Plate Tectonics
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Lecture – 38
Plate Tectonics and Mineralisation- II

Okay friends, welcome to this class of plate tectonics. And today we are going to initialize a new topic that is called plate tectonics and mineralization. So, before going to talk about plate tectonics mineralization, we should know the background, how the mineral systems forms and how it can be an extractable material which enriching the mineral for us so, that means you can say who is the natural money makers So, in which process the minerals are concentrated and which part they are concentrating on the earth's crust and particularly in relation to plate tectonics how the mineral systems are evolved and concentrated at different plate boundary settings. So, if you see these diagrams we know that plate tectonics mostly there are three types of plate boundaries like the divergent, the convergent and the conservative. And all these three types of plate boundaries they are prone to generate minerals and some plate boundary though the minerals are formed may not be preserved because of the lack of suitable geological environment or geochemical environment. But in certain cases the minerals are preserved and we are able to extract it economically.

So, if you see here this divergent plate margin and this divergent plate margin here the two plates they are separating from each other and there is a continuous magmatic supply. And if you remember earlier class when we were talking about the divergent plate margin settings we were talking about the hydrothermal leaching of this mineral the water is going down and it is heating and coming back and once it is interacting with the cool seawater the Eh-pH changes and the VHMS volcano hosted massive sulphide deposit they are found here. Similarly, at this plate boundary we have the black smokers, the white smokers they are rich in minerals and volatiles whenever they are reaching to this water level at the sea. So, this Eh-pH changes and with reaction with that so mineral is precipitated and we are getting the deposit.

But now the question arises when it happens whether these minerals can be extracted near to this mid-oceanic ridge because we know this mid-oceanic ridge the basalt which is formed here that is going down and it is subducting here so, there is very hardly getting chance that these mineral can be extracted because starting from the mid-oceanic ridge to the subduction zone nowhere it is exposed but at times these part of this basaltic system or the lithosphere they are abducted at the ophiolite sequences so, this may be the potential site for extraction of these minerals so, that is why though we have plenty of minerals found here, but hardly this type of tectonic setting giving us a chance to extract those mineral economically. And next come to this convergent plate margin. Here this plate is going down and here partial melting taking place of this mantle and this mantle material is erupting here at volcanoes and we have the volcanic clasts and the strata's so, they are containing the mineral volcanic rocks they are containing the minerals. And here is the conservative plate margin. So, the divergent plate margin as we have discussed it is rich in mineral and in the conservative plate margin here this mineral which are formed here they are dissected and relatively separation that occurs here and redistributed these blocks are redistributed by the transform fault so, that means by and large every type of plate boundary they are responsible for the mineralization purpose.

Addition to that before reaching this divergent system we started the journey from rifting. So rifting is a suitable environment for mineralization so, that means from rifting to drifting and from drifting to subduction so, all these type of tectonic environment they are suitable for mineralization however, the nature of mineralization and these components of mineralization are different at different plate tectonic setting. Addition to that here we have regional metamorphic system, we have contact metamorphic system. So, the minerals which are formed from this magmatic source that are modified by this metamorphic system and similarly before reaching this that is the mid-oceanic ridge system we had rift basins and the rift basins particularly they are rich in evaporites. So, that means every stage of plate tectonics starting from the rifting to drifting and this subduction and subduction related metamorphism, magmatism everywhere we are dealing with the minerals but now the question arises how much these minerals are enriched with respect to these crustal abundance.

So, that we can go for directly mining without any benefitization. So, this mineral deposits that form through this coincidence of favorable geological process. What is a favorable geological process? Then in a given spatial setting, then in a specific geological time, then it is tight time window, now, see how much restrictions are implemented here. There should be a favorable geological process. What is a favorable geological process? That means all the geological processes they are not favorable for mineralization.

Then that is a given spatial setting. So, spatial setting for example, I am talking about rift. Rift cannot be nth extent so, there should be a boundary up to which the rifting effect can be felt so, a spatial setting that is restricted. Similarly, in a subduction setting you cannot say the whole earth is affected by subduction. So, particular subduction zone it affects to a particular region.

