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

Week - 10
Lecture – 46
Plate Tectonics and Hydrocarbon Exploration- II

Ok Friends, welcome to this class of Plate Tectonics. In the last class, we were talking about this plate tectonics application in hydrocarbon exploration and in special emphasis on this divergent plate margin and the intraplate environment. And in this class, we are going to discuss about this plate tectonics application in hydrocarbon exploration, particularly at convergent margin basins. So, irrespective of its tectonics nature, we need sedimentary basins and we need organic matter. Their organic matter should be matured with the effect of temperature and pressure with depth and pressure-temperature with related to magmatic activity, hydrothermal activities and finally, it will release the petroleum hydrocarbon that will be stored within the pore spaces and it will be sealed by this sedimentary layer or sills and finally, we are going to extract it. So, this is the main theme of petroleum hydrocarbon exploration.

However, as per tectonic is concerned, different tectonic environment, they are giving different types of sedimentary basins with respect to this plate margin and their size, the geometry and depth varies from place to place. Similarly, sedimentation nature or this thickness of the sediment that varies from place to place, that is why different sedimentary basins have different potential of a hydrocarbon. And in today's class, we are especially emphasizing on the sedimentary basins associated with the convergent plate margin settings. Now, you see this figure, we have that means classified this tectonic environment particularly the convergent tectonic environment in different settings.

One is the collisional orogen, these two continent system they are colliding. So, in the collisional system, we are creating some basins, one is the peripheral foreland basin that means we have a sedimentary basin here. Then coming to this rifted continental margin, we are getting a remnant ocean basin then we have forearc basin, this is the arc system, we have forearc basin then we have back-arc basin, this is the retro-arc basin you can say, this is the back-arc basin. Then we have a different arcs of different generation. If you remember earlier class when we were talking about the convergent system earlier this plate was converging like this and with the phase change or with the loading of this overriding plate, this gradually bends down.

So, finally, we are having this volcanoes here, then we have arc here then we will have arc here. So, that means within that different sets of arc, we have sedimentary basins enclosed that is called interarc basin and then we have a trench itself here. So, now you see in a convergent setting starting from the collisional system to convergent system, we have different sedimentary basins that are arranged in a different place. Similarly below the sedimentary basins, the heat source is different somewhere it is at shallow depth, somewhere it is at deeper level. Similarly, the depth of sedimentary basins are different the sediment source are different from different basins.

So, that is why all these basins which are arranged in a subduction system they have different potential of hydrocarbon generation. So, that is why here both compressional as well as extensional basins can be developed. However, if you remember when we were talking about the sedimentary basins associated with the divergent plate margin setting, all these sedimentary basins associated with the divergent plate margin system, they are of extensional nature. However, here we have compressional settings or compressional sedimentary basins are also associated. And once we have a compressional system that means sediment whatever we are accumulating we are squeezing the system, we are compressing the system.

So, that means we are increasing its temperature, we are increasing its thickness due to squeezing, we are increasing the overburden pressure due to thickening. So, that is why petroleum hydrocarbon can generate easily as compared to other parts. So, that is why we have both compressional basins and extensional basins associated with the convergent margin setting. So, now here we have a convergent margin setting, the basins have been classified. So, here the basins are oceanic inter-arc basin, then continental inter-arc basin oceanic back-arc basin, continental back-arc basin, retro-arc foreland basin continental foreland basins and broken retroarc foreland basins.

So, now you see apart from that we have inter-arc basin, back-arc basin retro-arc basin, remnant ocean basin. So, that means a series of basins they are associated in the plate tectonic environment characterized by convergent setting. So, that means more number of basins, more sediments, more hydrocarbon accumulation or more organic accumulation and more petroleum hydrocarbon. So, talking about the arc system, we have a outer rise that is the bulge here there will be bulge will be there, then we have a trench, then we have a subduction complex then foreland basin, then volcanic arc, then back-arc region. And this mass or this region it is characterized by a series of sedimentary basins characterized by different depth, different pressure, temperature condition, different size and their source of sediments are different.

So, extensional or it is called starved basin when the velocity of rollback is more than the overriding plate. So, here this is the rollback that means, retreating of this trench when the rollback is more than the overriding plate. So, that means, over-riding plate that means, it is moving at a faster rate than the rollback. So, once the overriding plate rollback is more rollback is greater than the overriding plate. So, rollback it is moving at a faster rate than the overriding plate we are getting the extensional basins.

And if the reverse is true that means, rollback is less, but overriding plate trying to override it so that means, there will be resistive force so that means, there will be compression. So, here is compressional basins that is called Piggyback basin because once it is compressional basin so, we have different thrusts. So, within the thrust so, we are getting this sedimentary basins here sedimentary basins here so, that is Piggyback basin. So, that means, if the rollback is greater than the overriding plate we are getting the starved basin that is extensional basin and if this rollback is less than the overriding plate we are getting the compressional basin. So, anyway we are getting a sedimentary basin and we are putting sediment and we are generating petroleum hydrocarbon naturally.

