Plate Tectonics
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Week - 08
Lecture – 39
Plate Tectonics and Mineralisation at Divergent Margins- III

Okay friends, welcome to this class of plate tectonics. And today we are going to discuss about plate tectonics and mineralization. So far we have discussed the different type of plate margins, the mountain building systems. And from today onward, we will talk about the application of plate tectonics, where to apply this knowledge. Particularly, the plate tectonics may be used for exploration point of view. And from infrastructure development point of view and to study the research in terms of climate change and there are many things.

So, starting from your soil erosion, soil formation, rock formation, terrain accretion, all those things that can be studied or can be solved by the plate tectonics theory. So here, we are talking about this mineralization process at divergent plate margin. So in the earlier class, you probably remember that we are talking about the principles of mineralization in response to tectonics. There should be a fluid and there should be an event and that fluid should be passed through the rock pores and there should be a hurdle that fluid should stop there, so that it will cool and will create minerals, so like that.

So that means, till now we have completed the principles of mineralization with respect to plate tectonics. And this class, we will confine ourselves particularly the mineralization at divergent margins. And we know the divergent plate margin, it starts from rifting and eventually it completes the drifting stage. From rifting to drifting, it takes millions of years. And at rifting stage, when this continent was intact, it will be stretched, it will encounter an extensional environment where number of faults are developed and those faults they may propagate downward and they will allow the sedimentation so that may be continuous or discontinuous.

So depending upon that, so rifting stage will respond to different type of mineralization with respect to changing pressure-temperature scenario. Similarly, once the rifting stage completes, we will reach to the drifting stage there will be a full-fledged mid-oceanic ridge develop and at the mid-oceanic ridge due to decompressional melting, this magma will generate and through this magma the volatiles that will emerge as black smokers and white smokers and there is magmatic activity through that there will be mineralization. So that means, at rifting stage, we will have different mineralization at drifting stage that will be different mineralization and after all this mineral whatever is produced either in the rifting or drifting stage that should be preserved. So there should be an environment which is suitable for preservation of this mineralization or minerals, so that it can be extracted economically. So today exclusively will be in this mineralization at the divergent plate margins.

So in the divergent plate margins, mechanisms such as thermal insulation of this mantle by large continental landmass and the ascend of mantle plumes that form the base of this mantle that trigger rifting and in some cases, continent break-up and mineralization that will allow. So how it happens that if you remember our earlier class when we were talking about this supercontinent cycle, there will be a continental landmass which is mostly used as the insulator it will not allow this heat to radiate because it is composed of mostly quartzo-feldspathic rocks, granitic to granodaritic composition, so that it will not allow the heat to release. So heat build-up takes place and mantle plumes that also rise at places. So either of these cases, it will weaken the crust. So due to this weakness developed by this mantle plume as well as thermal insulation this crust will break up into different segments and finally the magma will release there.

So another is called the hyper-extended margins. So hyper-extended margins which is the continental break-up occurs over a cold mantle is known to contain petroleum splays. So here this margin, mostly it is responsible for petroleum hydrocarbon exploration. What is this hyperextended margin then? How it is different from this normal plate margin or normal divergent margin or rift margins? Here the hyperextension is defined by the stretching of the crust such that the lower and upper crust become coupled and embrittled allowing major faults to penetrate to the mantle leading to this partial hydration or serpentization of this uppermost mantle. So if you remember earlier class when we were talking about this compositional stratigraphy of this earth, we have upper crust, lower crust, then mantle and the lithosphere is the crust and the upper part of this upper mantle.

Here hyperextended margin it says that the lower and this upper crust becomes coupled and embrittled so that means they are totally welded together. There will be no differentiation between these. So there will be no heat difference because in the upper crust and lower crust we distinguish based on the heat flows, based on this composition and based on this mineral stability. So here they are coupled that means both are rigid and they are embrittled. Once there is rigid that means there will be brittle deformation.

So this can be well explained in this figure here. Now you see the upper crust and lower crust they are coupled together and finally once this fault is developing from this upper crustal system it will going down and it is affecting the lower crust. Otherwise in many of the rift basins where this upper and lower crust they are not embrittled or not welded together. The faults which are generated from the upper crust may be bending and it is developing listric type of fault. However, as it is embrittled and coupled together the fault which is generated from the upper crust it is directly going into the mantle system.