So, this spatial tectonic setting. Then in a specific geological time, so specific geological time that means we have a geological time everywhere we do not get minerals. So, probably you know in your basic level that was talking about this mineralizing that province or metallogenic province and metallogenic epoch. So, in that case some specific time is there that is the metallogenic epoch that is responsible. Then at last in a tight time window that means you cannot extend the mineralization process to millions or billions of years.

So, there is particular time and through this time that means we know process that all starting from the process to the end of the process you cannot expect mineralization. So, there is a particular combination and permutation through which that time is suitable for mineralization. So, that means after all these permutation combinations we are getting a mineral and that mineral is sufficient for extraction and that we are using nowadays. See processes that are formed mineral deposit can collectively termed a mineral system like petroleum system similarly, we have a mineral system and that is defined all the geological factors that control the generation and preservation of mineral deposit that is very important not only generation of mineral is important, preservation of mineral is also important so, otherwise we generated a mineral either from magmatic process, from metamorphic process, from hydrothermal process, from sedimentation process, but it is removed by weathering, removed by erosion, removed by oxidation. So, it does not mean anything so, that means not only the generation is important, but preservation of mineral is also important and those processes that is the geological processes that includes the geological settings.

Which type of geological setting? Is it a rift setting? It is a subduction setting or other type of setting? Then the driver, who is the driver? Who is taking the mineral components or the constituents from one place to another from mantle or from the lower crustal level to the upper crustal level? Because if a mineral is occurring about 10 kilometer depth it hardly matters to us so, we need a mineral which is close to surface. So, that means we need a driver who will take these minerals from deeper level to a shallow level so, that driver may be hydrothermal fluid, may be magma itself, may be thrusting, may be faulting. So, who is the driver? Who is taking these minerals from lower stratigraphic horizon to upper stratigraphic horizon? Then timing and duration of a mineralization so, when this timing, when this mineralization occured and what is the duration of mineralization? If the duration of mineralization is more we will get more mineral, if it is less, it is less mineral will get. So, when and what is the duration of this mineralization occured? Whether the mineralization is timing-wise, it is a Precambrian time, it is in a cretaceous, it is in a recent time so, all that matters and the mineralization fluid and its component. What is the mineralization fluid? Whether the fluid is crustal derived, the fluid is magmatic derived, the fluid is hydrothermal derived.

So, that is matter that means what type of mineral it will give rise that depends upon the fluid components and fluid origin of this fluid. Then the pathway along which the fluids flow. So, which pathway this fluid is flowing? It is flowing through sedimentary rocks, flowing through faults, flowing through folds, flowing through fold axis or it is igneous rock or metamorphic rock or that is pore space is already available or it is created its own pore space then depositional site that is the trap site there where is its depositing? Within depositing it is forming the mineral within the igneous rock it is forming mineral within the sedimentary rock and then it is post-depositional modification. Post-depositional modification means after the formation of the mineral how it is modified? Whether it is modified by this weathering effect, it is modified by the metamorphic effect or it is remobilized due to exhumation so, all these factors that is affecting and finally, it is giving rise to mineral deposits. So, this mineral formation and its preservation up to extraction, it is not an easy process.

It is going to several processes and this product is finally, we have a mineral and we are going for mining so, a mineral system involves the concentration of commodities like these metals through a number of different processes to the point at which the concentrates is sufficient to consider exploration. Otherwise, mineralization is there, minerals are forming, but it is not concentrated so, we have different cut-offs for different minerals. So, if it is concentrated below, so it is hardly of our use. So, when these commodities can be extracted economically, the product of a mineral system is an ore deposit. So, that it is sufficiently enriched, sufficiently concentrated, so that we are extracting it economically so, that we are saying it is to be a deposit either it is ore deposit or a mineral deposit and the processes operate at scales starting from global scale to microscopic scale.

