Plate Tectonics
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Week - 10
Lecture – 47
Plate Tectonics and Climate Change

Ok friends, welcome to the class of plate tectonics and if you remember in last class, we were talking about the applications of plate tectonics in petroleum hydrocarbon exploration. And before that we are talking about this application of plate tectonics in mineral exploration. So, that means we are talking about the application of plate tectonics in various sections like starting from our daily life to national economy to neighborhood relationship, research and so on. So, this climate change when we are talking about, so nowadays probably you have heard that number of meetings in international levels are going on, on this climate change effect. And we are spending billions of dollars on climate change. So, we think that the human influence on climate change is very significant.

However, one question now it arises in my mind that when there was no human being how the climate change was there. Even if in the past climatic record says in the sedimentary sections that the past climate change the temperature, it was much much more than the present day temperature. So, now the question arises why the climate change was there and whether the human influence it is significant to the present day climate change or earth's own cycle is there it is maintaining this climate change cyclicity it is a question of debate. So, now it is the climate change what is climate and how tectonic is influencing the climate.

So, climate as per this world metrological organization it says it characterises the average weather condition for a particular location over a long period of time. Now it is the average weather condition whether it is day to day variation and it is a long period of time long period of time in terms of climatologist around thousands or even if hundreds of year, but when it comes to geology we are talking about millions of years. So, here the ocean influences the weather and this distribution of land and sea it influence the climate because this solar distribution, its interaction with the sea is different and the interaction with continent it is different. So, this distribution of this solar radiation in terms of continent and ocean that define what type of climate will prevail in a particular region and that also influence the moisture condition that is the rain condition the temperature condition and all total it is affecting the weather system of a particular region. So, that means, when we are talking about this weather this climate all those are the metrological phenomena.

Now the question is why tectonics? Why tectonics is the culprit? Why we say tectonics can influence the climate change? Because when we are talking about the land and sea distribution, this land and sea distribution it is governed by the tectonics. So, we have heard about this supercontinent cycle we have heard about this Wilson cycle. So, through this Wilson cycle number of times there was ocean basins created and destroyed. For example, if you see this animated image here this is the development of Atlantic Ocean. So, now if you go back for example, now you see there is no Atlantic existing and there are supercontinent here and when there is supercontinent that means all land.

So, that means, this distribution of this solar radiation it was different and with time with the development of this huge ocean this is the Atlantic here it influence the climate change and particularly when there was supercontinent cycle and this continents were moving from here and there. So, that means, imagine you are just boarding on a boat and the boat is taking to you across this equator that means starting from this pole to next pole that means when you started from this pole you are feeling very cold then you are coming to this equator it is very hot again you are going to this pole it is very cold. So, that means, from a boat ride from this pole to pole you are facing different type of temperature regions and same thing happens with the continents. The continents they are just floating on the asthenospheric system and they are moving from one place to another. So, that means, they are just covering or they are changing one climatic region to another climatic region.

So, that is why this climate change it is affected and it is recorded in their respective sedimentary deposits. So, for example, Indian subcontinent in the Precambrian time it was somewhere and this proterozoic that means sediments were deposited which has responsible that means that climate on which it was staying the responsibility was there. So, the sediments deposited in response to that climate at that region and it is drifted back so that means this younger sedimentary unit which is superimposed on the older that will record the different climatic condition. And those climatic signatures in the rock record that also influence the present day food habit, present day soil development characteristics so like that. Because this minerals or these salts which are responsible for this formation during this hot climate or during the cold climate now they are getting weathered and now they are the integral part of our soil.

So, that means, the soil we are going for agriculture and whatever this agricultural crop we are growing on this soil they are also taking as intakes that salts. So, that means, whatever our food habit is there that is also influenced by the tectonics. So, in a broad sense if you think. So, now why the tectonics is the culprit? So, the main reason is that this due to tectonics new ocean basins are created, new continental mass is created and those continental mass that is moving from one place to another place. Similarly the ocean basin it is closing and opening.

