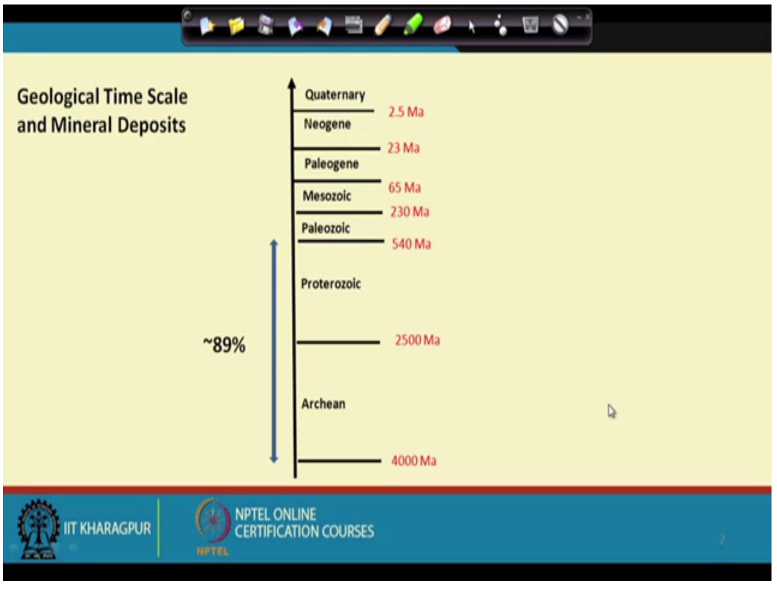
Mineral Resources: Geology, Exploration, Economics and Environment
Prof. M. K. Panigrahi
Department of Geology and Geophysics
Indian Institute of Technology, Kharagpur

Lecture – 03
Mineral Deposits in Space and Time (Contd.)

Welcome to the third lecture on the series on mineral resources. A brief recapitulation what we discussed in our last class is that we try to understand the distributional peculiarities of the mineral resources in relation to the broader earth processes which we classified them broadly into endogenic and exogenic process..

And we also looked at the distribution keeping a reference of the physical map of the world where we see the distribution of the land and sea; and in the continent, we also see the young mountain chains and the older rocks which are in the shield areas. So, that gave us a framework on the spatial distribution of the mineral deposits.

(Refer Slide Time: 01:20)



So, in continuation to that let us try to look at the temporal distribution because to understand the mineral deposit formation because we see diverse types of deposits. And these deposits also they did form in the geological past. Just for your reference with a very simplified column here the time range from the beginning if we take it from 4000 million years to the present day even up to in the quaternary even very distant because what we showed here what is happening in the mid oceanic ridges the mineral deposit formation are almost like present day phenomena..

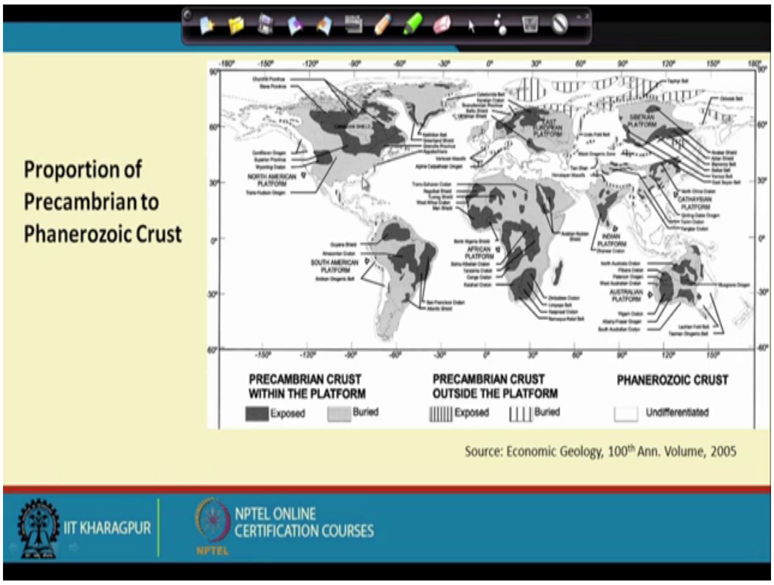
And the deposits of some of the important deposits which are associated with the present day or tectonic activity in particular in the destructive quaternary margins as well as the constructive quaternary margins, their age ranges are also pretty young within just a few tens or million years or even less than 10 million years of time.

