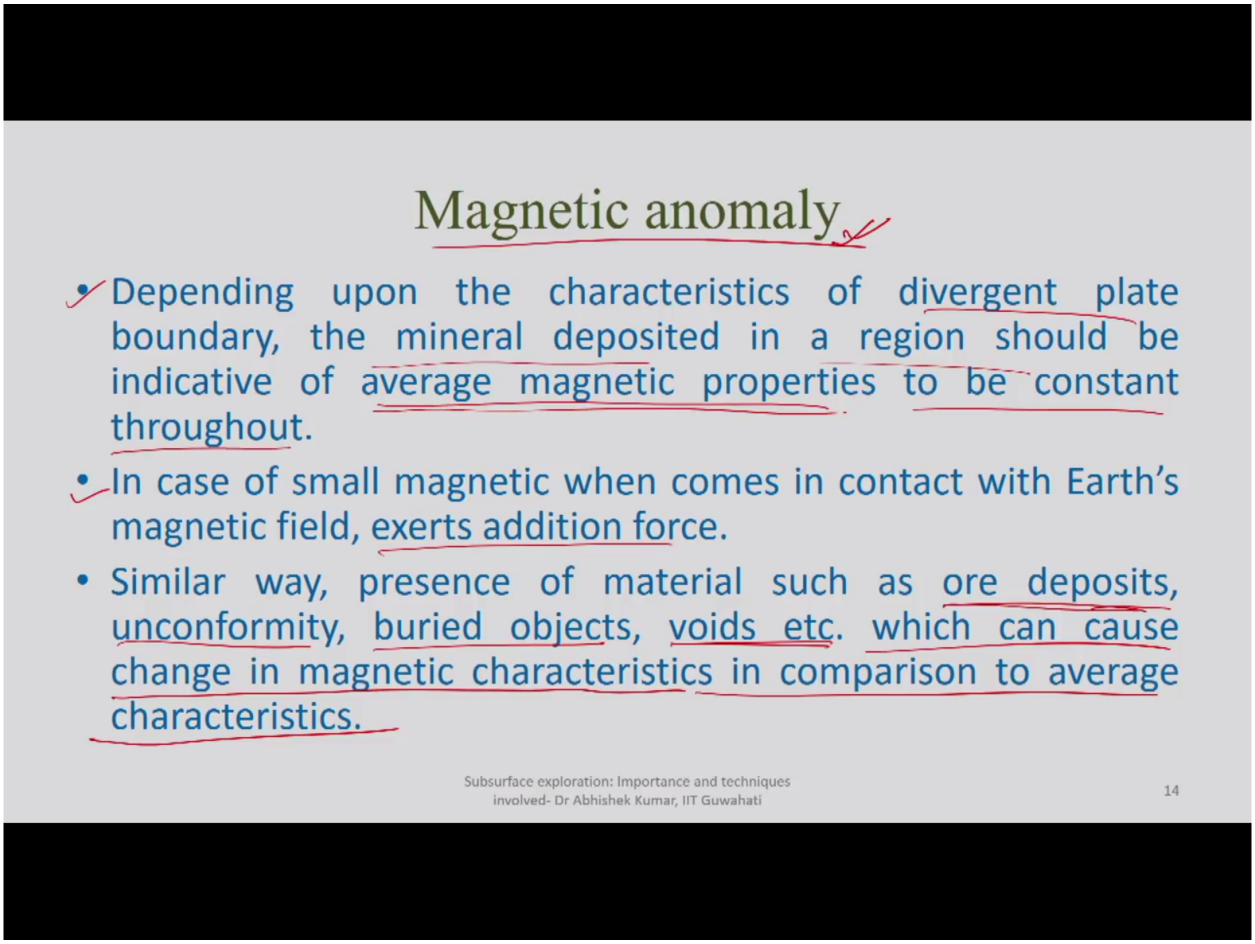

So such changes can be detected based on the field measurement is known as magnetic anomaly. So field surveys based on magnetic method targets to understand subsurface medium characteristic based on observed magnetic anomaly. To give you an example, if this is your ground surface and then you are having some buried object, may be here, which is not parental in nature. If you do some kind of magnetic observation here, it will actually show some kind of change in your magnetic properties here. Based on, so this is, you can consider it as magnetic profile. So any kind of jump or increase in your intensity of magnetic field… of magnetic field, possibly indication of subsurface characteristic change… change. So that is what magnetic anomaly methods targets to understand. Same thing you can go with… with case of ores also, faults, because again on either side of the fault, you may find depositions in different geological time scales, so again that can also be getting an idea about possible indication of faults.