So, now talking about the foreland basin, the basins form when two continents converge backarc floored by continental lithosphere, flexural lithosphere bending due to thrust loading. So, now, you have to understand it here. We have this sedimentary basin that is the Indo-Gangetic foreland basin here we have loading of the thrust sheet MBT, MFT, MCT. So, now, there are number of thousands of thrusts are here. So, finally, if you take this cross section like this here we have a Indian lithosphere which is flexing down and now we are loading this MCT, MBT whatever the thrust sheets are there we are loading.

So, finally, we are creating a sedimentary basin here. So, this is the foreland basin or this is the Ganga basin here and this back-arc floored by continental lithosphere it is flexural lithosphere bending due to thrust loading. So, now, we are loading the thrust and we are creating the Indo-Gangetic foreland basin and the sediment accumulates both head and frontal side area on this foredeep and within the smaller basins that occur the top of the thrust complex. So, we have Piggyback basins developed behind the foreland basins. So, here once we are loading the thrust as we have discussed we have thrust loading.

So, within the thrust loading there are small Piggyback basins for example, here we are loading the thrust here and finally, we are getting some small size basins here these are the Piggyback basins and Piggyback basins developed behind a foreland basins. Another is the retro arc basin, retro arc means back side of this arc frontal side we have forearc or

the foreland and the back side of this arc we have retro arc of the back-arc basin. So, if the basin develop continental side of this ocean-continent subduction and thrust developed led to flexure. So, here we have developed some thrust and it is leading to flexural system here. So, due to that we have this back-arc basins or retro arc basins generally formed and here you see this is the Himalayan foreland system this is the Himalayan system and due to this flexural say due to this overloading due to docking effect now this continental lithosphere is flexed and finally, we are getting this is Hoh Xil basin that is in China and this is the retroarc and Tarim basin here these are the retro arc basins.

So, now you take this cross section this is the Himalayan range and after the Himalayan range finally, we are getting the basins here this is retro arc basins. So, fore arc and retro arc basins in the Himalayan context if you trying to understand we have the Ganga basin is the foreland basins and we have Tarim basins just behind the Himalayas that is the back arc basin or the retro arc basins. Then another type of basin in the convergence setting it is called peripheral basin periphery that means, it is the boundary. So, form due to continent-continental collision and suture zone develops causing thrust formation that causes its bending sediments derived from the fold-thrust belt. So, now here if you see this peripheral basin.

So, this peripheral basin is here and mostly sediments are derived from this thrust sheets they are developing here. Then there will be basin which is associated with the transform plate margin. So, transform plate margin if you remember our earlier class there is neither destruction nor any gain of this plate. So, two plates they move side past each other finally, it is called transform fault or transform motion and the basins developed it is called trans-tensional basin trans-tension and another is called trans-pressional basin and trans-rotational basin. So, this trans is related to the transform fault and trans-tension that means it is tension that is stretching then trans-pression it is pressed it is squeezing then trans-rotational due to rotational movement.

So, this basins here trans-tension that is extension along the strike-slip releasing bend and steps and example is the dead sea basin. Then trans-pressional basins formed by shortening along the strike-slip fault that is Santa Barbara basin. Then trans-rotational basins formed by rotation about the vertical axis along the strike-slip fault. So, this is trans-rotational basins and apart from that there are certain hybrid basins hybrid basins that mixture of all these things that can be happen and now we are going to discuss about this basins which are associated with the transform plate margin. So, first is the strike slip basin, strike slip basin here the wrench basin it other words it is called it is occur where these sections of this crust move laterally with respect to each other.

So, now if you see here we have two blocks they are moving with respect to each other one is moving in this way another is moving this way. So, if this fault plane or the fault line is not straight for example, suppose the fault plane is like this. So, another is like this. So, now you see when if this plate is moving this way and this plate is moving this way. So, gradually what you are getting here you are getting a basin developing gradually.

So, the same is been shown here now see this is two blocks they are A and B two blocks they are moving with respect to each other and here we are getting a sedimentary basins. So, this is not only sedimentary basins we are getting it here there will be number of sedimentary basins of such kind that can found all along this fault plane. So, overlapping two strike slip boundaries and it also tends to form enchelon fold that is transpression is operating. So, here you can see the size of the basin or the shape of the basin here. Basin drift mega sequence that is the continental origin this is then post drift mega sequence.

