Plate Tectonics

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Lecture - 42
Plate Tectonics and Mineralisation at Convergent Margins-VI

Ok friends, welcome to this plate tectonic class. And, we are discussing the Mineralization at Convergent Plate Margin. In the last class, we were discussing about this mineralization at the convergent plate margin. And, in special reference to the porphyry copper gold molybdenum deposit at the convergent margin. And, we found that though it is found at the extensional as well as contractional subduction system, but this contractional subduction system is more preferred for this type of a deposit. And, continuing this discussion further, today we are going to discuss about a special type of mineralization system and these are the volcanic hosted massive sulphide deposits and Algoma-type banded iron formation.

So, this volcanic hosted massive sulphide deposit if you remember our divergent system So in that class we had also discussed and that is why in that case if you remember we were talking that some specific mineralization that is very specific to a particular tectonic regime. And, many of this mineralization, they can occur in a variable tectonic regime. So, out of that this VHMS deposit is one which can occur at the divergent plate margin setting as well as at the convergent plate margin setting. And addition to that we have algoma type banded iron formation which is different from this lake superior type iron ore formation and this is very characteristic to convergent plate margin setting.

So, let us talk about this volcanic hosted massive sulphide deposit in the convergent setting and how it is different from these characteristics by the divergent setting. So, the volcanic hosted massive sulphide deposits they are some of the most widespread deposits on the Earth and most of these metals are being extracted from that. Similarly, the lake superior type deposit that is leading in the iron ore formation and this algoma type also the second most that you can say second to this lake superior type that is also giving much of this iron ore to this society. So, this volcanic hosted massive sulphide deposit it is the most widespread on the earth and they were formed through this Earth history and known to exist that is all over this continent except Antarctica. Now, the question arises why it is except Antarctica? So, there are two possible solution for that.

One is exactly it is not occurring at this Antarctic continent. So, that means, we have to think about this temperature-pressure or this tectonic regime where this volcanic hosted massive sulphide deposits they are occurring at the convergent system. And other thing is that, that this Antarctic as it is covered with ice sheet So, very little exploration work has been carried out wherever there is exposure. Otherwise probability is there and so far it is not reported due to its blanketed effect by the ice sheet. So, this modern VHMS deposit, they are seem to be restricted to the retreating accretionary system.

So, in the last class we were talking about what is advanced accretionary system, what is retreating accretionary system. So, the advanced accretionary system that means, the overriding plate it is going to this under thrusting plate and they are amalgamated together that is advanced accretionary system. And the retreating that means, it is going back. So, that means, the retreating accretionary system as an extension of the overriding plate. So, the extension of overriding plate that means, we are creating a back arc basin.

So, the back arc basin is there and in this back arc basin that is very suitable for the generation of this VHMS deposit and that is rifted arcs that is essential to form this submarine system. So, this back arc basin which is an extensional basin particularly, which is responsible for this or it is suitable for this VHMS deposit. And the VHMS deposit that form both as exhalative bodies, exhalative body means that is formed with fluids. This minerals which are formed from fluids that is called exhalite. So, that is exhalative bodies or it may be replacement bodies which is replaced by or replaced to something else and it is occurring just below the seafloor and they may be associated with felsic volcanic rocks, or it may be associated with mafic volcanic rock succession.

And it may be associated with change in volcanic facies that means, from mafic to felsic or felsic to mafic. So, irrespective of that, that means, in a transitional type so, that may be, that means, VHMS may be occurring at the change in the volcanic facies of rock. And addition to that with the syndepositional extensional structures so that means, you see there is a wide range of tectonic environment and wide range of rock that is hosting or wide range of structure that are hosting the volcanogenic massive sulphide deposits. And these volcanogenic massive sulphide deposits they have changed its composition, the host rock and the change in composition of itself that means, mineralogy of this volcanogenic massive sulphide deposit they have been changed from archean to recent time or this archean to further younger rocks. So, how these changes has been recorded in these archean rocks and the younger rocks that been discussed here.

So, in the archean and, possibly the Paleoproterozoic terranes the VHMS deposits seem to be associated with juvenile and attenuated continental crust. Juvenile continental crust that you know in the archean time the tectonic was very severe. This continental crust or this lithosphere system it was moving very fast. So, due to this unstable juvenile continental crust, they are associated in the the archean time, which is indicated by this neodymium and lead isotope characteristics, but this relationship with this juvenile crustal system that is changed in the younger terranes. So, in the younger terrane it is associated with the stable continental crust.

