Plate Tectonics

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Lecture - 41
Plate Tectonics and Mineralisation at Convergent Margins-V

Okay Friends, good morning and welcome to this class of plate tectonics. So, if you remember our last class, we were talking about the plate tectonics and mineralization in special reference to divergent plate margin. And in the divergent plate margin setting, we discussed many types of mineralization including the uranium mineralization, then volcanogenic massive sulphide deposit and many others. So, today we are going to discuss about this mineralization which is related to a convergent margin. Because if you remember in earlier class, we were talking about that the plate tectonics in every tectonic setting, we have minerals and not only the tectonic setting, there are intra plate volcanism also. So, in the intra plate setting also we are getting mineralization.

So, that means, today our discussion will be mainly confined to mineralization at the convergent plate margin. And before talking about the convergent margin, we should know how this convergent margins started, when this proto-convergence started, proto-subduction started. And if you remember our earlier class, when we were talking about this origin of earth and the plate system, the lithospheric system, this convection system, the convergence-divergent system. So, this archean and proterozoic, they are playing the major roles.

And through geological time, when the earth was evolved from this archean to Proterozoic and it was initial time it was the hadean when this magma ocean was there. So, there is a change or a drastic shift in this temperature and pressure regime. And through this change of pressure temperature regime, there was changes in the lithospheric thickness, there are changes in the mantle convection, there are changes in the mantle composition. As a result, this mineralization through geological time that has changed. Some of these minerals which are very sensitive to this particular temperature and pressure and not found in the lower temperature and pressure, they are not also found at present day and they are only present at this archean time or the hadean time.

So that means, due to shifting of this evolutionary process, the mantle composition, the temperature pressure that changed and which had great impact on the mineralization process. So, what exactly is happening at the convergent plate margin and how it is related to mineralization, lets discuss. So, this convergent margins may witness convergence between these two plates and a result of convergence there is thickening of the overriding plate. And we know when there is a convergence, there will be partial melting of this subducting slab and this magmatic arc is generated and due to generation of this magmatic arc, the overriding plate it is thickened due to this magma emplacement, due to development of volcanoes or rather a series of volcanoes that is called the arc system. And addition to that, there will be local extension to back arc basin.

So, whenever there is convergence, if you remember our earlier class when we were talking about this back arc basin development, this is an extensional tectonic regime. However, this region it is a compressional tectonic regime. So, two tectonic regimes they are placed side by side and addition to that there will be orogenesis, we know this orogenesis means the mountain building activities when there is volcanic arc or there will be proto-continent which are amalgam with this main continental system that is called orogenesis so it is a part of the convergent system and the orogenesis is nothing due to this accretion of arcs, and this oceanic plateau, the seamounts, the microcontinents and other exotic terrains or it may change by this change in the vector dip of subduction. So, once this convergence system is defined by this element, addition to that there are two other element if this vector of dip of the subduction is changing. So, there may be transpression and transtension regime which is oblique motion which is representing the oblique motion of this plate.

If you remember this transpression and transtension we have discussed in the transform plate margin. So, here if the convergence is not head on there will be somehow angle that means, in the oblique to each other. So, there will be this transpression and transtension regime that is occurring. So, that means, I want to say all these regimes whichever we have discussed in this slide. So, all these regimes are associated with mineralization and all these are associated with the convergence system.

So, the evolution of the convergence margins is divided into three stages. What are the three stages? The first stage it is the subduction and the subduction is accompanied by the formation of the volcanic arcs. So, when this volcanic arc is forming that means, we are thickening the crust. So, that is why this crustal thickening. Then second phase it is the back-arc basin development and thinning.

So, thickening and thinning they are occurring side by side. So, whenever there is a thinning that means, there is a depressurization, when there is thickening there is a pressurization increase in pressure. So, that means, two pressure regimes they are placed side by side. Second thing that whenever there is a magmatic system that means, we have high temperature regime here and this means high-temperature regime and relatively low-temperature regime high pressure and low pressure. So, these two tectonic environments they are placed side by side as a result this magmatic characteristics that changes.

