Plate Tectonics
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Plate Tectonics and Mineralisation at Intraplate Tectono-Metallogenic System-VIII

Ok Friends, welcome to this class of plate tectonics. So, far we have discussed about the mineralization events, the convergent margin, divergent margins and the collisional margins. In today's class, we are going to discuss the mineralization system at the intraplate environment. So, that means, it is away from the active tectonic front. So, within that continental interior, so that is why called it is intraplate metallogenic system. So, now the question arises why this intraplate tectonic system or intraplate mineralization occurs.

If you remember our earlier class, when we were talking about this rifting system, we started with a mantle plume. And once the mantle plume is approaching towards the base of this crust or this lithosphere, it is increasing the heat and due to increase of heat, it is melting part of this base of this crust and this lithospheric base. So, finally, the magma which is generated, this magma is coming out and it is spreading on the surface that is called igneous province. And this type of environment, they are common in different geological environment that means in space and time, and these are responsible for magmatic or you can say this orthomagmatic mineralization.

So, when we are talking about magma and crystallization, every time it comes in our mind that the Bowen's reaction series, how it is happening that means whenever the Bowen's reaction series we study, we start with olivine and this is calcic plagioclase. So, these are the silicates. So, before the silicate crystallization, this mineralization or the or the metallogenesis happens and this is the in the sulphide environment, sulphide-rich environment. So, in this class, we will talk about what is these characteristics of this intraplate magmatism and what type of mineral we are expecting from this intraplate magmatism and what is the prerequisite and which type of geological environment are suitable for this intraplate magmatism as well as mineralization. Simply magmatism, if it is there, it may not have mineralized.

So, that means, magmatism would be there and this magma would be mineralized and particularly rich in metals. So, that type of geological environment, which type of environment is suitable for that geological environment and geochemical environment, we will discuss in this present class. So, this particularly when we are talking about this mantle plume or this continental interior magmatism, this is the orthomagmatic nickel, copper and platinum group of element. these minerals, they are the most dominant mineralization or metallogenesis in this type of system. So, this mantle plume is responsible for this magmatism.

If you see in this diagram, so, this mantle plume is rising and finally, it is reaching near to this crust and you can see there are number of pathways through which this magma is distributed and it is erupting to the surface. So, just you can say this vertical pipes, it is called conolith and if it is sheet like it is called dyke and if it is like this, that means, concordant structure that is called sill. So that means, we have different sills, different dykes different of conoliths. So, through which this magma which is generating from this mantle plume is redistributed among these different crustal levels and at the top of this surface. And this type of magma spreading on the surface, it is called large igneous province or it is in the other word in the short form it is called LIP, large igneous province.

These are very good reservoir of energy and metals and it is very important contributor to this metallogenic system or this metal extraction. And in this figure, if you see this is the global distribution of this large igneous province and in the Indian context, if you see here, we have the Deccan basalt, it is the continental magmatism flood basalt is there. So, in the ocean surface also, we have different large igneous that means, bodies are there in the submerged. So, these are called large igneous province or LIPs. So, many of this intraplate setting that give rise intracratonic basins are considered to be very part of this divergent tectonic system.

So, those divergent tectonic system which is later formed and it starts with this magmatic system. So, there will be stretching, there will be magmatism and there will be rifting and finally, it will be converted to drifting stage. So, from rifting to drifting that means, we are creating two separate plates, but until unless the plates are separated, the blocks are separated, we have a intact plate. So, within that we are allowing this magma to rise through this different conduits and it is spreading on the surface. So, we are saying it is the large igneous province.