So, these older VHMS deposits are strongly associated with high temperature that is A-type, felsic volcanic rock with the theoleiitic affinities and this relation again changed in the younger rocks that is suggesting the tectonic setting that hosts the VHMS deposits may have changed over time. Not only the tectonic setting changed the mineral composition, the mineral constituents or the mineralogy of the VHMS also changed from archean to modern or this younger VHMS deposits. For example, the geochemistry of this mineralogy is changed geochemistry of minerals is changed. So, the change in this geochemistry of VHMS associated with volcanic rock suggests that these changes with time could relate to general cooling of this upper mantle, then its longer stability of this arc system, the increasing importance of evolved continental crust as a substrate to the arc systems, and to an increasing importance of this peri-continental rifted arc and back arc environments as a preferential loci for the formation of the VHMS deposits. So, that means, it was started in the archean with a juvenile crust, but later it shifted to a stable crust because the stability increased.

So, this tectonic regime from juvenile system to stable continental system it has shifted and this mineralogy shifted which is indicated by the geochemistry of this VHMS deposits. So, not only the tectonic regime changed the mineralogy of this VHMS deposit if you compare this geochemistry of the VHMS of the archaean and this modern or in the younger stratigraphic regimes, you will find drastic change and that change is due to the change of the tectonic setting, the change of this pressure temperature regime, the change in the style of mineralization and this change of this composition of the host rock which is giving this host a room for its emplacement. Then addition to this there is a new type of VHMS has been deposited for the last or has been recorded for the last 2 decades. So, this is now becoming an attractive for exploration and how it is different from this other or the already existing one? So, these are nothing these the copper and gold rich deposits and it is associated with advance argillitic alteration assemblages that is high sulphidation deposits. So, high sulphidation, high sulphidation how it can happen? So, this high sulphidation that is copper, Au rich VHMS deposits may be a significant magmatic hydrothermal component.

So, we have a significant magmatic hydrothermal component that means, the hydrothermal fluid which is generated from this magma. So, the residual magma is generating the hydrothermal fluid and that is the source for this copper and gold deposit which is the new type of VMS has been reported so far. And these are thought to be a hybrid type between the porphyry emplacement that is the porphyry-epithermal deposit that form in the arcs and that is more typical to Zn-rich deposit or zinc rich deposit that form in the back arc. So, it is a transitional type from this arc to back arc in between this type of hybrid type of high sulphidation VHMS has been reported and now it is very attractive for the exploration. In many cases, this VHMS deposits they are associated with algoma type of BIF.

So, we know there are different types of BIF deposit and the most prominent one is the lake superior type deposit and second one is the algoma type deposit. So, this algoma type deposits they are small, very small pockets. So, here the algoma type deposit or near to the stratigraphic position which is related to mineralization. So, this algoma type deposit is associated with the VHMS deposit which is at shallower depth. So, in contrast to the lake superior type of BIF which form from passive margin the algoma type of deposits are much smaller and associated with the volcanic and this turbidite dominated successions, and are thought to be the product of exhalation related to volcanism, because if you remember few minutes back we were talking about this magmatic related hydrothermal fluid.

That means, magma derived hydrothermal fluid which is responsible for this VHMS deposit and that fluid also which is contributing for this algoma type of iron ore deposits. So, VHMS deposits developed predominantly during the Archean and Paleoproterozoic and algoma type BIF is also present some younger times. So, though in the younger times we are getting this algoma type of deposit. However the VHMS deposit of this kind that is Archean and Paleoproterozoic is restricted. Then another type of mineralization that is associated with the plate tectonics of convergent setting, that is called the orthomagmatic komatiite associated nickel copper and PGE deposit.

So, komatiite we know, this komatiite is very important in terms of, it is in an ultra mafic volcanic rock. So, ultra mafic volcanic rock, it is very difficult to get and all of this komatiite, that is archean product, archean greenstone belt. So, why in modern days we are not getting komatiite? Mostly it is the temperature and the composition of this crustal system responsible. Imagine at this archean time, when the crustal thickness was very small, the temperature was very high, the pressure was less, the overburden pressure was less because the crust was very thin. So, magma which was generating from the mantle it was coming to the surface.

So, that means the temperature at this depth or the mantle depth and at the emplacement depth there was very less loss of temperature because the distance which is to move is very less because the crustal thickness was very less. And second time that this through this crust, through which the magma was erupting less degree of contamination because it has to pass through less distance. So, less degree of crustal contamination was there and less heat loss was there from this emplacement from the magma that means origin from the magma at the emplacement period or the emplacement place. So, that means temperature was maintained and there is no contamination or relatively low contamination. However, at present day the Earth has changed its temperature, that means if you remember classes before we were talking about the crustal or this mantle temperature at that time it was 200 to 250 or more than this present day system.

So, that means the temperature was more and now the temperature is less and the crustal thickness become more. So, once a magma, is generating at this mantle level and once it is erupting, and it has to pass through this crustal system because for the volcanic rock it has to erupt on the surface. So, once it is coming to this much distance, so there is a chance that it will be contaminated by this interaction with the crustal system or this path through which it is passing through. So, that means the temperature is not maintained because from x temperature it was generated at higher depth and once it is reaching to the surface, this temperature loss is there heavy temperature loss is there because it has to pass through a large distance. Second thing that as it is passing through a large distance the chances of crustal contamination will be more.