Now that means through this fault we are releasing the stress and once we are releasing the stress from this mantle, this mantle is coming up. So there will be moving upward of this mantle because stress release, decompression occurs so that this mantle will rise and finally this segment that will be segmented into different faults like this. So this is called extended or hyperextension or hyperextended margin. So hyperextended margin is different from this normal plate margin. Here the upper and lower crust they are clubbed together and they are embrittled so that they are allowing these faults which are generating from the surface that can move up to this mantle system.

So either it is hyperextended margin or it is normal divergent margin or rift margin they allow mineralization. So this development of this margin it undergoes different stages. So first stage that is called the incipient stage that is the initial stage and second stage it is called the final stage. So different stages this rift margins they behave differently as well as the fluid movement will be in different manner. The generation of fluid at different stages, different depth so that's why this mineralization will be different.

So different minerals they are emplaced at different level and with different time because rift initiation to finalization it takes millions of years. So different stages of mineralization with millions of years of difference. So in the incipient stage, rifting initiates for this basin development and in the final stage it involves in the formation of mid-oceanic ridge, passive margins and the thermal subsidence. So each stage at the mid-oceanic reach development that will emplace different type of minerals, the passive margins there will be different type of minerals, then the thermal subsidence stage that will different minerals. So starting from the incipient stage to final stage, different stages of the rift margin that experience different type of mineralization.

So now although the incipient divergent systems are not well mineralized at mid-oceanic reaches that can contain active and extinct carbonatide volcanoes of zinc deposits. So at the initial stage for example, if you see this figure we have incipient stage here. So that means just we are stretching this lithosphere into different segments. So now you see different faults they are extending down and you can see this different type of magmatism they are occurring from different depth and due to this stretching and faulting there may be some hydrothermal fluid, there may be from magma which is directly deriving from the lower crustal level. So in this stage either there will be orthomagmatic deposits, so that means it is directly deposited from the magma which is generated or there may be hydrothermal deposit that is developed due to stretching, due to temperature rise and some other processes.

So that means either of this case there will be mineralization and mostly this carbonatides which were generated during this stretching of the system, this carbonatide mostly it is rich in zinc mineralization. So initial stage of rifting we are meeting with zinc and carbonatides and related alkaline magmatic rocks there are major source of REE rare earth element and copper. So that means now you see when we are started stretching the system what we are getting as a result we are getting the REE rare earth elements and we are getting copper and we are getting zinc. So mineralization starts from the initial stage. Then rift basins generally characterized initially by the continental and lacustrine sediments followed by many cases by marine sediment.

If you see here we have different stages, so here rift initiation that means we stretch the lithosphere into different segments we are started just so we are creating the horst and grabens and just lakes or lacustrine sediments are there that means basins are there and sediments are getting deposited from the surrounding area so we have lacustrine sediment. So in this sediment or in this stage generally it may happen that evaporation is more than this sedimentation. So in that case what we will get that is evaporate deposit. So we have sedimentary basins mostly small lakes in the form of small lakes so mostly this is lacustrine deposits are there and later on with further rifting and rifting now you see this lake is gradually growing and finally these two lakes they are joined together and forming a sea. So that means gradually we are shifting from a lacustrine environment to an marine environment.

So lacustrine environment there will be evaporate and marine environment there will be self-environmental slope environment like that. So that means this sediments and which was started from the lacustrine system or fluvial system now they are occupied by or overland by this marine sediments. So accordingly when there will be a faulting for example we have lacustrine sediment and then it was occupied by marine sediment and we are creating a fault. So a fault is passing from the surface through this marine sediment to lacustrine sediment. Its composition is different because in the lacustrine sediment mostly these rocks or the sediments they are derived from the upper crust.

So these are the upper crustal sediment and more and more stretching when this lower crust is exposed so this sedimentation composition will be different. So a fault we are creating from the surface and it is going down so that is cross-cutting different sediments of different composition at a different level and gradually we are increasing the temperature downward. So that means different sediments they will behave differently with the increasing temperature so that the fluid which is generated by the increase of temperature through the fault that will be different at the different level. As a result the mineralization will be different. So the basin fill it is dominated by silice clastic sediment and because thinning of the lithosphere that causes decompressional melting in the upper mantle that we have already discussed.

