Plate Tectonics

Prof. Pitambar Pati
Department of Earth Sciences
Indian Institute of Technology, Roorkee

Week - 03
Lecture - 13
Relative Motion of Lithospheric Plates

Ok friends, very good morning and welcome to this class of Plate Tectonics. Today, we are going to discuss about the relative motion of lithospheric plate. So, this sentence if you see, it consists of around 5 words and out of this 5 we have completed what is lithosphere and what is plate and what is motion. So, that means, at least up to now we know the lithosphere is divided into different plates. That means, the thickness is much less as compared to its aerial extension and they are constantly moving with respect to each other. And now this question around this is what is relative motion? So, in plates there are two types of motion, one is called the absolute motion another is relative motion.

The absolute motion is suppose for example, this Indian plate at present is moving around 5 centimeters per year. So, that is absolute motion. Any plate which is moving at certain rates at present or in geological past it is called absolute motion that is independent to others. However, once it says the relative motion that means, the dependency is added here.

So, for example, the Indian plate it is moving towards the Eurasian plate and the Eurasian plate is moving towards the Indian plate. So, two plates they are moving towards each other. So, here the relative motion it adds. So, that means, the Indian plate as well as the Eurasian plate the two plates they are moving towards each other that is why their motion will be added together and that will be relative motion. Similarly, any plate either it is divergent plate margin or it is a convergent plate margin or it is a conservative plate margin.

Once they are moving with respect to each other, so, their motion is either added or subtracted. So, that depends upon their direction of movement and this rate of movement at different direction with respect to each other. So, in today's class we will confine ourselves in relative motion that means, the motion of one plate with respect to other and how the relative motion it is changing throughout the plate boundary or it remaining constant. If it is remaining constant then what is the behavior of this plate boundary or it is changing with time and space then how this plate boundary geometry changes that we will discuss in brief. So, here the plate motion on the earth is necessarily involved some spherical geometry.

If you see here this is the earth which is composed of some lithospheric plate which are covering the inner space that is this asthenospheric material which is covered by this outer shell that is the lithosphere which is rigid and if you remember we have discussed this lithospheric plates are nothing they are behaving like curved caps. So, now, if you see this is the globe and here this is a plate and this plate if you see this geometry it is a curved one because the earth is a sphere type system and any shell, any rigid body or any rigid part of this crust or this lithosphere it is in curved shape. So, that is why any plate movement on this earth surface it is lithospheric plate movement on the earth's surface it involves the spherical geometric equation or something like that. So, but for this time being for proper understanding of the system let us not think that earth is a sphere. So, let it is a flat one.

So, for that I have to take to you back to this people of medieval time when they were thinking that the earth is flat and if the earth is flat then how these plates are moving with respect to each other. So, now, see if the earth is a flat body that means, we can divide into different shapes for say here we are dividing it into rectangles and this rectangle like this burfi here. So, if I am moving one piece from another so that means, I am creating a gap and that gap is uniform throughout and if I am rotating one block from here. So, this gap is varying from place to place. Similarly suppose for example, we believe that earth is flat and we have divided into different blocks like A, B, C, D.

Now this A block is separated from C block with a specific distance. Similarly here this specific distance similarly D and B they are separated from specific distance and now from C and D this distance is also specific. That means, if it is a flat body and once they are moving on a surface which is a flat surface then the distance from here and here can be maintained equally until and unless there is a rotational motion. Is not it? So, that is why the people of medieval age as they were thinking the earth is flat for the time being you also imagine the earth is flat. Now, if the earth is flat now let us talk about the different plate boundaries how this plate boundaries are behaving on a flat earth system.

So, now, here if you see this is a divergent plate margin and this is the mid-oceanic ridge system and you are the observer you are standing here on one plate and you are looking that this plate or plate A it is moving away from you 2 centimeter per year and your plate is also moving 2 centimeter per year in the opposite direction. So, this 2 centimeter per year it is called half spreading rate and if the relative motion I am talking about the relative motion will be 2 plus 2 equal to 4 centimeter per year. And this 2 centimeter per year this plate B is moving towards this direction 2 centimeter per year it is called absolute motion. Similarly here it is 2 centimeter per year it is absolute motion that means, this plate A and B they are moving independently 2 centimeter per year to opposite directions. However, the relative velocity or the relative motion is added together and that is the 4 centimeter per year.