And then this 4500 million year old earth where we get rock records up to 4000 million years. And 80 about 89 percent of this geological history is basically belonging to the era which we broadly refer to as a Precambrian up to five roughly about 540 million years. We do also get ore deposits which are which range in ages as low as even 4000 million years. The oldest iron ore deposit comes from the issuer complex in Greenland which is about 4000 million years. And the deposits of almost all the metals iron the base metal copper lead and zinc, gold, chromium and uranium, all these deposits we see that they these deposits are also present in the continental interiors associated in older rocks which are also very old.

Although in most of the cases the age relationship or the exact timing of mineralization of these metals or the minerals come rather more indirectly because here in the Precambrian we mostly depend on radiometric age determination on the associated rocks country rocks and the host rocks. And they give us the idea about the timing of the mineral of formation of these mineral deposits..

And then we also do have the Paleozoic, and Mesozoic, Mesozoic and these Cenozoic rock records in which also we do get mineralization. But as you will see just in a short while the majority of the continents this total in terms of the proportion of the area of the continent available we do have a sizable proportion belonging to these Precambrian rocks.

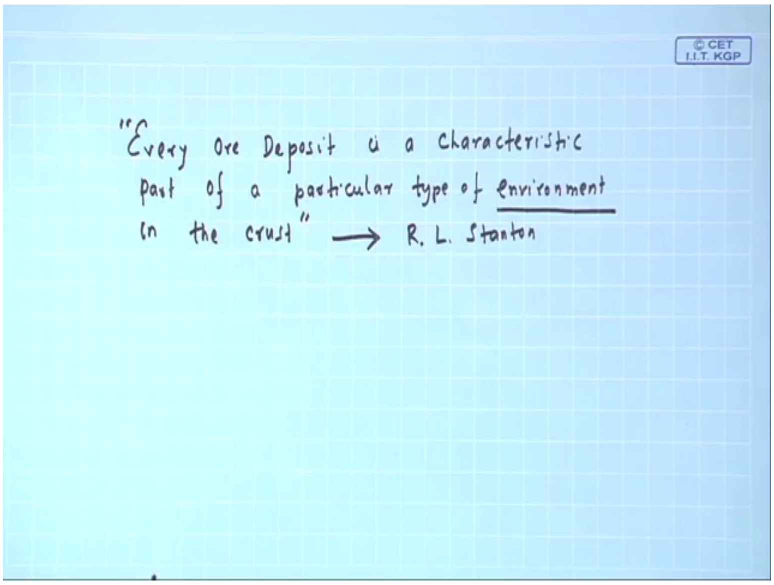
(Refer Slide Time: 04:33)



So, if we could have a look here whatever is marked in light gray and the dark gray are all basically covered by the Precambrian rocks is the North American continent, is the South American continent. And in the previous lecture we showed with we saw the locations of many such an important metals like gold, like iron, where they are present in these shield areas like for example, this is the Hamersley basin in Australia. This is the Jacobina uranium mined in Brazil and the superior next superior iron ore mine and so on so many many such deposits. A majority of the ore deposits mineral deposits actually come from rocks, which belong to the Precambrian.

And the basic question that comes to our mind that we have we have tried to or we have seen that it is quite explainable that the deposit formation are very well correlatable with the present day operative plate tectonic processes. And when we see a mineral deposits which are formed in the distant geological past as old as 4000 million years that the basic question that comes to our mind is that can they also be explained by the present day operative plate tectonic processes or we need to explain them in some different way. I would just like to point out a fact that the ore deposits or the ore body occurring in any part in the earth's crust is an integral part of the rock forming process or we say that every ore deposit..

(Refer Slide Time: 06:42)



We can even write it down this very, so every ore deposit is a characteristic part of a particular type of environment in the crust. This is a statement, which is taken from one of the very popularly referred textbooks on ore geology by R. L. Stanton. So, what we mean by this particular type of and this every part of the continental crust can be thought of as belonging to a particular environment this environment could be different in different domains. And also one of the important fact the problem that is posed by the ore deposits is that they are sometimes do they cannot retain the original characteristics, they have been they are subjected to deformation metamorphism along with the rocks that they occur in the older terrains.