So these basins also can contain extensive tholeiitic mafic or bimodal magmatic rocks and lavas, volcano clastic rocks and shallow intrusive bodies. So that can be well explained here in this figure. So at the upper part when we started stretching we are just affecting the upper crustal rocks. So mostly the felsic magmatism and when we are stretching further downward that means we are moving up to the lower crustal and mantle level we are going for tholeiitic magma generation. So there will be bimodal magmatism because earlier we had felsic magmatism and then we are creating this mafic magma.

So there will be bimodal magmatism and this volcano clastic rocks that whatever the volcanic rocks that was emplaced that will be erode and will contribute to this lacustrine and marine sediment mostly the volcano clastic rock. And as the fault is passing towards the deeper level there will be shallow intrusive. So all that can be explained here both in terms of sills and in terms of dikes and in terms of this type of a balance. So we have a stretched environment on this crust and this stretched area it is included by different magmatic elements. So these stages of divergence can also produce extensive evaporate phases that can be trapped to produce saline, basinal and hydrothermal fluid.

So that is very much important because this saline fluid or this hydrothermal fluid they are responsible for mineral leaching from the surrounding rocks and mineral emplacement in the pore spaces and the free spaces. So that is why when we are talking about this initial stage of basin development when there was lacustrine as environment was prevailing. So here it may possible depending upon this environmental condition that evaporation is more than sedimentation. So that means here evaporate deposit may present. So those evaporate deposits when it is passes or the fault is passing through the evaporate phases.

So this will be activated and may produce this saline, basinal fluid and maybe hydrothermal fluid because the temperature is more at depth. So high heat flow associated with magmatism can drive moderate to high temperature hydrothermal fluid flow and the magmatic events themselves can emplace nickel and copper and PGE-enriched intrusions. So this is very important. So that means here we have two that points that the mineral that can be emplaced one is due to hydrothermal fluid that is the brine solution and hydrothermal fluid and when we are emplacing magma at the stretched environment in a rift environment that magma which is generating from this decompression melting of this mantle that may contain nickel, copper and PGE- enriched that means platinum group of element PGE- enriched intrusion or small carbonatite at related alkaline bodies into the evolving rift succession. So that means within that rift what we are getting? We are getting zinc, we are getting copper, we are getting REE, we are getting nickel, we are getting PGE.

So addition to that we are getting carbonatites. So that means we have a range of minerals that are emplaced at the rift basin and mind it, it is I am talking about the rift initiation stage. Intrusion within rift can be zoned in time and space with early emplaced alkaline bodies which form from low degree of partial melting of this mantle located on the rift flanks and more voluminous tholeiitic bodies which crystallize from the high degree of partial melting of this mantle occupying the central part of the rift as it evolves. Now you see once we are creating a rift basin, so gradually we are going at the deeper level. So, we started from the shallower level and we are going to the deeper level that means we are at the initial stage we are creating these faults which is extending up to this crust and gradually when we are stretching the system the faults are further added and to the deeper level.

So that means from crustal level we are moving to this mantle level. So once we are decompressized this is this mantle system that will create some melts and this magmatic emplacement will be there. So that is why it is more voluminous tholeiitic bodies which crystallize from the high degree of partial melting of this mantle occupying the central part of the rift system. So here at the central part of the rift as this decompressional melting of this mantle occurs here we are getting this type of magma which is mostly it is the high degree of partial melting it is showing in the mantle. So in the rift flank we have carbonatites and in the initial or the middle part at the central part we are getting the tholeiitic systems.

Now in this rift system the mineral composition that is we are getting that is zinc, Pb, Ag, Au, copper deposits. So that means a series of minerals you can see addition to that we have this carbon right we have this PGE group of minerals we have nickel that is there. So this is the dominant mineral phases that we are found in this rift basin at the rift initiation stage. So base metal deposits hosted by siliciclastic dominated succession that is the shale-hosted deposit or other clastic dominated deposit are the largest global source of zinc and Pb and significant source of Ag in some cases it is Au. So now see how many minerals we are getting that is zinc, Pb, Ag, Au all these minerals we are getting at the ripped initiation stage.

This broad group of deposit was divided into fleece hosted and epiketronic platform hosted types most of the flysch-hosted deposit of are also associated with the mafic volcanisms. So here the flysch and molasses that we have talked while we are talking about this continent collision. So, this flysch mostly it is fine grain deposit that is deposited at the inside of this basin. So that is why we are getting mafic magma here at the central part. So this flysch hosted deposits mostly it is associated with this mafic volcanisms.