So, once the magmatic characteristics is changing the mineralization also changing. So, in the intermediate stage the overriding plate goes fully into contraction. So, why contraction? This contraction is maybe due to the change of angle of subduction. We know once this shallow angle of subduction so that means, there is a chance that this trace can directly be transferred from this under-thrusted plate to overriding plate. So, that is why due to this contraction so that means, fresh transfer and either change in this geometry of the subduction or the accretion of the exotic blocks so that may occur.

And at the final stage where is the post subduction extension this is accompanied by the post orogenic collapse. Why this post-orogenic collapse? Because to compensate the gravitational stability and reinitiation of subduction delamination of the under-thrusted material. We know when there is change in phase to eclogite phases from granulite to eclogite phases. So, this eclogite phases they are heavy in terms of specific gravity. So, that part of this lithospheric material or the crustal material that is sinking down so that is called delamination.

So, once there is delamination that means, we are depressurizing. So, that means, directly we are disturbing the temperature and pressure regime of the system. So, that means, starting from the initial phase through intermediate stage to final stage we are disturbing the temperature and pressure regime. We are changing the composition of the lithospheric system, we are changing the partial melting or the degree of partial melting at different depth. As a result we are generating magmas for different depth and their emplacement at the surface.

And as the magma is of different composition it is coming from different depth that means, they have the tendency to hold different types of minerals. So, those minerals and those magmatic system they are valuable for us for the mineralization purpose. So, now the question arises how these processes the initial process or the intermediate or the final process or during this convergence how they are related to mineral deposits. So, lets discuss how they are related. Different convergence stages they produce a large range of ore deposit type.

What are these large range? First is the porphyry copper, molybdenum and gold related to thermal as well as skarn deposits. So, epithermal and skarn deposits so, that is the porphyry copper, molybdenum and gold deposit. So, here we have the convergence system and we have a magmatic arc mostly we have this porphyry copper veins here. So, this is the region where the porphyry copper, molybdenum and gold deposit is associated. Then we have orogenic gold deposit.

Orogenic gold deposit if you remember earlier classes when we were talking about this accretional system this volcanic arcs or the island arc they are accreted with the main continental system or this proto continent which is accreted with the main continental system. This is the orogenesis the mountain collisional system this two continental plate they are colliding. So, this orogenic system that is responsible for orogenic gold deposit. Then there is Mississippi valley type deposit. Then there is granite-related tin-tungsten and molybdenum deposit.

So, all this tin, tungsten, molybdenum, copper deposit there arise here. Then possibly the iron ore oxide, copper and gold deposit IOCG type deposit. So, that means, starting from this accretional regime to far into this continental lithosphere this area in the convergent system they are mineralized. Additionally, ancient VMS deposits appear to be restricted to the convergent margins as the subduction and seafloor oxidation appears to remove deposits formed along the mid-oceanic ridge system. So, that means, here whenever the mid-oceanic ridge system was there if you remember in the divergent margin classes we have discussed about the mineralization particular the volcanic hosted massive sulphide deposit.

So, once it is formed here so, it must be blanketed by sediment. It must be in a reduced condition because it is volcanic massive sulphide deposit. However there are certain geological environment where it is totally oxidized. So, once it is oxidized that means, this whatever the deposit whatever the mineral that was formed that will be vanished that will be depleted or it will be removed. So, that means, that is why this convergent margins addition to these mineral deposits they are also responsible for preservation of this Volcanic hosted massive sulphide deposit at certain cases.

So, some types of deposits that to be associated with specific stages. So, we have three stages that is the initial stage, the intermediate stage and this final stage and some of the stage we can very specific with that. That means, with change of this specific temperature, pressure regime that means, specific position with respect to the subduction system they will not appear. So, that is why they are very specific to different stages of this convergent tectono/thermal metallogenic systems that is for example, this orogenic gold deposit and Mississippi valley type deposits that are associated with orogenesis. So, they will not in the convergent system they will be in the orogenic system or this orogenesis during orogenesis they form.

