Plate Tectonics

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Plate Tectonics and Mineralisation at Divergent Margins- IV

Ok friends, welcome to this class of plate tectonics. And today we will continue the discussion which was left in earlier class that is the mineralization at divergent plate margin. So, if you remember our earlier class, we were talking about the incipient stage of basin development that means, at the initial stage of the Wilson cycle where this rift basin is developed. And today we are going to discuss about the final stage of the basin development and how the final stage it influences the mineralization that will be discussed in today's class. So, in the final stage there will be thermal subsidence of the basin and formation of the passive margin. For example, if you see here this is the incipient stage that means, the rifting has started and we have a rift basin developed.

If the rifting continues further, so, further extension is going on we are creating mid-oceanic ridge system here and once this mid-oceanic ridge system it moves away from the heat source. So, this is the heat source the asthenosphere and the magma chamber is here. So, once it is moving away from the heat source, so, this is the scenario. So, that means, we have a basaltic carpet that is pillow basalt and this ophiolite sequence that we have discussed earlier.

So, on this basaltic sequence once you are coming to this continental side this is the called passive margin. So now, at the final stage we have a basin which is thermally subsided basin and we have a passive margin which are responsible for mineralization. And if you remember earlier class when talking about divergent system most of this petroleum hydrocarbon they are found at this basin margins. So, that is why not only for this metallic mineralization or silicate mineral or sulfide mineralization this petroleum hydrocarbon is also here it is richly preserved. So anyway, So now, after the initial phase and cooling and the underlying lithospheric mantle leads to continued subsidence and due to this subsidence, So, this rigidity increases and the sedimentation is become more dominant.

So, that means, here sedimentary fill becomes dominated by shallow water marine sediments. So, first this basin is initiated and this marine is shallow. So, this shallow water environment which type of sediment it will produce mostly the silicicastics and the carbonates. So, silicicastic mostly derived from this weathering and erosion of this continental system just hosting the basin. And the minerals are the carbonates which are due to interaction between the basement rock and this water.

So, this quartz feldspar or the feldspar particularly which have Ca it will go into solution and other salts that will go into solution with sufficient change in this Eh-pH condition that carbonate precipitation takes place. Addition to this we have brines that is the hydrothermal system. So, from which the carbonate is added to the system and as a result we have a sedimentary basin which is of different depth and it is mostly of silicicastic and occupied by huge carbonates. So, the thermal subsidence basin and the passive margin basins they are generally atectonic and let up or lack of magmatism. So, atectonic because now we are going away from this plate margin.

So, that is why it is atectonic and as it is away from this active plate margin. So, it is devoid of magmatism. So, that is why it is lack of magma and lack of tectonic activities. So, that is the out of area tectonic events. So, that is mostly responsible for this deposit of zinc, Pb and Ag and possibly for uranium mineralization.

What is this out of area tectonic events? So, this out of area tectonic event that means, it is away from this tectonic event. So, that is why a tectonic margin, but tectonic margin or anywhere it is occurring the tectonic it is affecting here. That means, at the deeper inside of the basin in the basement level or there is the mantle level what is it is happening. So, it is affecting this mineralization here that is why it is called out of area tectonic event which are commonly subtle and very weakly expressed that triggers the mineralization and that mineralization it mostly zinc, Pb, Ag and uranium mineralization event. So, that means, now we are at the passive margin setting and we know this Wilson cycle it is a cyclic process we created a basin again we have to close it.

So, once we are closing the basin we are coming to a closing stage that means, again we are compressing the system. So, final stage so that means, this subduction is gone. So, now, this is the system where compression is going on and finally, the crustal thickness is increasing. So, that means, whatever the basins that were formed and sedimentary rocks were deposited there will be a crumbled there will be deformed this is folded and finally, that means, the basin will be inverted. So, that means, at the final stage of the basin closure we are going to invert the basin.

So, due to basin inversion so, we are increasing the thickness, we are increasing the temperature, we are increasing the pressure. So, those sediments or those minerals which are present there they will be remobilized and that will be reprecipitated in the existing temperature and pressure condition and at places they will be enriched. So, mineral system may be present in many phases of this basin development and termination, but some places that appears to be developed better in the different settings. So, that means, it is a continuous process that this basin development and basin closure. However, there are certain sectors within that cyclic path those certain sectors that means, temporal as well as spatial they are responsible for enrichment of this minerals and the best example is Northeast Australia where mineralization by tectonism due to change in the rotational pole.

