Plate Tectonics
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Week - 12
Lecture – 58
Continental Drift- II

Okay friends, welcome to this class of plate tectonics. If you remember our last class, we were talking about this continental drift and today we will continue the discussion regarding the other evidences of this continental drift. If I summarize the last class, we were talking about this continents, they are drifting apart and you can see this edge matching techniques that people are using and during edge matching, we are talking about this continental slope rather we are talking about the coastline. Because the coastline changes with time, however, the junction between this continental shelf of land and this is the oceanic crust where they meet, that is the continental slope, it does not change with time. That's why we are talking that point and during edge matching, we are matching those points only and during this edge matching what we found, there are certain deficiencies, and there are some overlapping areas, and that can be explained by stretching and normal faulting during this continental rift. And today we are going to talk about other evidences which are suggesting yes continents are drifting apart from each other and the valuable evidence and this quantitative evidence, you can say, is given by chains of volcanic islands.

So, if you see we have hotspots and hotspot magma that if you can recall, we are talking about D double prime layer, which is providing the hotspot magma to rise and this lithospheric plate it is just moving on it. So, that means, at places when this lithospheric plate is moving the lithospheric system it is punctured by this hotspot magma. So, if you see this is the hotspot and this magma is generating and it is puncturing the lithospheric system and finally, we are getting a volcanic island here and if you go in this way this arrow is given that means, the plate is moving. So, this is the oldest one and finally, gradually, it becomes younger and younger and this is the newest one.

So, the distance between these two and the age difference between these two we can use to say about what the rate of plate movement is. So, similarly, this hotspot system in the specific not only they say about this quantitative plate motion that also say about the directional change of plate motion with time. For example, if you see here this earlier or this oldest segment whatever it is shown here the oldest hotspot segment is here and its direction for example, it is north south and at this point you see the orientation is changing it is to northwest to southeast. So, that means, it indicates that earlier the plate motion was in this direction and now the plates are moving in suppose different direction. So, that means, directional change of a plate that can also be studied from this hotspots association, but unfortunately this method can be used up to early cretaceous.

The reason being if you remember when we were talking about this convergent system the oldest oceanic life lithosphere we are having is the up to this early cretaceous So, that means, beyond that this lithospheric system has already been subducted and destroyed and we do not have that one. So, that's why this method of hotspot providing this continental drift hypothesis that means support to continental drift hypothesis is only valid up to this early cretaceous system. And this method gives an absolute reconstruction of both latitude and longitude of this plate motion. Then another evidences is the stratigraphic section and stratigraphic section which is mainly people are using up to this Gondwana section because beyond that the stratigraphic section it is highly deformed and it is obscured. So, now, up to this Gondwana or particularly the Gondwana system it is less deformed or deformed or undeformed and you will get uninterrupted section.

So, that people are using from different part of the world if you see here these are the different stratigraphic sections from different geographic locations there is Argentina, Brazil then like this you are coming to the Australia and Tasmania. So, that means, all around this world people are using this Gondwana system for correlation and they are finding that coal, tillite, then glossopteris flora-bearing sequence and Gongamopteris flora bearing sequence they are well correlating with each other. And now these continent or these geographic regions they are 1000s kilometer apart from each other and across this oceanic system. So, that means, it is indicating these land masses once upon a time were together and later on they are drifted and separated. And this for this correlation geological correlation they have used marker bed of tillite, coal, glossopteris, and Gangamopteris-bearing flora that we have already discussed.

In addition to that another evidence is the metallogenic province. Metallogenic province you know there are geographic regions which are very prone to metallogeny in geological past. When we are talking about this crustal evolution probably you can remember we are talking about different regions of this earth they are prone to magmatism, large igneous province and metallogenesis. And those metallogenic province they were confined to particular geographic region at that time. Now, imagine we have different continents once upon a time they were together and there was metallogenesis in this region for example, and now they are separated.