Some of the geological processes that are extending to global scale, for example, it is crustal differentiation it does not obey your political boundary, continental boundary, it is global scale and magmatic processes including melting, melting may be localized, fractionation, fractionation may be within that magma chamber. Then crystallization, magma mixing, immiscibility and magmatic hydrothermal fluid evolution, hydrothermal process including leaching and deposition process such as boiling, fluid mixing, then cooling and fluid rock interaction, physical processes include density separation, biological processes and post-depositional enrichment and upgrading. So, that means these are the processes involved for mineralization. And mineralization when I am talking, I am talking about economic mineralization because we need money. So, who is the money maker, who is the natural money maker out of these processes that is describing all these are they are just involved to making enriching the mineral commodity for us.

So, these are certain elements and their global distribution that is crustal distribution. So, throughout this crust if you remember our earlier class we were talking about the compositional stratigraphy. Different elements they are compositional stratified from crust to core. So, now the question arises when we are interested for a certain type of mineral and we want to extract it economically that means this type of global distribution or the crustal distribution it hardly matters to us. So, this matters to us that where these type of element of interest they are concentrated.

Now, the question arises who is concentrating that, that is the geodynamic process, that is the tectonic process so, this from global distribution or this crustal distribution to particular area enrichment of a particular mineral that is done by the tectonic process. And the tectonic process that involved all these hydrothermal fluid, magmatism, metamorphism, thrust movement, fault movement all those things they are related and addition to that weathering and erosion they are also concentrating minerals for us so, to getting a mineral deposit of economical use these type of processes they are given the credit so, economic extraction of many commodities required extreme enrichment relative to bulk earth average continental crust. So, here the bulk earth crustal composition is given and some of these minerals we need very less enrichment and some the it needs very high enrichment. For example, here with few exception iron and aluminum the formation of an ore deposit requires enrichment factor generally excess of 100 and some cases the excess of 1000 like platinum gold like this and relative to continental crust and the host is virtually all ore deposits. So, here this is the differentiation, magmatic differentiation or the crustal differentiation that means how the crust was differentiated during the formation of the earth.

So, we have elemental stratigraphy, compositional stratigraphy from there we are going to this crustal level that means you see with the upper crustal level with timing and this is the fluid system or this is the evolving system how this geodynamic system is evolving and it is giving from crustal differentiation to mineral deposit. This is the source of metal fluid and that is the ligands and sulphurs like that. So, these are the different geodynamics and tectonic processes how from this crustal distribution to enrichment it is reaching so, these geodynamic process at different plate boundaries specified spatial distance so, these are working in that domain and giving rise the enriched mineral deposit for us so, this enrichment factor relative to bulk earth are extremely variable with ore grades for some commodities such as nickel, iron, platinum lower or approximately equal to the bulk earth concentration and these commodities are strongly concentrated in the core. Some commodities such as this tungsten, tantalum, uranium and Pb have enrichment factor in excess of 10,000 relative to the bulk earth as the elements are highly concentrated in the continental crust so, that means depending upon the mineral the concentration changes and depending upon our requirement so, here some of this enrichment factor of some common minerals are given here you see the gold we need 500 enrichment factor. So, the bulk crustal distribution it is not enough so, someone should be there who will enrich the gold 500 times compared to this global distribution so that we can extract it economically so, now the question arises who is doing it who is making money for us this is the tectonic process there is the geological process.

So, the tectonic process in a particular geological area in a particular geological time and in a particular duration this process becomes active and we need a suitable tectonic environment, suitable geological environment for such enrichment. For many mineral system the first process of concentration was initial chemical differentiation of this earth and many commodities of the economic interest for example, the series of minerals are given here are highly enriched in this crust relative to the bulk earth. Whereas other commodities are weakly enriched in the crust and other are not significantly fractionated like Ag Some elements are fractionated into this mantle and core either moderately or strongly. For example, nickel and platinum group of element mostly that are in the core and in the crust their abundance is very less so, some are very strongly fractionated at the crust and some are strongly fractionated at the core and some are distributed throughout it so, by and large we need these elements for example, nickel and PGE and we know most of this nickel and PGE they are at the core level or the lower mental level so, now we need a process that process has to track it track these minerals and these minerals should come near to the crust. So, that process that is driven by the tectonic process and small number of commodities like molybdenum and Au have complex distribution being enriched in the core and crust relative to the mantle.

