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

Week - 09
Lecture - 43
Plate Tectonics and Mineralisation at Convergent Margins-VII

Ok friends, welcome to this class of plate tectonics. And if you remember in the earlier class we were talking about this plate tectonics and mineralization and we emphasized on different tectonic settings, their mineralization and we are continuing at the convergent margins mineralization and in this class we were talking about this VMS Volcanic hosted Massive Sulfide deposit We were talking about this porphyry copper gold molybdenum deposit. And today we are going to discuss some other deposits related to the convergent setting and particularly at the middle stage of this convergence. Because if you remember we have classified this convergent system into three stages, the incipient stage or the initial stage, then we have the middle stage then we have end stage of the convergence. So, we are now at the middle stage of the convergence and the mineralization so far discussed that is on the middle stage only.

And in continuation to that today we are going to discuss about the orogenic base metal deposit. So, this name itself says it is orogenic deposit that means related to orogenesis continental-continental collision and that is the base metal deposit associated with the collisional system and this collisional system base metal deposited says it is syn-tectonic that means it is related to the tectonic system where the tectonic process is going on because we are at the middle stage. So, that's why the tectonic system is going on. Then it is remobilized , another terminology , it is remobilized.

Remobilized that means it was earlier deposited, earlier formed and due to this continent-continent collision, due to increase of temperature and pressure. So, this is redistributed, remobilized. So, that means for remobilization we have to keep this mineralization first due to certain reason and at this stage we have to remobilize it, redistribute it among these rock types and third thing is that it is structurally controlled structurally controlled because during this collision that means continent-continent collision we have different thrusts, we have different folds. So, long running thrust sheets are there very highly or tightly folded system are there.

So, that's why we have this mineralization mostly they are structurally controlled either within the fault planes there are joint that means bounded, there is fault bounded, there is fold axis or the hinge zone bounded like that. So, that's why these three terminology are very important in this stage one is syn-tectonic, another is remobilized system, third is the structurally controlled system. Now what is the product , which minerals are getting deposited here mostly it is dominated by copper gold mineralization. So, that means during this stage we are expecting most of the mineralization that are confined within the copper and gold. And the mineralization event may be due to metamorphism and local remobilization of the early VMHS.

So, that means if you remember our earlier class we were talking about volcanic hosted massive sulphide deposit. So, that means we have already this deposit it is present there and due to this orogenic collision, continental-continental collision orogenesis these VMS deposit that is remobilized and through these faults through these joints through these folds they are remobilizing and they are enclosed within this fault plane with that suitable structures within that orogenic zone. So, this is the early VMS mineralization which is remobilized and the formation of the orogenic base metal deposit which is called the cobar style of deposit. Then this mineralization that is orogenic base metal deposit it's also arranged in a particular fashion. So, that particular fashion that means it is concentric metal zoning is there.

So, like if you remember when we were talking about the metamorphism at this convergent system we are talking about this contact metamorphism when there is a contact that means it is an igneous body emplaced. So, around this igneous body there is metamorphic aureoles are developed. So, there is specific zones for specific minerals. Similarly this mineralization it also follow a particular zoning type. And in the zone at the central part is occupied by gold.

Then next if you are coming away from the center then it is occupied by copper and at the periphery it is Pb, Zn and Ag mineralization is there. So, central part is gold dominated then it is copper dominated then at the peripheral side we have lead zinc and silver mineralization is there. So, other type of mineralization associated in the middle stage is Mississippi valley type deposit. So, the Mississippi valley type itself says this Mississippi river is associated with it. So, this is a foreland system here is a schematic diagram here this Mississippi valley type deposits are named after the type area of the Mississippi valley in the central United States where many mines have extracted zinc and lead over past hundreds of years.

So, that means very old system and very huge mineralization is there. So, for the last hundreds of years these mines are working. So, that means it is huge mineralization. So, this Mississippi valley type deposit how it is distinguished. So, this is Pb and Zn deposit temporally associated with orogenesis and these deposits form when oxidized low temperature basinal brines are gravitationally or tectonically driven away from this orogenic front into the carbonate platform sequence.