So, that means, it is influencing the solar radiation distribution, it is influencing the land and sea distribution that is why this tectonics is thought to be the main culprit for this climate change. And even, even if you see this geological rock record there are huge rocks that were deposited in particular time that are solely responsible for this climate change, responsible for this tectonics related climate change because climate change there are number of reasons. So, the tectonic related climate change it is easy to identify from the rest. So, we will discuss in the later time. So, now, if you see this an animated image we are creating this mid-oceanic ridge basaltic system and the basalt which is going down and it is subducting here.

So, that means, we are creating a ocean basin here. Earlier there was no ocean basin for example, here no ocean basin is existing, but now we are introducing one ocean basin that means, we are disbalancing or you can say we are rebalancing this land and sea distribution and that is the rebalancing of this solar radiation distribution. So, now, changes in sea level and the seawater chemistry that tectonics has influence on this changes on sea level and the seawater chemistry. So, not only the sea level is fluctuating it is going up or down, but the seawater chemistry is also being influenced by the tectonics. At the sedimentary record in the continental areas is characterized by the marine transgressions and regression due to change in the sea level.

Here you have to understand these two terminologies one is the change in sea level another is the marine transgression and regression. So, change in sea level that means, either increasing or decreasing of the sea level. You probably have heard about one term that is called Eustatic sea level changes, Eustatic sea level, Eustatic. So, what is this Eustatic sea level changes? So, that means, it is the sea level changes which is measured from the centre of this Earth that is called Eustatic sea level changes and it is global Eustatic sea level changes it can be affected this you can fill it in the global level rather than in the local level otherwise there are local sea level changes. So, now, this up or down of the sea level that is called changes in the sea level. And now comes to the marine transgression and regression. Marine transgression that is very familiar word in sedimentology and sequence stratigraphy that this transgression that means, it is the coastal encroachment of sea.

So, for example, this is the coastline and this side is the landmass and this side is the water body. So, this sea is encroaching to the coast. So, coastal encroachment of sea it is called marine transgression and the reverse is marine regression, but how it is related to the sea level fluctuation. So, here the sea level rise and fall and the marine transgression regression may or may not match. For example, suppose this coast is subsiding, the coast is subsiding it is going down at a higher rate as compared to the sea level fall.

The sea level is also falling down and the coast is also subsiding. However, the rate of subsidence of this coast is more than the rate of fall of the sea. So, you can see the sea level is falling down there should be marine regression no, in this case there will be marine transgression because the coast is subsiding at a higher rate as compared to sea level fall. So, instead of regression there will be transgression. Similarly opposite thing may occur.

For example, suppose the sea level is rising and also coastal upliftment is there and the sea level is rising at a higher rate or suppose the sea level is rising at a slower rate as compared with coastal upliftment. So, that means instead of transgression there will be regression. So, you cannot say the sea level is rising that means there will be transgression or sea level is falling there will be regression. That depends upon the coastal condition. So, these two permutation combination that means rise and fall of the sea level and the coastal subsidence and coastal upliftment that decide whether there will be marine transgression or regression.

Simply coastal encroachment of sea is called marine transgression and the reverse is called marine regression. And the sea level rise and fall that also depends upon the climate, that depends upon the tectonics, that depends upon this sediment input. For example, if you heard about this crow and this pebble story in your childhood this pot was there having less water and the crow that is collected certain pebbles and it is filled with that so water level increased. Similarly we have a marine that means a basin marine basin. So now we are putting much sediment with that.

So the rate of sedimentation is high so that means we are putting much of its sediments into the marine basin. So obviously the sea level will rise. Similarly suppose we have mid-oceanic ridge we have this volcanic islands inside and we are rising this mid oceanic ridge system. So that means we are occupying the space we are just occupying the space so that the sea level is rising. So that is why sea level rise and fall there are number of regions and one is the global region which is tectonic is playing the broad role, sedimentation is playing the broad role and another is the local sea level rise and fall that depends upon local condition.