So, following this initial chemical differentiation of this earth that the geodynamic process further fractionate the commodities within the crust to this upper mantle. So, now you see from this crustal fractionated this geodynamic process it is fractionating it again and it is taking to this upper crustal level. These processes which operate at this cratonic to province-scale generally occur along active tectonic margins and can include processes such as mantle metasomatism, the formation of mafic and under plate and many others. So, these are these processes which are responsible for enrichment of these metals or minerals. The combination of the initial global chemical differentiation and subsequent tectonic enrichment that is associated with magmatic and metasomatism that is hydrothermal processes redistributed the mineral commodities and taking from the deeper level to the shallower level.

And surficial processes like weathering that we have discussed and sedimentation and some cases produce regions of the upper mantle and crust that act as a source of the commodities and that are concentrated into mineral deposit by hydrothermal and magmatic processes. So, that means we have an elemental distribution at a different part of this globe at a different stratigraphy level and these hydrothermal processes, magmatic processes they are recycling it and due to this recycling process it is coming to this surface or near surface and which can be mineable. In addition to the producing geochemically fertile metallogenic province tectonic processes initiate crustal and province scale architecture that is critical for the movement and production and later ore forming fluids. So, we have ore forming fluids we are taking from the deeper level to the shallower level. Now where to put it? We need a room, a suitable room it is needed and that is the tectonic processes that create rooms for that.

It is a fold axis, that is the fault zone, that is the shear zone, that is the basin that is formed by these tectonic process so, not only fluid creation or mineral rich or metal rich fluid creation is important it should have sufficient room to accommodate minerals, those metals and the tectonic force not only create this or recycle this mineral system, it also create rooms for them. In many cases, this architecture is developed early in the tectonic history of a mineral province. In some cases, tens to thousands of millions of years prior to mineralization with the fluid flow, felicitated by reactivation of the pre-existing structure and architecture. So, that means during the metallogenesis or during this mineral formation, either room was formed or the rooms were earlier existing by this pre-tectonic system, pre-tectonic events in contrast, the time involved in the formation of mineral deposit may be relatively short in many cases, in order to 1 million years or less system associated with magmatism so, once room is available, whenever we are producing minerals by any of the processes, we can provide sufficient room for that. Otherwise, we will create minerals, but we do not have room, so that we cannot preserve it.

The final concentration of commodities by hydrothermal or magmatic processes generally occurs during critical window of time during which hydrothermal fluids or magmas are driven along structures or other zones of permeability. That means we have structures like fault, like fold axis, the axial planes, like the shear zones these are nothing, these are the pathways and these are providing this permeability for these rooms for mineralization. And the presence of such fluid or magma pathways at the time of mineralization is one of the most fundamental keys to the formation of significant mineral systems that we have already discussed if we do not have room, so creating mineral is useless. So, we need a sufficient space to preserve these minerals and that sufficient space is also created by tectonic forces. The drivers of fluids may be the hydrothermal fluid, may be the magmatic fluid, may be the brines so, that may flow in temperature gradient or may be magmatism, which produce hydrothermal convection that is unroofing via erosion tectonic forces, stress changes, then magmatic buoyancy and release the magmatic hydrothermal fluid during magma crystallization and metamorphic de-volatilization and during contact or regional metamorphism formation of expulsion of a basinal brines, hydraulic pressure gradient caused by contractional or deformation and other processes so, suppose we have the fluids now how to drive this fluid from lower crustal level to upper crustal level.