However at this flank of this rift we are getting the felsic volcanism the carbonatites like that. And here this is a diagram which is showing this 5 element veins that is 5 element veins that is Ag, Bi, Cu, Ni and As. The initial uranium mineralization consists of quartz, carbonate, fluorite and pitchblende. So remobilisation of this uranium occurred at the later stage producing polymetal veins containing silver, cobalt, nickel, arsenic and other elements. So now we see how this mineral system it is associated with the rifting and we have different normal faults and these normal faults are going down they are affecting subsequent deeper levels from the initial state to the later stage.

And finally, at different levels and different position of this basin that means we here this is the basin interior and this is the basin flank. So starting from the basin flank to the basin interior once we are going this type of mineralization we are getting. So now we see the whole rifting system that is completely mineralized. So this lithological makeup of this initiating rift basin has a significant influence on the characteristics of siliciclastic mafic Zn-Pb deposits. How these lithologies are arranged in a rift basin.

So that means depending upon the sediment properties when this hydrothermal fluid is acting on them. So what is the composition with which the hydrothermal fluid is interacting that will leach similar type of mineral and that will also precipitate different type of mineral. So initial lithological makeup initial lithological composition of this basin that also it is influencing the type of mineralization in this rift basin. In many districts around the world so like this Broken Hill deposit Australia and this is Sullivan in

Canada. The stratigraphic position of hosting the ore body correspond to this position at which the mafic magmatism ceases.

So gradually the mafic magmatism mostly it will be in the central part and the deeper part of this basin and felsic and carbonatic sequence that will be in the upper part or the flank of this basin. So gradually stratigraphically if you are going down and down at certain places that means stratigraphically if you are moving from lower side to upper side at certain depth or this magmatism which is related to mafic magma that will be ceased and the upper part it will dominated by felsic and carbonatatic magma and the lower part of the stratigraphic sequence that will be dominated by this mafic magma. So here magmatism has a close relationship with these syngenetic ore formation either directly or by leaching the evolving mineral system. So that means the magma itself it is providing some minerals and the magma when it is interacting with this country rock. So it is leaching the elements and finally it is giving the mineral.

So magma has two effects that is why the type of sediment or type of hoist rock through which the magma is interacting that will also playing major role and which type of mineral that will occur in this related to a particular phases of magmatism that depends. So the magma composition as well as the sediment host or this host rock may not be sediment in the host rock that will define which type of mineral we are expecting at which stage. The high heat flow and geothermal gradient associated with the rifting causes the convection of relatively high-temperature fluid which are reduced as a consequence of reaction with reduced that is Fe2 rich basin fill that is mafic volcanic rocks and immature turbidities. And these fluids not only transport zinc, Pb and Au but can also transport copper and also Au. So that means this composition and the reaction the magmatic composition and it is reacting with this basin host that will give rise to this type of mineralization we are expecting.

So sediment-hosted zinc Pb deposit in siliciclastic mafic host succession commonly contain low but recoverable Au. So that means I want to say the magmatic type and the host type they are deciding factors the which type of mineral that will be emplaced through a rift basin and at the basin flank and at the basin interior. Another characteristic of many continental rifts around the world is the presence of evaporite towards the base of the basin fill and imagine when we are talking about the evaporite why at the base of the basin fill because it was started it was deposited initial time when this was in a lacustrine stage. So further it was superimposed by this marine sediment so that is when stratigraphical lower level we are getting the evaporite and this evaporite it is very common in world every rift basins. So interaction of circulating hydrothermal fluid with these evaporites would increase the salinity of this fluid and this salinity once it is increased it has two effects and two important and effector.

What is that? First higher salinity fluid can transport higher concentration of base metals making them more potent for ore fluids. So higher salinity its metal intake increases so it becomes a large transporter for this metal deposits. Second in a significant increase in salinity also increase ore fluid density making the formation of the brine pool possible when the fluid reach the sea floor and can be very effective in trapping the metals. So the salinity has two effects first it is making the transporter for these metals for the particularly for the base metals and second thing is that it can form this brine pool which can trap the metals. Active mafic magmatism combined with the presence of evaporite at the depth in the succession produces saline and reduced relatively high-temperature ore fluid capable of transporting zinc, Pb, Ag and Au.