Now you have to understand this total theory what exactly happening here. First is it is oxidized fluid. So, now how the oxidized fluid can occur near to the surface the oxygenated system. So, now, near to the surface when oxidized system fluid is there. So, how it will go inside because it will go through gravitational system.

So, due to this gravitational action this fluid is going down if you see here this is schematic diagram this fluid is going inside. Otherwise it is tectonically driven tectonically driven means it is an orogenic environment. So, it is total system is squeezed. Once the system is folded, faulted, thrusted and squeezed. So, whatever the fluids in the rock that will be wiped out it will be driven out.

So, now the question is where this fluid will go that will go into the carbonate platform sequence. Now, where this carbonate platform comes? So, if you remember our earlier classes when we were talking about this convergent system we have that forearc basins, we have trench slope basins and those basins are characterized by carbonate sedimentation. And those carbonate sedimentation once these basins are squeezed due to orogenesis. So, whatever the fluids are released either gravitational system or by tectonic system that fluid there now it is that means this carbonate rock that is hosting those fluids. So, that means those fluids when reacting with the carbonate rock sequence that give rise to mineral deposit that is called the MVT deposit or Mississippi valley type deposit.

Base metals are deposited when the fluids encounter a source of reduced sulphur. So, now this fluid which was squeezed out that has to react with the reduced sulphur with environment. So, now, reduced sulphur environment where we will get that is from carbonate. Now how from the carbonate we will get the reduced sulphur because we know the carbonate that are mostly organic rich or the convergent system we know due to this high temperature or temperature environment the coral reefs are there coral carbonate deposits are there. So, that means from that deposit we are getting the biogenic sulphur which is of organic origin from this carbonate deposit.

Addition to that that may be other process of fluid which is reduced sulphuric fluid that means fluid. So, these two fluids when they are mixing together they are giving rise to this deposit that is this Mississippi valley type deposit within this carbonate sequence. So, most Mississippi valley type deposits are geologically young. Why it is geologically young? And with most deposits of phanerozoic age. So, the reason may be that the older rock that means older than phanerozoic that rock has no potential to preserve this MVT type of deposit.

And another reason is that so, we need reduced sulphur we need vast carbonate deposit and this vast carbonate sequence they are only dominated in this phanerozoic sequence though in the protozoic and the archean we have the carbonate sequence, but their amount is less. So, once this carbonate sedimentation becomes prominent those type of mineral deposits that are found in nowadays or in the younger deposits. And the other explanation is that the older deposit having this MVT type of deposit had no potential to preserve it for geological future. So, either this phanerozoic rocks are more potential for preservation or due to the flourishing of the carbonate sedimentation in the phanerozoic this type of deposit becomes possible. So, this Mississippi valley type deposits are far field response of orogenesis which drives low temperature and H2S poor basinal fluids into platform succession.

Because this H2S poor basinal fluids were squeezed out from the system and they are reaching to this platform sequence which is H2S rich. So, once this H2S poor fluid is reacting with the H2S that means, source so that is giving rise the mineralization. Zinc and lead are then deposited with H2S either driven from a separate fluid that we have discussed maybe this H2S fluid it is that means, originated from a different source or it is from this biogenic reduction or the organic reduction system. So, now so far we have discussed about the middle stage of this orogenesis or the conversion system. Now, we are at the end stage or the final stage or it is called the post subduction extension.

What does it mean post subduction extension? We have orogenesis, we have subduction and during subduction or during orogenesis what is getting that this abducting plate due to this collisional system it becomes thick. And once it becomes thick its lower part it is reaching to high temperature and pressure zone and finally it is converting to eclogite system. And as the lower part or the root of this mountain system which is developed due to collisional system. Due to root of this mountain system once it is converted to eclogite facies of metamorphic rock. So, it becomes heavy and finally, it is detached from the root zone and that is called delamination.