We are talking about in terms of tectonics that means we are talking about the global level. So here one of this highest sea level stand that occurred during the late cretaceous time when pure marine limestone that is chalk was deposited throughout and that is much of this northwest Europe. So this is the most important global sea level high stand that means much of this continental area and particularly this European that is inundated by this rise of the sea level and this rise of sea level this cretaceous the name comes from this chalk this creta. So this cretaceous name is derived from this because you see global limestone deposits you can say the global scale limestone deposit that occurred during that time and if you remember our earlier class we are talking about this carbonate deposit it is a shallow water phenomenon. So that means much of its coast or in much inside the continental area it was covered by the seawater and finally, its chalk deposit was there limestone deposit was there and except during the ice age or such major changes in the sea level about hundreds of meter or more it is difficult to explain without incorporating tectonics.

So ice age there are number of ice age throughout this formation of this earth and during ice age much of its ocean water that was freeze within this ice body. So that is why the sea level will fall down. Once the sea level is falling so that whatever the rivers they were working here and there they will go much deep inside the ocean basin to divorce their sediment. So this sea level is falling at the ice age time and in the interglacial time the sea level is rising nowadays what is happening also. So this sea level rise and fall related to this ice age and this interglacial stage if you remove it from the geological time scale.

So that means except that there are also number of reasons number of times in geological time scale that the sea level is rise. So how will we explain because there was no climate change or much climatic variation is there so how can you explain that is the incorporation of tectonics is there. So not only the climate change it is influencing the sea level rise and fall. Its the tectonics also it is influencing the sea level rise and fall and that effect of sea level rise and fall that is giving rise different types of deposit which is also distinguished from this climate change related sea level rise and fall and this tectonics related sea level rise and fall. It can easily be distinguished based on this trace element based on this sediment record.

See water depth above the oceanic crust it is related to the age of the crust and younger crust occurring at shallow depth. If you remember our earlier class when we were talking about the age-depth relationship of this starting from this mid-oceanic ridge to this subduction zone. So, at the mid-oceanic ridge as it is just moving up so here the depth water depth is less and gradually the water depth is going increasing and increasing. So, this is only valid when your oceanic blanket that means there is a basaltic blanket it is of uniform thickness. But suppose we are introducing an oceanic island, volcanic island here.

So, that means here once this volcanic island that means there will be addition of material. So, here that formula fails. So, that is why the volcanic island or volcanism if it is there and if its mid-oceanic ridge is developing. So, much of its oceanic area it is covered by this space which is taken by this shallowing of this material which is intruded below and this region the sea level is rising. So, essentially uniformly thick oceanic crust that is 6 to 7 kilometer become more thick at MOR and hotspots and plumes.

So, this 6 to 7 kilometer that is average thickness of this ocean floor crust. So, it will be more thicker. If you remember our earlier classes it was more thicker at the mid-oceanic system, it is more thicker at this oceanic plumes, oceanic islands. So, that much space or the additional place is taking. So, that much water is just moving up.

So, that the sea level is rising. So, the enhanced rate of seafloor spreading and hotspot plume activity can produce elevated ocean floor that will displace the water upward and cause the rise of sea level. So, this enhanced rate of seafloor spreading it comes under the domain of plate tectonics. Hotspot activities it is coming under this plate tectonics domain. Plume activity plate tectonics domain. So, now see this at during this seafloor spreading suppose there is a region there is a time where enhanced seafloor spreading is noticed and that enhanced seafloor spreading for example, this cretaceous, it is characterized by enhanced seafloor spreading and high plume activity and high plume activity, high hotspot activity.

So, that means much of this ocean basin that is occupying by the basaltic system and due to this puncture of this basaltic system below the hot plume below. So, the sea level or this crust is moving up. So, once this crust is slowing up so that means it is displacing the water just above it. So, that displaced water definitely it is coming to this land and the sea level rising arise occurring. So, that means the tectonic activity it is influencing the sea level rise and it happened during cretaceous period.