If you remember when we are talking about Euler's pole. So, this Euler's pole due to that so, the plates are moving and once this pole is changing so, the plate movement direction changes and now imagine when the plate was moving in a particular direction there is a state of motion and that is why the mantle or this asthenosphere and the lithosphere they are adjusted, but once there is a change of motion so, that means, there will be a disturbance within the equilibrium system. So, that is why there may be magmatism, there may be change in pressure, there may be change in temperature so, that is why mineralization occurs. So, that is the mineralization that is occurring in the rotational pole change which is best studied in the Northeast Australian province and within that system when we are creating or we are closing these basins there will be some epicratonic basins and there will be some platformal basins and they are characterized by relatively shallow water sedimentation succession which is siliciclastic rock and mostly the carbonate bearing rock. So, this siliciclastic rocks and carbonate bearing rocks once they are going to high temperature-pressure regime we have different fault systems they are active.

So, through this fault these fluids are coming and once we are increasing the temperature this system with the re-adjusting itself so, there will be leaching. So, this mostly they host this zinc, Pb and Ag deposits. So, the example is North Australian zinc belt, Howards pass belt in Canada, Red dog in Alaska and Gamsberg in South Africa. So, these are the best studied basins which are related to this zinc, Pb and Ag deposit in the epicratonic and platformal basin particularly. So, along with the siliciclastic the carbonate deposits rock package that contain oxidized red beds.

So, red bed we know it is a product of oxidation event, but lack of mafic magmatism coeval to the mineralization that rules out the magmatism is the result. So, now we have epicatonic basins, we have platforms, we have passive margins, we have subsided basin. So, we need mineralization if you remember our earlier discussions we were talking about magmatism is there which is responsible for the mineralization, but here we do not have any magmatism which is that means, coinciding its time of magmatic emplacement which is related to this mineralization. So, that means, it says magmatism is not related for this mineralization so that means, how the mineralization emplacement is there. So, that is the question that we have to address in this class.

So, here the basin lack of reductance and this magmatic heat source the fluids are very less temperature that means, it is cold fluid. So, that is temperature is less than 200 degree Celsius and that 200 degree Celsius it is therefore, likely that the metal source from these deposits are felsic and mafic volcanic rock underlying the host basin. So, now, if you remove the sediment remove this water from this basin what you will get the basement rock and the basement rock is here in particular that basins we have discussed that is the mafic volcanic rock is the source and the felsic rock is the source. So, if we do not introduce a magmatic system so that means, from where we are leaching this minerals for this zinc, Pb and Ag deposits. So, this is the source which is the felsic magmatic rock or felsic volcanic rock which is lying below and the mafic volcanic rock which is lying below they are the source and through the faults the solutions are coming out and sediments are enriched within that minerals.

So, that is why this underlying host rock which is rich in mineral source so, that is also supporting the mineralization to the overlying sedimentary rocks. So, further researchers reported that intermediate to mafic rocks underlying the host basin have lost 90 percent of zinc and Pb during K-feldspar-hematite alteration. So, another event is supporting that this rocks which are underlying this sedimentary rocks they are the host for this mineralizing sedimentary rock. So, there will be alteration events. So, that found that 90 percent of zinc and Pb had leached and that leaching event that is time wise that leaching event is coinciding with the mineralizing event at the sedimentary rocks.

So, that means, it is easily correlated that the leaching from this basement rock and emplacement of this mineral in the sedimentary rock they are coeval. So, that is why it is nothing to related with magmatism. The ore deposits here are generally hosted by sulphide rich black shale and environment represented by black shale where a source of hydrogen sulphide is required and it is formed by this biogenic reduction which is enriched in the black shale and that hydrogen sulphide which is required for metal sulphide deposition. So, that means, we have black shale or any other rock which is by biological action that is we are creating hydrogen that means H2S and that H2S when it is reacting with the metals it is giving to metal sulphide. So, nothing to do with magmatic system.

So, fluid flow in the silicates and carbonate that is lasted for a longer time because more time you will allow this fluid to flow with that more reduction taking place and more sulphide mineralization taking place because more interaction between the rock and fluid. So, that means, for more mineralization we need to allow this fluid to interact with this host rock for more time and that happened in these basins we are discussing. That means, the sedimentary rock which are overlying this basement rock and this sedimentary rock due to black shale and other rocks where the rich source of H2S and this fluid which is passing through the sedimentary rock from this underlined rocks that is the felsic and mafic rocks they are taking this metallic ions and with H2S reaction they are creating the metal sulphides. So, two depositional environment has been proposed for this one is the early diagenetic mineralization. We know we have diagenesis and liquification for converting sediments to sedimentary rock.