Once the system is delaminated so that means, this asthenospheric magma or the asthenospheric mantle it is coming to the near to the surface or to the base of this crustal system. So, once the asthenospheric system it's moving up so, asthenospheric system it is a heat source. So, once it is moving up that means, the temperature at the base of this crust it is increasing. So, once there is crustal base it is feeling a high temperature that means, again this convection may start. There may be subsidence and there may be extension so, that is called the post subduction extension.

So, the convergent margin commonly go into extension following orogenesis and that is called the orogenic or the post collisional relaxation stage. And this relaxation stage is related to orogenic collapse and we have discussed so far what is orogenic collapse that once the asthenosphere is reaching here this becomes high temperature zone. So, due to high temperature zone again there will be it is swelling up then there will be normal faulting so, like that so, system is collapsing down and this crustal thickness again gradually decreases. So, due to that there are number of type number of types of mineralization that occur. So, those are this alkaline porphyry copper and gold deposit.

Then intrusion related this deposit of tungsten, tin, molybdenum and gold deposit. Then skarn zinc-lead and silver deposit. Then IOCG that is iron ore copper gold deposit. So, these are the different types of deposits that mostly we found at this orogenic collapse stage or it is called the post subduction extension stage. So, we will discuss one by one how this mineralization system is happening in this stage.

First is alkaline porphyry copper gold deposit. So, this porphyry copper gold deposit associated with intermediate alkaline volcanic rock are formed during post subduction extension. And this alkaline metals are thought to have produced by the remelting of this subduction modified mantle triggered by delamination of the mantle lithosphere. Now imagine we have a root zone, we have a collisional system and this root zone due to phase change to eclogite it is sinking down and that material which is sinking down it is going into the asthenosphere and due to the asthenosphere it is high temperature. so, this delaminated material it is again getting melt.

So, once it is melting so, this magma is rising up and those magma that is entering here and there due to this fractures because it is a collisional zone it is a fracture zone. So, number of fractures, number of folds , thrusts , joints they are there. So, that means, through this earlier defined this discontinuities this magma is intruding and giving rise to mineral deposit. So, asthenospheric upwelling and crustal extension occurs. These

post collisional deposits can overprint the earlier deposit that is calc-alkaline volcanic rocks that were formed during this arc growth.

So, that means, when there was arc growth we have this type of deposit earlier existing that is particularly the porphyry type of deposit, the volcanic hosted massive sulphide deposit earlier there. Now due to remelting of this delaminated crust so, again this magma is going up and finally, intruding here and there. So, finally, the earlier formed deposit and the newly formed deposit they are intermixing together and maybe the earlier forming deposit they will be remobilized due to increase of temperature due to this intrusion of this magma. Then intrusion related tungsten, tin, molybdenum and gold deposit. So, one of this central theories in this deposit it is like that this the intrusion related mineralization has been the recognition of this variation of the granite properties such as oxidation states.

So, different granite properties, different oxidation states of this granite of different generation they are intruded here. And as different generations of granites with different oxygen states they are cross-cutting each other intruding within each other. so, it is giving rise to mineral deposit. And how much mineral will be there, what should be this mineral properties that depends upon the degree of fractionation of this magma and their oxidation states and they are related to behavior of this ore metal within that. What should be the characteristics of the ore bearing metal that depends upon the degree of fractionation of those magma and the oxidation state of this magma.

So, whether they are compatible or incompatible and whether or not concentration of much mineral or such metals are the highest in this compositionally unevolved or compositionally evolved magma are decided by these parameters. What are those parameters? This parameter is the oxidation state and the degree of a fractionation. These two parameters that decide what should be this metal bearing fluids characteristics, whether the metal will precipitate or not, if precipitate how much it will be precipitate and the degree of fractionation and the oxidation state along with other factors such as sulphur, chlorine and volatile content of this magma are all or to be at least to some degree a function of this source components of this magma and so are all indirectly related to metallogenesis. Therefore, intrusion related deposits are may occur in a variety of tectonic environment that is largely characterized by extension. So, this intrusion related deposit like tungsten deposit, tin deposit, molybdenum and gold deposit though they are related to different type of environment that we have discussed in many classes, but this key point is there, they are characterized by extension deposit, rift deposit.