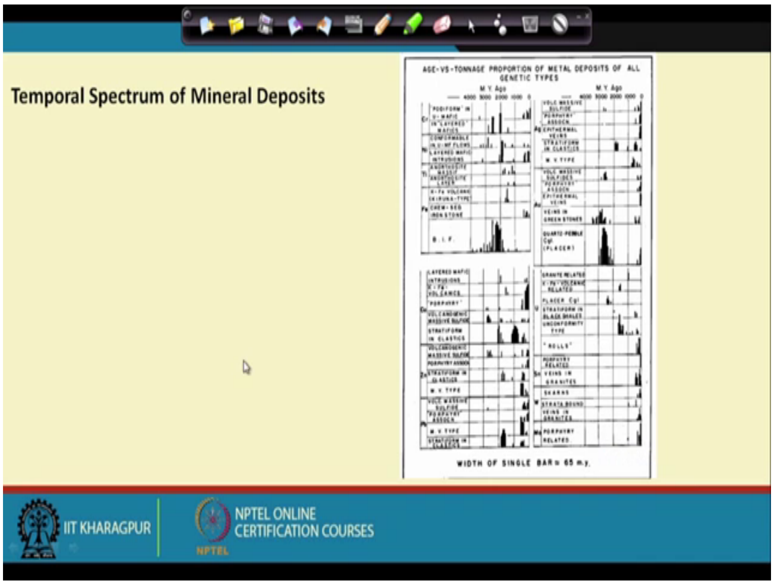
So, it sometimes becomes very difficult to sort of a compare them and try to find out the similarity or dissimilarity in their characteristics with the ore deposits which we see them which are very young and have been forming in only very recent times within the time range of a few million years from now..

So, these are one of the very important challenges that is faced by ore geologists in general, but we shall try to see how well or how good we can we will be able to correlate them and where on what situations we do fail. And then because we visualize that there exists the parallelism between the evolution of the continental crust or the lithosphere is a whole, they crust in the upper mantle in time and the different types of mineral deposits they have resulted.

So, if we go by the principles of uniformitarianism which say which tells us that the present is the key to the past. Then we would expect that ore deposits that we are finding today also would have formed in the distant geologic past or just the reverse that the deposits which we are forming in the distant geologic past would also be forming in the present day earth processes. So, we will see how correct this statement is a where we agree on them or where we are not able to agree to such situations which would be constituting our knowledge on the ore deposits.

So, one thing is very clear that you could see the proportion of the phonology crust which is be very, very small like for example, these are the regions in which the Western American cordillera is here. And this is the part where you have the Japanese island arc and this Alpine Himalayan Mountain chain. So, all these are the younger the constitute the areas where younger rocks are exposed. And the rest of the areas where those are the shield areas where the very old cationic blocks and surrounded by the old mobile belts are exposed.

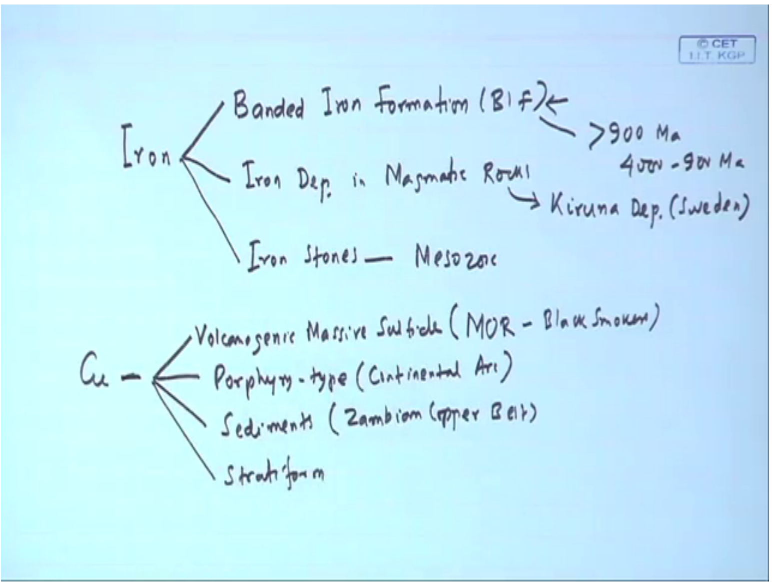
(Refer Slide Time: 10:36)



Now, this is very popularly known as the mayor's spectrum. So, the mayor spectrum here in this diagram the deposits of chromium some selected metals chromium, nickel, titanium, iron, copper, zinc, lead, silver, gold, uranium, tin, tungsten and molybdenum depending on whatever the data were available this diagram itself is possibly was prepared some sometime in the mid of a eighties. After which there has been quite a bit of development in the field about geology, there are many new deposit types which are come into existence..