And other span of this other types of deposit they span through the system that means, starting from this initial stage to the final stage starting from this trench system to this inside this continent all these other deposits they may range. However, the specific deposits like this Mississippi valley type deposit and this orogenic gold deposit they are very restricted that is to orogenesis not beyond that. So, for example, porphyry copper, gold and molybdenum and related deposits are mostly associated with subduction and with alkaline magmatism during the post-subduction extension. And the convergent tectono-metallogenic system evolved in less than 50 million years and that means, it is says that this mineralization it is a very rapid process. Though this convergent system or this orogenic system that spans millions of years or billions of years, but mineralization within that, that is very restricted time duration that is around 50 million years all these systems that happens.

And in some cases the existing geochronology may be too coarse to resolve stages, particularly the older systems or this older deposits because these older deposits they are very deformed, highly contaminated. So, due to this high degree of deformation and it is undergone many phases of metamorphism that is thermal events. So, deriving a particular age it is difficult because the whatever the age we are deriving some error is there, but our duration it says 50 million years. So, to for a higher that means, older system getting a age may be 50 million years or 10 million years will be the error. So, that means, more older the deposit getting the exact time of this mineralization it is quite difficult tasks, but younger deposits they are relatively precisely dated and that is why based on that we could interpret that though this convergent system or this orogenic system that spans of millions to billions of years, but the mineralization is only restricted within a duration of about 50 million years.

So, how the secular variation of convergence that is implication to mineral system. We know there is a evolution of this earth lithosphere starting from the hadean to present day and present day also it is going on gradually the thickness of this crust is increasing, the thickness of this mantle that is decreasing. So, that is this type of secular variation that means, variation gradual variation with time. So, in the convergence and implication to mineral system is also tremendous. So, both tectonic processes and the underlying geodynamics drivers has changed through earth because if you remember our earlier class when we were talking about this earth's formation, we are talking about this convection current.

The convection current which is just at the mantle that was very rapid during this archean time and gradually its speed decreases. So, that means, similar the mantle thickness it is decreasing with time, the crustal thickness it is increasing with time. So, this is the secular variation that means, a gradual variation through time and these gradual variation of the time that also putting some effect in our mineralization system.

Because some of these minerals as we have discussed they are very specific to a particular temperature, pressure, composition and time. So, that those shifting of this composition, shifting of this temperature regime, shifting of that pressure regime that also affect the mineralization.

So, that is why some of the minerals which are some of the rocks particularly which are very specific to archean nowadays though the same tectonic environment is prevailing, but the rocks we are not getting it because they are very specific to that temperature, pressure, composition and thickness regime. So, this archean period it was a period of fundamental change in this geodynamic process on this earth that is the transition. So, how this river transition? In the Hadean time there was magma ocean and the magma ocean during Hadean it is converted to a planet with some features of modern style of plate tectonics that is the archean. So, the archean it is a transition from this single lead type that is this you can say that is the thermal lead which we will discuss in the later time it is a single lead type of system to a plate tectonic system. So, that means, this archean it witnessed the drastic change of this earth's nature, the lithospheric nature, the mantle nature, the tectonic nature, the geodynamics nature and that is with a shift from the Hadean that is the magma ocean to this modern day of plate tectonic system.

So, this modern time of plate tectonic system just started from this archean and it is due to this thermal evolution. So, thermal evolution is the key that shifted from this Hadean to archean as a result the modern day plate tectonics started forming or circulation of this plates that real development of the plate the rigid plate was developed from the archean time. Of this the mantle that was temperature that time was 150 to 250 hotter than the mid to late archean and it is cooled to form the late archean early proterozoic onward. So, this late archean to early proterozoic due to this cooling it is formed the real crust which is of brittle nature which could sustain the pressure and temperature for behaving as a lithospheric plate for plate tectonics. And the secular changes in the global geodynamics can be directly or indirectly linked to this cooling process and changes to this manner in how heat is lost through time.