So, in earlier stage when we were talking about the rift related magmatism and metallogenesis that time also we have discussed this tungsten, tin, molybdenum and gold deposit and now also the same thing. So, what is the common these two is the extension. So, there also it was associated with the extension type plate tectonics and here it also associated with the extension type of tectonics but in contrast to the porphyry style of mineralization they are commonly not found within environments directly related to arcs. So, they are not related to arc system. So, arc will treat mostly the porphyry style of mineralization they are typically to arc.

However, this extension type mineralization that is intrusion related this type of deposit that are not related to arc, it is away from this arc system. So, regions of intrusion related deposit mineralization are separated spatially and temporally from the regions of porphyry style mineralization. So, that means, porphyry style of mineralization as we have discussed it is related to arc system. However, this intrusion related mineralization same mineralization, but intrusion related , it is away from this arc system. So, present day researchers have suggested that porphyry style mineralization was associated with the arc environment versus the back-arc or non-arc crustal environment for the intrusion related deposits or such type of a mineralization.

So, now you see the porphyry is totally different than the intrusion related this tin ,tungsten, molybdenum deposit is different. One is related to arc system another is related non-arc system one is that means, this is away from the arc system. So, with changing tectonic environment arcs associated with porphyry mineralization evolved into back arc or post collisional setting associated with the intrusion related tin tungsten deposit or mineralization. So, that means, you know the tectonic system we have decided we have discussed many times the tectonic system is evolving system. Nowadays which one is arc in geological feature may not be in the arc position.

Similarly in the past which was not in arc present it is in arc. So, though this tectonic system is changing so, the mineralization characteristics are changing one is over printing on another and depending upon these conditions that means which type of fractionation is there, which type of oxidation state is there which type of other minerals that means, other influencing factor like the sulphur chlorine and volatile content is there. So, they are deciding how much mineralization will be there and when this mineralization will occur. And the best indicator for regions with potential intrusion related tin tungsten mineralization are either the granite themselves or known mineralizations. So, where from this mineral will come? So, this did not granite intrusion that we are talking about the intrusion related mineralization.

So, the granite which is intruding itself having this minerals otherwise the granite which is intruding within the rock it is due to temperature high it is leaching the mineral system which is existing from this host rock and it is getting concentrated. So, for example, a region with potential for intrusion related gold mineralization may be recognized by the presence of tin mineralization. So, these are the path-finder elements. So, if tin is there then intrusion related gold will be there. So, these are the exploration strategy or exploration formula how will you go for targeting one type of mineral in a particular tectonic setting.

Then another type of mineralization associated with this last stage that is called IOCG iron ore or iron oxide copper gold deposit. This is very known deposit worldwide and in India it is very newly established by Dr. M. L. Dora from geological survey of India.

So, he has done tremendous work in this IOCG type of deposit in the central Indian province. So, these are diverse family which is characterized by copper with or without gold as the major economic mineral. Then hydrothermal epigenetic ore style and strong structural controls then abundant magnetite and/or hematite, then iron oxides with Fe/Ti ratio greater than those in the most igneous rocks and commonly associated with volcanic and/or intrusive rocks and their close relationship with the shear zones typical for type of mineralization. The fifth point it is very important for the Indian context so far discovered this IOCG type deposit they are associated with the shear zone or near to the shear zone and some of this field photograph and laboratory analytical photograph here if you see here this is iron ore breccia and this is the BSE image which showing gold is there and this is the EDS spectrum of gold and this is the trace element composition of magnetite that is Ti versus Ti and vanadium showing IOCG signature. So, these are the field signature and these are the laboratory signature which converge together to prove yes this type of mineralization that we are looking it is of IOCG type or not.