So, that means a magma of composition x which is generated at the mantle and during eruption at the surface it will not remain at this composition x. So, it will be changed due to some contamination from the crust. So, that is why the komatiite magma which was typical to the archean it is not present at or not erupting not emplacing at the present day. So, due to this, this changes the crustal composition and crustal thickness change in the temperature so like that. So, anyway this komatiite magma and which is very specific if you see this field photograph of the komatiite, the lines which you are seeing this is showing, typically it is showing the spinifex texture and these are nothing, these lines are the olivines.

So, these olivine crystals, they are arranged in this broom type you can see here it is looking like a broom. So, this broom type arrangement of the olivine crystal it is typical to this komatiite magma and it is found in the archean greenstone belt. So, this magma which was generated during this archean time nowadays it is not there and those magma which contain the nickel copper platinum group of elements deposit at places. Though komatiite was there, but there are few specific reasons that reason or that specific reason a specific composition of this magma which was holding this nickel copper and PGE deposits. So, they are formed along this continental margin is the nickel copper PGE type associated komatiite volcanic and related shallow intrusive rocks.

So, it is associated with mafic-ultramafic greenstone sequences that are controlled by the interaction of the mantle plume with the thinned margin of the continental lithosphere. So, now you see the specific tectonic regime it was talking that it is the interaction of the mantle plume, mantle plume was coming up and it was a thinned margin of the continental lithosphere. So, even if the crust was thin that time, but within that thin crust, at the margin, it was again thin. So, that means, this magma was erupting with a very limited distance. So, the thinned continental margin lithosphere where this komatiite magma was emplaced and komatiites are found mostly in archean granite greenstone terranes, but nickel sulphide mineralization associated with these rock that as very restricted distribution.

Though komatiite was very widespread in the archean greenstone belt, however, when we talk about mineralization like nickel copper PGE deposit that was also very restricted environment. And more recently researchers suggested that that komatiite hosted nickel sulphide deposits are restricted to archean and Paleoproterozoic terranes, are associated with isotopically more evolved crust in contrast to the juvenile crust that is characterized by VMS type deposit. So, in this, few minutes back when we were talking about VMS type deposit, we were talking about this juvenile crust, unstable crust. However, the komatiites, they are associated with more evolved crust that is more rigid type of crust and that was thin crust at the continental margin. And this evolved lithospheric architecture played a key role over the Archean Eon to genesis of komatiite hosted nickel sulphide deposit.

So, those areas where evolved crust was there, the evolved lithosphere was there, those areas where the komatiite was emplaced that was responsible for the mineralization. And so far we have discussed number of mineralization systems and we are talking about this convergent system and very importantly we are talking about the initial stage of convergence. That means, we are putting a oceanic system into this continental system or we are under thrusting an oceanic system into the continental system with a different angle. Based on the angle we are deciding whether this will be convergence that will be an extensional back arc basin or in a compressional back arc basin. And we are deciding how much temperature, pressure? how thick the continental crust will be depending upon this magmatic eruption, we have different pressure and temperature.

So, that means, at the initial time of this convergence we were talking about the mineralization system and summarizing all this mineralization system with this convergent system which is of the initial stage. We can say the incipient stage of the convergent margin tectono-metallogenic system is typically ended by either accretion of an exotic block that is large or small or a shallowing of subduction which places the overriding plate into contraction. And mineralization, how it is given? One is the Calc-alkaline porphyry copper gold and molybdenum deposit. Then we have volcanic hosted massive sulphide deposit. Then we have algoma type banded iron formation.

Then orthomagmatic komatiite associated with nickel copper PGE deposit. So, these type of mineralization which are responsible or which are commonly available at the subduction zone at the incipient stage or the initial stage of subduction. So, we know there are three stages of subduction one is initial stage, then intermediate stage, then we have final stage. So, that means, at the initial stage now we are very rich in minerals. So, that means, as an exploration geologist you have to find out whether what type of minerals you are dealing with in the field or what you are getting in the field.

So, based on that you can say which type of subduction system was existing and whether it was evolved or it was stopped there that can be determined. Now, let us shift to further, that is to intermediate stage of orogenesis. So, that means, once we are reaching to the intermediate stage that means, we have consumed the oceanic lithosphere. Totally the oceanic lithosphere is consumed. Now, the continental of one side to continental plate of other side, they are interacting.

So, that means, we are at the orogenesis stage that means, mountain building stage. So, this is mountain building stage so, that means, a compositional change is there because here no more basaltic system/lithosphere is there. So, we have only this continental system and this continental system there. And here there is a compressional regime no question of extension because no basaltic lithosphere is here, no oceanic lithosphere is here. So, only the compressional system is existing.

