Plate Tectonics

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Week - 03
Lecture - 14
Euler's Theory on Lithospheric Plate Motion

Okay Friends, welcome to this class of Plate tectonics. And, if you remember in the earlier class, we were talking about this earth to be flat and the relative motion between this plate it remain constant throughout its boundary and in later we disagreed with that because the earth is not flat and it is spherical rigid plates are there and like curved gaps of lithosphere it is on the asthenosphere and they are moving at different rates. And that is why we introduced a term and a theory that is called Euler's theory which signifies this plate motions and this relative velocity of different plate with respect to its Euler's pole and that is why this plate boundary geometry changes the relative motion between this plates along its boundary it is changes at different places and how this will define this plate boundary position with respect to this Euler's pole that we will discuss in this present class. So, relative motions once we say what we generally think that the one plate remain static and the other plate is moving at a same rate. So, that is why the relative motion is defined that the one plate is fixed and this other is moving relative to it that is rotating its away from or towards each other from a fixed point. So, that means, if you see here there are two plates suppose plate A and this is plate B.

So, now, these two plates they are moving on the surface of this earth and we know the surface of the earth it is a spherical geometry. So, that is why if I trace this motion back of these two plates they will move towards each other and they will somehow they will coincide here. Now, I am splitting it and after splitting this plate is moving this way and this plate is moving this way and once they are moving what exactly they are doing they are rotating and this way it is rotating and this way it is rotating and they have to rotate within this earth surface only. So, that is why they are rotating and this rotation is around a fixed axis is a fixed point.

So, now, if we insert an axis through which is passing through the center of the earth and merging here. So, these two plates they are rotating on the surface of the earth with respect to that point and that is called Euler's point and that axis which is joining those two points and passing through the center of this earth that is called Euler's axis. So, here provided it remain rigid each point of a moving plate describes an arc of different small circles about this Euler's pole. For example, suppose I am talking about this point and these points motion so that means it will be here, here, here, here, here. So, that means I can construct an arc or small circle on the motion of each point of this plate. Similarly, if I am considering this plate so this motion of this point should it will create an circle.

Similarly, motion of this point will create an circle like this. So, these are nothing these are Euler's small circle. So, Euler's small circle has nothing to do with Earth latitude and longitude or earth latitude particularly. So, it is totally different and these are imaginary lines that define the way or the pathway of each point that are moving or a rotating plate. So, the motion between this plate is equivalent to a relative motion about their mutual Euler's rotational pole.

So, that means once this is moving in this way and this is moving this way. So, they are rotating about a fixed axis and that axis is passing through the center of this earth and as if they are tied through threads and just rotating around this axis. So, this is just for your understanding. Now suppose the divergent plate margin is here and it is lie along the line of a longitude that is a great circle. For example, here suppose this is the E and this is the Euler's pole and this is another point through which an Euler's axis that is the rotational axis it is passing through the center of this earth and merging here.

So, this has nothing to do with earth's rotational axis or earth's magnetic axis or something like these are simply imaginary points. So, now imagine this is a plate boundary and it is a divergent plate boundary it is starting from this Euler's poles and ending this Euler's pole. And that is why once it is a fracture developed here due to this divergent margin this plate it is moving in this way and this side is moving this way. So, now if I am tracing this motion so, it will move like this. Similarly, these points if I am tracing its motion it will move like this.

So, that is it is creating a Euler's small circle. So, this Euler's small circle can be generated from here. So, now if you think about suppose there is a point P and this is a point and this is a point and suppose this is a point that is for example, we take it is Q, Now this Q, P and suppose this is R these are the different points on the same plate at the edge of this plate. Now suppose it is moving with the angular velocity omega or so. So, now this how much distance this Q will move from this plate boundary.

How much distance this P will move from this plate boundary and how much distance the R will move from this plate boundary that defined this the away from this point of this rotation of this point and this rate of angular velocity. So, now Euler's pole E suppose it is north pole, but for your convenience it is just told that this Euler's pole is your north pole, but it is nothing to do with earth's rotational axis or earth's pole. Now relative plate motion along this lines of latitude these are the small circles that we have discussed here. These are the small circles different points they are moving like rotating like they are creating the small circles and this rate of rotation about this Euler's pole gives to the variable linear velocities calculated at point P. So these are the linear velocity that means how much distance this will move, how much distance this Q will move and how much distance this R will move. So, that depends upon this that the linear velocity depends upon certain factors. What are these factors we will discuss in just few minutes after.