And these are generally will be such kind of a diagram can only be drawn if near accurate data are available on the quantity in which they are represent and they are available to us. So, before getting into this diagram, so we can just have to we can see because for each metal. Say for example, I will be taking only if you pick up a few example from here and then try to make the point which I am try to explain or try to highlight the ones which I want to make here.

(Refer Slide Time: 12:08)



Say for example, iron occurs in the deposits, which can be which are the different types like these one is the banded iron formation or the BIF. In fact, this BIFs or the banded iron formation at this bridge because whatever quantity that we showed in the first lecture in our availability in the quantity that we see them while when we are trying to correlate with the crustal abundance. So, we actually refer to the total iron resources which are coming major bulk is coming from this banded iron formations. So, banded iron formation is although we will be looking at their detail characteristics in the lectures to follow. They are essentially present in old sedimentary basins, and are generally marine shallow water where oxidation the oxidation state has been high, so that it resulted in the formation of the iron oxide minerals hematite and magnetite. And then we have iron deposits in magmatic rocks, these rocks are generally of all intermediate an orthositic kind of composition.

Then we have so these constitute the very negligible at this point of time, they do not constitute what basically are the resource of iron. And they are the iron stones. And these banded iron formation which I showed occurring in the continents like in the superior province of Canada in the Indian synchrotron in India, Normandy basin in India or Hamersley basin in Australia basin in Australia and or in the Damaran belt in Namibia. They characteristically as you will see here they are essentially very old, they are generally greater than 900 million year the range in age from 4000 to say about just about little less than 1000 a little less than 900 million year.

These rocks the iron deposits of magmatic rocks which are which is one of the major important deposit which is the Kiruna deposit in Sweden is one such which is also Precambrian age. Ironstones are essentially iron bear in clays, which are much younger they are Mesozoic. So, in the diagram, for iron the these three types the ions which are the Kiruna type the iron manganese iron and so potassium iron volcanic which is basically as I said they occurring in intermediate type of rock. And the ironstones and the banded iron formations are shown.

If you could see here that the banded iron formations are very much restricted in time as I showed you just this is thousands. So, the just little about 1000 and two about 4000 with a very prominent peak occurring in the middle Proterozoic time. So, plate Archaean to mid Proterozoic time they formed in the maximum quantity of the majority of the form the deposition of iron took place in this particular time..

Very interestingly, so when you look at the temporal spectrum even picking up such examples what something which is to be very interesting it to be noted here is that these kind of banded iron formation do not occur anytime in the later part of the evolution of the crust. Such deposits such banded iron formations of younger than 900 million years that mean any time in the Paleozoic Mesozoic they simply do not occur.

Now, let us look at a metal like copper. In our previous discussion, we also saw that a metal like copper which occurs in the most number of ore minerals oxide, sulfides, carbonate, silicates and so on. And also it occurs with very wide spectrum of rock types they do occur in volcanic rocks they do occur along with the magmatic rock like grenades they do occur in sediments, they do occur and use in the most diverse type of deposits.

So, they occur as volcanogenic massive sulfide the one which we showed at the example in Quebec, there is a Noranda deposit in Quebec; and the cypress deposit in the Tudors (Refer Time: 17:31) Volcanogenic massive sulfide, you have the porphyry type in the continental arc exemplified by the Chilean Andes they do occur in sediments like the example which I gave was Zambian copper belt and they also do occur in Stratiforms in Clastics.

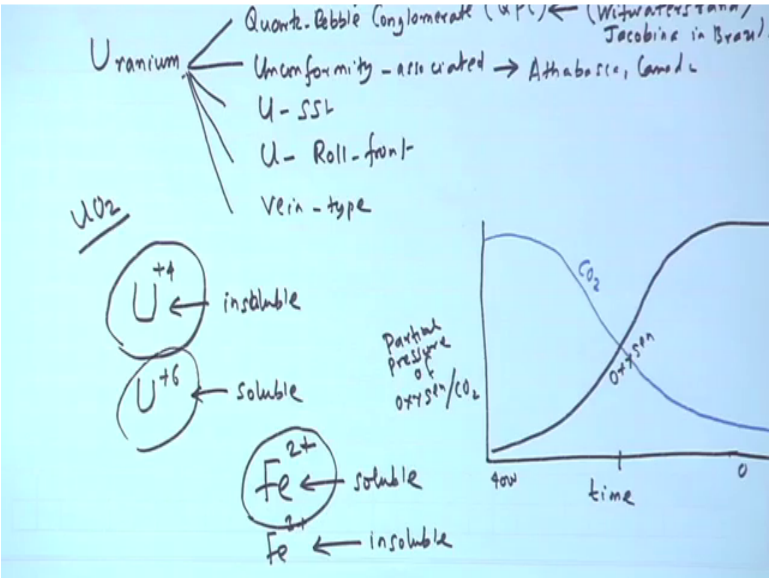
Now, if we look at the temporal spectrum of such type of deposits one thing which is very peculiar is that if we see volcanogenic massive sulfide deposit of copper. They have been forming almost very almost of though although we cannot expect them to be exactly very continuous, but as it looks like they from almost like the late Archaean to almost present day..

