Plate Tectonics

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

Week - 02
Lecture - 09
Continental Crust- I

Okay Friends, good morning and welcome to this class plate tectonics. So, today we will continue with the discussion about this continental crust. If you remember earlier classes, we have talked about this continental crust and particularly its composition. And finally, we concluded that the upper continental crust it is of granitic to granodioratic composition and the lower continental crust it is of amphibolitic, then anorthositic, then it is of basaltic. So, like that that means, there is no clear cut compositional boundary that how the lower continental crust is composed of. So, today we will continue with the discussion that the how continental crust varies laterally either it is compositionally, structurally, it is uniform or there is certain places where we can get different composition and structure and how the height of this continental crust varies what is its rheology and what are these parameters that influence the rheology of the continental crust and how this continental crust evolved because the crustal evolution it is an integral part of plate tectonics with this a collisional system with the rifting system the continental crust it is modified and finally, converted to a different type of crust.

And these type of evolution it is imprinted or it is preserved in terms of folding, in terms of metamorphism, in terms of magmatism, in terms of partial melting so, like that. So, today's discussion will mainly confined to this continental crust and particularly to the lateral variation of this crust. So, here there are two terminologies one is called shield another is called craton. So, what is a shield? Shields are the stable part of this continent composed of precambrian rocks with little or no sediment cover.

So, here if you see this exposed part of the Precambrian crust that is called shield and here there is a diagram if you can see this is the basement rock that is the granitic gneiss migmatite that is metamorphic rock and it is if you can say it is a positive structure here and at the periphery it is covered with sediment. Similarly this periphery it is covered with sediment it is topographically similar to this shield which is very tight and which is very strong enough to bear the blow of a shore. Similarly this type of continental crust that is the shield which is metamorphosed and it is metamorphosed at higher grade and it is composed of minerals that is representing the higher grade so that this is very hard and compact and it can bear the stress to max extent. So, here this is called shield area that means this is the area where this Precambrian basement rocks that are exposed here and at the periphery if you see it is covered by sediments. So, this sedimentary part this part and this part they are called platforms.

So, platform that means it is the covered part of the shield which is covered by the sediment and the sediment thickness may varies from 2 to 3 kilometers or 5 kilometers or so. Rocks in the shields may range in age from 0.5 to 3.5 giga annum and now if you see this image this crustal stretching can occur in this crust that means if you stretch this crustal rock you will find a thin crust here. Similarly at the collisional mountain zones you will find a thick crust is there so that means I want to say though this is crustal system which is very hard and compact, but its thickness vary from place to place.

At this rift basins at the rifting regions this is very thin crust exist and at this mountain regions that is the collisional mountain regions the crustal thickness is more. And if you see this field photograph it is mostly composed of granitic gneiss and magmatites which is the characteristics of a shield area. Now the same thing it is expressed in this diagram. So, here you can say it is a rift margin that is exemplified by Cambay rift. So, here this crustal thickness is very less as compared to the surrounding crustal thickness and once the crust becomes thin.

So, here the Moho is uplifted it is decompressional melting takes place here. So, that's why once this Moho is uplifting. So, there is a chance that this rocks from this mantle that may be exposed or intruded here. So, now you see once this crust is extended. So, we are creating certain cracks here that means, we are thinning this system this mantle material which is lying below that is under plating the crust and due to this under plating its provides heat to the surrounding crust and finally, the crust deforms and it becomes more and more thin and if it is continues further it create a full phase rift basin and there will be ocean basin created here.

However in this particular case it is a failed rift system. Similarly, at this collisional mountain zones if you see for example, if it is the Himalayas taken into example here we have this crustal thickness of this much, but once I am reaching this Himalayan zone due to this collision of the India and Eurasian plates this crustal thickness it is increasing. So, that means, by and large we can say crustal thickness is not same throughout and this is the global crustal thickness map you can see here the crust is very thick in Indian subcontinent in the northern and that is the Himalayas. Similarly, we have thick crust here and we have thick crust at the periphery that is the collisional mountain zones and the subduction zones and if you see this East African rift valley here the crust is thin. So, that means, at the collisional mountain systems at the subduction mountain systems the crust is very thick and at the rift basins the crust is very thin.

