Plate Tectonics

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

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Lecture – 37
Plate Tectonics and Mineralisation- I

Okay friends, good morning and welcome to this class of plate tectonics So, we have discussed different type of plate boundaries like convergent, divergent and conservative. And today we will talk about how these plate boundaries or the plate tectonic settings they are related to mineralization. Because we need money and we have to identify who is the money maker? how naturally the tectonic settings they are integrating the mineral resources then enriching the mineral resources for us and we are going for mineral extraction. So, whether all these tectonic settings or all type of plate boundaries they are responsible for mineralization or in the other word all mineralization it is responsible or it is confined in plate boundary only or is there any mineralization which are away from this tectonic setting or the plate boundary setting. So, of course, none of this inch of this land in this earth's crust is useless. So, that means every inch of land it is mineralized, but now the question arises when we are talking about mineralization that means we are talking about the commercial one.

So, whether that naturally mineralized portion of this earth or this you can say the background mineralization whether it is sufficient for extraction or we need some enrichment. So, that enrichment we will talk in next class and today we will have some background about different types of plate settings and intraplate environment that means those environment which are away from this plate boundary, how they are responsible for the mineralization and which type of mineral they are particular to which type of plate boundary and which type of magmatic event and in terms which type of mantle that means condition which is responsible for this mineralization at the surface. So, mostly the mineralization when we talk about the first in chance come in our mind that it is related to magmatism. Yes, of course, there is related to magmatism and depending upon the magmatic compositional change so this mineralization also vary.

In addition to that we have minerals which are metamorphic origin, which are minerals which are of sedimentary origin. So, these sedimentary minerals and metamorphic minerals they are the secondary ones which are derived from this enrichment from this magmatic system or this crustal abundance or crustal distribution. And in today's class we will have a background knowledge which type of crustal setting or which type of

tectonic setting are responsible for which type of magmatism and in turn which type of mineralization. So, if you see here there is a reasonable evidence to suggest that metallogenesis changes as tectonic process evolve. So, if you remember our earlier class we were talking about the plate boundary it is not permanent, it shifts, it changes a convergent margin maybe of high-angle dip or maybe a shallow angle dip with time.

Similarly along this convergent margin different segments may dip differently and similarly in the divergent setting somewhere we have a failed rift and somewhere we have a full-fledge rift we are creating this mid-oceanic rift system and degree of a partial melting that varies from place to place. So, that is why this evolution of this tectonic setting that is important to understand for this mineralization or metallogenesis. And we know there is different geological times and geological places which are enriched in mineral. So, we say it is metallogenic epoch if it is time constant and metallogenic province if it is spatial constants. So, that means, different metallogenic province and metallogenic epochs that can be related to tectonic setting or tectonic evolution.

So, how this tectonic evolution is responsible for that we will discuss in detail in today's class. So, this gentleman that is Sillitoe and another is Hutchinson in 1972 and 1973 they are the pioneer workers to establish the relationship between this tectonics and mineralization. And this relationship that was first established from this porphyry copper deposits and volcanogenic massive sulphide deposits. So, these are the prominent mineralization events or mineralized field where there is porphyry copper is associated and volcanogenic massive sulphide deposits are associated. So, these two types of deposits first they were linked to tectonics and later on many other mineralization events they were correlated.

So, we know we have different types of tectonic setting like the divergent margin setting which is responsible for mineralization. We have convergent margin that is responsible for mineralization, then we have transform margin that is responsible for mineralization and we have intraplate setting. That means, it is not related to plate boundary it is away from this plate boundary but it is related to some mantle region mantle convection or some pressure-temperature changes in the mantle. So, that is magmatism occurring and that magmatism is responsible for mineralization. So, we have three prominent plate boundary settings and one intra plate settings but all these four they are responsible for magmatism, metamorphism and in turn for mineralization so, here this figure can be understood in this sense that we have metals that means, which metal is responsible for which area and we have deposits so, if you see this discrete age pulses of mineralization that preserved in this regional rock record may be related to episodes of terrain evolution and which rapid geodynamic changes have been occurred.

