Plate Tectonics

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Lecture – 36
Fault Plane Solution

Okay friends, welcome to this class of plate tectonics. In today's class, we are going to discuss about Fault Plane Solution or in the other word it is also called Focal Mechanism Solution. So, what exactly it means to you and what is it use? So, before going to fault plane solution, we should know what is a fault? and after all whose fault is it? So, this figure it is self-explanatory. So, it says it is not me, it is not my fault. So, fault maybe someone's others. So, I am not talking about this fault, but we will talk about the faults which is of geological origin.

So, you know that there are different schemes of classification of a fault. So, broadly it is a normal fault, reverse fault and if it is low angle reverse fault like less than 15 degree, we called it is thrust fault and it is strike-slip fault. So, these are the basic classification of faults. In addition to that, we may say it is dip slip fault if this slip is vertical or it is a strike-slip fault if it is horizontal and we can say it is a oblique-slip fault if it is mixed.

So, based on the different scheme of classification, the fault is further may be named differently. The same fault may be classified in based on different parameters and may be named differently. But overall the fault it is through a plane it is separating two blocks either it is a reverse fault, strike-slip fault or normal fault. So, everywhere the common thing is that we have a plane and that plane it separating the two blocks and one is called foot wall another is called hanging wall. So, the foot wall this is called the foot wall.

So, this is the foot wall block and this is the hanging wall block. So, foot wall it name itself it says you can keep your feet here you can stand on it. However, you cannot stand on this plane. So, this is the foot wall block and this is the hanging one block. So, now we have a plane this is the planar surface we have a plane that is called fault plane.

Now, the fault plane solution it says that what is the origin of a fault either it is a normal fault or reverse fault or it is a strike-slip fault and what depth it was originated and at what time it was originated and what is the movement type and what is the depth and what is the distance from this point of measurement that means, source of faulting. So, all those information they are retrieved and that is used for tectonic analysis, fault analysis that is fault plane solution. So, if you see this is a fault plane and here you see this is the plane you see just I have removed the upper part only the fault plane is shown to you and these are the lines these are called the lineations that is the slickensides and this is the plane on this plane there are some linear structures that is called slickensides they are indicating the movement direction and which direction the block has moved and this plane if it is there. So, it should have a dip and strike, dip and strike you know if they are the basic things dip is the inclination of a plane with respect to horizontal measured in a vertical plane. And the dip and strike here that means, a plane which is here this should be the dip amount this angle should be dip amount and the strike is here that is the horizontal plane where it is cross-cutting the inclined plane it is creating an imaginary line that is called the strike.

So, now on this fault plane whatever the lines are there we can measure their rake like this rake or plunge, plunge means here if you see a linear structure how much its inclination with respect to horizontal that is called plunge and the basic difference between dip and plunge is that dip is the inclination of a plane with respect to horizontal and plunge is the inclination of a line with respect to horizontal As it is a linear structure so, its inclination with respect to horizontal it is called plunge. So, anyway these are the characteristics of the faults and in this class we will talk about fault plane solution how to derive a fault plane solution and if you see these figures there are series of figure we have a fault here and due to the movement of this fault we are creating an earthquake here and this is the focus or hypocenter and vertical to it on the surface this is the epicenter and as the fault movement is taking place the failure is taking place. So, there is a ground shaking, so, waves are generated. So, these waves are called seismic waves and the seismic waves there are two types one is called the body wave another is called the surface wave. So, body wave that means, they pass through the body of this earth earth's internal body through which the waves are passing.

For example, if this is the earthquake occurring at certain distance or certain depth the waves generated from here that will move here and there. So, here you see the wave is moving through this earth's body and this is the seismometer or in the other word it is called seismograph not seismogram it is called seismograph and it is recorded here. Similarly, through the earth's body this wave is moving and it is recorded at this seismograph and ultimately this is called waveform. So, that means, the wave which is passing through this earth's body or on the surface when this seismometer or this seismograph records it it will give this type of curve so, this curve will be like this. So, some opposite that means, some opens down some waves are there.

The first arrival it is by the P-wave the primary wave. So, its velocity is more so that from this origin it travels very fast and reaches at the seismograph and the next wave is the S-wave this is secondary wave. So, next wave one is coming again there will be some waveforms that will be generated and this part where the amplitude is very high this part it is called the surface waves the L and R wave we will show you in the next to next slide. So, this is called the waveform. So, that means, after an earthquake the seismologist they get this type of graph from this seismometer or the seismograph and based on this they create some waveforms and that waveform is this and it is the work of a geologist to define which type of fault was responsible for this earthquake and what was the depth at what depth the earthquake occurred or the fault failure occurred and what is the distance from this present recording station all these information and what is the time when this earthquake occurred all those information that can be retrieved from this waveform and that retrieved form that is presented in this format these are called beach ball diagrams.