It is mentioned here the high sea level stand might well be due to exceptionally high rate of seafloor spreading and plume activity. If you see this sea level record global sea level record during this cretaceous time here it is the highest you can say and this highest of sea level that is correlated with the highest plume activity highest mid-oceanic ridge development activity active zone of mid-oceanic ridge development plume activities that are very much confined in the cretaceous time. So, that is why it was responsible for this sea level rise because there was no interglacial time, there was no climate change record. So, this tectonic is very well explaining the how this climate that means how the sea level rise can be explained. So, changes in spreading rate and this total length of active spreading ridges that change the net rate of formation of the oceanic crust as well it is influencing the sea level rise.

So, the spreading rate is increasing that means that means we are creating more ocean area spreading rate increasing in a less time and we are adding more and more basaltic system. So, that means once we are adding more basaltic system that means we are just occupying whatever the ocean basin was there from that area we are or from that space we are putting some basaltic crust there. So, that means obviously we are asking the water to move up. So, it changes the proportion of young elevated ocean floor and hence affect the long term changes in the sea level that already we have discussed when there is a young ocean floor activities, young hotspot activity, young mid-oceanic ridge system development. So, it is just slowing up because it is putting this oceanic crust below we have a plume system it is rising this system up.

So, that it is displacing the water from this ocean to land. Variation in net accretion rate also imply changes in the amount of igneous and hydrothermal activities. Now, another factor is coming. So, when we are talking about this sea floor spreading when we are talking about plume activity, igneous activity so that means we are adding igneous body hydrothermal fluids that means newly formed rock into the oceanic system. So, that means if you see here during this mid-oceanic ridge system development we have huge volatile material, huge dissolved gases, dissolved salts they are interacting with the ocean water.

So, that means this ocean water which have x composition now it is interacting with the magmatic system it is interacting with this hydrothermal system that means it is changing its chemistry. So, this seawater chemistry it changes by this tectonic activities. And interaction of the circulating sea water and the hot basalt at the ridge crest remove magnesium and sodium from the seawater and release calcium ion into the rocks. So, now you see what is the changes or the major changes it is taking place. So, it is removing magnesium and sodium from the seawater.

Now the sea water is deficient of magnesium and sodium and it is going to the rock and it is releasing calcium ions from the rock. So, this from this rock it is exchanging this calcium with sodium and magnesium. Now the seawater is taking calcium and the rock is taking magnesium and sodium. Sulfate ion is removed from this water. So, sulphate ion it is removed from the water when it encounters in an oxic condition at or near the sea floor.

So, now this exchange between this newly formed rock and this sea water it is changing the water chemistry, it is changing the rock chemistry the sedimentary rock which are being deposited at that time that is incorporating this salt which is available near about. Similarly, the water is changing its chemistry and that is why the ocean circulation to certain extent is also influencing because we are heating this water at the mid-oceanic ridge. So, we are creating hot water. So, finally, it will automatically remove to the cold region and that is why this cold region water it will come towards the hot region. So, that means, it is the exchange of heat, exchange of salt and exchange of material, exchange of many things that means, finally, it is influencing the climate and influencing the that means, this rock chemistry or this water chemistry.

These changes would predict that this Mg-Ca ratio and this sulphate-chlorine ratio and Na-K ratio in seawater decreases during the period of high rate of formation of this oceanic crust and this hydrothermal activity. Now, you see whatever this changes in the rock record that means, if you remember few minutes back we were talking about we can distinguish this by the deposit their salt or their mineralology that will distinctly say which type of that means, deposit during this sea level rise and fall is related to tectonic or it is related to climate. So, that means, you see during tectonics when we are creating the mid oceanic ridge system we are talking about this plume activity system. So, there will be exchange of this salt with the sea water and finally, it will be incorporated in the sedimentary rock. So, the analysing the sedimentary rocks, the salt chemistry that will say about whether this time this related to sea level changes was related to tectonics or related to simply climate change.