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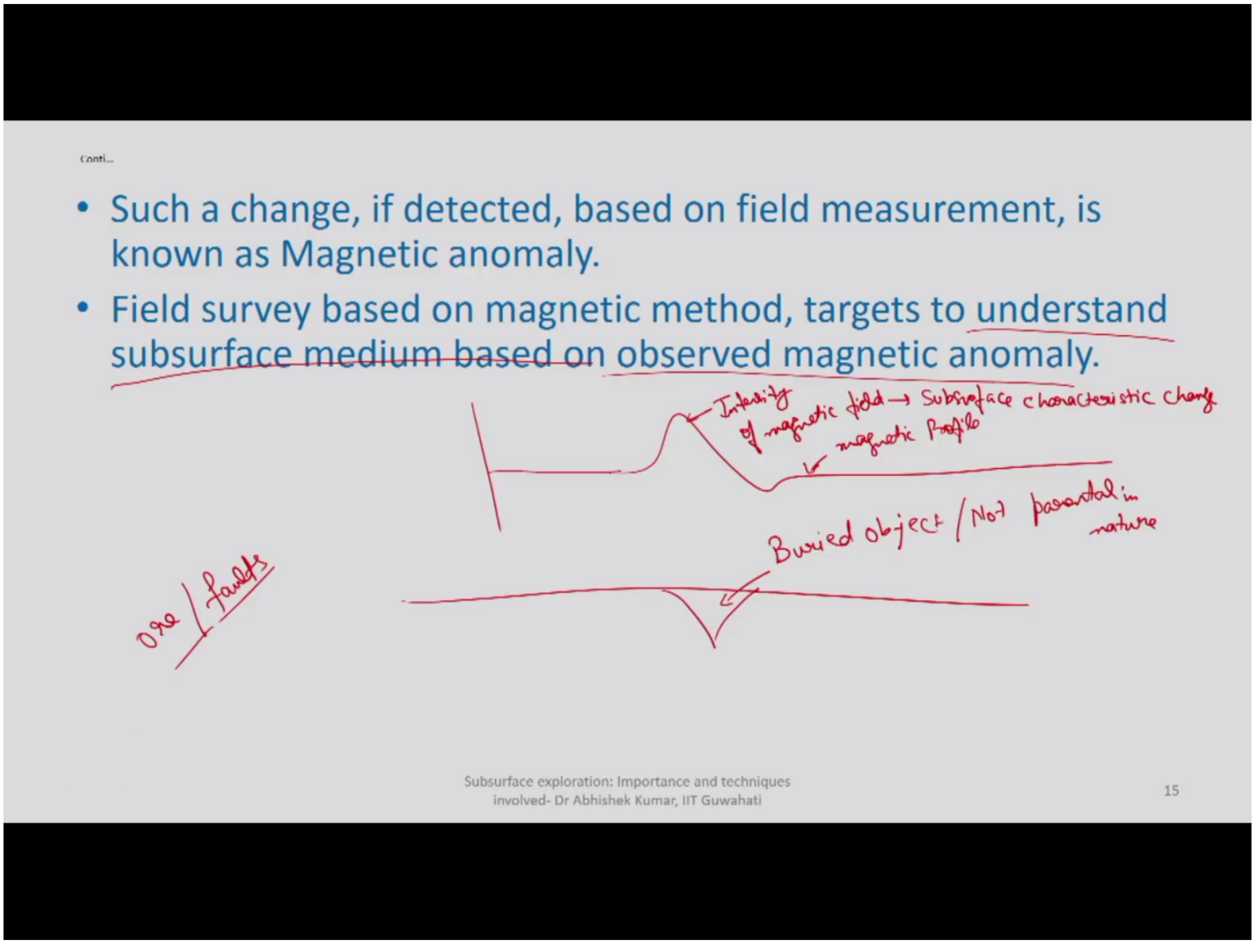

The instrument you used, magnetic.... Magnetometer, which is generally used for measuring the absolute value of magnetic force intensity at the site of the interest. Commonly used methods, instruments are proton procession, then alkali-vapor or optical pumping, flux gate magnetometer. Not go into detail of these methods.