So, here that is post drift system then post transprational mega sequence after transpression then we are getting this deposit. That means different stages of this basin they are receiving the sediment and it is accumulating and if you taking this cross section each and every stage can be distinguished based on the facies association, based on the textural analysis, based on the rock type analysis. So, here subsidence associated with strike-slip basins are small and the sedimentation is rapid, facies belts are isolated. So, as wrenching continues the basin and its fill can be detached from the sediment source areas evidenced by the river drainage pattern which are displaced across the range system. For example, you imagine suppose here river was debouching and it is putting its sediment here like a pan or something or delta like that.

So, now once the size increase so gradually this size will increase. So, once this is increase it will disrupt this drainage system here. So, number of a poly channels you can see here the disturbance of this channel and finally, deposition occurs here at the periphery and this part become cut up from the diffusional site. And the individual basins are short lived and rhombohedral shape mostly lacustrine, fuvial and alluvial deposit at initial stage it happens. We have lacustrine deposit very small lags then we have fuvial deposits like this alluvial fans, this river deposits they are also dominating in this sequence.

So, here this is the dead sea sequence you can see here along the dead sea fault one is the here that is the red sea from and this is the red sea that is the divergent system and this is the strike slip or the transform system here we are getting the dead sea deposits

here and here this side we are getting this another Gulf of East Akbar. So, here one basin is there. So, two basins has been exemplified here and this mechanism is shown here how it is happening. So, this is oblique spreading you can see here now see this fault system or the joint system here see this orientation of the joint and the orientation of this motion it is not perpendicular to each other.

So, there is a rotational type. Then another reason for developing sedimentary basin is subsidence. So, subsidence its main control is tectonics again tectonics comes in the picture. So, due to extensional and compressional force acting on the lithosphere then this subsidence may be thermal. So, due to change in the lithospheric heat flow then subsidence may be by coupled force that means, response of lithosphere due to load of the sediment acting downward on it and this causes the lithosphere to subside creating more space for sediment to be deposited. So, anyway we are creating sedimentary basins by subsidence and we are filling it with sediments and once we are filling it the sediments if it is having organic matter it will mature with time with temperature and pressure and finally, give rise to petroleum hydrocarbon.

Then burial history of this rift basin suggest the scene rift burial history is typically dominated by fault control subsidence because at the initial time of the rift basin when the faults are active. So, the subsidence will be by fault related and coarse continental and shallow marine sedimentation will be there because mostly it is dominated by continental sediment initial time of rift. So, just to add created a depression and from the surrounding we are putting sediments into this basin. So, mostly it is dominated by this fluvial sediment and gradually once the size increases it is occupied by the marine system. So, marine sequence then it will be dominated the later states.

So, the post rift burial history reflects slowing subsidence that is thermally controlled and progressively deeper water fine-grained sedimentation is there. So, gradually once the water depth increases so fine-grained sedimentation at the bottom of this water and this periphery will remain at this coarse-grained sedimentation will be there. So, here you can see the depth and the time and it is the scene rift system and it is the post-rift system. So, how it is happening? So, at this subsidence it is occurring fast at the scene rift system and gradually in the post rift system the subsidence is gradualized. So, that means at the scene rift system the subsidence is more because of the fault activities.

But here at the post-rift system the subsidence is due to sediment overloading and this is very less pronounced as compared to this fault overloading. That means the tectonic is playing more role in the subsidence rather the sedimentation. In foreland basins

subsidence is characterized by in response to lithospheric loading as already we have discussed we have lithospheric loading like the Himalayas is loading under this Indian plate or Indian lithosphere. So, due to the overloading of this extra weight we are loading at the northern boundary of this Indian plate this system is flexing down.

So, we are creating a foreland basin here. So, this subsidence is created in response to lithospheric loading. So, that is why this due to subsidence and due to this loading we will find this normal faults developed at this northern edge. And the load generated by crustal shortening itself a product of a compressive tectonic forces and it is weighs down the lithosphere. The load act like a weight on this end of this bending beam as we have discussed how this Indian lithosphere is flexing down due to loading at the northern edge. The effect of repeated deformation in a foreland basin because we are putting a basin and we are filling with the sediment and then at the same time we are allowing the tectonics to modify.

So, that means more and more loading, more and more sedimentation, more and more subsidence and tectonic activity is continuous it is adding to the system. So, that is why this basin subsidence it is a repeated phenomena. So, more and more subsidence that means more accommodation space it is creating and more accommodation space that means more and more sediment it is allowing to deposit. So, that is why more sediment thick or you can say the thick sediment that means more organic matter and more petroleum hydrocarbon. So, that is why over-thrust loading, flexular deformation, relaxation phase, then viscoelastic response, renewed over-thrust loading, flexular deformation all these are responsible for this repeated deformation of this foreland basin.