So, once they are separated that means, the same metal which is found here. Similarly, from this side and this side may be similar and from Madagascar to India it will be similar. So, that means, this metallogenic province having similar metallogenesis they are this good indicator for continental drift hypothesis to prove. Then another is the climatic region, distribution of this climatic region on the earth. We know this climatic regions they are latitude controlled.

So, different latitudes are starting from 90 to 0 that means, equatorial region to polar region this system or this earth surface has been divided into different climatic zones. And those climatic zones they produce a particular type of rock characteristics of that climate. For example, coal it is a product of warm and humid climate and ice it is the product of cold climate. So, we are not expecting that an ice site can be formed in the equatorial region. So, now, if it is happening so, in the geological past in the rock record if you are getting this ice deposit and tillite it is in the equatorial region that means, it definitely says that once upon a time there was either climate was changed here or this region which was in a cold region now it is drifted to here.

So, that means this latitudinal region like cold zone, then temper zone, then subtropical zone, then tropical zone; these are the classification and products of that means, I am talking about the sedimentary product, sedimentary rock product, there are characteristics of this climate and their distribution that says that once upon a time these regions were not here or not in this proper climatic zone where they are lying now. For example, some of these climatic indicators in this world in the rock record their people are using that carbonates and reef deposits. They are mostly it is warm water deposit because if you remember when we are talking about deposit because, if you remember, when we were talking about the forearc backarc basin there is due to warm water environment, the forearc basin was prone to generating these carbonate platforms or reefs. So, this carbonate deposit is particularly a reef carbonate reef deposit that is of warm water deposit. So, if now it is if we are getting a rock record in Antarctica, We have this carbonate reef deposit that definitely says it is not the product of that place. So, this continent has moved.

Similarly evaporite it is a hot arid condition. So, red bed it is the sediments containing hematite under oxidizing condition. So, presently found in latitude less than 30 degree. Coal is the vegetation accumulation rate exceeds than removal and it is tropical rainforest. So, that means, similarly there are phosphorite, bauxite, glacial deposits.

So, there characteristics of particular climatic design. So, deviation from that that means, it is indicating either there was past climate that means, promoting for their formation or the region which was in a different climatic region now they are drifted to this. So, any exception from this above condition indicate the shift of climatic condition or shift of the depositional site. So, that is the continental drift. Then another very prominent support for continental drift is paleontological evidences.

Paleontological evidence, if you see that it has affected the distribution of ancient animals and plants by creating barriers to their dispersal. So, once upon a time, if you see, when these continents were together, forming this pangea, there was free passage of animals among it. So, now, they are separated. So, once they are separated and they are separated by huge ocean inside. So, this become a barrier for their movement.

So, their restriction is now within a particular continent. So, that's why there's growth of an ocean between these two fragments of the supercontinent which prevented migration between them and the terrestrial life forms. And the past distribution of tetrapods implies that there must have been easy communication between all parts of Gondwana and Laurasia so here Gondwana and Laurasia it were well connected, and these tetrapods could pass easily that distribution is easy and uniform everywhere. However, now there are separated. The remains of the early Permian reptile Mesosaurus are found in Brazil and South Africa like that. Here is a very nice representation of this Glossopteris, this green part, then Mesosaurus, this is the blue part, and Lystrosaurus, this is the red part. Now you see, once upon a time, when these continents were together, their distribution was among this.

So, you see, their distribution is different, that means you are getting this fossil record in those areas and also in this marine sequence here. So, it is not possible. So, that is why it is believed that those continents were together and they are separated, and this is also the same thing that is shown in a different image. Not only for this Mesosaurus and other reptiles, this plant fossil also plays a major role and is a major indicator of this continental drift because their distribution also climate controlled. So, the widespread dispersal of marine invertebrates can only occur in their larval stages and when they form part of this plankton and for most of the species the larval stage is too short lived that it cannot cross this huge ocean inside.