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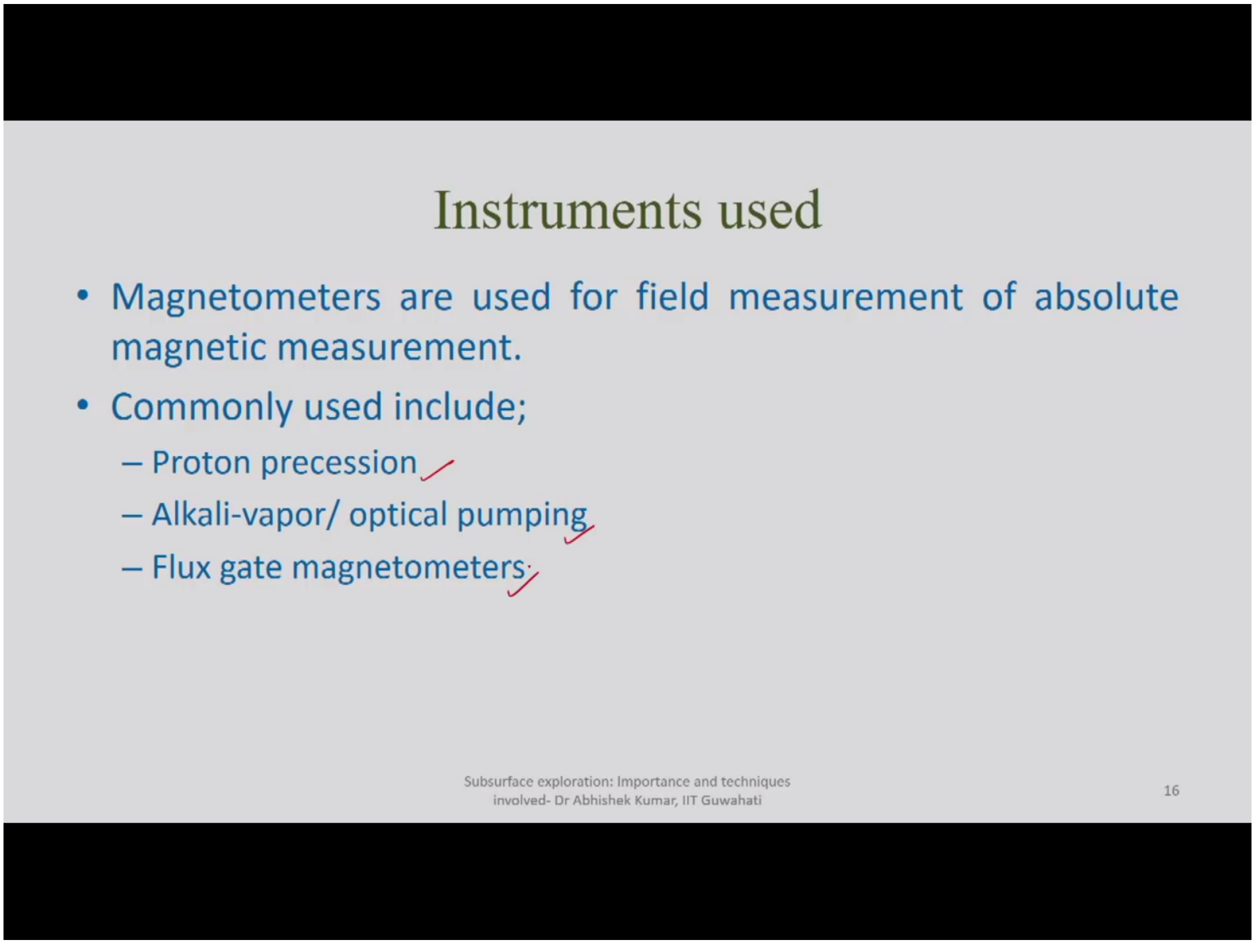

But overall the purpose of this, today's lecture is to give you an overall understanding, what magnetic anomaly method or what magnetic survey targets in terms of subsurface exploration, which is particularly the objective of present work. Then survey you can do this magnetic anomaly test, you can do on ground also from air also you can do and based on satellite data also you can do, if the data required for these kinds of analysis is there. Offshore vessels, lot of people, because this test particularly started when people started understanding the sea floor characteristics. So it is more commonly used in offshore investigations also and in order to also understand the continental drift or oceanic drifts.