These diagrams they are called beach ball diagrams the name beach ball it is because it is looking like the beach balls that we play. So, that is why this is called beach ball diagram. So, that means, earthquake occurring, seismometer it is recording giving this type of waveform from this waveform analysis the geologist are able to create this type of diagram that is beach ball diagram by looking this beach ball diagram we have to interpret what kind of fault is involved for this generation of this earthquake. So, this is all total about the fault plane solution. So, already we have discussed this beach ball diagram that is graphically represents the geometry of this moment tensor derived by this seismologist using sophisticated waveform analysis and these are the waveform and from this waveform analysis we are getting this beach ball diagrams and from this beach ball diagram we say which kind of fault is responsible for this earthquake generation.

Now, these are these different waveforms that are generated during the earthquake and these two are called the body wave that is the P- wave and S-wave and these two are called the surface wave that is called love wave and rayleigh wave. So, these two waves they are responsible for the damage of properties breaking of these buildings, the infrastructures because they are travelling at the surface or near surface so, they are very strong. So, most of the damage that is created during the earthquake are by the surface waves and the body waves they travel inside the earth and they have less potential to damage compared to this surface waves. So, focal mechanism solution is the result of an analysis of waveforms generated by an earthquake and recorded by a number of seismographs. So, here you see number of seismographs are installed at a different part of the body of this surface different part of this earth.

So, you are looking at the cross-section only. So, if you see this surface as a whole as a globe you will find different part of this earth has been equipped with different seismograms and if you see here there are different seismograph stations they are installed at different part. So, the complete characterization of an earthquake's focal mechanism provides important information. What are the important information can be derived from these waveforms that is the origin time when it was originated, then the epicentral location where this epicentral is, then its focal depth at what depth the earthquake occurred and this plate tectonics when we are talking about this focal depth you probably you can recollect the classes when we were talking about the Benioff zones the highest depth so far recorded around 670 kilometer so, this 670 kilometer this is depth there is the focal depth which is derived from this waveforms. Then seismic movement that means, a direct measure of energy radiated by the earthquake how much energy is released for this earthquake.

So, that is called seismic movement. Then the magnitude and spatial orientation of this 9 components of the moment tensor it is a 3 by 3 matrix. So, that is why we have 9 components I will show you. From the moment tensor we can ultimately resolve the orientation and the sense of slip of this fault. So, which direction the movement has occurred either it is a normal fault or it is a reverse fault or it is a strike-slip or oblique-slip fault and in which direction the movement has occurred with respect to north.

So, that can be detected by this movement tensors by this waveforms. So, this is the stress tensor and this is the moment tensor. Stress tensor it says the state of stress for example, here you see the 2 arrows they are pointing towards each other. So, that means, it is saying it is the stress is like this compressions and moment tensor here you see during movement what was the state of stress. So, that is the moment tensor in just for Layman language.

For any moment tensor there are 2 possible planes that is called nodal planes and they are at right angle to each other. For example, here you see we have here that means, 2 during movement. So, here 2 planes they are moving away from each other. So, that means, we are creating a normal faults. So, here it is a strike-slip fault in the strike-slip fault these are the 2 nodal planes that means, moment may occur here or moment may also occur here like this.

So, that means, we have a nodal plane here the movement is occurring like this or we have a nodal plane here this movement is occurring like this. So, that means, we have 2 possible planes these 2 possible planes are called 2 nodal planes. So, out of this one will be the fault plane and another will be the auxiliary plane. So, that means, if the movement is like this. So, here will be some compression here will be some dilation similarly this side here there will be compression here will be dilation.

Similarly, if this movement is like this is the compression, dilation and this is the compression, dilation So, that means, for both planes I am getting the same result. So, that is why from this Beach-ball diagram we will get one or we are getting 2 possible planes one is the fault plane and another is the auxiliary plane which is perpendicular to that. All the seismologists that can only say with reference to the moment tensor is that the earthquake was generated on one or other of these nodal planes but they cannot say which plane is actually the fault plane and which one is the auxiliary plane. So, to confirm that which one is the fault plane and which one is the auxiliary plane we have to take geological input. For example, suppose there is an earthquake which is occurring from this Narmada valley and from the Narmada valley we know this fault it is around northeast-southwest the rift basin.