So, this is well explained in your inter that how the relative velocity in the vector format that can be B it is subducting down into the asthenosphere. So, here in the geological map also in any geological map you will find the thrusts generally represented like this. Suppose for example, this is the thrust line and these are this triangles they are arranged and this also indicate that this is the up thrown block or the up thrusted block and this is down thrusted block anyway. So, now, you see in this figure this 10 centimeter that is the relative velocity between the plate A and plate B. Similarly, in case 3 here this is plate A and plate B this is a conservative plate margin and this relative velocity of plate A with respect to B equal to 6 centimeter per year and similarly it is also 6 centimeter per year, but it is opposite to each other because plate A is moving in this way plate B is moving in this way.

So, similar to the divergent case, but here neither the plate is destroyed nor the plate is created. So, that is why this is conservative plate margin, this is destructive plate margin and this is constructive plate margin. So, now, in this block diagram here plate A and B they are moving away from each other and that is relative velocity equal to 4 centimeter per year and here plate A is overriding on plate B and the relative velocity equal to 10 centimeter per year and here plate A and B they slide past with respect to each other with a relative velocity of 6 centimeter per year. Now, if this is so, that means, on the flat surface and this plates are moving in a linear pattern and in a flat surface that means, we say this 4 centimeter per year it is constant throughout the plate boundary. Similarly this 10 centimeter per year it is constant throughout the plate boundary and the 6 centimeter per year it is also constant for the whole plate boundary.

That means, starting from this beginning and up to the end the plate velocity or the relative velocity of the plate remains same as we assumed that this earth is a flat body and all these blocks are flat. Now, in this system let us talk about two plate system. Suppose we have two plates one is plate A and another is plate B, but before the generation of plate B imagine that plate A was only existing and it was moving in this direction only one plate was existing and with time we carved out plate B from here and finally, we created a mid-oceanic ridge here and this is the half spreading rate 2 centimeter and 2 centimeter to opposite direction and the relative velocity is 4 centimeter per year. Now imagine if we are carving out a plate and creating a plate boundary here that is the divergent plate boundary that means, we are adding some area, but the basic assumption in the plate tectonics if you remember it says this earth total area remains constant. So, now this area which is added here or increased here that must be consumed or adjusted somewhere.

So, that is why at the other end of this plate here in plate A and B to accommodate this area we are creating a subduction zone. So, in the subduction zone either this plate A it will subduct under plate B or plate B will subduct under plate A that is different issue, but here anyway this question mark we are creating a subduction zone. Now the plate B is bounded by a divergent plate margin on the west and then convergent plate margin in the east. What about its north-south? If this plate B is moving in this way and plate A is moving in this way so that means, this northern boundary it is representing a strike-slip fault. Similarly, here at the southern boundary it is also representing a strike-slip fault.

However, the difference is if you see this northern boundary is representing a sinistral strike slip fault and in the southern boundary it is representing a dextral strike slip fault. So, this image can be analogued here this Nazca plate which is part of a pacific plate and this is the South American plate and it is subducting down here and this is the videos decrease similarly here and this is the subduction zone it is similarly here. So, we have transform fault both dextral and sinistral one here. Now if this is so and here two cases may arise. The case one it says if you see this is plate A and this is plate B similarly here, here the subduction zone is pointing towards plate B that means, here the plate B is the obducted plate and in case two plate A is the obducted plate and plate B is subducting down.

So, that means, once we are creating a subduction zone here either plate A may subduct under plate B or plate B may subduct under plate A. So, now let us talk about what exactly is happening if plate A is subducting or plate B is subducting. So, suppose in case one that is the plate A is subducting under plate B. So, here plate A is being subducted beneath the plate B equal to 4 centimeter per year because this is the relative velocity and this means that that plate B is increasing its width in 2 centimeter per year and this being the rate at which the new plate is formed at the ridge axis. So, now here this is the relative velocity of plate A and B equal to 4 centimeter per year and plate A is being consumed at 4 centimeter per year under plate B.