So now if we have a brine there and we have a magmatism there so both that means we have a plus point. So we have that is own minerals magma will release there then that brine solution that will transport this type of minerals and will give rise to mineral deposits. So here the structures and the aquifers formed during the basin evolution focused the ore-forming fluid along the metal sourcing and determining the locus of ore deposition that is the simulations that were carried out by many researchers that is showing that how the increase of salinity how the metal intake increasing and which metal intake is increasing depending upon the saline the composition of the saline solution as well as the composition of the host rock that is involved. Then deposits associated with carbonatite and alkaline ultra-potassic igneous rocks that is most carbonatites and all kimberlites are of this interplate origin and located on these Precambrian cartons. So all these kimberlites or the carbonatites if you see the geological map mostly they are at the Precambrian cartons interplate region or the basin margins or the carton margins.

A majority of these carbonatites especially young carbonatites are associated with the crustal domain and the extension of the rift system or near rift setting, but some are associated with extension of orogenic or collisional settings. So most of these carbonatites they are emplaced in this type of geological conditions and many kimberlite but not are related alkaline rocks are associated with rifting. If you see here this is the African rift you see this kimberlites the distribution most of this kimberlite which are diamond bearing and they are occurring at the rift systems and may be result of a partial melting of the continental lithosphere produced by the mantle film activity producing hot spot by fluid subduction. So these are the places where this partial melting will take place at the mantle level or the lower crustal level and finally, the magma is rising and giving rise to carbonatites and kimberlite deposits. Large-scale lithospheric structures play an important role in controlling the location of both kimberlite and carbonatites at this regional scale within this carton.

Now if you see here the repeated episodes of magmatism that is very important. Repeated episodes of magmatism focused at the carton margin and intracratonic domain boundaries typically result a re-fertilization of the subcontinental lithospheric mantle because repeated magmatism that means repeatedly we are losing the volatiles and the magma is enriched. So, that is why here if you see this magma which is generating from the asthenosphere that is at the first initial stage that is we are getting high H2O. However, repeated magmatism occurs so that means the mostly the volatiles are released and here once it is coming this magma is generating that is having lower H2O. So that means repeated magmatism once it is occurring so gradually the mantle is enriched and once it is enriched it will be very useful for this kimberlite type of emplacement.

Alkaline rocks especially kimberlite, lamproites and lamprophyres and carbonatites typically have a high abundance of minerals like this. So, a series of minerals like Sr, Zr, Nb, Ba, LREE, tantalum, thorium, uranium and are commonly other incompatible elements as a result of their vaccination during partial melting of this mantle source. And they host a range of deposit including those of the diamond, rare earth element and other rare metals like niobium, tantalum, zirconium like that which are the increasing importance at the higher technology metal. Nowadays whatever the technology we are using starting from this Chandrayan to Mangalyan or whatever this modern day technology we are very much dependent upon this REE and this type of minerals. And these minerals generally found this type of deposits particularly the REE margins.

So, that is why it is an exploration strategy how the mineral and which minerals can be explored at which type of tectonic settings. So, this is a cartoon diagram. So, how the tectonic of a REE system that is responsible for this mineralization at a different level. So, this is the idealized genetic model of carbonatite and alkaline contracts related REE mineral system. So, here there it is explained at which stage that means, here and that means, here and here and here which mineral will be emplaced and what should be timing and which part of the basin it will host which type of minerals.

But not only this magmatism that is carbonatite or kimberlite that will give rise to mineralization at the rift basin. And reef basin if you know that is number of faults are there, number of a fracture then that means, rock are rocks are totally shattered by faulting and fracturing. So, that is allowing this water to percolate down and it is giving a deep weather zone. So, in the deep weathering zone, so, there will be some mobile elements, some immobile elements. So, those who are mobile that will be released and immobile element that will be remain in the weathered zone finally, it will give rise a thick mineral deposit.

So, weathering also it is playing a larger role in the rift margins and some of these felsic alkali suites are strongly enriched in yttrium, zirconium, niobium and REE are extended crystal fractions and other processes leading to potentially economic concentration. And similarly leaching and dissolution with enrichment of the resistant minerals and formation of secondary REE-rich phosphates. So, due to weathering the mineral that means, leaching is occurring and these minerals which are resistant that will remain there and give rise to mineral deposits. So, that means, I want to say not only magmatism in the rift basin or not only the tectonism in the rift basin is associated with the mineralization, but with that this weathering is added and will be a gift for the mineralization at the rift margin. So, thank you very much.