So, within that compressional system we are increasing the temperature, we are increasing the pressure, we are also decreasing the pressure by delamination. So, with the change of this tectonic setting with the change of the pressure, temperature regime which changes the composition of this lithospheres, they are interacting with each other, which type of mineralization is going to occur let us discuss. So, this results in orogenesis and metamorphism and the development of three types of mineral deposits. What are those three types? One is orogenic gold deposit very much important it is very forerunner of this gold producing rocks.

Mostly derived from the orogenic gold. Then the orogenic base metal type of deposit, that is copper, gold, zinc, lead and silver deposit that is orogenic deposit. Then a Mississippi valley type deposit that is the foreland basin mineralization. So, that means, now see in the three cases we are just getting this compressional system, no extensional system is associated with it. So, let us first talk about this orogenic gold deposit how it is happening. The orogenic gold system typically form late in the evolution of this convergent margin during the main contractional orogenic stage and largely in the fore arc to back arc setting in an accretionary margin.

So, very important thing here to understand is that though it is in the orogenesis, but during the main contractional orogenic stage. So, here the main contraction is going on. Two continental lithospheres, they are colliding. So, during colliding so that means, once it is colliding that means, it is increasing its height.

So, this is the contraction stage. So, during this contraction stage the orogenic gold deposits we are getting and they are the result of stabilisation and cratonisation of this accretionary assembly. So, that means, we have different accretionary systems. So, due to accretion so they get stabilized. So, once they accreted and stabilized so pressure is very high that means, stress is very high. So, that is why it is there and it is preserved in most Archean to tertiary accretionary setting.

So, both the Archean accretionary system it is there and the tertiary accretionary system is there. So, that means, it does not think about its age, it is talking about the process, the accretionary process, the pressure build process, the contraction process irrespective of with age. So, that means, orogenic gold deposit, it is widespread from Archean to Tertiary and its main reason is the contraction, it is the orogenesis. And this excellent preservation is due to its depth because it is occurring at depth ranging from 3 to 15 kilometer. So, it is not near to the surface had it been near to the surface that means, weathering and erosion might have removed these things.

So, as it is occurring at great depth so it is preserved and these are formed due to the orogen wide release of fluids and magma from previously metasomatized subcontinental lithospheric mantle or fertile lower crust at the near surface environment. Whenever we are talking about the subduction system when it was existing so due to this release of material from here dehydration and something. So, this type of mantle which is this enclosed mantle lithosphere, mantle here that was enriched and now we are colliding this two plate and due to collision we are increasing the temperature, we are increasing the pressure. So, this materials are released and that material which are released, now they are intruding in terms of veins you can see here how these faults are there through the faults these veins are or this magmatic dikes are there through these dikes, this gold deposit is reported. So, these are the reasons how these orogenic gold deposits are occurring at the orogenic belts and this magma or fluid which is released in response to the thermal relaxation followed by accretionary suturing.

Then metamorphic dehydration reaction, then change in farfield stresses due to anomalous plate geometries and their interaction with the continental margin of the previously accreted terrains. So, these are the reasons, the magma and fluids are released. So, once the magma or fluid is released from here that is the accretionary margin is here or this, that means, enclosed lithospheric mantle is here. So, we are getting the gold mineralization in this. So, metasomatized subcontinental lithospheric mantle which can form during the earlier subduction stage is now also recognised as a potential source of gold.

So, that means, this metasomatism it was occurring here when this fluid was released from here and now this part it is very prominent for releasing gold due to increasing of stress. And the orogenic gold systems in most cases are spatially linked to large scale that means more than 100 kilometer length that is transcontinental deformation or transcrustal deformation So, that means, lengthwise and depthwise it is very high around 100 kilometer length will be there and transcrustal deformation that means, deformation from crustal and below that means, there is deformation that means, it is depth-wise, it is extending to a deeper level and lengthwise it is also extending around more than 100 kilometer because in tectonics, we are talking about this subduction system where high pressure temperature reside so that means, it is tectonically very widespread. So, the orogenic gold system may show metamorphic overprinting also. So, that is by the amphibolite facies during the subsequent orogenesis process.

So, the VMS deposit and the porphyry systems that were coeval with volcanism or plutonism during the initial stage of the arc and back arc basins may subsequently overprinted during synorogenic deformation. These distinct events show substantial age difference we have VMS deposit then we have gold deposit. So, both deposits they can be dated and you can say the VMS deposit was much older than this gold deposit, orogenic gold deposit because VHMS deposit that was formed at the initial stage, but this gold deposit during the orogenic stage. So, two distinct tectonic events, two distinct mineralization events they can be separated by dating process.

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