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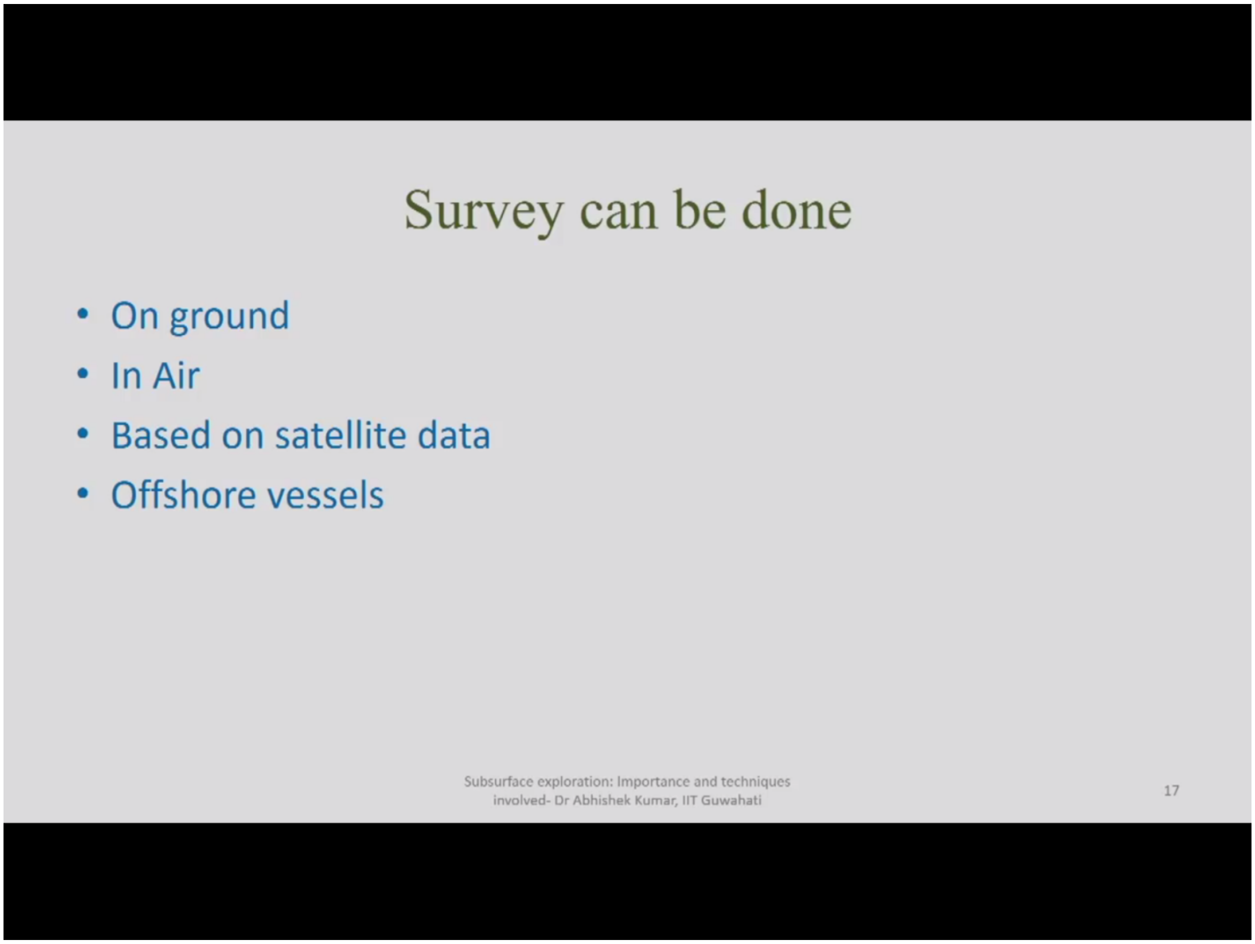

Then application, it can be used to locate drums, piece, metallic objects, buried military objects, such as shells, bombs, and other things, and underground coal burns, mine shut. But in order to detect it, it should have some kind of effect of on magnetic property at that particular location, otherwise, it will give you completely, I mean you will not be detect or identify the possible magnetic animal here. Then this is like, based on this you can actually locate, if those kinds of material are there, also you can use it for mapping archeological structures such as symmetries and then landfills, dikes, faults, as I mentioned because… because of unconformity or deposition characteristics and weathering characteristics on two sides or the medium characteristics on two sides of the faults, it may give you some kind of magnetic anomaly, which can, if you can detect by magnetic survey, you can get an idea, okay possibly there is a fault here. Then steep geological features, which is also contributing to significant change in your magnetic properties.