So, that may be one nodal plane will be like this another nodal plane will be like this perpendicular to that. So, as a seismologist he or she cannot define whether this is the fault plane or this is the fault plane which one is fault plane which are auxiliary plane it is difficult to identify for it But as a geologist when we are putting the geological input that is the Narmada valley from where this earthquake is occurring and we know that Narmada is a rift basin which is like this orientation. So, that means obviously we will prefer to put it as the fault plane and this is the auxiliary plane. So, that means geological input must be required to confirm which one is the fault plane and which one is the auxiliary plane. Similarly, suppose for example we are creating an earthquake here and this is the San Andres fault and we know the San Andres fault is a strike-slip fault its orientation is like this.

So, definitely an earthquake which is occurring from this region it will attract this orientation of this fault plane will be like this and the auxiliary plane will be like this so, the great circle arcs are the nodal planes one of which coincides with the fault surface that generate the earthquake. So, these are the great circles. So, there are different great circle we will see here. Now, the focal mechanism solution, beachball diagrams or this lower hemisphere stereographic projections. So, lower hemisphere stereographic projection that means it is equal area net.

So, if the projection is to the upper hemisphere we are going for this equal angle net. So, there are two types of net that is called Wolf net and Smith net this is called equal angle net and this is called equal area net. So, if the lower hemisphere once we are projecting so that means this is the equal area net we are preparing. So, whenever you are going to carry out this fault plane solution so you will prefer this equal area net rather the equal angle net. So, that means the lower hemisphere stereographic projections that show two block quadrants and two white quadrants separated by great circles are oriented 90 degree from each other.

Now, here some of these diagrams they are representing it this is the equal angle net that is a wulff net and here if you see this is the fault that is a normal fault you see and this normal fault it is dipping around 45 degree or so. Now, you see with respect to north how this fault plane is represented here. So, this is the lower hemisphere. So, we are presenting the fault plane here. So, once we are projecting it at to the upper hemisphere.

So, here we are getting this circle that is the great circle. Isn't ? So, in this equal area net we will carry out this fault plane solution not from the equal angle net. So, here the pure dip-slip fault include the normal fault or the thrust fault and the normal fault that is represented by this two black shades from both side and the white in between. However, if it is reverse fault this two white parts and in the middle it is a black shade or black area which is representing a cat's eye view. So, why it is actually happening? This black area that is represent the compression and the white area that is representing the dilation.

So, now the question arises how we will do it, how to identify whether it is a compression whether it is a dilation and if it is a strike-slip fault and it is perfect strike-slip fault it will be look like this. So, here that will be black and here this will be black and this is white this is white if it is perfectly strike-slip fault, but if it is in oblique-slip fault like partly normal partly strike-slip. So, this will be the oblique-slip normal fault because the center it is lying on the white part that means, it is the dilation part. So, it is the strike-slip fault having normal component or a normal fault having strike-slip component. So, that is why there are two planes one plane is like this and another plane is like this they are meeting at a point.

So, if this is the plane so, this strike will be like this and if this is the plane this strike will be like this. So, that means, one plane if this is the fault plane so, this strike will be like this and if this is the fault plane this strike will be this and this "u" and "d" that represent the up-thrown and down-thrown. For example, suppose this is the fault plane this is the orientation of this fault for example, like this. So, here this is the down-thrown plot and this is the up-thrown plot and if this is the orientation of this fault. So, here is the down-thrown part and here is the up-thrown part and if it is a reverse fault at the up-thrown we will find the compression and if it is a normal fault in the up thrown we will find or this upper part we will find the dilation.

So, here are some examples suppose for example, this is a fault type which type of fault is it? It is strike-slip fault. So, in the strike-slip fault pure strike-slip nature so, here you see either this may be the fault plane or this may be the fault plane. So, if this is the fault plane now you see this black part this is the compression so, that means, if this is the fault so, I am moving in this way so, that means, here I am finding the compressions. So, the other part it will be the dilation. Similarly, if this is the movement other side this is the compression and these are the dilation.

So, that is why this orientation will be like this and the movement will be like this and if this is the fault plane similarly this will be the movement and this is the beach ball diagram. It is representing oblique slip normal fault because the center is at the dilation part. So, it is in oblique slip normal fault. If it is oblique slip normal fault for example, so, one plane is like this or another plane will be like this if this is the orientation. So, this is the strike of this plot and the if this is the orientation of this great circle.