So, this heat loss through time, so there are many reasons how this heat loss through time it was there and what was the different reason for heat generation was also there. So, that has already been discussed. So, that is why due to this heat loss due to this thermal shift this Hadean to Archean, so we could able to nowadays study the modern day plate tectonics. So, this tectonics transition from an unstable stagnant lead tectonic regime with intense mantle plume activities and the mantle overturn event to a plate tectonics regime it was occurred in this Archean time. So, this Archean is characterized by a drastic shift of this tectonic regime of this mantle temperature pressure regime, the characteristics regime, the evolution regime.

For example, if you see here this is well explained through this series of diagrams this is the magma ocean that is the initial condition for most of the silicate bodies then there as heat pipes you see number of volcanoes or weak lithosphere. So, number of volcanoes are here and there. So, with time this gradually thickens the system thickness is increasing. So, number of volcano reduced only specific type volcanoes are there for specific type that means specific number of volcanoes are there and is this crust gradually thickened. So, that means it started behaving as a insulator.

So, that means as the it is was behaving as a insulator it was trapped the heat. So, due to trapping of the heat this partial melting this took place and finally, this that is this material which is going down that is called delamination system. And further the thickness further increased and you see the delamination gradually become less prominent as compared to this. And finally, we are here at this stage we have a thick mature crust and this is the mantle and this is core. So, this is a gradual shift from this hadean time to Archean time.

And here also we have this plate tectonic system which is modern day plate tectonics one slab is going down and it is recycling and again it is coming up. But if you see this stagnant-lid convection system that means we have a just we have a blanket or insulating blanket or somehow it is radiating heat and this heat radiation is due to this conduction only. And this mantle material which is convecting inside and there are just few volcanoes are there through which magma was erupting and this is called the stagnant-lid convection. And here this is the modern day plate tectonics that plates are subducting and there will be divergent there will be convergent system. So, this shift from the stagnant-lid to a full-fledged tectonic regime at the modern-day tectonic regime that was the Archean was responsible.

For in that time there is a shift from this tectonic regime and which was very important for this modern day tectonics as well as for mineralization. So, this rapid continental crustal growth with over 60 percent of the continental crust formed at the end of archean. Then most of this subcontinental lithospheric mantle that is the subcontinental lithospheric mantle that is 70 percent that is formed between this time 3.

3 to 2.7 million years. So, this compared to this later formed SCLM that is archean SCLM is highly depleted and thus buoyant and rigid which preservation through time and play key role in the plate tectonics because number of time it was recycling as more recycling was occurring. So, more depletion was there. So, as more depleted so, whatever the crust which was formed there it was more felsic nature. So, if you see this continental crust nowadays most of the continental crust there of Archean origin, Archean time. So, that time that was formed and become the part of this continental system as a result this amalgamation of different continental crust they grew together and formed the continental crust nowadays which you are seeing.

So, that means, this was a very prominent process which was responsible for this modern tectonic system and there is a transition that transition is the Neo-proterozoic and Palaeo-proterozoic transition. So, Neo-proterozoic to Palaeozoic transition that witness significant change in geological record which includes the fast widespread occurrence of ophiolites and blueschist. So, we know this blueschist which is a high-pressure regime drop and this ophiolites mostly this formed at the divergent system and it is abducted at the convergent system. Now how this happened, how the blue cyst can occur because we need a high tremendous pressure and how this pressure if there is no rigid system we cannot create this pressure which is responsible or which is required to form blueschist. So, that means, this Neo- proterozoic and Palaeozoic the crust or the lithosphere was so thick that during this convergence it was able to produce the required amount of pressure which is responsible for the development of the blueschists species of rocks.

So, this ultra high pressure terrains that was developed during the Neo- proterozoic to Palaeozoic transition and this cold apparent geothermal gradient in the subduction zone settings. So, we know when we are talking about this convergent system it is this convergent margin it is responsible for low geothermal gradient because this subducting slab it retains its rigidity and its temperature regime to larger depth. So, that is why it will only possible if we have a thick crust and we have an evolved crust or evolved lithosphere. So, that means, this Neo-proterozoic to Paleozoic transition that was responsible for this development of this blueschist group of rock and this ophiolite groups of rock. And these transition in geodynamics drivers can be related to changes in the characteristics of mineral system for example, that is the volcanic-hosted massive sulphide deposits.