Mostly some types of uranium systems and salt like deposits, there is also few intraplate mineralization. Apart from this nickel, copper and PGE deposit, we have uranium system, we have salt deposit. Salt deposit is very important source for many minerals and this orthomagmatic nickel, copper, PGE deposit already we have discussed and magma emplaced at this large igneous province provide direct information about the elemental distribution at the subsurface because magma generating from different level, they are taking different elements through it. We do not know what exactly this elemental distribution, what is the fashion of distribution from top to bottom. So, once this magma is coming to the surface, it is giving the direct evidences that what are the exactly this elements they are distributed, what is the compositional stratigraphy of this particular region and this large quantity of nickel, copper, PGE are being extracted from the depth and they are deposited at the deeper crust and those deeper crust deposits, they are coming to the surface due to crustal exhumation.

So, crustal exhumation is one of this tectonic process that we know this system is going down at part of the crust which is subsiding and later it is coming to this near to the surface, this process is called exhumation. So, when the deep crustal rocks that were formed at the deep crust when they are coming to the surface, this process is called exhumation. So, these nickel, copper, PGE deposits once upon a geological past, they were formed in somewhat deeper level and due to this crustal exhumation, they are coming to the surface. But though they are emplaced away from this crustal margin, in many cases, these deposits are located near the edge of the cratonic block. Why this edge of the cratonic block? Because these are the environment which is providing the easy passage to the magma to this mid-crust.

So, these crustal boundaries, they are the weak zones. So, those weak zones, they are this magma is taking advantage to emplace itself near to the surface. And we know during this decompressional melting, there are different types of melting processes involved here. And this is the decompressional melting, which is responsible for stretching and another type of melting that is the increase of temperature and third type of melting, it is due to that means induction of some water that is what that is volatiles due to the subducting of the slab. So, there are three types of melting is there, but here we are talking about the decompressional melting by stretching the lithosphere and the fluid flux from dehydration of the subducting slab that produce mantle plume, enormous volume of mafic magma giving rise to LIP.

So, any of these reasons may be responsible for this magma generation and once this magma generation is there, magma is coming out and spreading on the surface or near surface, it is near surface emplacement, we are saying it is the large igneous province irrespective of its region. So, large volume of mafic magma that is generated through partial melting, once it ascends the crust via interconnected network of sills, dikes and conoliths and those sills and dykes and conoliths, they can travel up to 2000 km. So, that means, these pathways are capable of moving the melt vertically over 2000 kilometer and laterally around 200 kilometers or so. So, that means, simply sills and dykes, they are nothing that means, they are not restricted to this near to this igneous body, they can transport the magma about 1000 kilometer or even 100s of kilometer. So, that's why magmatic emplacement one particular place that does not mean the mineralization will occur here only.

So, through this distributary channels, the magma may be emplaced 1000s kilometer away from its actual emplacement and that can be responsible for mineralization. And addition to that, these sills and dykes when they are intruding into this host rock, they are altering the rock, they are leaching the rock and they are metamorphizing this rock. So, finally, what is happening is related to metamorphism, the mineralization related to leaching, related to alteration whatever the mineralizations are there, they are also taking place here. And this magma or the basaltic magma particularly, when it is emplaced near to the surface that is called flood basalt like the Deccan, it is one of this Indian example that is deccan flood basalt or you can say this Deccan traps. So, same thing it has been written here that the sills are capable of transporting magma laterally about 100s of kilometers and this different crustal levels.

So, if you see this diagram here, these are the sills which are parallel to the surface at different level they are emplaced. So, this is giving rise the large igneous province. And this magma that leaves the mantle that ascend through different crustal generation that enriched in nickel, copper and PGE and which is favorable geochemical and geological conditions are required to concentrate those elements together to giving rise to this deposit. So, what are this suitable environment or geochemical environment or geological environment responsible for this system that comes under this economic geology class, when this magma it is giving rise to mineralization, what are the different processes, what are the different geochemical changes that is occurring, how this magma is contaminating, how it is fractionating. So, this comes under this economic geology class.