However, the plate B is increasing its width 2 centimeter per year. So, ultimate result is that that plate B's area is increasing. So, if plate B's area is increasing so that means, earlier the subduction zone we have constructed here and once with time the plate B is increasing its width. So, that means, the subduction zone position is shifting towards east, but if in the case two that this plate B is subducted under plate A. So, what is happening here? If you see here plate B is being subducted beneath the plate A at equal to 4 centimeter per year which is faster than the plate B which is created at the constructive plate boundary because here plate B is created 2 centimeter per year, but here it is subducting at 4 centimeter per year that means, 2 centimeter of its width is annually decreasing.

So, once the 2 centimeter width is decreasing annually so that means, the subduction zone position which was earlier here. So, gradually it is shifting towards west. So, that means, once this subduction is shifting towards west gradually finally, it is meeting with this divergent plate margin. So, that means, the whole plate B is consumed with geological time. So, that means, once this plate B is totally consumed that means, whatever the earlier configuration was that means, plate A was only existing.

So, now, the same situation arises again. So, that means, similar way the number of plates on the earth's crust has been totally consumed and number of new plates have been developed and this plate boundary either it is shifted in this way or that way that depends upon the rate of relative velocity. If the relative velocity between these plates that decide whether this subduction zone or this divergent margin that will shift or will remain static at its position. So, the present day distribution of subduction zones and this mid-oceanic ridge were not the same as the geological past and will not be in future. And why this is not because of this change in relative velocity because if you remember our earlier class we were talking about this velocity changes with geological time and the same plate it may change its velocity at different geological time for example, Indian plate it was moving around 16 centimeter per year then 10 centimeter per year now it is moving at 5 centimeter per year.

Similarly other plates they have changed their relative velocity with geological time and this relative velocity along this plate boundary as we have assumed that it is a flat system that we believe that 6 centimeter per year relative velocity that means, throughout the plate boundary it remains 6 centimeter per year. But let us talk about what exactly it is happening whether it is remaining the same or there is any change it is occurring here. In geological past to the recent many times the plates configuration has been changed and in the geological future this present day plate configuration will also be changed too. So, there will be no constant plate configuration from geological time up to now. So, starting from this beginning of this earth there are many supercontinent cycle there are many Wilson cycles and this plates dimension has been changed their velocity has been changed the direction has been changed.

So, that is why there are number of things the earth has evolved in terms of plate tectonics. Now, let us talk about 3 plate system. So, here this plate A it was earlier existing and then plate B we carved out from this plate A. Let us introduce another plate C which is a common boundary between plate A and plate B. But the difference is that here plate C and plate A they are sharing a convergent margin and here they are also sharing a convergent margin and here they are sharing a convergent margin, but it is co-linear convergent margin that means, with respect to plate B and A this plate C this boundary is co-linear.

So, now what is happening if it happens with the relative velocity that we have mentioned earlier. So, this plate velocity or the relative velocity between plate A and B it is known to us. So, plate A and B are spreading away from each other the half spreading rate of 2 centimeter per year and the relative velocity is 4 centimeter per year. The eastern boundary of plate A and B is a subduction zone with plate A being subducted beneath the C at rate of 6 centimeters per year. Here if you see this plate C is an obducting plate though it is a plate we introduce later, but let us assume it is obducting plate.

So, that means, it is a overriding plate and plate A is subducted under plate C. Similarly plate B is also subducting under plate C. So, now, relative rate of plate motion at this boundary between plate B and C would be vector addition simply the relative velocity of B with respect to C equal to with relative velocity of C with respect to A and A with respect to B. So, this is vector addition formula that we adopt to calculate the relative velocity of different plates. So, now, let us talk about what exactly it is happening here with this relative velocities.

So, here the net rate of destruction of plate B equal to 10 minus 2 equal to 8 centimeter per year because if you see this is the relative velocity of plate B and C equal to 10 centimeter per year. However, this plate B is rising or it is increasing its area or adding 2 centimeter per year. So, what is the net loss equal to 8 centimeter per year because 2 centimeter it is increasing, but 10 centimeter it is consuming. So, annually 8 centimeter of this plate B is being consumed under plate C. So, if this is happening so, 8 centimeter per year it was it is consuming.