So, that means, you see, if we believe that it can be possible that maybe in the larval stage, these organisms have crossed this ocean like that. So, crossing a ocean of 5000 kilometer width is a time-consuming procedure and this time taking procedure, which means more than the larval stage and in the larval stage it is very too short time. So, that means, though it is possible in the larval stage that we believe or we can believe, but due to this shortage of time for the larval stage it is not possible to believe that yes, during larval stage, these organisms have travelled across this ocean and they are distributed among this continent. Then continuing with this paleontological evidences there are very prominent fossils, one is the trilobite which is Cambrian and another is the ammonite fossil, which is of Jurassic, is an index fossil. You can say that is an indicator of this continental drift theory.

Because their distribution here, you can say between ammonite species is found in Madagascar, Africa, indicates that shallow seas could have been existed between these regions in the Jurassic time. So, during this shallow sea which was existing there, if you see this time it is indicating the time of the separation between Madagascar and India, and when there was rifting taking place, this shallow sea existed. So, probably at that time, it is indicating that their distribution would be, So, that means, all those paleontological evidences they are saying that yes continents have drifted apart from each other and apart from this paleontological evidences climatic zones, metallogenic province like that. So, there is a very prominent example or prominent supporter of this continental drift it is called the paleomagnetism. So, last class if you remember we were just initiated what paleomagnetism is.

So, this paleomagnetism and polar wandering curve they are very good indicator and this is not a qualitative indicator this is the quantitative indicator too about this continental drift theory. So, this fossilized magnetism, this fossilized magnetism what this fossilized magnetism is there. So, now imagine we have a globe, we have earth and we have this north-south geographic pole, and we have magnetic poles also. So, as long as the magnetic pole exists, we have magnetic lines of force just it is like this and any mineral which is forming on the surface of this earth when their magmatic origin or igneous origin when it is cooled below the curie point when it is solidified. So, it freezes this existing magnetic field on its surface within the magnetic minerals and this direction of magnetization it is fixed and depending upon the magnetic latitude.

The inclination that is proportional to the magnetic latitude where this is crystallized. Similarly, in a sedimentary basin, when the sediments are getting deposited, the fine-grain particles, particularly these magnetic particles, when they are settling down, they are also oriented themselves according to the existing magnetic field. And once they are traced within this rock record that can be used that is called fossilized magnetism and that magnetism can be used to study the paleolatitude of this rock formation and that is a very good indicator of this continental drift. So, when paramagnetic substance is placed in weak external magnetic field, such as the earth's field, the atomic dipole rotate so as to become parallel to external field direction and this induced magnetization is lost when the substance is removed from the place as the dipole returns to its original orientation. And the paramagnetic minerals are capable of retaining a record of this past direction of earth's magnetic field when they freeze below the Curie point.

And Curie point it can be established or defined as the temperature at which a material's permanent magnetism changes to induced magnetism. And rocks can acquire natural remnant magnetization, that is called NRM by several ways that is called primary ways or secondary ways. Primary ways, that means when the rock forms, magnetization is imposed in that and that is the thermo remnant magnetization, which means the thermo itself is saying about the temperature. So, that means it is the minerals which are forming or the rock which is forming from lava when they are cooling down below this Curie temperature when they are getting solidified this magnetic minerals like magnetite and other ferro-magnetization minerals they are orienting themselves according to the earth's existing magnetic field. And then another is called DRM or depositional or detrital remnant magnetism.

So, that term itself it is saying talking about the sedimentary rocks. So, the sedimentary rocks when they are depositing during settling down in the water column, they are orienting themselves, particularly this magnetic minerals they are orienting themselves according to this earth's magnetic field and they are responding to this magnetic field and orienting likewise. Another is the CRM that is chemical remnant magnetism that means it is talking about some chemical reaction that means there is a diagenesis that means after the deposition when the diagenetic reaction takes place within the sedimentary rock, some new minerals are created, like magnetite, hematite. So, this magnetic mineral if you are creating so, those magnetic minerals they are orienting themselves according to the earth's magnetic field. And this is isothermal remnant magnetization, that means we are talking about lightning-effect thunderstorm lightning effect when there is lightning effect to this earth surface.