So, we will not discuss much about this, but such deposits form high flux magma system that developed by self-organization of flow within that magma pathways. And sulphide minerals typically accumulate in mafic and ultramafic igneous rocks in such magmas and through such conduits. Now nickel, copper and PGE sulphide mineralization forms, if what is this conditions first is the magma reaches sulphur saturation triggered either by contamination of a sulphur-bearing crustal rock or by sudden change in magma chemistry. So, now we need sulphur inside, so that sulphide mineralization will occur. So, for sulphur what it should be the source either is the host rock which is putting clasts are putting within that the magma system it is contaminating the magma So, that may be one source for sulphur, another is the magma chemistry changes due to fractionation.

So, that that sulphur may increase. So, either of these cases we are increasing sulphur is the first condition. Second condition is that, the resulting sulphide droplets can scavenge nickel, copper and PGE from this large volume of magma. Once this droplet is forming this is the that means the sulphide droplets are forming. So, they are attracting this nickel, copper and PGE from this rest of this magma and they are concentrating within that.

The third is the sulphide droplets aggregate and are transported and deposited from a coherent over body. So, those which are concentrated in terms of nickel, copper and PGE due to the attraction from the different sides of this magma. So, they are concentrated and they are moving up and finally, somewhere they are emplaced due to this magma cooling and giving rise these deposits. Now another type of deposit which is mostly deposit hosted by intra-cratonic basins. So, we are talking about large igneous province that means this mineralization or metallogenesis within this magma.

And now we are talking about if there is any intra-cratonic basins, how it will be mineralized because we are talking about this intraplate mineralization system. Mostly this sandstone hosted uranium deposit, it is most eye-catching deposit that is the epigenetic deposit and which uranium minerals are present as disseminations and replacement primarily in fluvial, lacustrine and deltaic sandstones. So, now what is essential condition? We need a sandstone and we need some fluvial chain that will either it is fluvial sandstone or lacustrine or deltaic sandstone it is there. So, some other condition also required we will discuss in later times, how the sandstone is enriched in uranium with time. So, uranium is precipitated under reducing condition.

So that means, we need a reducing environment and caused by one or more reducing agents. So, what are the reducing agent? So, within that sandstone including the carbonaceous material, if this carbonaceous material is there that means, we have organic material that can create reducing environment. Then sulphides, sulphide is there that is provide the reducing environment. Then hydrocarbon if it is there sandstone is oil bearing or hydrocarbon bearing that will create a reducing environment. Then it is inter-bedded with Fe2 rich volcanic rock that is few minutes back we were talking about the sills.

Suppose it is inter-bedded with sills, so which is a volcanic rocks, so Fe2 rich. So these are the conditions, they are providing a reducing environment and within that reducing environment we have a sandstone and that sandstone is allowing the uranium to precipitate there and giving rise to the sandstone-hosted uranium deposit. And most basins that host these deposits form on stable cratons that were close to the sea which produces local reducing conditions during and after sedimentation forming chemical trap that is essential for uranium precipitation. So that means, we are producing and reducing environment after deposition, so that means, this basin is now fit to attract the uranium to precipitate within that. And there are 5 important prerequisites for this uranium mineralization within the sandstone.

What are the prerequisites? First is the formation after the oxidation of the atmosphere and hydrosphere. Second thing that a leachable uranium source should be there, uranium source should be there which is leachable otherwise how can you concentrate the uranium. The third is the presence of a stable permeable aquifer and stable aquiclude that means, they can create a reducing environment. A stable groundwater system to form an upstream oxidized zone, the upper part should be oxidized and the lower part should be reduced. A reduction front where the uranium is precipitated and concentrated.

So, now if you see these diagrams, we have oxygenated sandstone that is yellow color you see and we have reducing environment here and this is the reduced sandstone, this is the reduced sandstone, this gray color and whatever you are getting here this is nothing, these red colors are the uranium deposits. So, that means, we have uranium at the front which is separating the reducing environment to oxidized environment. So, that means, oxidized environment at the top and reducing environment at the bottom and from this oxidized environment, either it is granite or any rock, it should be leachable through this that means, through solution that this uranium it leaching down the solution once it is reaching to a reducing condition due to the change of the Eh-Ph condition, the uranium is precipitated there. So, this sandstone is this region, this region, this region, they are reaching uraniums. Similarly, if you see this groundwater is flowing here and this groundwater once it is flowing that means, it is oxidized.