So, this early diagenetic stage there will be some mineralization there are different minerals which are formed in the sedimentary rock in the diagenetic type. So, these minerals which are in the particular basins they are considered to be of early diagenetic product and another reason is the syngenetic precipitation with the brine pool. So, brine pool that is the rich in mineral. If you remember our earlier class when we were talking about this evaporite deposits mostly it is from brine solution. So, they are rich in minerals.

So, syngenetic precipitation within the brine pool it is another interpretation for the mineralization and both be very effective at precipitating the minerals and retaining it and the minerals are nothing that is the zinc and Pb deposits. And this North Australian zinc belt shows temporal association of mineral deposits and that is related to far-field tectonic event and that is for the change of this pool that is change of the plate movement direction. For example, if you see here this is the path of this plate that have been reconstructed and you see wherever there is a bend in this movement there will be mineralization and this is called the far-field tectonic. That means, here tectonic event is not occurring, but due to the change in the Euler's pole position the plate movement direction changes and that plate movement direction changes. That means, it is changing the pressure temperature regime in this plate system or the plant interior and finally, it is giving rise to mineral deposits.

So, here the timing mineralization related to the late paleoproterozoic apparent polar wandering path in the North Australia element shown here and the paleomagnetic poles associated to the mineralization post filled at it of a folding. So, here once there is a change in the path of this plate there will be mineralization and that is called far-field tectonic event. So, that means, it is not immediately the plate boundary nothing related to the plate boundary system and evolution of tectonic environment it changes with time and different kind of mineral system that also evolved for that. So, tectonically influenced upwelling of the reduced Fe-rich bottom water into the passive margin may deposit iron ore at this passive margin it is very important here you see.

In this figure if you see that is this influenced upwelling is there we have tectonic compression maybe there is a magmatic intrusion just below it and or maybe it is far at a depth range, but it is influencing the fluid here it is fluid is escaped from the system. And the escaped fluid once it is coming to a different environment of Eh-pH condition. So, finally, it is giving rise the iron ore deposit. So, here the lake superior bended iron ore formation is the largest you can say in the world. So, this type of deposit was formed from this type.

So, that means, it may deposit the iron ore at the passive margin. So, that means, here active tectonics active magmatism is not required, but anyway we have to disturb the fluid and fluid has to escape and due to change in the Eh-pH condition it will give this deposit and precipitate the iron ore. So, during tectonic quiescence period after a supercontinent assembly several large intracratonic basins are formed and evolved which is produced unconformity-bound uranium deposit that is also very important. So, after this supercontinent breakup we created this tectonically quiescence periods relatively tectonically quotient period and we created this intracratonic basins and those basins are that means, they are placed on this underlying basement rocks like granitic gneiss, migmatite or so. So, those basins which is filled with sediment and at the unconformity surface which is separating the sediment and this underlying basement rock that is giving rise the unconformity bounded uranium deposit it is very important.

So, unconformity related uranium deposit generally formed at the redox boundary near the unconformity between a thick sandstone unit and the underlying metamorphosed basement lithologies. Now you see it is required a redox boundary. So, if it is oxidation state or oxidized so, uranium deposit will not occur. So, we need an redox environment and what is requirement we need a sandstone unit which is overlying the metamorphosed basement lithology. So, basement lithology which is metamorphosed like the granitic gneiss, migmatite and we have a sedimentary basin where filling with sediment and particularly sandstone.

So, this boundary here this boundary it is the uranium it is the unconformity surface. So, this is metamorphic basement rock this green color and this is the sandstone body and at this stage at this junction we are getting the uranium deposits. So, the largest and best known unconformity related deposit is Athabasca basin that in Canada and this Kombolgie subgroup of McArthur basin in the north Australia. So, these are the uranium deposits, unconformity bounded uranium deposit is there. So, here no acting pragmatism is required only at this basin closing stage thermal subsidence stage we are creating this type of deposits.

Unconformity related uranium deposits are structurally hosted either in the basement or in the unconformity overlying the sandstone unit. And most known unconformity related uranium deposits are hosted by mesoproterozoic basins. So, here the time is required. So, why this mesoproterozoic basin which is responsible for this uranium deposit because if you remember we are talking about this oxidation reduction state. So, we need a reduced environment that reducing environment is suitable for uranium deposit particularly the unconformity bounded uranium deposit.