So, this will be the orientation of this part. So, now imagine suppose this is the orientation of this fault for example, like this if this is the orientation of the fault so, compression at the upper part so that means, we are getting the compressions here isn't it ? and dilation is other side so, it is the "d" means down-thrown. So, here this is down-thrown block and here this is the down-thrown block if the fault orientation is like this. Similarly, here this is purely reverse fault. So, in the purely reverse fault so, this is the down-thrown, this is the up-thrown and this is the down-thrown, this is the up-thrown.

So, in both cases this is the orientation of this fault. So, here you see there is no change. So, in both cases this is the orientation of this fault that means, the strike of the fault will be like this, but they will be perpendicular to each other two planes they are perpendicular to each other. Similarly, this is also strike-slip fault, this is normal fault, this is oblique-slip reverse fault and there are up-thrown block and down-thrown block they are represented by "u" and "d" respectively. So, now, the question arises if these are the beach ball diagrams and so, far we are discussing this is the up-thrown, down-thrown and black, white compression dilation like that.

So, how to do it? This is the challenge just in front of us how to do it in practically. So, the basic techniques for using this P wave first motion records by an array of seismograph So, the basic techniques for using this P wave first motion records by an array of seismograph to define the fault mechanism solution or focal mechanism solution of the beach ball diagram. So, how it is created? So, for example, just I am going somehow back to explain you how the first wave of P can be used. For example, here now we have two waveforms. So, here you see the P wave which is recorded here and also it is recorded here, but the difference you can notice here.

Once the P wave is recorded the first motion is upward and here the P wave recorded the first motion is downward. So, that means, here once the first motion is upward that means, the compressional wave. So, the seismograph which is recording this P wave arrival first it fills the compression. So, this is the compressional wave it is written here this is the compressional wave it is arriving first and it is the downward movement that means, it is the dilation wave that is recorded first. So, in our fault mechanism solution we will consider this part whether the first arrival at this seismograph it is compressional or dilatational.

So, that is the fundamental behind which we have discussed so far that can distinguish whether this first motion will be compressional or dilatational that will define which part of the black and which part will be marked as white. For example, if you see here we have different seismic stations for example, like this ABC like up to N. So, that means, we have earthquake which is occurring at the center/ epicenter is here at the center of this circle and we have different seismographs they are installed at different part of this globe around this epicenter we recorded the data. And the data which is recorded may be here first wave will be compressional may be dilatational. Similarly, the first wave here whatever recorded it may be compressional or may be dilatational.

So, if it is a compression we will write C or we will give a black dot for this and if it is a dilatational we will give a circle which is not black or which is the open circle. So, that means, or we can write is D so, that means, we have different seismic stations. So, based on the first arrival of this P wave either it is compressional or it is dilatational based on that we will mark the circles or mark the point either we will fill it if we are filling it it is compressional wave or the stations which is recording the compressions and these stations which are not recording the compression or this dilation that will marked as open circle. And here if you see this is the epicenter and these are this position of this seismic stations with respect to this epicenter with angular distance.

So, what is the angular distance that means in degrees. So, this data plotted on the lower hemisphere in the stereographic projection on an equal area stereonet. If you are projecting at the lower hemisphere then it is equal area projection if you are projecting to the upper hemisphere that is called equal angle projection. And the data from each seismograph station is plotted with one of the three symbols. What are the three symbols? May be a circle where this P wave is recording the extension motion or dilation motion or may be a black dot which is filled it is the compressional or may be x that is a null point so, that means imagine suppose from origin of a earthquake is here and the waves are passing to different direction somewhere it is compression somewhere it in dilation. So, in between there may be some seismic stations which may not record pure compressional or pure dilation wave that means, this seismic stations are confused whether the wave they are recorded they are compressional or dilatational.

So, that means, due to this confusion that can be null point. So that means, neither it is compressional wave nor it is dilatational wave so, that is the null waves. So, this is the first motion was too weak to differentiate between the compression or dilation. So, in these three symbols if you see this figure here one is compressions compression, compression, dilation, dilation and some of the x point these are the null points so, there it is not clearly defined whether it is a compressional wave or dilation wave. Now, there are different stations and that different stations their first arrival has been represented by these symbols.