So, thus linear velocities are maximized along the Euler's equator that is 90 degree from the Euler's pole and it is minimum or 0 at the Euler's pole. So, now if you see here this maximum separation it is occurring here or it is occurring here that is along the equator and gradually once you are moving towards the Euler's pole. Similarly gradually once you are moving towards the Euler's pole you see the distance is decreasing. But maximum distance is here at the Euler's equator. So, that means starting from the Euler's pole to Euler's equator the relative velocity of different plates they are changing.

But earlier our assumption was the plate was flat and the linear velocity whatever we are assuming that 6 centimetre per year it is throughout for this plate boundary, but it is not true. So, once we are introducing the system like this curved system. So, not only simply it is moving linearly they are rotating and due to this rotation this velocity or this relative velocity at different points that it depending upon the position from this Euler's pole it is changing. So, Euler's fixed point theorem it says that the most general displacement of a rigid body with a fixed point is equivalent to the rotation about an axis through that fixed point. And the relative motion between two plates is uniquely defined by the angular separation about the pull of relative motion known as the Euler's pole.

For example, now you see here you see this is the geographic pull or this pull of rotation. Now I am talking about this two plates suppose plate A and this is plate B. If this motion is traced back these two plates they will merge here forming this plate for example, AB. So, now this due to this divergent margin these two plates they are separated and now once they are separating so that means they are rotating and which way they will rotate. So, this is rotating this way and this is rotating in this way, Now imagine once they are rotating so this is the axis and it is passing through the center of this earth imagine it is a globe and we are inserting an axis here and that axis is passing through the center of this earth and these plates they are moving like this.

The plates are moving like this and it is rotating around this axis. So, now any point on this plate that will create a small circle any point that subsequent motion that will create a small circle and these are called Euler's small circle. Now you see the earth's small circle if this is the rotational pull so earth's small circle will be like this. So, now Euler's small circle is like this so it is nothing to do with that. So, Euler's small circle, Euler's axis, Euler's rotational pull, Euler's equator it is nothing to do with earth's equator or small circle or earth's axis, These are simply imaginary points and imaginary lines as we believe that say plates are motion and this plates motion is creating these lines by joining subsequent points on these plates.

So now taking this plate as the rigid body and the center of the earth at a fixed point this theorem can be explained that every displacement from one position to another on the surface of this earth can be regarded if the rotation about the suitably chosen axis passing through the center of this earth that we have discussed already that here if you have a point and here we have a plate. So, these two plates they are moving like this that means they are rotating on the surface of this globe. So, now once they are rotating here so that means we are inserting an axis like this. So, around this axis they are moving, but if these plates are moving like this for example this is the globe and the plates are moving like this. So, we are inserting another axis here.

So, these are imaginary axis no such axis is existing. So, these are imaginary axis, but either the plates are moving in this way or the plates are moving this way or plates are moving this way. Any time when we are introducing the axis that axis must pass through the center of this earth this is the fixed point. So, any motion of these plates on the surface of this globe it is with respect to the center of this point. So, through the center we are binding a thread to this plate and just we are rotating it through the center and here we are inserting an axis that this axis they are emerging on the surface of the earth somewhere here and the other end of this axis is emerging somewhere here these are called Euler's pole.

So, one pole is here another pole is here and around these poles on the surface of this earth these two plates they are on motion with respect to this two poles and around this axis. So, this suitably chosen axis which passes through the center of the earth is called the rotational axis and it curves the surface of this earth at two points that is the pole of rotation that we have already discussed and if you see here if this is the plate which is moving this way and we are introducing axis here. Suppose this is the plate and it is moving in this way so that means, we have to introduce an axis like this it is moving like this. So, this motion is always and always perpendicular to this rotational pole. So, that is why this once this is a plate and this will be the axis and this is the plate and this is the axis so like that.