Now, if you see this map we have shield area and we have mobile belt. So, shield area that means, you can say here there are number of shield area like the Indian shield, Canadian shield, African shield, Australian shield, Antarctic shield. So, there are number of areas on the earth's crust the shield area is composed of and in Indian context if you see here this is the Baster Craton, we have Singbhum Craton, we have Dharwar Craton, we have Aravalli Craton, we have Bundelkhand Craton like that. So, this is nothing within that's craton there are Precambrian rocks which are well exposed and that part is called shield area and those areas which are not exposed or covered by sediments that are called the platform covers. And metamorphic and plutonic rocks types dominant at the temperature-pressure regimes record in the exposed rock suggests this burial of this rock it range from to 40 kilometers.

That means, those rocks which are earlier it are around 5 to 40 kilometer depth due to this exhumation, due to this mountain building activity, due to thrusting, due to erosion or removal of the overburden they are now exposed to this system and they are representing the shield area. And shield area in general that is exhibit very little relief and have remained tectonically stable for long period of time. So, here this key point is the little relief, why it is little relief? Because it is the Precambrian, Archaean age. So, now, once it is exposed in the archaean time or the Precambrian time it is undergoing continuously erosion and weathering and finally, degradation of this height and that's why they are representing little relief. If you go to this peninsular gneissic complex, banded gneissic complex in a south India and particularly the peninsular part you will find hardly there is variation in relief in this area.

So, this little relief it is a characteristics feature in the shield area and the shield that comprise around 11 percent of the total crust by volume and with the largest shield occurring in Africa, Canada and Antarctica. Now, if you see here we have the shield here largest shield they are exposed here and we have the Indian shield also the Precambrian rocks are exposed, we have African shield. So, these are the different Precambrian shields they are exposed. But now the question arises whether this compositional difference is there among different shield or they are compositionally similar. So, these studies around this world among different shield it says they are compositionally more or less similar and that indicates once upon a geological past during Archean time they were evolved simultaneously or similarly rather similarly and the similar process was involved in their formation and subsequent evolution.

Not only this Precambrian rocks or the shield rocks they are exposed in the Canada and Indian shield or something like that, but there are these Precambrian rocks or the shield rocks they are exposed in the Antarctic region. So, here there is field photograph very recently received from Antarctica that you can see these are the Precambrian rocks that is the Granitic gneiss, Migmatites they are exposed and they are intruded by the pegmatites. They are the pegmatite rocks and they are intruded with that. So, that means, I can say this Precambrian rocks or the shield rocks there are not only exposed in the continents which are exposed or which are accessible, but the inaccessible parts also in the world this Precambrian rocks are exposed. Now, the other component of this craton that is called the platform.

The platforms are nothing, they are also stable part of this crust with little relief and mostly they are composed of the sediment. If you remember our earlier class we are talking about this compositional variation in the platform. So, mostly the platform as composed of sediments they are rich in radioactive elements. So, compared to this basement rock or compared to this Migmatites and Granitic gneiss. So, if you compare this radioactivity this platform they are radioactive wise they are more rich as compared to the basement rock because these are the sediments which are derived from the erosion of the upper crust and the upper crust it is rich in radioactive minerals.

So, they are composed of precambrian basement similar to this exposed in the shield and about 1 to 3 kilometer of the relatively undeformed sedimentary rocks. So, that means, you can say these platforms rocks they are mostly undeformed. So, probably you have heard a term that is called supracrustals. So, the platform rocks are nothing, but supracrustal rock. There are two types of supracrustal depending upon the age this is called older supracrustal and younger supracrustal.

The older supracrustals they become the part of this craton and they are deformed and they again re-exhumed and this younger supracrustals they are relatively undeformed one. If you go to this peninsular India you will find this Proterozoic sedimentary rocks they are undeformed and they are lying on this Archean and Precambrian shields. So, these are representing the platform cover sediments. In shields and this precambrian basement platforms they are collectively known as craton. So, craton by and large it is an active or you can say it is the most stable part of this continent and which stabilized from the Archean-Proterozoic boundary.