So, it magnetizes the rock where it falls. Then BRM that is viscous remnant magnetization, that means when this magnetic minerals are placed under weak magnetic field for millions of years. Its magnetization changes and it is adopt the new magnetic field. So, that is all about this magnetization processes and we will talk in detail how this magnetization process their help in plate tectonics and particularly providing evidence about this continental drift. So, talking about this thermal remnant magnetization or TRM which is acquired as the rock cools from its motion state to below the cure temperature which is realized after solidification.

At this stage it ferromagnetic minerals picks up this magnetism of the same sense as the geomagnetic field that time which is retained during subsequent history. So, example is the magnetite in basalt. For example, if you see here, we have lava which is coming down and you see this there is no magnetization because it is above the curie temperature. So, once this temperature is going down, once it is reaching below this curie temperature. So, this minerals this magnetic field is freezed and that freezing it is according to this earth's existing magnetic field.

So, for example, we have different basaltic flow layers for example, we are talking about the Deccan trap we have different basaltic flow layers and here when this magnetic minerals which are formed here this was reverse magnetized system was there. So, that means, we will find reverse magnetic axis here or magnetic minerals are here, but suppose during another flow there is a normal magnetization. So, we will get this magnetic orientation opposite to this previous one. So, accordingly, there will be normal reverse stratigraphic sequence and it is used as magneto-stratigraphy to study. So, that means, during subsequent basaltic eruption formation of this basaltic rock this magnetization is varying with time and that is best studies in the ocean floor because we know the ocean floor is a carpet of basalt, it is continuously forming.

So, during its formation from starting from the zero to this early cretaceous because beyond that we do not have this ocean floor's life. So, up to that this whole carpet of basalt can be divided into different segments according to this normal and reverse magnetic field. So, here we are talking about the DRM, ditrital or depositional remnant magnetization. As the sedimentary particles settle through this water column any ferromagnetic minerals present align in the direction of this ferromagnetic field. On reaching the bottom of the particle it is flattens out and if of elongate form preserve the azimuth of this geomagnetic field but not the inclination because it is sedimentary system which is squeezed system that is settled down.

So, its inclination is not preserved however the azimuth that the direction of this magnetic field it is preserved. Then chemical remnant magnetization that already we have discussed this is the magnetization which is remained in the diagenetic reaction mineral product particularly the hematite when it is producing due to the diagenetic reaction. And if you see here, we have different sandstones, we have red sandstones and this red sandstone is nothing; it is the oxidized product that is oxidized product is nothing this is the magnetite or hematite which is forming and those minerals this minute magnetite minerals which is forming here, and these minute hematite minerals, which is forming here, they are orienting according to this earth's magnetic field. Then isothermal remnant magnetization that means during this thunderstorm or lightning when it is falling on this rock you see how this rock system is changed and this is called this isothermal remnant magnetization. And very important here to note it that this isothermal remnant magnetization it is easy to distinguish because no preferred orientation of magnetic axis nothing.

So that means very haphazard orientation, so if you are keep on measuring this magnetization in an area if you are coming to an area which is affected by this lightning event so you will find that means suddenly your magnetometer it will give haphazard reading. So this type of area can be distinguished from the surrounding which part that means the actually it is affected by this lightning effect. Then another is the viscous remnant magnetization or VRM it is when this rock is placed under is placed under weak magnetic field for millions of years, this natural remnant magnetization acquires the external field direction and the natural remnant magnetization of ultra-mafic igneous rocks that can alter in this process. So that means now you see we have any subsequent magnetization in rocks, are regarded as noise and because to conduct this paleo-pole position, paleo-magnetic pole position only the initial magnetic field is required. Otherwise there are number of times this magnetic reversal are normal and some lightning or something like that, that means all they are the noise they are superimposed on that.

So this geologist or those people who are working in this paleo-pole position construction reconstruction of the paleo-pole position their work is to first clean this sample. So cleaning that means it is called magnetic cleaning that means subsequent superimposed magnetic fields they are cleaned out and we are going to this original magnetic field that means when this rock was formed. So this paleo-magnetic measurements provide the intensity, azimuth and inclination of this primary remnant magnetization that means subsequent cleaning we are reaching to this product, that is, we are getting this azimuth intensity inclination of this primary remnant magnetization which reflect the geomagnetic parameters that time and place at which the rock was formed. Inclination I can be used to determine the paleo-altitude that is phi at this formula

$$2 \tan \Phi = \tan I$$

So in this formula, we can calculate which geographic region it was formed.