So, it is reaching in an environment which is reducing environment. So, that is why you can say at the periphery where this groundwater is mixing with another environment with another fluid which have different pH condition. So, at this periphery we are getting this uranium deposits. So, this is the chemical front, this red dots, these are called the chemical front that means, mixing of two solutions are there. Then surficial uranium deposit that is mostly it is young, paleogene or recent, near surface concentration of sediments or soil and mostly it is calcrete-hosted.

Calcrete hosted uranium deposit that the most significant of this kind and uranium is leached from the source rock transported by oxidized surface water at the shallow groundwater and when it is reaching at the reducing environment it is giving rise to the uranium deposit. So, calcrete you know there are different terminologies used for this concretions, it is calcrete, silicretes, ferricretes, if it is calcium carbonate it is called calcrete, if it is silica rich silicrete, this iron it is called ferricate. So, different concretions are of different shape there. So, another is the vanadium is extracted from this mafic rock. So, that means, there is a vanadium deposit.

So, that is extracted from mafic rock or iron rich metasediment. So, third thing is that we have this carnotite, carnotite is nothing it is the evaporite. So, evaporation of the surface or groundwater triggers precipitation of carnotite, it is hydrated uranium and K bearing vanadate, it's chemical formula here and the vicinity of a playa lakes this precipitation of a carnotite can occur due to mixing of valley groundwater along with the more saline lake water. So, now you see everywhere there is a change of salinity, there is a change in a pH is condition where this mineralization is going on. So, either it is a salinity change, it is a chemical change of this fluids when there are mixing together that front that is the reaction front which is giving rise in mineralization.

Then another deposit is called salt lake deposit. Salt lake itself the name is self explanatory, we have salt deposit and in the lake. So, that means, mostly these playa where this evaporation is more inflow. So, the salt lakes they are major source for lithium, potash, borate and other strategic mineral. So, lithium nowadays very recently Indian government has declared we got a lithium deposit in Jammu and Kashmir.

So, these are very rich that means, it is salt lakes if it is there ancient salt deposit if you can identify. So, that is very rich in this type of mineral systems. So, salt lakes that is otherwise it is called salars that is the semi arid to arid regions of Chile, Peru, Argentina, Bolivia contain most of this world's low cost supply of lithium. Whereas, salt lakes in Jordan, Israel, China they are significant source of potash, but there are certain preconditions how this salt will be precipitated there and how it will be rich in minerals. That precondition says much inflow to form water body with no or restricted outflow only inflow is there only receiving end is there no giving end.

So, evaporation must exceed inflow then fluid source may be surficial or it is hydrothermal. So, any of this fluid flow path or any of the fluid, but the main requisite is that it should contain salt. So, we are precipitating salt we are accumulating salt from the surrounding either there are some structure may be some hydrothermal fluid may be mixing here. So, anyhow we are increasing the system with salt with evaporation of water only and salt remain there.

So, this is evaporate conditions. Then all those deposits whatever they are so far we have discussed what is their exploration implication, how this can be explored. These triggers, drivers and the mineralizing events and the chemical composition of this ore fluid, depositional mechanisms evolved in different tectonic systems and different stage of individual tectonic system have fundamental difference in properties. So, the triggers who is triggering the mineralization it has the difference. The drivers of a mineralizing event that is also differences, the chemical composition is also difference, the depositional mechanism it is also different, the depositional front is different that means the host rock it is also different, but irrespective of all those differences so we are getting the minerals. So, now there is something else which is working behind that is the geochemistry.