So, that means, after that there is no tectonic deformation significantly affected this region. So, that is called craton. So, we have different cratons like Dharwar craton, Baster craton, we have Singbhum craton, we have Aravalli craton, Chotanagpur craton so like that. So, that means, these are the stable part and this stabilized from this Archean-Proterozoic boundaries. And as I was talking about here we have the basement rocks and these are the sedimentary rocks this is representing an unconformity.

So, these are the supracrustals and you can say these are the older supracrustal and then there is another layer this is the younger sedimentary rock they are exposed. So, the whole system that is called craton and wherever this is exposed this area is called shield and this area is called platform and these are the supracrustal rocks they are resting on the top of this crustal rocks. Here if you see the shield distribution, shield platform and orogen, basins and large igneous province and extended crust are exposed here. So, we have most of these sedimentary rocks they are confined in the Himalayan regions and we have sedimentary rocks here we are exposing here and some of the sedimentary rocks they are exposed at the rift basins. So, these are the platform sediments otherwise we have the Indian shield is exposed and this is the large igneous province the Deccan trap which is exposed at the western margin.

So, a craton it is an isostatically positive portions of this continent that is tectonically stable relative to the adjacent orogens. So, it is isostatically positive portion, isostatically positive means if you remember when we are talking about isostasy we have some compensated region somewhere overcompensated region and somewhere undercompensated region. So, this isostatically positive portion that means, you can say it is isostatically compensated region and it is a stable part which is lying adjacent to this orogenic belt. So, if you see the Indian subcontinent system we have the Indian craton and we have the Himalayan orogen here. So, here this Indian craton is relatively unaffected by this Himalayan orogen because the basic assumption of the plate tectonics if you remember we can say this the stress can migrate laterally to large distance without affecting the area and it is the plate boundary where the most of the stress is accumulated.

So, that's why during this Himalayan collision so, this Indian crust or the Indian craton though it was affected, but it is negligible. So, that's why it is remain tectonically stable from this Precambrian time and during this Himalayan origin around 55 Ma it was relatively unaffected. So, that's why it is a craton is isostatically positive portion of this continent that is tectonically stable relative to the adjacent orogen. So, that's why either this is the adjacent origin either the Himalayan origin or there was eastern Ghat origin that time also the middle part of this craton that was undeformed. And the sedimentary rocks on the platform range in age from Precambrian to Cenozoic and reach a thickness about 5 kilometer or even more.

So, that means, this platform cover it is not only very thin cover it may reach up to this depth of about 5 kilometer. So, more the depth more the radioactivity and because more this upper crustal rock it is accommodated within the sedimentary basin. So, the platforms that composed most these continental crust in terms of both area and volume. So, here you can say these that the precambrian rocks they are exposed and the rest part it is covered by the sediment. So, these are the platform cover sediments.

So, they are representing the most and this continental crust in terms of their volume. So, volume wise this platform sediments they cover most part. Then another terminology about the crust it is called collisional orogen. Collisional orogen this term is self-explanatory it is the collision between these two continental system for example, the live collision is going on between India and Eurasia. So, these are very long and curvilinear belts of the compressive deformation produced by collision of continents.

So, very key point to discuss about it is a curvilinear belt. If you see this Himalayan system it is curved it is a arc shaped and this side it is called Eastern syntaxis and this is called Western syntaxis. So, it is a curvilinear belt in between it is arc shaped why it is arc shape? we will talk about this continental collision or the subduction system why it takes arc shape? why it is bend? and which direction it bends? So, we will talk in detail at that time. And it is a curvilinear belt of compressive deformation that is very also important it is a compressive deformation because we have the Indian plate which is moving from this side and we have Eurasian plate which is moving from this side. So, this is the zone which is representing the compressional deformation.