Now, for each station the symbol is placed toward the azimuth of the station with respect to the takeoff angle. So, now, the question arises what is takeoff angle? In geology we are talking about dip, strike like this. So, dip it is the angle of an inclined plane with respect to horizontal measured in a vertical plane now, the takeoff angle is opposite to dip. For example, if this is the earthquake occurring for example, here suppose this is the globe or you can say this is the globe and this is the hypocenter the earthquake is occurring and the waves are generating and moving at a different directions and these are the recording stations they are recording it now, vertical to it is the epicenter. So, the hypocenter and epicenter if I am joining these two in a straight line it is moving down to the center of this earth.

Now, the angle which is created by the wave which are generating from this this angle it is called takeoff angle and this takeoff angle based on that takeoff angle that means the takeoff angle defines the angular distance from the center of this plot to the symbol so, that means, I have a globe here and these are these recording stations at different places and here the earthquake is occurring this is the hypocenter or the focus and if this is the recording station so, this wave which is generating from there. So, it is occurring here so, how much angular distance it is occurring with respect to the hypocenter or the focus.

So, that is called the takeoff angle. So, here the best way to measure the takeoff angle is join the hypocenter and epicenter to the center of this earth and this angle which is generating here that is called takeoff angle for this wave. Similarly, this is the takeoff angle for this wave so, the angle of incidence at the earthquake source is the angle from this vertical at which the ray leaves the source and this is the angle at which the ray intersects the lower focal hemisphere and this is opposite to dip that means, 90 degree minus dip equal to takeoff angle.

So, here if you see the stations are here. So, here dip equal to 90 degree minus takeoff angle. So, then based on that this is the epicenter and these are the recording stations and the recording stations these are representing the compressions and these are representing the dilations and these are the null points they neither pure compressional or pure dilatational. Now, these null points they are very much helpful in determining or creating this beach ball diagram because these null points they are separating the compressional area from the dilatational area so, that means, I can put a plane which can separate the compressional region to this or from this dilatational region and that plane is passing through this null point so, that means, this stereographic net that is the equal area net I have to rotate in such a way so, that these null points they are fitting with a great circle, great circle means that is a plane. So, if I am rotating that equal area net in such a way these great circles they are putting they are falling on this plane so, that means, this plane this is separating the compressional region from the adjacent dilatational region. Similarly, this plane this is separating this compressional region from the dilatational region.

So, that means, two planes which are carrying this null points or they are separating the compressional and dilatational region they are cross cutting here and finally, those compressions. Now, you see all these compressional points they are confined in this zone and the dilatational regions they are confined in this zone similarly in this zone So, I can make it black I can make it black. So, like this you see and this is white and this is white because this is dilatational. So, now, what I am getting? I am getting a beach ball. So, this is compressional, compressional and dilatational so, dilatational and the center it is lying on the compressional region.

So, that means, it is an oblique slip reverse fault because here the center is at the reverse region and this is the strike-slip fault we have 4 quadrant isn't it. So, that is why it is a oblique-slip reverse fault which is responsible for the formation of this earthquakes. So, these are this nodal planes on which it is in coincidence with the fault that produce the earthquake finally, we fill these quadrants according to this convention either compression or dilation so, finally, we are getting a beach ball diagram from our data.

So, generally focal mechanism solution for divergent and convergent margins if you remember when we were talking about the divergent plate margins mostly the divergent plate margins they are represented by normal faulting and some strike-slip faulting around this transform fault. For example, if you see this is the ridge crest and in the ridge crest the earthquake that is normal in nature however, the transform fault it is strike-slip fault in nature and now the convergent margin mostly it is of reverse fault.

So, it may be some normal fault or mostly it is oblique fault and strike-slip fault like this. So, mostly it is oblique slip reverse faults are there or reverse fault will be there because it is a compressional regime so, that these are this arrangement of this earthquake that is this focal mechanism solution or the beach ball diagrams. But if there is a nuclear explosion that will create some seismic waves that will also be recorded by these seismometers so, how to distinguish whether this seismometer which is recording these waves it is created by nuclear weapon or it is created by this fault movement. So, this is very a that means, clear cut distinction if you are creating a compression or dilation by this that means, nuclear explosion. Now, just see this video there is compression that means, starting from the center explosion site everywhere the first moment it is like this so that means, it is compressing so, that is why if you see this beach ball diagram it is whole total is representing the compression.

But here if it is by the faults so, we are getting 4 different quadrants or 3 different quadrants depending upon the nature of fault. However, here there is no quadrant and only one and which is totally by the compression. So, by this way you can identify whether this is nuclear bomb or it is due to this earthquake generated by these faults. So, this is all total about the fault plane solution. Thank you very much, we will meet in the next class.