So, this mineralization event it is not a very long period of time the duration is very small. So, this rapid geodynamic changes which is responsible for mineralization and if you see starting from this divergent margin system to convergent margin system and within that convergent margin system we have the forearc, we have this back-arc extension we have this magmatism, it is regional metamorphism, then we have batholithic intrusion. So, that means, starting from this origin of this plate up to its depth and other part which is mostly of continental side everywhere we have mineralized event. However, where it is concentrated we say it is deposits and this concentrated based on our cut off that we have fixed the cut off depending upon our requirement and availability. So, that means, if you start from here this mid-oceanic ridge we have copper-zinc mineralization and how it is occurring? Occurring as volcanogenic massive sulphide deposits.

So, this metal is copper and zinc and it is occurring as volcanogenic massive sulphide that means, it is a volcanic origin or volcanic hosted massive sulphide deposit we can say VHMS volcanic hosted massive sulphide deposit. Then coming to this ocean floor away from this mid-oceanic ridge system we have a manganese, we have cobalt, we have nickel. How it is occurring? That is manganese nodules. Then coming to this subduction zone we have chromium that is magmatic chromite deposit. Then coming to the forearc basin, forearc basin extension or compression that is giving to lead zinc and copper that is stratabound sediments within the stratabound sediments.

So, now, how it is coming from the strata bound sediment because it is a heat zone. So, heat is being provided due to this magmatic intrusion and due to heat there will be leaching from this rock and that leached minerals they are concentrated within that strata, it is stratabound system. Then we have magmatic arc itself which is responsible for mineralization. You see a variety of minerals you can say the big bazaar of minerals here that is copper, gold, silver, tin, lead, mercury, molybdenum. So, variety of minerals there at the arc system it is the volcanic arc system.

Coming to the back arc system we have copper, zinc, gold, chromium that is here. So, here at the arc system very prominent is the porphyry copper. So, this copper this is it is intermediately riched rock and this is very vast area huge amount. So, that is that is why it is economical. Then coming to the back arc spreading we have volcanogenic massive sulphide deposit again and stratabound evaporites.

So, evaporite in the last class we have discussed when we were talking about this basin rifting. So, initial phase of basin rifting we found that evaporite deposit. Then coming to this granitic pluton which is continental crust we have tin, tungsten, bismuth, copper and it is vein type and contact metamorphic type. So, that means starting from this origin of this mid-oceanic ridge system and at this end of this passive margin or inside this continental system we have everywhere different mineral deposit due to different processes and those minerals their emplacement mechanism is also different. So, we have to understand the emplacement mechanism of that minerals in different plate tectonic setting and we have to correlate the tectonics with mineralization.

The same thing it has been discussed here we have magmatic ore deposit mostly this side. Then we have hydrothermal ore deposit that is this side and we have subsurface or surface related ore deposit mostly this placer deposit or secondary enriched deposit mostly weathering and erosion. However, that origin is from here and here. So, that means we have already discussed in brief which environment is responsible for which type of a mineral deposit. So, this mineral deposits starting from this origin of this earth up to now it is occurring in cyclic manner.

So, we know different cycles of plate motions that means plate is generated here then it is destroyed at the subduction zone and this cyclic process it is moving. And this cycle there are some stages involved here first stage of the cycle is the crustal extension and the mid oceanic ridge formation here. Then the second phase of the cycle it is the arc formation and the crustal extension that is back arc basin associated with rollback of the plate being subducted. So, once this plate is created here we have to subduct it and depending upon the subduction angle and this compression between these two and the degree of metamorphism of the two that means there will be trench rollback, there will be slab rollback which has been already discussed in our convergent plate margin settings. So, this rollback that is that creating different magma at different level due to different degree of partial melting.

So, that means once we are creating magma so that means we are creating minerals. So, similarly in divergent setting we are creating magma we have the basaltic system we have this black smokers, the white smokers they are also reaching mineral. We have hydrothermal system which is going down and coming back and leaching this rock system here and it is depositing here we have minerals. Then the third is the crustal shortening associated with terrane accretion flattening of the subducting slab. If you move to the eastern side of the pacific we have this terrane accretion before there is

subduction.