So, the geochemistry is very much important in terms of mineralization. So, as many types of mineral deposit form as a consequence of geodynamic processes that occur at different tectonic systems, individual type of mineral deposit in most cases are not diagnostic of tectonic system. Because if you remember our earlier classes, we were talking about VMS deposit both in divergent and convergent margins. We were talking about the porphyry deposit both at convergent and divergent system. So, talking about one particular mineral type we say it is particular geological environment is responsible for its formation it is not ok.

So, that is why we have to take a mineral assemblage rather a particular deposit. So, that is why assemblage of deposit it is important. So, for example, assemblage type produces within one metallogenic system can be strongly indicative of tectonic system which they are formed. So, rather one particular mineral assemblage of mineral is very much important to detect which type of tectonic setting is responsible or was responsible for its formation. Many of these chemical characteristics of ore fluid appears to depend to a significant degree upon the stages of tectonic metallogenic systems in which they form.

For example, at high heat flow and extreme mafic and magmatic, magmatism through all evolutionary stages of this convergent system and the rift stages of divergent system produce high temperature and relatively reduced and ore fluid associated with the porphyry, copper, VMS, siliciclastic, mafic, Zn and Pb deposits. So, that means, you see starting from high temperature to low temperature divergent to convergent we are getting the mineralization of that means same type of mineralization we are getting. So, that is why mineral system is not diagnostic, but if you are taking the assemblage that may be the diagnostics. So, therefore, steep temperature decrease water rock reaction that mean depressurization and fluid mixing are the major causes of mineralization that we are talking few minutes back that is the geochemistry. So, this geochemistry is playing major role in mineralization and that geochemistry that is depended upon this temperature pressure condition and this temperature pressure condition that depends upon tectonic environment and tectonic environment that depends upon this their convergent divergent system that is plate movement.

So, that means, you see how directly or indirectly our mineral system our national wealth that means wealth building system how it is governed by the plate tectonic system. And depending upon this reactive rock, water rock reaction can increase the pH that means with carbonates and desulfide with Fe rich rock and reduce with Fe or reduced C-rich rocks or ore fluids that is that mechanism which can cause mineral deposits. So, every mechanism listed here they are related to geochemistry change in geochemical behavior. So, this contrast with the later stages of this divergent tectonometallogenic system which is amagmatic and therefore, characterized by low heat that is less than 200 degrees celsius produce oxidized H2S-poor, low-temperature fluid promoting shale-hosted copper and cobalt unconfirmity-related uranium siliciclastic carbonate and Zn-Pb deposit. So, that means, if you see we have a divergent system where that is low-temperature system is there, we have a convergent system, we have a high-temperature system is there, but either it is convergent or divergent system that is irrespective of that tectonic setting the geochemistry is playing the role key role.

For example, if you see here at this low temperature system here this system that means, this copper sulfide and copper this whatever is there that is precipitating here. At high temperature system this system is precipitating here and similarly there is a that means, oxidized system to that means, reducing system once we are going at this stage we are getting this uranium mineralization system is there. So, that means, everywhere this is the play of geochemistry in this tectonic environments and the most effective way of depositing metals from such fluids is the provision of H2S. So, this is very much important for metallogenesis we need the sulfur present should be there. So, either through sulfate reduction or interaction with local H2S resource any of this region may be, but we need sulfur for sulfide mineralization and the sulfur may be of any source, maybe it is organic source, may be from rock source, may be from fluid source, may be from magmatic source, may be the change of this magmatic fluids characteristics.

Mineral deposits are the result of nested processes that can occur over periods of millions to thousands of million years it is not one day process. So, through multiple geochemical enrichment event multiple geochemical enrichment events. So, that means, you see how geochemistry is playing the role. So, it is produced enriched source of regions and the development of crustal architecture that is later used to mineralizing fluid to get result. So, that means, we should have a proper room for allowing this geochemistry the change of geochemistry fluids that to be accommodated there.