So, IOCG deposits they occur in the crustal setting with extensive and commonly pervasive alkali metasomatism. So, this metasomatism is very much important here. So, that means those deposits IOCG deposits they are occurring in this area where extensive alkali metasomatism is there and many are enriched in distinctive geochemically diverse suite of minor element including uranium, REE then some other elements listed here. So, these are the prerequisite for getting this IOCG type of deposit. So, although not closely related to igneous intrusions many IOCG deposit display a broad space time association with batholithic granitoids and IOCG deposit formed from this Archean and recently at the Mesozoic.

So, that means a range a long span of time these deposits are associated they are forming. So, some facts about the IOCG type of deposit. So, a source for an enormous resource of a polymetallic character that is copper, gold, iron, silver, uranium and rare earth element. Diverse in age that means starting from the archean to recent Mesozoics and this diverse tectonic setting. So, age is diachronous, tectonic setting is many diverse tectonic setting then diverse P-T condition, pressure, temperature condition also varies depending upon the tectonic setting and characteristics alteration is there then host rock package and mineralization style is also different.

And these deposits are characterized by dominant copper sulphides and gold with abundant magnetite or hematite occurring at the host rock. So, if you see this field photograph we have magnetites. So, this is the host rock and we are getting here copper and gold deposit within that. Mineralization and alteration halos of IOCG deposit may reach hundreds of meters width and many kilometers in the length. So, that means you see intense mineralization is there hundreds of meters of width and some kilometers wide.

So, that means you can expect the life of a mine if it is established. So, it will give rise it is in high amount of mineralization from this type of settings and these deposits can form at a shallow and moderate and you can say at the deeper level. So, that means depth wise also it can range from a shallow to intermediate to deeper level of deposit. So, that means if it is a very wide zone and very long ranging zone even the deep zone that means we have billions tons of material that can be expected. Then crustal domain boundary zones initiated during earlier orogenic events are believed to form part of this crustal scale magma and fluid pathways for this IOCG type of deposits.

That means it says when there are the earlier orogenic events there were weak zones there were feature zones there were shear zones there are joints that faults that means all these geological adverse features are preserved there and if there is intrusion so intrusion will find an easy way to pass through. So, this IOCG deposit type that will promote for that. And there is a growing consensus among the researchers that that IOCG deposits can be the product of mixing of two distinct fluids that is very important mixing of two distinct fluids. So, what are these two distinct fluid? One is an oxidized fluid. So, that means an oxidized fluid that is, if it is oxidized then it's source be near to the surface that means it is evolved meteoric or groundwater.

So, one fluid is going from top to bottom which is oxidized. Another is the deep sourced high temperature brines that is magmatic hydrothermal fluid that is reacted with the metamorphic rocks. So, that means another fluid is coming from the deep source either it

is magmatic fluid or it is metamorphic fluid and they are coming through this passage earlier that means preserved passage that is these faults these joints and they are coming. So, in some places that means at some depth this down going fluid and this upcoming fluids they are mixing together and due to their reactions they are giving rise this IOCG type of deposits. In many IOCG system there is also evidence of gas rich fluids during the formation that is CO2 bearing and the source of copper, gold, sulphur, chlorine, CO2 may be either coeval magmas or sedimentary and igneous rocks that were leached by this ore fluid as marked by the presence of sodium and calcium this regional alteration zone. So, these are the evidences how this IOCG system is forming how the mineralization is forming.

Uranium and REE were most likely leached from the granitoid or the felsic volcanic rocks. So, these two are not getting because due to leaching effect. Then another type of deposit which is related to this post collisional system that is called enriched BIF hosted iron ore deposit. Enriched BIF source that means the term itself says is the enriched of iron that means high concentration of iron and this enrichment of BIF to form enriched low and high grade BIF hosted iron ore deposits occurs during post subduction extension following the contractional deformation. So, we have a contraction system, we have a convergent system then we are extending the system.