So, at the middle part of this Andes mountain earlier it was existing the back arc extension basins so that is accreted. Similarly in the Australian subcontinent or Australian continent it is accreted with this accretionary plate margin at the west and post-collisional extension and magmatism. So, all these four cyclic processes or the all the four stages in a cyclic processes they are related to magmatism and in terms related to mineralization. So, that means, we need more and more plate tectonics settings to create more and more mineral systems. So, this more plate tectonic setting that means, if you are going to this Archean time, if you remember when we were talking about this formation of this earth in that class we were talking about in the Precambrian we have severe plate tectonics because the crust or the lithosphere was very thin and this magma ocean was just below it.

So, the convection current was moving at higher speed. So, that is why higher plate tectonic setting was there. So, that is why if you move to this vast amount of mineral deposits. So, mostly during the Neoarchean or later it suggests a nexus between the mineral system and the plate tectonics. So, that means, more tectonic more mineral and most active and geologically young mineral deposits are spatially and generally associated with plate boundaries.

Present day also this mineralization going on you go to this mid-oceanic ridge system we have the mineral systems. So, that means, not only this Precambrian time only responsible for mineralization present is also mineralization is going on. And many ancient mineral deposits are closely associated with paleo-crustal boundaries and that may be marked the plate boundaries in the past. So, that means, in the past if you remember when we were talking about this accretional system the lateral accretion system when the earth was formed the felsic crust was formed. So, different felsic crustal part they are floating here and there and they amalgam together and due to this crustal accretion this continental growth occurred.

So, this amalgamed point or these lines they are the suture zones and they are the plate boundaries and those plate boundaries nowadays they are rich in mineral resource. And the tectonic process have evolved through geological time and the respective changes are reflected in temporal distribution of characteristics of mineral deposit. So, we have already discussed how the evolution of tectonic process change how a convergent margin setting is changed to divergent margin and vice-versa. And along this convergent margin how different segment they evolve differently depending upon their angle of subduction. So, that means, once there is evolution of this tectonic setting there is evolution of

mineralization.

Some mineral deposits they do not have association with the plate boundary setting and that is why they are called the intraplate settings so, intraplate setting it is the best example is the salt lake-hosted potash deposit in Australia. So, there is nothing to related with plate boundary, but intraplate setting. So, that means, there may be plume and this plume is coming out and it is inside this crust and due to this heat dissipation heat transfer this mineralization occurs and there will be magmatism. So, due to magmatism mineralization occurs. So, it is nothing to related with the plate boundary away from far away from this plate boundary that is called intraplate setting.

A mineralizing system driven by a geodynamic process can occur in different tectonic setting. So, different tectonic setting convergent, divergent that is conservative all the tectonic setting they are related to a geodynamic process. Geodynamic process that means, an interaction of this mantle and lithosphere. So, for example, modern black smokers deposit as a consequence of new crust formation along the mid-oceanic ridge in rifted arcs, back arc basin in convergent tectonic settings. So, present day is also wherever there is geodynamic setting associated mineralization is also going on there.

Some deposit types seem to be restricted to time and space that is the type of that is called the metallogenic province and metallogenic epochs. And this is metallogenic epochs some deposits they are restricted in geological past. Similarly, some areas of this earth crust they were mineralized in the geological past and due to this change in the tectonic setting of this particular region the sites of mineralization has been shifted. For example, that is the orogenic gold deposit which are associated with the crustal thickening and commonly it is follows by the crustal thinning is the most common associated with convergent margin. If you move to this eastern part of this Andes particular the middle Andes system earlier there was extension later on there is contraction extension that is back-arc basin was existing, but now there is a contractional environment.

So, this extension followed by contraction which is responsible for widespread orogenic gold deposit. Hence, the presence of individual deposit type can be used to indicate the geodynamic process in this mineralization process and different deposit types in close proximity with time and space can be used to confirm yes it is because this convergence of evidences taking one deposit talking to a particular system it may not be so true. So, that we have to take the association different mineral deposits their associated their association is particular or peculiar to a particular type of plate boundary setting. So, rather taking one minerals and predict this type of geodynamic process was involved

there maybe somehow it will be wrong. So, that is why the association once it is there one with supporting to other so that means, that may be good perspective for mineralization and searching for mineral or exploration of this minerals.