So, that means, these changes which we have so far discussed the temperature regime change, the pressure regime change, the magmatism, this subduction all those things which are responsible for the shifting of this tectonic regime and that is the volcanic-hosted massive sulphide deposit was formed. So, the first major peak of volcanogenic massive sulphide deposit that was evidenced in 2.75 to 2.65 Ga and it corresponds to the time of proto subduction. So, this proto subduction that is the first subduction that the earth is witnessed and it was responsible for this volcanic-hosted massive sulphide deposit and this time was that is 2. 75 to 2.65 Ga.

And later on different other phases also that was recorded. So, the second phase or second major peak of the VHMS that is about 1.9 to 1.7 Ga and they are hosted by volcanic succession with higher abundance of mafic volcanic rocks and the third peak of the VHMS it was around 0. 75 Ga.

But the first and second peaks are the most closely associated with volcanic succession with the tholeiitic affinities where is the third peak associated with calc-alkaline volcanic succession. So that means, it says with passage of time from 2.75 Ga to 0.75 Ga the magmatism also changed, the magmatic characters change which indicates the compositional change in the mantle system which indicates the compositional change of this plate that means, the composition of the plate also changed. So, that is why there is a shift of magmatism or the magmatic characteristics that is from 2. 75 Ga to 0.75 Ga through which the volcanic hosted massive sulphide deposit it was there.

So, volcanic hosted massive sulphide deposit that means, we need a room by volcanic rock and here the first two that is mostly it is the tholeiitic system mafic system, but the third one that is the calc-alkaline system that means, the magmatic characteristic change with time. The volcanic characteristics which is hosting this volcanogenic massive sulphide deposit they change with time. Tholeiitic volcanic rocks associate with Paleoproterozoic to Archean system may indicate a greater geographic spread between the back arc basin which host the deposit and associated arcs. And the neo-proterozoic and this Phanerozoic VHMS deposits are affiliated with Calc-Alkaline rocks which indicate proximate to subduction setting.

So, that means, with time the magmatic composition is changing from the tholeiitic volcanic rocks to Calc-Alkaline volcanic rocks and their position also one is proximate to the subduction setting. So, this continuation of the subduction slabs at a depth of two significant consequences. What is this consequences? First is the presence of coherent, deep and cold slab would favor slab pull and rollback. We know when we are going down or this plate is going down that means, there is a phase change. So, this phase change that means, when we are reaching at the eclogite phases.

So, the eclogite being heavy so, it is pulling the slab down. And second consequence is that subduction of crust encouraged fertilization of this mantle wedge enhancing the production of calc-alkaline magma. So, here the system is going down and this is the mantle wedge which is there. So, the material which is dehydrating from here and due to dehydration it is partial melting is taking place here. So, that means, this mantle wedge which is restricted between the overriding and it is under thrusting plate it is enriched and this enrichment is due to this sequence or this material which is released from the subducting slab.

So, it is gradually fertilized it becomes enriched. So, two broad type of convergent margin that is known so far one is called the east Pacific type margin and the west Pacific type margin. We have already discussed the east Pacific type margin which is this one that is shallow dipping subduction zone and due to the shallow dipping subduction zone the interaction between the overriding and the order thrusting plate is high. So, that there is direct stress transfer from this under thrusting plate to the overriding plate as a result we are getting this thrust sheets. So, this is called the compressional back arc basin is forming. And addition to that this plate which is the subduction angle is high that is the western side of the Pacific.

So, like this Mariana trench here this interaction between the over thrusted and this or the overriding plate and this under thrusted plate is very less and that is why we are getting a deep trench here. And due to this extension or the crustal extension backside of this arc we are getting the back arc basin which is of extensional regime. So, these two types of convergent margins has been recorded so far. Although both of these convergence margins they contain magmatic arcs and associated fore arc basin, but the western Pacific type which one is the high angle of subduction that is extensive back arc basins has developed. So, this extensive back arc basin that we have discussed so far and another side we have this compressional back arc basins.