So, these axis are imaginary axis simply and these are purely mathematical point and has been no relation with the earth's rotational axis or something something like that. But the beauty of this point is that if you see here suppose plate 1 and plate 2 and this is the rotational axis. So, what is happening this plate is moving this way and this plate is moving this way and gradually if you see this separation this linear separation of this plates along this plate boundary it is decreasing and finally, it will be 0 here Similarly in other part when this axis is emerging somewhere here the other part similarly it will gradually 0 will be here and it will increase somewhere here So, that means if this is the Euler's pole and this is the Euler's pole the Euler's equator will be somewhere here. So, at the Euler's equator the separation is maximum and the Euler's pole the separation is minimum. Similarly, it is plate A and it is plate B.

So, this plate A and B they are moving and this is the divergent plate margin this divergent plate margin this is the transform fault the transform fault transform fault. So, this how much separation will be among different plates along this boundary that will define from this position of the Euler's pole and this Euler's equator. So, around this equator the separation will be maximum at the pole the separation will be minimum. Now, the magnitude of angular velocity about the axis then defines the magnitude of relative motion between the two plates. The magnitude of angular velocity how fast it is rotating.

So, if it is fast rotating so, the separation will be maximum fast and if it is minimum rotation that means the magnitude of this angular velocity that defines how much these two plates will be separated annually. And the sign convention of these two poles either it will be positive or the negative that depends upon the plate and depends upon the type of rotation. For example, if you are a viewer and you are looking this plate motion outside of this earth. So, this plate is moving according to you it is moving anticlockwise and this plate is moving clockwise. So, that means this Euler's pole will be a positive pole for this anticlockwise motion and this is a negative pole for this clockwise motion.

That means the same Euler's pole may be a positive pole for this plate A and this this same Euler's pole is negative pole for plate B. So, that means if it is a an observer is observing it the outside from this earth and it is motion is recorded anticlockwise that means it is a positive pole and if it is motion is clockwise that is a negative pole. So, now come to this end of this axis. So, another axis will be somewhere here it will emerge. So, in here this motion will be clockwise if you are a viewer from this side.

So, this will be the clockwise this will be anticlockwise. So, that means if it is anticlockwise that will be positive if it is a clockwise that is negative. So, that means for one pole this plate may be positive, but this plate for this plate that may be negative. Similarly, this pole for this plate may be positive this plate may be negative. So, provided that you are a viewer and you are viewing from outside of this earth.

However, if you are the viewer and you are looking from the inside of the earth from the center of the earth, so the reverse will be true. So, that means the positive will be negative and the negative will be positive. So, that means I want to say on the surface of this earth if this motion is anticlockwise this point is called positive pole and if it is clockwise this point is called negative pole. And how much it will be separated that depends upon the angular velocity the magnitude of this angular velocity. So, now calculating the linear velocity from the rotational pole.

So, we have angular velocity we have different rate of angular velocity for different plates for at different Euler's pole. Now to calculate the linear velocity along this plate boundaries to calculate that let us consider there is a point which is P or here we can say this is the point P on the surface of this earth at P the value of linear velocity

$$v = \omega R \sin \theta$$

So, this theta what is this theta? Theta is the angle between the center of this earth that point of observation P and with respect to the rotational pole. So, this angle rotational pole and that point which they are making at the center of this earth this is the theta and what is R? r is the radius of this earth and this sin theta sin theta it says theta will be maximum at 90 degree and 0 it will be at the pole and at the other side of this pole. So, that means at two poles theta will be 0 that means the relative velocity or the velocity will be 0, but the maximum when this theta equal to 90 degree.

So, this $v = \omega R \sin \theta$ if you see theta is the angular distance between this rotational pole E and this point P and R is the radius of this earth and omega are the magnitude of this velocity. So, now if you see omega R sin theta. So, here theta is equal to 0 here theta equal to 90 degree. Now any point which is in between suppose for example this P. So, here theta will be somehow 60 degree where theta will be 30 degree here theta will be 20 degree theta will be 10 degree and theta will be 90 degree here.