So, this changes in the seawater chemistry are reflected in the mineralogy of the marine evaporites and carbonate sediments throughout this Phanerozoic age And the low Mg-C ratio that means, that is called the calcite sea period when there is low Mg-C ratio that was called calcite sea period is associated with high sea level stand. Non skeletal carbonates are composed of calcite and marine evaporites are characterised by late forming caseal. late forming KCl. So, that means, and the absence of Mg salt. So, now, you see how these changes are occurring when there is mid oceanic ridge development, when there is plume activity development, how there is a dis-balance or rebalance of the salt distribution among this water and the sediment.

The periods of high Mg-Ca ratio that is called aragonite seas that appears to correlate with time of low concentration of carbon dioxide and the low surface temperature and which include the ice age that is Icehouse earth. So, that means, if it is high Mg-Ca ratio is there that means, we are expecting the cooler period and low Mg-Ca ratio is there we are expecting the hotter period. And the variation of this concentration of CO_2 in this atmosphere in the geologic past are thought to have been largely due to outgassing of CO_2 from the volcanic activities. Because from the volcanic activity we have different types of gas that is exchanging that it is incorporating in the atmospheric system.

So, that means, these are related to tectonics. Volcano, we will take separate class for talking about the volcano and their product. So, these volcanic activities, the mid-oceanic ridge, basaltic, continental, flood basalt development all are the tectonic related. So, this is influencing the climate change not only the atmosphere, it is also changing the seawater chemistry, it is changing the that means, you can say the cell chemistry of these organic bodies. So, thus the eustatic changes in the sea level that is changes in sea water chemistry and variation in the past that means, concentration of CO_2 of the earth's atmosphere, it might have released to variation in the rate of sea floor spreading and this plume activity.

So, that means, all total it is explained in one sentence. So, this eustatic sea level changes that it is influencing the CO_2, it is influencing the salt exchange ratio, it is exchanging the heat distribution, it is influencing the land and sea distribution, it is influencing the size of this ocean body, the ocean basin that will be there. So, all these that is influenced by the tectonic activities. So, the configuration of the ocean basin affects the transport of heat into the ocean by surface currents and deep water circulation Now you see the deep water circulation is suppose here and now we are putting a mid-oceanic system here that means, it is a barrier for the deep water circulation. So, that means, once it is barrier is there and we are circulating this water.

So, finally, it will move up. So, once it is move up it is mixing with surface water or near surface water. So, that means, it is exchanging the salts, it is exchanging heat. Similarly, from hot water from here it is going down and it will somewhere it will release. So, that means, this deep water circulation it is affected by the mid oceanic ridge development, it is affected by the plume activity in the oceanic island systems. So, thereby affecting the temperature and moisture content of the atmosphere over the oceanic areas.

And landmasses also that is influencing the climate change. So, landmasses with northsouth trending shorelines, for example, is low and intermediate latitudes will deflect the equatorial and circumpolar currents to right and northern hemisphere and to the left in the southern hemisphere, it is controlling the heat distribution. So, imagine when we have this sequence that is supercontinent system. So, how they are influencing this circulation pattern, ocean circulation pattern. And during past 200 million years, a rifting in the supercontinent of Pangaea, fragments have drifted across the face of this globe changing the earth's climate evidenced by the sedimentary deposit and in the stratigraphic record. So, now, you see there is this breakup of this Pangaea and the system is going down.

So, we are creating new and new ocean basins. So, that means, we are influencing the heat distribution, we are influencing the water chemistry distribution. So, the extinct distribution and topography of land-sea area affecting the earth's climate. Here topography is also there. For example, it is the rise of the Tibet, rise of the Himalayan mountain.