So, that means, this mesoproterozoic basins are largely spatially related to paleoproterozoic origin. So, this paleoproterozoic orogenesis after that whatever the basins were formed and that time the reduction, the reduction condition was prevailing and the sediments were deposited within that basins. So, this unconformity which is separating these basins sedimentary package from this metamorphic basement package there most of this uranium deposit which are particularly this sandstone or unconformity bounded uranium deposits are located. So, although this uranium mineralization can occur above the unconformity, but in Australia it is typically occurs the basement below the unconformity. So, how it can go below the unconformity due to the fault action.

So, that means, we have faults which has cross-cutting this system. So, once this fault is there that means, fluid is coming and through this fault there are different places that mineralization can occur. So, though it is unconformity bounded in many places, but at some exceptional cases where there is fault activities going down and the reduction environment is there. So, along this fault zone we may get this uranium deposit. And two separate models are explained the unconformity-bound uranium deposit in these basins.

One is the basement as the source of uranium basin as the source of this fluid and here the uranium source from the breakdown of monazite along the fault zone. So, basement is the source only the reduction environment it is at the unconformity surface. The second is the basin as a source of growth uranium as well as a fluid. So, that means, this uranium is precipitated here in the oxidized basin brine carrying the uranium it reacts with the reduced basement lithology and mix the reduced fluid and giving like the uranium deposits. So, that means, fluid may be from the basin or maybe from this basement.

So, in this model uranium is sourced from the background of the uranium bearing detrital phase by basinal fluid and in deep paleo-aquifers. So, at the deeper level the uranium was present and it was breakdown by basement fluid and it is coming to the surface and near to this environment or the unconformity environment it is getting deposited. Then another type of deposits which is the sedimentary basin most of this proterozoic sedimentary basins they are known for that is shale-hosted Cu-Co-Ag deposits. So, that means, host rock is shale and deposit is copper cobalt and Ag. So, these are the largest producer of copper and cobalt and major producer of this Ag.

So, major deposits that is here Kupferschiefer in the central Europe and this Zambian copper belt in South Africa. So, many shale hosted copper cobalt and Ag deposits have peripheral Pb-Zn halos. So, that means, not only we are getting this deposit at the periphery we are also getting the Pb-Zn halos that are part of the deposit to regional scale metal zonation and that can be related to oxidation state of the host rock. So, that means, not only we are getting these deposits on the regional that means, zonation. So, at concentrated zone we are getting here at the core zone we are getting copper cobalt and Ag.

However, if you are going to this periphery within that zone we are getting Pb-Zn deposit and a Zn-Pb enrichment zone may overlie the copper rich zone also. So, here some of the field photograph that is how this copper deposits are showing in the rock record and this color is changing. Where the host rock progressively becomes oxidized with stratigraphic depth with a highly oxidized, but barren Rote Faule underlying the copper and cobalt mineralized transition zone which in turn underlies the Zn-Pb-Cu mineralized reduced zone. That means, stratigraphically we are going downward and the mineralization is changing depending upon the degree of oxidation and degree of reduction condition. So, what is this rote faule? Rote faule is nothing it is a zone of post depositional oxidation.

So, that oxidation is characterized by the presence of extensive amount of Fe(III) oxides replacing syn-sedimentary phagmodal pyrite. So, this is the zone that is particularly here this is called this pink color that is called this rote faule zone. After deposition it is getting oxidized and pyrite framboids what is that? They are densely packed generally spherical aggregate of submicron size pyrite crystals. So, once this is oxidized and it is giving rise to Fe(III) oxides and this Fe due to this presence of Fe(III) oxides. So, this color changes and this oxidation signatures are shown in the field.

So, this is called the rote faule zone. This zonation is interpreted to be consequence of influx of highly oxidized diagenetic brines from below and with mineralization caused by progressive reduction of this ore fluid. So, we have a oxidized fluid now we are reducing it, we are changing its pH condition so that means, it is precipitating minerals. So, uranium, Au and PGEs also form part of this metal zonation and Au PGEs are enriched in the oxidized zone and highly enriched that is about 100 ppm of Au and 14 ppm of platinum in this transition zone, but low in the reduction zone. Uranium is most enriched in the oxidized zone, but also in extent to reduce zone. So, earlier we were talking about reducing zone is mostly responsible for this say an uranium deposit.