So, this compressional deformation as it represent. So, there are geological evidence representing the compressional deformation there are folds, there are thrusts, there is nappe they are present. So, most of this Himalayan system they are deformed by this folding they are deformed by the thrusting. So, most the thrust like the MBT, MFT, MCT all these thrust they are representing the compressional deformation going on at the Himalayan system. So, joint thrust sheets and nappes are found in many orogens.

So, represent the joint thrust sheets if you see this Himalayan cross section you can see here how this crystalline rocks they are moving from a greater depth and a distance of around some hundreds of kilometer they are exposing here. So, these are these joint thrust sheets and nappes the nappes are nothing they are the thrust sheets and mostly it is a planar and it is a thrusted and the sheet like body which is detached from the main body and travelled a long distance around more than 2 kilometers or so. So, these are called nappes. So, if you see this Himalayan system it is a compressional top collisional system and here we have mostly the thrust sheets like MBT, MCT and most nappe they are present in that. So, this collisional orogen it is a characteristics of development of this compressional system like thrust, nappes and it is representing curvilinear mountain belts.

The same thing is shown here we have nappes, we have this mountain systems that is the MBT, MFT, MCT mostly the larger thrusts they are coming out from this Himalayan system. Then collisional orogenn range from several thousands to tens of thousands of kilometers in length and are composed of variety of rock types. So, if you see this collisional origin starting from here to here it is around here to here around 2500 kilometer and this 2500 kilometer it is composed of a variety of rocks starting from the degree of metamorphism, starting from the generations of different generations and starting from this degree different degree of deformations. So, you will find both igneous, sedimentary high-grade metamorphic to low-grade metamorphic rock Similarly, sedimentary rock starting from this marine sequence to fluvial sequence to lacustrine sequence and similarly igneous rock starting from the deep mantle origin to the shallow crustal origin. So, all types of rocks that can be found in the collisional mountain system.

They are expressed at the earth surface as the mountain range with varying degree of relief depending upon their age. So, that is also very important depending upon their age their relief varies. The younger mountains or the younger segments they are representing very sharp relief whereas, this older segment they are representing relatively eroded relief. So, as the Himalaya is segmented as we have discussed earlier it is coupled and segmented with the adjacent Ganga basin. So, different segment that represent different degree of upliftment.

So, due to different degree of upliftment this topographic geometry that varies from place to place. So, this area where representing high rate of upliftment they are showing sharp topography and those area who are representing at the relatively less degree of upliftment relatively showing less topography. And this topography is a result of the rock type, the result of degree of erosion and degree of upliftment and this geomorphic system which are acting there and like that. So, if you see here the older collisional orogens that is the Appalachian orogen in the eastern North America and the Variscan orogen in the central Europe are deeply eroded with only moderate relief. Where is the younger mountain like the Alpine Himalayan system and this you can say this they represent the highest mountain chains in the earth.

So, this similar thing happen in the different mountains in Indian context if you see this the eastern Ghat, the western Ghat and the Himalayan system this relief is different and this relief is nothing is due to its age. Similarly if you see this Appalachian mountains and you see this relief is like this and similarly in the Variscan mountain system this is the relief is there. However, if you compare this Himalayan mountain system its relief is like this. So, here it is a representation how with age this topographic profile varies with the older age we have not very sharp topography. However, the younger age we have very high and sharp topography existing.

Tectonic activity decreases with the age of the deformation orogen. So, this age of deformation that indicates how much tectonically active this area should be. For example, in the Himalayan context if we talk about the Himalayan orogen this collision active collision is going on here, but however, this side you will represent somehow different topography similarly this side you will get some of different topography. So, depending upon the age so, the topography also vary. So, orogens which are older than Paleozoic are deeply eroded and now part of the Precambrian craton.

If you go to this orogens like this Vindhyans, like this eastern Ghat orogen, like the western Ghat. So, we are very old orogenic systems and this old orogenic system they are representing now the part of this precambrian craton because they are completely eroded. It is reduced topography is there. So, it is a replant system.