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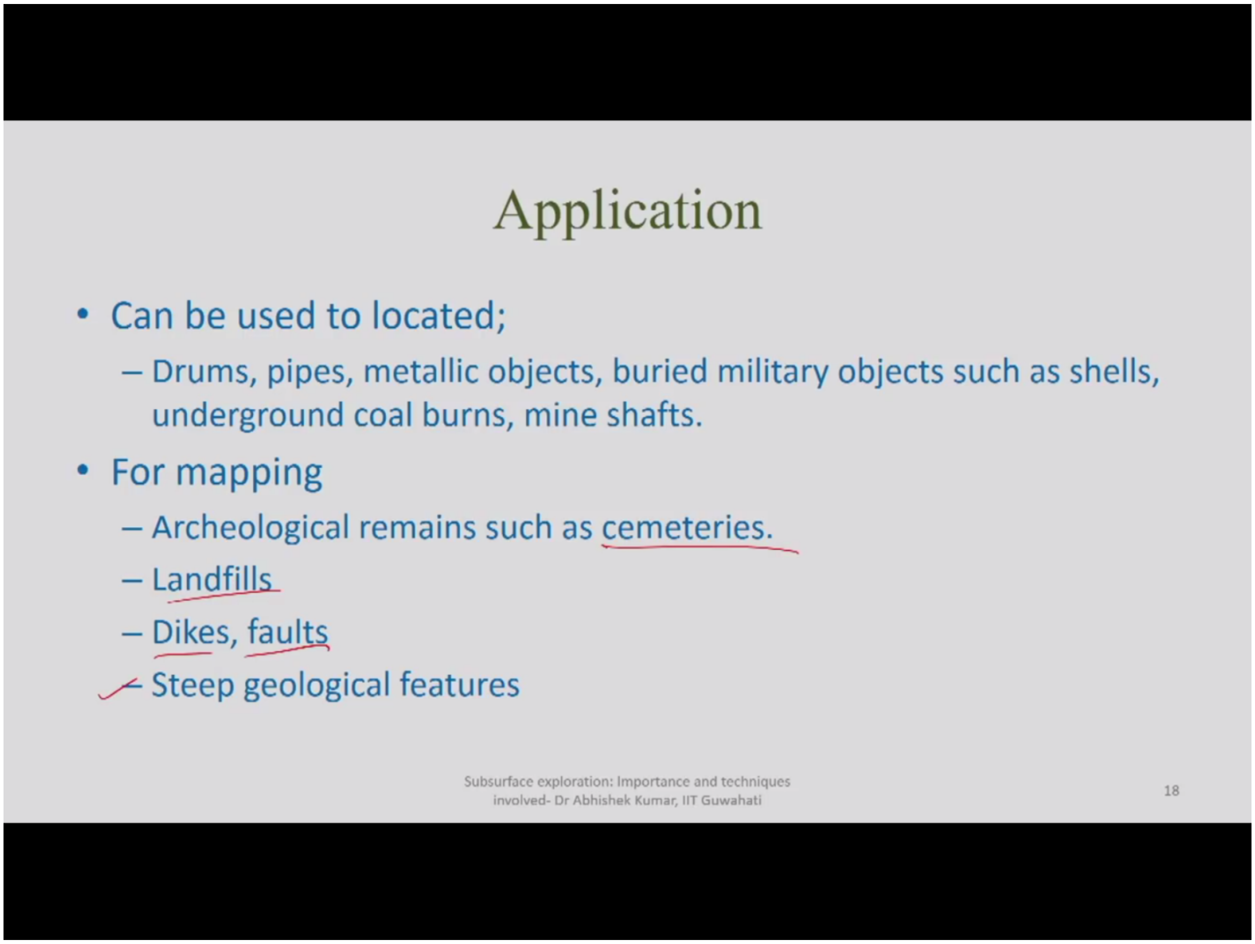

So usefulness and limitation of the test. Though it is very quick method of exploration. Field observation again are very easy and less expensive. It can… you can do the test even from a small vessel to large vessel, particularly if you are doing for offshore environment. Even now a days, people when trying to understand the seismic characteristic of adhesion, such tests are very well used to… to understand the ongoing seismicity or identification of new faults. So magnetic method also can be used. Disadvantage, the presence of scrap metal, electric cables, probably is not your target, but it is available in the surrounding area, can actually partially alter your measured field magnetic intensity values and thus this method is not suitable, as suggested by expert for urban areas. So the material, again the material with magnetic characteristics can be detected. So the material which are not in magnetic characteristics, you cannot use it for those kinds of met… subsurface medium identification. The resolution decreased with depth. It decreased very quickly with the depth, so that is another limitation with the… this particular method.