So this CRM, TRM and DRM tend to be hard and remain stable over long period of time whereas certain secondary components of NRM notably the VRM are soft and it is lost relatively easily. So it is thus possible to destroy this soft component and isolate the hard component of this magnetic field or magnetization through these magnetic cleaning procedures. So once the magnetic cleaning is complete whatever this result we are getting we are using it to reconstruct the paleo-pole position of this rock where the rock was formed. So now you see if a paleo-magnetic study provides a magnetic pole position different from this present pole it implies that either that the magnetic pole has moved throughout this geologic time that is the magnetic pole has wandered relative to the rotational pole or the geographic pole, and that's why it is called apparent polar wandering or APW or if the pole have remained stationary that the sampling site has moved that is the continental drift has occurred. So this first one is ruled out why it is ruled out because it appears that wandering of magnetic away from this geographic pole is unlikely because all this theoretical models for this generation of a field predicts that dominant dipole component paralleling to this earth rotational axis.

So that means the first component is ruled out, that means there is no movement or that means no you can say a considerable movement of this magnetic pole from this geographic pole. So that means the other option is that the sampling site has been changed so that means this continents had moved. So consequently the paleo-magnetic study can be used to provide a quantitative measurement of this continental drift. So that means it is not that this continent was fixed and the pole has moved. So it is now this pole is fixed and the continents had moved so this is the correct one.

And the observation that apparent position of this pole at different rocks of different edges from the same continent demonstrate that these continents have moved over subsurface on the surface of this earth. Now imagine we have a stratigraphic succession and we are taking a sample from here and we are taking a sample from here and we are taking a sample from here. So that means in the stratigraphic column different interval we are collecting samples and through this magnetic cleaning we are getting some result that means some latitude longitude like that. So that means we can say when this sedimentary layer was deposited which was the position of this region geographically which latitude longitude and when this was deposited what is the latitude longitude similarly where when this was deposited or this layer was deposited what is latitude longitude. And now that means similarly this position of the depositional site with respect to this latitude longitude can be reconstructed using this formula

$$2 \tan \Phi = \tan I$$

So this is the key formula that this paleo pole position can be reconstructed. So apparent polar wandering paths can be used to interpret the motion, collision, disruption of continents and are specially useful for pre-mesozoic continents whose movement cannot be traced by pattern of magnetic lineation in their surrounding ocean basins. So now you see the ocean basin up to the early cretaceous we can move. So whatever this continental drift of the sea floor spreading that can be studied using this paleomagnetism that is up to the early cretaceous in the ocean floor. But beyond this early Cretaceous, that means beyond mesozoic if we want to study this position of a place so we have to go to this continent because no more ocean floor older than that it is existing.

So this pre-mesozoic continental reconstruction that is from lake sediments we can get from this paleomagnetic study. Suppose for example this is an area we have continent for example we have a continent continent and two different positions, we have collected a sample. So whatever this position we constructed yes this is the latitude longitude condition. So now it is moving so we are collecting sample again This is the latitude longitude. So it is collecting samples, so that means now you see these two points getting closer.

So now at this point, one is moving in this way another is moving in that way that means its latitude changes its latitude changes, that means what I can say here is the rifting starts, Isn't? Up to this latitude and longitude, the motion was together. However, from here, it is a separate basin this became a separate basin and two moved independently to opposite direction and after some millions of years after movement here and there. So now you see at this point again that they are colliding. So because their latitude and longitude are the same, we can say these two plates, which was earlier together, they rifted, they drifted, and they collided. So that means whole plate tectonics that we have studied so far rifting, drifting, collision that can be studied by this value magnetic studies.

So thank you very much we will meet in the next class.