For example, subduction is not only directly responsible for the formation of many porphyry copper deposit as the melt that form these deposits are subduction-related. So, de-volatilization of the subducting slab also enriches the mantle in volatiles and slab rollback causes the extension of the over this overriding plate. Both of these later processes can have important ramifications in later metallogenic system. So, that means, not only shift convergent divergent is related this volatile emplacement the geochemistry change these are very much important rather than convergent divergent system. Formation of IOCG deposits may have involved in the melting of the mantle that was fertilized by a de-volatilization of the subducted slabs during prior period of subduction that we have discussed earlier also.

Moreover, it is likely that extension-related subduction produces the structural architecture utilized by the syn-volcanic mineral systems that is VMS and later by orogenic system it is reactivated. So, this crustal scale that is the discontinuities which was formed at the earlier stage of orogenesis may be reactivated later stages and giving rise the pathway the for mineralization system. Hence chemical and structural architecture may develop before the metallogenic event and can create favorable condition for development of fluids and melt critical to metallogenesis and can also channel the compartmentalized fluid flow. So, these are the processes how this metallogenic system are related. In some facts most easily discovered deposits have largely been found and future discovery will increasingly be made poorly exposed and under cover terrains.

Why so we are discussing? Why are more emphasizing on this geochemistry on this plate tectonic setting? Because easy to find deposits as already we have exhausted. So, now we have to find out those deposits which are hidden based on this concept. Otherwise we have the concept which type of environment, what should be the temperature pressure, to go in with type of mineralization, where the minerals will be found that depends upon the concept rather searching here and there. So, that is why nowadays the concept based mineralization or the concept-based mineral exploration is the need of the hour. So, that is why understanding the tectonics, the tectonic setting and their mineral that means potential at tectonic setting starting from this tectonic boundary to intraplate systems that is very much important.

So, that is why conventional exploration techniques will become less effective and new exploration method based on concept will be required. So, this is the use of this plate tectonics, why we are going for this, why we are emphasizing on that. So, analysis of the link between the evolution of the tectonic system and metallogenics suggest that the understanding of the tectonic setting can be used to predict characteristics of mineralization in a poorly known terranes. So, it is not explored at all, but the concept you have there that means where this mineralization will be there if you are talking about a convergent system which type of mineralization will be there, what extent the mineralization can go. So, that depends upon the plate tectonics concept, this geochemistry concept.

Otherwise we are not going to discover any new mineralized field in this world. The concept of tectonically linked mineral deposit association can be used to predict unknown style of mineralization in a known mineral province. And if needed major mineral deposits are products of perturbations of tectonometallogenic systems, documentation of such perturbations and their spatial and temporal effect could assist the development of regional exploration models that specifically target the mineral deposit. So, based on our finding, based on this tectonic system we have to develop a model. So, based on this model we have to go for mineralization that means we have to develop a conceptual model based on the tectonic setting, based on the temperature, pressure, based on the geochemistry and based on that model we have to search for which type of mineral we are searching for.

So, if a mineral is not available at a particular tectonic environment, but we are searching it that means we are just putting our time in the vain, nothing else. So, that is why concept based mineralization is the need of hour, rather searching here and there. So, that is why tectonic understanding can be gained either from this better exposed terrain along the strike or some cases regional or national scale geochemical isotope and geophysical and geochronological data sets. So, now, every third for Indian context everything is there, we have rock record every inch of Indian subcontinent we have rock record, we have 1 is to 50000 geological map. Now, we have NGCF National Geochemical Mapping Program that means every toposheet we have geochemical data we have.

Now, we have to just match those we have to overlap those which rock, which element, which type of tectonic setting that means structural data, lithological data, geochemical data, geophysical data we have to converge them together. So, once we are converging that means we are coming to a tectonic model and based on the tectonic model we have to go for exploration. So, we can predict from the laboratory itself from that model that whether a particular mineral X is available here or the suitability of getting this mineral X is here or not depending upon the tectonic model.

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