So, these are the processes that accelerate or they help the fluids to flow. So this becomes the driver and that may be due to tectonic forces, that may be stress change, may be magmatic buoyancy that means unroofing via erosion, we are unroofing we are releasing the stress, releasing the overburden pressure, so that this fluid is coming up. So, these are the drivers of taking these fluids from lower level to upper level. And in some cases, production of a fluid is slow relative to its flow. So, we need a flow, but its production is slow and particularly this case it is the metamorphic de-volatilization.

So, metamorphic de-volatilization is a slow process so, that means we need some other thing that means to release that fluid from these pore spaces. So, that other thing that means this other support is supported by this seismic pumping. For example, suppose there is some metamorphism, the metamorphic system is going on and the fluid is releasing, but this release of a fluid is very slow process. So, in that case, suppose there is a seismic activity, there is seismic shaking. So, once there is seismic shaking, so that means it is providing suitable geological environment, so that this fluid which was released very slowly that can easily escape.

So, the seismic pumping sometimes it adds as a driver to flow the fluid from this system. So, fluid flow pathways may from prior to or during the fluid movement. So, that include extensional structures that is faulting, then developed of horst basins by volcanic terrains formed and reactivated during subsequent tectonism, permeable zones formed during basin development and diagenesis and structure formed during these events so, that means this before this fluid generate we should have sufficient rooms and the rooms that has created or the pathways that are created by volcanic terrains, by crustal extension, by rifting and by tectonism. And suppose there is earlier the fault was there, the pathway was existing, but it is choked. So, during subsequent tectonism that may be re-opened so, that means I want to say tectonic not only creates the fluid, tectonics creates the pathway, tectonics provide the room.

So, that means all total system it is driven by the tectonic itself. And the formation of mineral system requires the concurrent availability of a driver, a metal source, a fluid pathway during the discrete critical window. And these are triggered in many cases by the specific tectonic events or switches and may be relatively short lived so, if you are not providing the room so that means it will go to the vein because this metallogenic process it is a short lived. So, we should be ready with our pathways, with our rooms so that whenever this metallogenic processes occur we should provide that room.

Yes, concurrent, accommodate here. In addition to the mineral system requirement formation of significant mineral and ore deposits require two other features. What are two other features? A hurdle that concentrated fluid flow fluid is there, it is flowing so, we need to stop its flow so that it will give us mineral. Otherwise, it can flow to nth extent along this path and finally, it will release to the surface. If it will be oxidized there will be no mineralization so, that means it should concentrate that means we need a hurdle, we need a barrier like the petroleum hydrocarbon we need a trap, we need a cap rock so that it will hurdle and it will stop its migration. Similarly, when this fluid is migrating from the lower crustal level to the upper crustal level we need a hurdle so that it will stop its further movement.

And a gradient which can be either chemical or physical or both that cause efficient deposition and segregation and trapping of commodities in the economic interest. In hydrothermal mineral system, common causes of mineralization include rapid change in temperature, pH, redox caused by water-rock reaction and fluid mixing. However, in the magmatic system or other hydrothermal system, physical changes such as depressurization can include chemical and physical reactions that is boiling and volatile loss that cause the mineralization so, that means I want to say different processes are responsible for mineralization and all these processes if you trace them back they are triggered by tectonism. And in some hydrothermal system or some orthomagmatic systems these chemical changes such as magma mixing or contamination by wall rock can produce immiscible melt or cause crystallization of minerals containing the commodities of interest. In magmatic system, final enrichment to form mineral deposits results from density driven physical process and physical trap that control the location of mineralization.

So, that is the magmatic differential density driven physical process that is the concentration. Suppose we have a magmatic system we can remember our Bowen's reaction series. First the olivine among the silicates they are forming and they are settling down at the magmatic system because their density is more so, the density driven physical process. So, in the later on we have quartz feldspar like lighter element. So, that means within a magmatic system the high density mineral they will occupy the bottom and the low density they will occupy the top so, these are these density driven physical processes that is in the orthomagmatic system they are responsible.

So, thank you very much we will meet in the next class.