For example, here presence of volcanic hosted massive sulphide deposit, orogenic gold deposit, porphyry copper deposits that means, three systems one is porphyry copper system another is orogenic gold system another is volcanic massive sulphide deposit. So, these three systems they are peculiar to this convergent margins. So, if nowadays in the Precambrian terrane we are getting such association that means we can say with confirmation yes it was the previous convergent margin or earlier convergent setting was there. Then mantle-derived magma and its composition that are also responsible for different type of mineralization. And what should be the composition of magma that depends upon the degree of melting then the source composition that volatile content and post-melting modification that like fractionation, assimilation, contamination, mixing like this.

So, that means, if a magma of x amount is coming from y depth and it is coming to the surface in this time it has number of changes expected and this change are like this. And once the magmatic composition changes the mineralization also changes. So, that influence the mineralization. So, the degree of partial melting and the temperature and pressure of partial melting and their associated rocks through which it is coming out, the depth from which it is derived and the degree of contamination from this country rock and different mixing or mixing of different groups of magma, different pulses of magma that all they define which type of mineralization we are expecting from this magma. So, not only this plate tectonic setting or the convergent divergent setting as responsible for mineralization.

So, the magma which is responsible for mineralization. So, what extent it has fractionated? What extent it is contaminated? To what extent temperature and pressure it is coming through? What depth is coming through? What is the degree of partial melting the mineralization occurred to create this magma that is also responsible for which type of mineral we are expecting. Particularly the continental rift, intraplate environment and oceanic islands that experience small degree of partial melting which are characterized by more alkaline magma emplacement. So, this type of environment like continental rift is there, then intraplate environment and oceanic island small degree of partial melting they experience. So, once the small degree of partial melting that means, we are talking about the alkaline magma emplacement because the magmatic composition it is the alkaline nature.

So, there are certain melts which are also unusual for example, kimberlite, lamproite, ultra-potassic melt like leucitite. So, these are very small in amount and this small in amount that is small volume of the asthenosphere and possibly metasomatized lithospheric mantle. So, what they are indicating? They have a strong association with the continental lithosphere. So, once this type of magmatic emplacement is there, we cannot say that is this oceanic lithosphere is responsible because these magmas in particular they are of continental origin. So, without this continent or continental intervention we cannot create this type of magma.

So, that means some are very peculiar type that is of continental origin. Nowhere in this oceanic basaltic system or oceanic lithosphere this minerals of these rocks are reported. So, that means they are particular to continental site. The convergent margin setting shows a major exception in the generalized view. Why? All these were discussed that the continental system it is responsible for this type of magma oceanic system for this type of magma, then earlier it was extension then convergent this type of magma.

This is the generalized view that we have adopted. But there is certain exception in terms of where we are talking about the convergent margin because here the partial melting it is not due to this temperature or pressure it is related to fluid flux. So, this is the convergent plate which is converging plate which is going down it is dehydrated, it is releasing water and that water which is interacting with the mantle wedge it is decreasing its temperature of melting or melting temperature. So, that this partial melting taking place.

So, this is special kind of partial melting. So, that is why here the water and other volatile that is introduced into the mantle slab Rocks in such setting are characterized by consistent geochemical signature including enrichment of LILEs especially the light rare earth element and depletion of niobium, tantalum and titanium relative to the other incompatible element. So, why this depletion or enrichment is going on we will talk in the next to next class. So, the enrichment in this LILEs is due to this metasomatism of variably depleted mantle wedge, variably depleted mantle wedge why because you see the mantle wedge which is here it is like this. Here its thickness is different, here its thickness is different, here its thickness is different. So, that means once the subducting slab is going down it is releasing its water.

So, here you see this water it is interacting around here this volume of this mantle is very small. Here this water it is interacting with here the volume of mantle is removed that is why it is variably depleted mantle system has been noticed. And the depletion of

niobium, tantalum and titanium it is due to sequestration into rutile. So, this mineral it is particularly found here and due to this presence of rutile. So, whatever this mineral which is depleted now that is intruded into this mineral to form it.