So, becomes a part of this craton system. However, large plateaus which are uplifted crustal block that have escaped major deformation are associated with this some orogens such as the Tibetan plateau in the Himalayan orogen. So, we have Tibetan plateau here and we have the Indian plate which is moving in this way and the Russian plate which is moving this way and due to this docking effect this craton or this plateau Tibetan plateau it is uplifted and it is not undergoing any major deformation because it is above the deformation level. So, that's why this plateaus are uplifted crustal blocks that are part of this orogenic system that is collisional orogenic system. So, this cratonic system which is divided into different segments that is shield, the platform that is this collisional mountain belt, this plateaus like that. Then size of this continent, how the size of the continent varies and why it varies? and how it affects the height of this continent.

If you see here there is a graph it is the mean height in meter of this continent and this area in square kilometer. So, if you see here this line it is representing the Eurasia, Africa, then South America and Australia. So, all these things all these continents they are lying on the line that means, there is a positive correlation between this mean height as well as the area and there are certain exceptions. You can say there are certain exception like this Arabia and India there are exceptionally more height than the other compared continents. Similarly, this Agulhas and this New Zealand they are showing exceptionally low height than the normal what is this graph says.

So, why these exceptions are there? So, there is an overall positive correlation though exist between the area continents and the micro continents and their average age elevation from the sea level, but these exceptions representing some types of tectonic deformation, some types of orogenic movement, the mountain building activities. For example, if you see the height of this continent depends upon the uplift rate and the rate of erosion and subsidence. How height it will be? That depends upon the upliftment rate. So, it is a tussle between this tectonic forces that uplift this continent and the erosional forces that downgrade it that means, that erode it when a plane make it when a plane. So, these tussle that represent how much height at continent can attain.

Collision between this continent resulting in crustal thickening is probably the leading cause of the continental uplift in response to isostasy. So, we have this Indian plate which was moving and it is colliding with the Eurasian plate and you can say it is the upliftment of the system and this upliftment is nothing due to this collision. And this due to this collision due to this high upliftment this isostatic imbalance is there. The anomalously high height of Arabia and India is undoubtedly reflect that the collision of this continent with Asia between 70 to 50 million years and this case of India this collision is continuing also today. So, that's why this height of this Himalayas is increasing and the northern belt or the Himalayan belt it is acquiring height at present also.

And this other side of this Indian subcontinent like the eastern ghat, the western ghat, the Satpura, the Vindhyan they have compensated this becomes the part of this Indian craton. The 6 large continents that have undergone numerous collision in the last 1 Giga year each thickening the continental crust in the collisional zone leading to the greater average continental elevation. So, this continental elevation or the continental elevation acquiring this elevation it is not a one day process or it is not due to one go. It is a subsequent and number of collisional event is responsible for that. For example, these 6 large continent that we are discussing here.

So, this not only undergone one phase of deformation or one phase of collision. There are number of collisional events that occurred and this continents have experienced and due to this subsequent collisional system it is gained their area as well as their height. So, this present day height is nothing related to only the last collisional event. It is the subsequent collision event from the starting from the beginning up to now. So, another component of this continental system at the hotspot activity can also increase the height of this continent.

For example, suppose we have a slab we have a continental slab and we are increasing this height or we are providing this hotspot magmatic system below. So, there will be hotspot activity and due to the hotspot activities this height of this continent is increasing. For example, if you see here we have the hotspots here and due to the hotspot how this oceanic lithospheric height is increasing. Similar case happens at the initial phase of this rift basin development we have hotspot magma which is at the below or underside of this continent and that's why the continental system it is moves up.

So, finally, it gains height due to this hotspot activities. So, hotspot activity can also elevate continents and it is possible that the high elevation of this Jan Mayen and the model height of this Africa may reflect the numerous hotspot beneath the north and west Africa. We have number of hotspots existing here and number of hotspot existing here. So, this due to this hotspot activities this African shield or the African continent it is also gaining the height. So, this collisional system it increases the height, the subsequent collision it increases the height, the hotspot activity is increases the height. So, these are the numerous reason how this continental lithosphere can gain height. Thank you very much. We will meet in the next class. Thank you.