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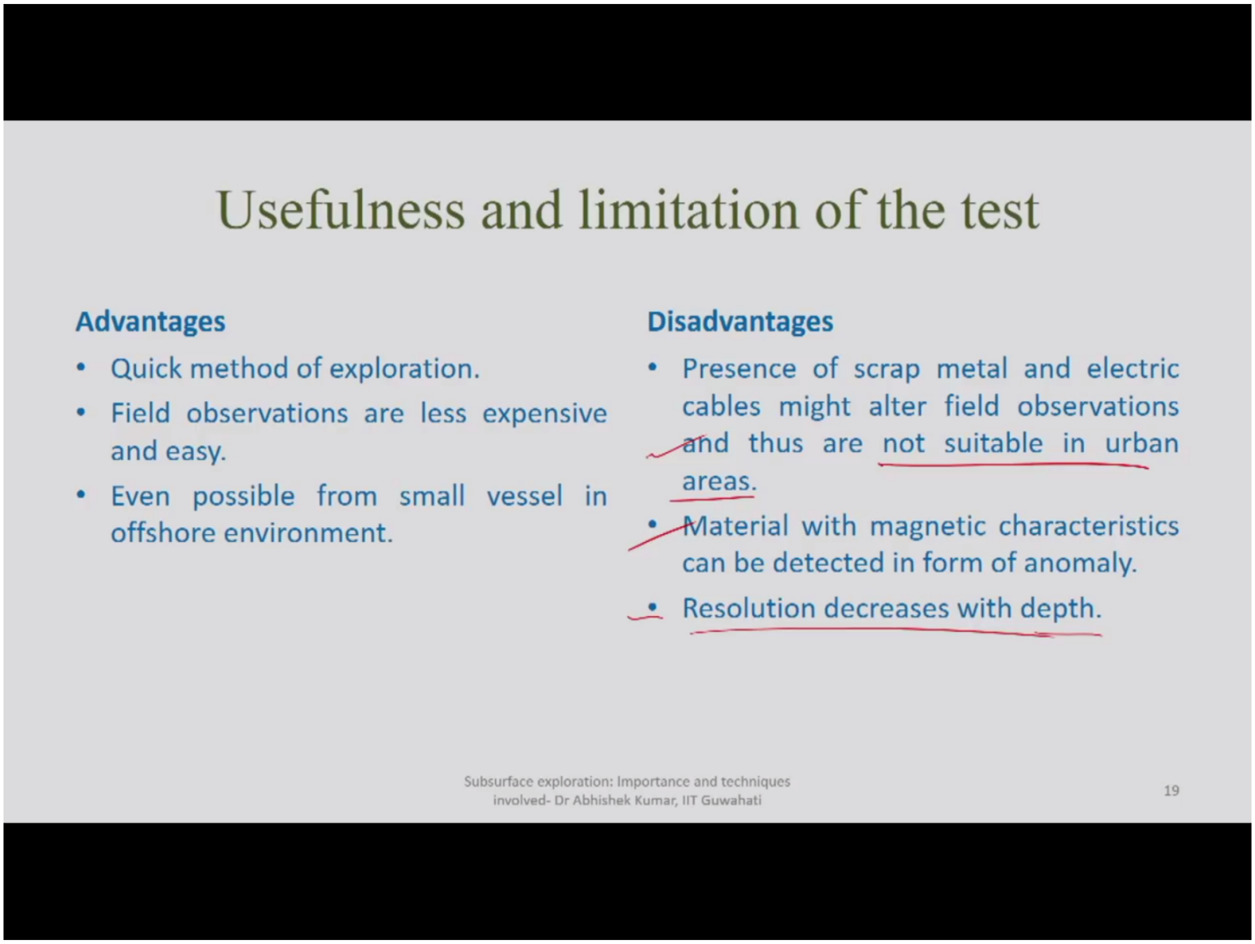

So with this I come to an end about magnetic anomaly method. I hope this method or this today's discussion has given you some input about how magnetic anomaly method is used, how… how probably the field observation can give you an understanding about subsurface characteristics. Though interpreting the result based on field observation may not be possible in terms of lecture, but next time when you see based on some published report or field observation or published literature also, you can actually get an idea, how intensity is matching and how it is giving… giving you some indication about change in the medium characteristics. So with this I stop here. Thank you so much.