So, in that case we are getting this enriched BIF deposits like the other deposit we are discussing and this type of iron ore system has produced the world's largest and highest grade of iron ore. So, this is very important here this iron ore that were nowadays this world is leading it is mostly of this enriched BIF hosted iron ore deposits. And the hydrothermal fluid flow and mineralization are controlled by kilometer scale normal strike slip fault systems and allow voluminous ascending and descending hydrothermal fluids during the Archean or Proterozoic orogenic system and during the extensional events. So, now we have pre-existing fracture zones, pre-existing geo fractures like the faults with the joints and that the kilometer that means, deep seated and they are allowing the fluids to mix, they are allowing the fluids to pass from top to bottom and from bottom to top and somewhere they are interacting with each other and giving rise this enriched type of BIF deposits. So, at the depositional site the transformation of a BIF to low and high grade iron ore is controlled by one is structural permeability, how structure is allowing this fluid to pass and another is the hypogene alteration caused by ascending fluids largely it is magmatic or basinal brines plus descending meteoric water and the third is the supergene enrichment via weathering process.

Another process is added here though it is not purely of tectonic however, it enhances the mineralization. So, you have heard about the supergene sulphide deposit. So,

similarly here the supergene enrichment it is by weathering process. So, the hypogene and the supergene fluids of varying composition are paramount for this upgrade of a BIF to higher grade system. So, this is this how this is the key point this hypogene and the supergene fluids.

So, hypogene which is coming from bottom to top and supergene which is going from top to bottom. So, they are mixing their mixture at certain level with a some particular Ph-Eh condition that is very important and this is paramount for this upgrade of BIF for enrichment. And processes causing this upgradation require enormous amount of some points is discussed here. What is One is it is warm, silica undersaturated and alkaline fluid necessary to dissolve quartz in the BIF. Why? Because we need an enrichment because we have a BIF bended iron formation and the bending which with the silica.

So, now, our main purpose is to reduce the silica percentage. So, silica percent that means we need a silica pore fluid. So, that this fluid will be once it is reaching with the rock it will absorb this silica from the rock. So that once it is absorbing so, the remaining rock that will be enriched in iron. So, that's why we need a warm and silica under-saturated alkaline fluid and that is very much important for leaching the silica from the rock.

So, that the remnant rock will be directly enriched in iron. Another is the oxidized fluid that causes the oxidation of magnetite to hematite. So, magnetite is there we have to convert to hematite. So, that we need the oxidized fluid. So, that this due to oxidation magnetite will convert to hematite.

Third point is that alkalic fluid that form widespread metasomatic carbonate. The fourth point carbonate under-saturated fluid that later dissolve the diagenetic and metasomatic carbonates. So, whatever the carbonate is produced that carbonate is removed back and oxidized fluid to form hematite species in the hypogene and the supergene enriched zone and hydroxides in the supergene zone. So, by these are the processes by which this enrichment is occurring. So, this enhanced or the enriched BIF deposit nowadays which are the leading iron ore producers that is the processes involved in their formation. And the extensional tectonic setting includes two discrete and end members that models for this formation of the hypogene and this low to high grade BIF hosted iron ore.

So, what are those? In the deposit hosted by granite greenstone belt that is algoma type of BIF is upgraded by early magmatic system. And late metoric water controlled by

strike slip fault zone. So, this we are allowing this fault zone that means, through this fault zone the fluid to go inside and in rift-related basins and passive margins. BIF is upgraded by basinal brines and late meteoric water focused along the normal faults. So, we have basinal brines is there, it is brines are coming and interacting with the BIF and it is enriching there.

And it is during the orogenic event that is upgrade of a BIF to low to high grade hypogene iron ore takes place. So, that means, these are these processes at different tectonic environment starting from this that means, this greenstone, granite greenstone belt to this rift-related basins and during this orogenesis all the three environment how this iron ore is enriched due to this leaching of this silica and that has been discussed here. And these are these very high grade iron ore nowadays this world is producing. So, thank you very much. We will meet in the next class.