So, that is why a particular minerals also they are also very peculiar to a particular type of geological environment and particularly the particular geochemistry of this mantle system or this magmatic system which is derived or from which it is derived. So, other rocks in the subduction zone that includes tholeiite which is this arc signature there are largely confined to this island arc setting. Then it is shoshonite that is alkaline rock which is often located further behind the arc and the late history of the arc formation. Then boninite it is derived from this metasomatized highly depleted mantle and thought to be largely generated to supra-subduction zone settings. So, that means, here some of these minerals or some of the rocks they are very peculiar to certain settings and somewhere not.

So, back arc regions can be dominated by tholeiitic magmas without an arc signature. However, even this often have hybrid signature that is between mid-oceanic system and arc basalts. So, that depends upon the degree of extension here. So, if the degree of extension is less or it is more so, either it will be in the mid-oceanic system purely or it the arc system or in between hybrid. So, rocks derived by arc setting are often more strongly oxidized than the other mantle as a feature which is bearing on this mineralization.

Because in reduced condition we have different type of mineralization, in oxidized condition we have different type of mineralization. So, if it is a oxidized environment then the different minerals are expected. So, that means, in a particular tectonic setting not only the magma composition it is important, not only the degree of partial melting it is important, it is also important whether it is in mineral it is emplaced in a oxidized zone or a reduced zone. The Calc-alkaline signature is not however unique because in Calc-alkaline it is emplaced in different geological environment. Here the majority of the continental crust it is carried and it involvement of such crustal material will impart this signature to certain degree.

So, this is a problem in general with the mantle derived magmatism that is identify compositional effects due to crustal contamination versus that may be of primary. So, what extent of crustal contamination is there though that is a problem but due to this isotopic signature we can now detect that whether this is purely of mantle origin or it is degree of contamination is there, what is the degree of contamination and that contamination how it is changed the magmatic composition that can be derived. Felsic

magmatism is more ambiguous than mantle derived magmatism and very few generalizations can be made about this association of geodynamic environment. And felsic magma it is compositions are largely non-unique. So, that is why this felsic magmatism it may occur in different tectonic environment.

So, taking a felsic magma and predicting a tectonic environment it may be somehow errorless. And this mostly reflect the strong primary control of the continental crust as over the geochemistry of this generated melt. So, this continental crust influence is very well pronounced in deriving the felsic magma. The geochemistry of this magma largely mirrors the type of and nature of this source rock that is crustal rock with which it is interacting which can be mixed and therefore, not unique to a geodynamic environment.

So, that is why we have already discussed. With regard to felsic magmatism the associated mantle derived rock are often more diagnostic of geodynamic and tectonic environment and may help to distinguish for example, felsic rocks are generated in an arc to those in the extensional back-arc both settings which are important for specific mineral system. So, irrespective of this tectonic setting irrespective about the felsic magma that means origin of the felsic magma, but the main theme here is the mineral system. So, that is both cases it is containing minerals. So, mineralization is very much important.

So, that is why irrespective tectonic setting it contains minerals. In some regards even the general igneous association can be of informative. How? The bimodal association with the tholeiitic rocks there are suggestive of extension and rifting A linear belt of Calc-Alkaline rock of mafic to intermediate felsic composition are more indicative of arc setting. To certain extent the magmatic composition that can give information about the tectonic setting on which they are derived. Volume wise the tectonic environment dominate that is mafic or felsic magma generation. One is the mid-oceanic ridge high volume rock is generated high volume mineral is or the high volume magma is generated.

Then the subduction setting including the back-arc zone another high volume magma is generated. Then the intraplate environment where large igneous province form large igneous province that is very important. So, more volume of magma then more mineral we are expecting. So, different tectonic settings they are responsible for mineralization, but if you compare these three only the later two are likely to be preserved in the rock record. Because mid-oceanic ridge whatever this rocks are formed again due to subduction it is going to this mantle again.

So, it is recycling system. However, if there is any ophiolite sequence that may be useful for mineral extraction. Otherwise these two that the subduction setting and the intraplate setting this mineral can be extracted to full extent or to certain extent. However, this mid-oceanic ridge whatever this minerals are formed they are going down to this mantle again due to subduction. That is why the later two one this later two that is the subduction setting and intraplate setting that preserve the minerals in the rock record. So, thank you very much we will meet in the next class.