So, that means now you see a point which is here when theta equal to 10 degree this omega R sin theta at sin 10 degree. Similarly omega R sin 20 degree omega R sin 30 degree and omega R sin 60 degree omega R sin 90 degree. So, that means maximum distance of separation is occurring here that is the Euler's equator. So, that means now along this plate boundary if you see these points the separation or the motion is changing minimum motion at this pole and maximum motion at the equator. So, that means along this boundary there are different rate of motion it is observed here, but in earlier classes as we are talking about the earth is flat we are assuming that 5 centimeter motion that 5 centimeter motion was taken throughout this plate boundary.

So, that is not true. So, that means along this plate boundary depending upon the position with respect to the Euler's pole. So, this motion is changing is not it. So, this factor sin theta it is meaning that the relative motion between the two adjacent plates changes with position along this plate boundary and it is constant to this earlier observation that the earth is to be flat that we have discussed earlier. So, thus the relative velocity is 0 at the rotational pole where the theta is 0 degree and theta is 180 degree and the maximum where omega r theta equal to 90 degree at the rotational poles. Now, if you see here this is v1, v2, v3 there are different positions and this is the Euler's pole this is the Euler pole position.

So, now you see v1 is less than v2 is less than v3. So, maximum velocity if this is the divergent plate margin position and here you see this is the maximum separation is occurring here then the separation is occurring here if the separation is occurring here. So, by chance the plate boundary passes through this rotational pole the nature of this plate boundary changes. This is very important point to understand here. Now imagine we have an axis which is passing through the center of this earth and it is here.

Now we have two plates. So, this is plate A and plate B and this plate A and B in this side it is representing a divergent plate boundary. So, imagine a system on the globe we have two plates. So, now these two plates are separated. So, once they are rotating here so, somewhere once we are creating a divergent plate boundary at one end. So, now there is a collision this end this is this is a experience in collision here.

So, once that is colliding so, that means one plate has to undergo under others. So, that means here we are creating a subduction zone. So, that means here this is the rotational pole. So, that means if the two plates they are separating here two plates they are separating here and this rotational pole is lying on the plate boundary itself. So, that means the other side of this system or the other side of this rotational pole these two plates now you see they are moving towards each other.

One side they are moving away from each other, but here you see it is rotating and it is rotating. So, these two plates they are coming towards each other. So, this subduction zone or a collision zone is expected. So, that means if the plate boundary or if this rotational pole lying on the plate boundary itself then the nature of this plate boundary it is changing once it crosses the Euler's pole.

This is very important point. So, lines of constant velocity it is defined by theta or the small circle about the rotational pole. So, that means here if this theta is constant the velocity will be constant. Similarly here the theta is constant the velocity will be constant. Here the theta will be constant the velocity will be constant.

So, every theta from 0 to 90 degree or 0 to 180 degree. So, that point which is lying on a particular theta that means particular angle with respect to this Euler's pole position it is moving at a constant rate and that varies from 0 to 90 and 0 to 180. Now the pole and its antipole are the two unique points on this earth surface and of this earth that do not move relative to each other. So, now you imagine this is the pole and this is the antipole. So, they are constant points. So, that remain constant and poles of these two plates that tend to remain fixed relative to them for a longer geological time that is why the plate velocity is.

So, here for longer geological time this position remain constant. So, it may possible that after few millions of years this position of this pole changes for example, suppose this two plates one is moving in this way another is moving this way and this is the Euler's pole. It may possible that the Euler's pole position is changing from here to here. So, this is the Euler's axis. So, that case this plate which is moving in this way that will rotate in this way and this will rotate in this way.

So, that means the position of this Euler's pole it remain constant throughout this geological time for longer time and that is why the plate velocity also remain constant for a longer geological time. And if you see here if this is the transform fault this is the convergent margin and this is the divergent margin here and this is the Euler's pole. So, that means I want to say any type of margin it is following the Euler's pole theorem. So, either it is convergent, divergent or it transform boundary every boundary every plate is Euler's pole every two plates have a constant Euler's pole and they are moving with respect to that. Now the question arises if this is so how to determine the position of this Euler's pole.