So, the eastern Pacific which is called compressional back arc basin, the western Pacific which is the extensional back arc basins. If the rate of advance is greater than the rate of retreat, the overriding plate is entirely in contraction and the back arc basin do not form. And this style of convergence is termed advancing accretionary orogenesis. So, advancing accretionary orogenesis occurs if the rate of advancing of this plate is greater than the rate of retreat. So, once it is advancing at a greater rate so that means, there will be accretionary system and that is called the advancing accretionary orogenesis.

And the result is the eastern type eastern margin of the Pacific or the east Pacific type. And if the rate of advance is less than the rate of slab retreat or slab sinking. So, the overriding plate is partly or wholly it is get extended and finally, the back arc basin is the west Pacific type or the extensional back arc basin is there. So, the subducting system can switch rapidly it is also very interesting. So, whatever we say that this shallow dipping subduction zone or it is a high dipping subduction zone, but this system is not permanent.

A shallow dipping subduction zone may with time convert to a steep angle subduction zone or vice-versa. So, along this subduction zone also there are different segments of this plate they are also subducting at different angles. So, that means, the subducting system it switch rapidly from one style to another style and that style change that means, it is changing the temperature pressure regime. It is changing the composition of this mantle wedge which is enclosed in between. So, this suggesting that the mineral system can evolve in a complex manner in space and time along with the individual convergent margins.

So, here if you see one side is twisting down another is just going subduction another is resisting to subduct. Similarly along this subduction zone that this scenario is here. Similarly across the subduction zone, so, here it may be high dipping it may be less dip, but reverse may be true at time. So, as a result it is affecting the mineral formation system. Then another type of mineralization at this convergent margin which is the Calc-alkaline porphyry copper gold and molybdenum deposit which is related to epithermal deposits and associated with calc-alkaline magmatism in the magmatic arcs that develop over most thickened part of the overriding plate.

So, here if you see this is the most thickened part of this overriding plate and we have calc-alkaline magmatism and that calc-alkaline magmatism is responsible for this porphyry copper gold and molybdenum deposit. And they appear to have formed overall contractional setting. If we have a overall contractional setting, so that means, that is typical to that that is the porphyry copper gold and molybdenum deposit. And these deposits form in both advancing or retreating accretionary continental margin.

What is advancing and retreating continental margin? We have discussed earlier. So, anyway so, these deposits form both in their contractional setting as well as the extensional setting, but here it is typical to that contractional setting only. So, this magmas responsible for subduction related porphyry thermal mineral system were derived from this melting of the subduction enriched that is mantle wedge with the ascent into the upper crust driven by buoyancy. And the overall contractional setting of this environment promotes the formation of porphyry copper gold and molybdenum deposit because first is the contraction implements magma ascent through the upper crust and thus impedes volcanism. Second thing that the resultant magma chamber in these settings are larger. So, these are the two conditions or the in house condition which is happening below which is responsible for this porphyry copper gold and molybdenum deposits.

And the third is the eruption is impeded, fractionation in these magma chamber is promoted resulting in the generation of large volume of magmatic hydrothermal fluid. Because we know this porphyry copper deposit or porphyry deposits they are larger in volume. Though their tonnage is less, their enrichment by mineral is less, but due to larger volume they are economical. And this contraction restricts the number of apophyses that form in this magma chamber providing the potential for this efficient fluid focusing. Then rapid uplift and erosion promote efficient extraction and transportation of this magmatic hydrothermal fluid due to abrupt decompression.

So, this decompression is due to erosion that means removal of the overburden due to erosion. So, that is why abrupt decompression is there. So, formation of porphyry copper gold and molybdenum deposits seems to be triggered by perturbation in the overall contractional stress field that reflect changes in the geometry of this convergent system.

So, that is overall about this porphyry copper deposits. So, thank you very much. We will meet in the next class.