Now, at the oxidation zone also so certain extent uranium is found and oxidized fluid that are the natural products of the relatively oxidized rock assembles that characterized many thermal subsidence basins or passive margin. And this presence of Coeval uranium, copper, cobalt, Ag along with Zn and Pb that deposits some metallogenic provinces suggest that these depositional process and the path might apply to larger scale with redox gradients within that basin producing a range of deposit from this oxidized fluid. So, we have a oxidized fluid, but gradually we are reducing it and this reducing path through which it is travelling this fluid is passing through. So, this reduction gradient if it is there so we are getting a range of minerals and that range of minerals are nothing, this is creating a zone of mineralization. And at these basins hosted metallogenic system required oxidized ore fluid that form at the oxidized basins.

It is restricted temporarily to after oxidation of this atmosphere in the paleo-proterozoic time. Why this oxidation reduction we are talking about? This because this is the paleo environmental condition, paleo that means, they are talking about proterozoic environmental condition that was also somehow responsible for this type of mineralization. And which for the first time produced oxidized rock package and surficial fluids that is we are talking about this Nuna type that means, when this is supercontinent cycle was there. That time that oxidation-reduction condition of the atmosphere and the oxidized fluid which is coming from this rocks there was interaction and there is a reduction gradient was prevailing within the basin and that is why a responsible for that development or precipitation of this wide range of minerals. So, another important factor is the amalgamation and the breakup of the supercontinent Nuna and later Rodinia that produce extensive passive margins and shallow seas and these are also coinciding with the metallogenic events.

So, we need a basin, we need a fluid, we need oxidation and reduction condition and finally, there will be leaching of these minerals and there will be enrichment. So, in a number of world basins like uranium, copper, cobalt, Ag and Pb-Zn-Ag is linked both at the deposit scale as well as the basin scale. And in many deposits these metals are spatially zoned and in some basins deposits with these are diverse metal assemblages appear to be closely coinciding in time and that time that is related to tectonics and the crustal evolution. Although in detail these deposits and basins are many ways different in most cases the fluids are thought to be oxidized, saline and sulphide poor. With production of sulphide at the site of mineralization begin at the critical process of the mineral system.

So, that means simply it is nothing we need a fluid it should come and it should be oxidized or at oxidized fluid should be reduced. That means a state of oxidation reduction state should be changed so that it will precipitate the mineral system. Ore deposition in shale hosted copper, cobalt and Ag deposits was caused by reduction of the initially oxidized fluid and that can be seen in this figure. And this process can account for these Cu-Fe and S mineralogies and that is in the form of chalcocite, bornite, chalcopyrite, pyrite and metal zonation like copper, Zn and Pb at low temperature around 100 to 150. For example, here if you see 100 to 150 temperature region So here these minerals are getting precipitated.

So, here the log of this H_2S and SO_4 diagrams are showing here and this is the diagram showing the solubility of Zn copper and uranium in the stability of FeSO and you can say this shading indicates the FeSO mineral stability field and dashed black line indicate the copper FeS mineral stability field and colored solid light indicate the solubility of copper Zn and uranium. So, if you go through this figure you will find when and what temperature and what is this concentration of these two or ratio of these two is suitable for mineralization. And finally, you will find how the mineralization is changing with this change of this temperature as well as this concentration of this ratio of this sulfide to oxide system. So, as the ore fluid is reduced for example, here once we are coming from this lower part to the upper part and as the ore fluid is reduced the copper solubility decreases and initially it is chalcocite and then bornite are deposited with the hematite followed by deposition of chalcopyrite and pyrite. That means, the sequence of mineralization it is following and zinc and Pb deposition only occurs when sufficient H_2S becomes available otherwise there is no zinc mineralization.

So, because zinc sulfide we need H_2S. So, when the sulfur is more available then this zinc sulfide will be deposited. In case of B here at this point if the initial fluid conditions are sufficiently oxidized the uranium precipitates at very earliest stage of the reduction process and if the temperature are sufficiently high that is more than 300 degree Celsius ore fluids cannot transport significant uranium and Zn and Pb. That is why the Zn and Pb will not precipitate at this fluid and the evolution parallels to Zn solubility controls line C. So, that means, it is explaining how this solubility and this reduction potential of this system or the fluid is responsible for mineral deposit at a different part of this field. And this evolution path will in fact dissolve the zincs due to the very high temperature and high temperature high zinc solubility is there.

So, that is why zinc will not soluble here. So, once it is coming to a low temperature that means zinc will precipitate.

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