So, it is very easy to determine the position of the Euler's pole, but three methods are used there. The fast and the foremost method and the most reliable method is the transform fault along this common boundary. So, transform fault we will discuss in detail in the future classes, but at this stage I can say this transform fault are very common across the midoceanic ridge system. For example, suppose here we have midoceanic ridge system this is midoceanic ridge and here we have a transform fault. Similarly, here you say this is the mediocinic ridge this is the mediocinic ridge segment and this is the transform fault.

Similarly, this is the segment of mediocinic ridge and these are the transform fault. So, the transform fault they are easy to detect and this method of detecting Euler's pole for using transform fault is also very easy one. In this case what exactly we are doing that if you remember our few minutes back we are discussing that this Euler's equator and Euler's pole. So, Euler's equator are nothing the points where constant motions is there it is 90 degree. Similarly, Euler's small circle are there where for every theta the motion is constant.

So now, if we have a divergent plate margin and we have a transform fault here this transform fault that behave like the Euler's small circle. So, if I am creating this Euler's small circle taking this transform fault into account. So, now this is the Euler's pole and these are the Euler's small circle. So now, Euler's small circle if we have then perpendicular to that is the Euler's pole. So similarly, for that reason what we generally do we have a transform fault we draw perpendiculars we draw perpendiculars and we are doing perpendiculars and when this perpendiculars meet with each other that is the position of the Euler's pole.

But it may possible that when we are doing this perpendicular or drawing this perpendicular it may not meet at a particular point. For example, here it is meeting at a particular point that is the perfect position of this Euler's pole. However, there may be due to some error due to some uncertainties that this type of error occurs that either meeting instead of meeting here they are meeting in a zone rather a point. In that case what we generally do we take the statistical midpoint of this zone and finally, this we assume this is the position of this Euler's pole. So this is the most convenient type of plate margin to which the apply this technique is the accretive type or this is the divergent type plate margin.

Because of inaccuracies involved in mapping of oceanic structure zones the great circle rarely intersect at a particular point. In that case that we have discussed we take this statistical method we use this statistical method to find this position where exactly this point is lying. So this is the most reliable method of finding the Euler's pole. And the next one it is the relative velocity measurement and we know the relative velocity it increases from Euler's pole to Euler's equator. So for example, if you see this is the Euler's pole position this is 90 degree and this is the Euler's equator.

So maximum velocity will be here and the minimum velocity will be here. So if you are able to measure this separation the relative velocity along this plate boundaries then we can say then where this minimum velocity is there or zero velocity is there. So that is the position of this Euler's pole for this particular plate. So this velocity of spreading is the maximum at the equator and the minimum at the Euler's pole. So, the determination of the spreading rate at a number of points along the ridge then allow this pole to relative rotation to be found because the minimum spreading or the zero spreading will be found at the Euler's pole position.

So velocity is measured based on the magnetic lineation. How to calculate the velocity based on the magnetic lineations because in the future classes we will discuss whenever there is a spreading system, when there is a midoceanic ridge system and this minerals which are crystallizing at this basaltic magma in the midoceanic system they capture the earth's magnetic fields at particular time or that time. So these strips the width of the strips that depends upon the relative velocity. So gradually towards the Euler's pole the strip velocity or the strip width generally decreases. So that is why based on that we can calculate that where this position pole position Euler's pole position is. Then the third one and you can say the least reliable method is from the fault plane solution.

What is the fault plane solution? What is the fault plane solution? We will have a separate class for that. So for your understanding at present I can say if we have normal faults the beach ball diagram or the fault plane solution will be like that and if it is a reverse fault this is the beach ball diagram and it is a strike slip fault this is the beach ball diagram. And why this beach ball diagrams or the fault plane solution that is used? Because at this divergent plate margin we have different types of faults particularly the normal faults and the strike slip fault. But once you are moving towards the pole only the normal faults are dominating no more strike slip faults are there. So that is why the focal mechanism solution of earthquakes and the common margins they are used to determine the pole position.

If the inclination and the direction of slip along the fault plane are known then the horizontal component of the slip vector is the direction of relative motion. So that is the relative motion how we determine but this is the least reliable method and the most reliable method is to determine the Euler's pool is the putting or drawing this perpendicular from this conservative plate margin or the transform fault is the most reliable one. So thank you very much we will meet in the next class. Thank you.