So, that means, this subduction zone between plate B and C gradually it shifts towards west. So, now, this earlier it was believed that this subduction zone is co-linear with plate A and plate B and C and at this B and C this plate will move or the boundary will move in this way, this boundary will move in this way and a faster rate; faster rate because the annual consumption is more as compared to its annual formation. So, that is why at a faster rate this plate boundary or the subduction zone it is shifting towards west and that is why plate B will totally subducted and a simple two plate subduction model will be operational. So, now, plate A and C will remain and totally this plate B will be consumed from the system. So, there therefore, and this way there are number of times in geological past many plates have totally been consumed without having some trace and some of have some trace existing nowadays.

So, if this is happening so, what should be the north-south motion? We have already discussed about this east-west motion how this relative velocity change how it is changing the configuration of this plate boundary. Let us talk about some north-south motion here. So, this western boundary of this plate B is a ridge and that is spreading at a half rate of 2 centimeter per year that means relative velocity equal to 4 centimeter per year and the northern boundary of a plate B is a transform fault. Here if you can see it is a transform fault here and it is a sinistral transform fault and boundary between A and C is a transform fault with a relative velocity equal to 3 centimeter per year. So, here it is relative velocity is 3 centimeter per year.

Now what is the relative velocity of B with respect to C? So, here the plate B is undergoing oblique subduction beneath plate C equal to 5 centimeter per year because if you see here we have a vector addition system here this is 3 centimeter and this is 4 centimeter and finally, we are getting 5 centimeter and with this direction. So, that means, plate B is consumed under plate C equal to 5 centimeter per year. So, now imagine a plate B which is spreading in this direction and finally, it is consumed in this direction. So, what will happen in future? So, that means, this spreading axis or this mid-oceanic ridge gradually it shift in this way and in this way and this way. So, these are these future stresses or this future predicted stresses of this mid-oceanic ridge if the rate of consumption and the rate of formation prevail in this rate and if it changes then this configuration or the boundary configuration and the plate configuration also in change.

In that case the boundary between C and B would not remain co-linear with the boundary between plate A and C that will move steadily to the east and the other possible solution for the C to be subducted beneath the plate A is 5 centimeter per year. So, here it is 5 centimeter per year it is consuming here and that is why once it is consumed here. So, this boundary that will move that will not remain as it is. So, that is why the plate boundary configuration is changing when this rate of plate motion is changing and the relative velocity is also changing. So, now, this way this earth's configuration from this beginning up to now it has changes many times.

So, now, if you see it is starting from this 100 or 250 million years up to now if you notice here this time is changing and this plate configuration is changing now it is starting from 0 then it is increasing with time up to if you can say around 200 million years. So, this plates configuration is changing different plates are moving at different directions and these are the plate configuration at different geological time and this geological time-wise change in plate configuration it is nothing due to this change in the relative velocity of this plates and this relative velocity that defining how this plate boundary either it will remain constant or will shift eastward, westward or north-south depending upon this earlier configuration and depending upon this plate motion or the relative motion along the plate boundary. So, the real earth however it is not flat as we have assumed so far. So, that means, in our assumption whatever we have discussed so far we believed that earth is flat and this 6 centimeter per year or 5 centimeter per year or 2 centimeter per year that we believe that the rate of motion or the relative velocity it is remain same. If we assume it is 5 centimeter per year throughout the boundary it is 5 centimeter per year and it is 6 centimeter that means, throughout the boundary it is 6 centimeter, but it is only and only possible if the plates are flat.

However, in the actual world the plate is not flat it is on the curved surface that is in a boundary and this is on the sphere and on the sphere these rigid blocks are moving. So, it is not a linear motion and it is not just a flat surface. So, they are curved. So, that is why whatever we have discussed so far for understanding the relative motion only. In real world this theory does not work we have to adopt some other criteria to describe this plate motion and to understand how this plate boundary configuration is being changed with time.

So, in the real earth however the spherical it is not flat therefore, we need to use some spherical geometric calculation. Plates move on the surface of the sphere which following the Euler's fixed point theorem. So, this Euler's fixed point theorem that defines the plate movement direction and the relative velocity along this boundary among the different plates. So, in the next class we will talk about what is this Euler's pole and what is Euler's fixed point theorem and how it is defining the place motion, how it is defining the plate boundary, how the plate boundary configuration changes, the orientation changes and how this rate of motion of the plate changes with respect to this position of this Euler's pole. So, thank you very much and we will meet in the next class.