It is affecting the monsoonal system of Indian subcontinent. And the daily cycle of sea-land breezes the coastal area is well known consequence of this in the long term. So, daily we know this continent it heats up fast and also cools down fast and the reverse is true for this ocean body. So, there will be wind circulation pattern change, isn't it? So, this is also affecting the long term climate system. And the formation of this mountain belt may affect the climate in the more substantial way by changing the rate of weathering in the earth surface which in turn affect the amount of carbon dioxide in the atmosphere. So, this mountain system erosion for example, we have a carbonate system for example, here carbonate system is eroding it will have different effect than this silicate rock erosion.

So, for example, we have a carbonic acid development and this carbonate rock weathering is there. So, weathering of carbonate exposed on the land by a weak carbonic acid solution it is formed either by some soil from the rain water or some any produces calcium and bicarbonate ions that are then transported to this ocean by the river. So, whatever this product the calcium and bicarbonates which is produced from this weathering or erosion of this carbonates and the land finally, that is transported to the ocean basin. Now, what is happening to the ocean basin? In the ocean this weathering reaction is reversed. So, calcium carbonate is secreted by organism to produce their test which is preserved after the death of this organism forms carbonates on the sea floor.

So, the carbon dioxide which was released to the atmosphere so that means atmosphere it was interacted with the soil with the water and it was responsible for weathering of the carbonate and finally, when it is coming to the ocean basin the same carbon dioxide is coming back. So, thus the carbon fixed is the carbonates in the land redeposited in the sea floor with no net change in the CO_2 condition in the atmosphere because whatever it was collected or absorbed it is again coming back to the atmosphere from the sea. However, the weathering of silicate is different. So, weathering of silicate rocks by carbonic acid however, is important difference. For example, you see silicate minerals with carbon dioxide and water that is carbonic acid.

So, it is forming the bicarbonate clay mineral and some cations and in the ocean this bicarbonate ions combine with calcium it is forming the calcium carbonate. In this case 2 molecules of CO_2 are removed from the atmosphere for every 1 molecule returned to the atmosphere then $CaCO_3$ calcium carbonate it is forming the ocean. So, now this amount of CO_2 is reducing from this atmosphere so that means it is a cooling phase. So, increased weathering of silicate rock would therefore draw down the CO_2 content in the atmosphere and be possible for cause of global cooling. So, now you see how this rock record how this rock distribution it is influencing the climate change effect.

Most recent phases of the continental drift in Cenozoic promoted the mountain building throughout this alpine Himalayan belt and culminating the uplift in Tibetan plateau in the late Cenozoic greatly increased the physical and chemical weathering processes. And through this chemical physical weathering processes the material which is going down into this system into this Bay of Bengal and finally, the Indian ocean it is affecting the that means CO_2 circulation pattern in this region. So, this elevation of the Tibet plateau greatly intensified in southwestern monsoon causing much more intense weathering of the southern slope of the Himalayas. Greatly enhanced the weathering of silicate rock in the late Miocene would have removed CO_2 from this earth atmosphere and might be well account for the pronounced global cooling revealed by the oxygen isotope data.

And near the Miocene-Pilocene boundary about 6 Ma ago. Thus the plate tectonics process influenced all the major factors that are currently thought to be determines earth long term change in climate. And CO_2 in the atmosphere at any particular point of the time it determined largely by the amount of volcanism at that time. So, now you see this atmosphere not in the present day in the past atmosphere, atmospheric condition it was also influenced by tectonic processes. And here the super plume activity and high rate of sea floor spreading and this subduction of the cretaceous period giving rise to the enhanced volcanic activity. And you see how this volcanic or the landed sea distribution from starting from the 245 Ma to 30 Ma is distributed it is shown here and it is affecting the oceanic circulation pattern.

So, this land and sea distribution, creation of new sea then consumption of this old sea it is influencing the heat and heat distribution and that heat distribution it is also affecting the oceanic circulation pattern and undersea mountain chain like this mid-oceanic ridge system and this undersea depressions like this trenches they are affecting the oceanic circulation pattern and finally, it is affecting the climate. So, thank you very much. We will meet in the next class.