So, irrespective of its regions repeated deformation means more and more sedimentation, more and more accommodation space. Then let us talk about the sediment supply into the basins. So, the sediment supply from the surrounding only, so the sediment supply it is less, but the basin is now empty. So, what to do? So, we are not expecting petroleum hydrocarbon. So, the rate at which the space is created by the tectonics and thermal forces is filled depends upon the availability of sediments.

So, we created a large basin, but having no sediment. So, it is useless, no petroleum hydrocarbon. So, that means not only creation of a basin is important, filling of the basin is important and filling of the basin with organic-rich sediment is important, otherwise no question of hydrocarbon exploration. So, the type of sediment depends upon the climate and the nature of the sediment supply which can use to characterize the basin type.

So, here another culprit is climate. So, climate decides how much sediment it will be produced, how much sediment it will be transported and how much will be remain at this place of sediment formation. So, this climate should be suitable for transporting the sediments from the source to sink, otherwise basin is empty, sediment is created at the hills, it is remaining there, no water, no source of transportation. So, that is why climate should be suitable also. So, that means in the four land basin, they experience early basin history with a sedimentation rate that is slower than the subsidence rate. So, sedimentation rate is slower than the subsidence rate.

So, that means what is happening? We are subsiding a basin, it is more rapidly than it is filling with sediment. So, that means what is happening? We are creating more accommodation space. So, that means fine grained sediments deposited in deep water with time. So, no peripheral input, no that means surrounding input, only the fine grained sediment is there or the basin's own sediment is there that is carbonate sediment or chemically precipitated sediment. But in the later stage, the sediment supply exceeds the rate of subsidence which lead to upward coarsening sequence of the sediment.

So, that means now the basin is filling very rapidly as compared to its subsidence. So, that means the totally the basin is filled, so that there will be coarsening upward sequence that will be hide in the stratigraphic sequence. In the rift basin, the fault controlled and rapid and early subsidence history creates coarse, non-marine and alluvial and fluvial sediments. Already we have discussed in the initial stage for example, rifting what should be the sediment supply, what should be the sediment source from the surrounding and the sediment are deposited in terms of alluvial fans, in terms of deltas like that. So, stagnation of this water column promotes the organically sediments that becomes petroleum source room and this stagnation because water should be stagnant.

If water will be mobile that means flowing water is there. So, once flowing water is there that means the water is oxygenated, the sediment is oxygenated and for petroleum hydrocarbon, we need a reducing environment like if you remember when we were talking about mineralization, the mineralization for you in particular the uranium mineralization we need a reducing environment. Similarly, for petroleum hydrocarbon we need a reducing environment. So, water should be stagnant, if water flowing is there that means continuous supply of oxygen is there whatever the organic matter would be there that will be oxidized and once it is oxidized it is no more required, it is useless. So, that is why stagnation of this water column it promotes organic rate sediment they become petroleum source rock that means it is settling down and finally, it becomes a part of the sediment later it will be transported by the flowing water.

So, later stages have marine transgression and progressively fine-grained and deeper water marine sediments are deposited here. So, that means whatever the organic matter that was settled down now they are blanketed by the marine sediments. So, if you see this petroleum hydrocarbon distribution throughout this globe there are two areas particularly they produce 70 to 75 percent of this petroleum hydrocarbon. One is Gulf of Mexico this side, another is the Middle East this side and these two regions they are 180 degree apart or near about 180 degree apart in the globe. So, that is why they are called also oil poles like North Pole, South Pole 180 degree apart.

Similarly these two regions they are also near about 180 degree apart from each other and that is what called oil poles. So, apart from these two prominent region there are other regions like here this yellow marked these are also producing petroleum hydrocarbon. So, that is running from the northwest of southern part of Americas one this is northwest southern part of Americas another is running from Iraq to India and bend southward. So, in Iraq to India and it is bending southward. So, there are two belts apart from these two oil poles these two belts they are by that means creating or they are the reservoir of the petroleum hydrocarbon.

So, now the question is why such uneven distribution? So, uneven distribution if you go back to the flat tectonic setting we have two types of areas one is shield area which is tectonically stable that means whatever this Archean-Proterozoic boundary it is stabilized technically no more tectonic activities. And another type of area for example, here this is called the mobile belts and the mobile belts they are more that means disturbed tectonically. So, more tectonically disturbance that means more sediment creation more accommodation space creation. So, more accommodation space is there more sedimentation is there and more sedimentation means more organic matter more organic matter more petroleum hydrocarbon. So, that is why those mobile belts are more important in terms of petroleum hydrocarbon generation as compared to this shield area and because these are tectonically stable.

So, now imagine how tectonic is playing its role giving this accommodation space giving the sedimentation giving this temperature and pressure for maturation and giving the faults and folds for their trapping that means this structures structural for creation of structural traps. So, that is why tectonic is playing a major role in hydrocarbon accumulation and hydrocarbon formation. So, this is all about this today's class.

Thank you very much. We will meet in the next class.