Because we saw we saw that this type of volcanogenic massive sulfide deposits which are essentially supposedly the older analogues of the phenomena which is occurring on the mid oceanic ridges the black smokers that we pictures that we saw in the last class. We will be getting into the details of such characteristics in the later in the way as the class will progress see the essential characteristics of them.

So, here one thing to be marked here that what basically is the porphyry copper these porphyry copper deposits are only very young which I also showed you just now that this in the previous class that they are very much confined to the destructive type plate margin the continental earth type plate margin almost a majority of them coming from the Chilean Andes whereas, the massive sulfide deposits are occurring all across the geological edge..

The stratiform clastic are a little restricted in the time range almost like from proterozoic to about late Mesozoic, but actually we do sometimes see that there is a peak or the time period in which such type of deposits formed in much larger quantities compared to what they formed in other time periods.

(Refer Slide Time: 20:21)



Similarly, if we look at say uranium, let us see one of the important deposit which is uranium, I shall be giving you some more information in the handouts on giving you a glossary of the different mineral deposit types that will be helpful. Because it is not possible to discuss each individual deposit types it is there in the spectrum and only I am picking up the only the important ones..

So, uranium so one of the deposits one of the major sources of uranium are the Quartz Pebble Conglomerates, they are known as the QPC. They come from there are so essentially their they resulted by processes which are exogenous process occur in sedimentary basin as is a product of a deposition of the titled sediments which will see them in greater details in the later part of this lecture as you will be seeing them.

Uranium is one is quartz pebble conglomerate the unconformity associated. So, this is the famous Witwatersrand deposit in South Africa and also Jacobina in Brazil. Unconformity associated there is one of the major uranium producing deposits it is the example is that I showed you Athabasca Basin in Canada. Then we have a uranium in sandstone then we have uranium deposits which are known as roll-front also associated sediments. And maybe as vein types mostly associated with felsic magnetism and like the one which I showed you when I were discussing about the spectrum of deposits that occur in the continental areas took a sketch took a soil sketch where the tectonic domain was changing from a subduction zone to a collision zone.

So, now, if we just concentrate on a couple of them, now if we look let us look at the distribution of this quartz pebble conglomerate which is written in a pressure conglomerate this term pressure will be explained to you later on. So, this particular deposit type is also very much restricted in time we could see that they are just occurring just about middle Proterozoic kind of time later came to be middle Proterozoic. And these type of deposits never occurred anytime in any part of the geological history of the continents continental crust I rather say.

So, then here as it looks like if we go by the fact that deposits if we go by the principles of uniformitarianism that they present is the key to the past then here they seem to be somehow failing the banded iron formations they never occurred in the later part of the geologic history and the pressure conglomerate bearing uranium deposit. If uranium present in the quartz pebble conglomerate type of pressure deposit also never occurred in any part of the geologic history. Now, whether the question is that whether we could rationalize that?

Now, as we know uranium occurs in two states uranium plus 4 and uranium plus 6. Uranium plus 4 is insoluble. When we say insoluble generally we mean insoluble in a fluid, let us say whatever or watery fluid. And this is soluble. Now, one this diagram let me just give you quickly a situation where this is time before present almost starting from 4000 to 0. And this is on the y-axis, I will put the partial pressure of oxygen versus carbon dioxide.

Now, let us look at the situation where the partial pressure of oxygen. So, partial pressure of oxygen is kind of was very very low in the in the beginning part of the evolution of the earth’s atmosphere the carbon dioxide content of the atmosphere was low. And if you look at a sorry the oxygen content, this is for oxygen and this is Co 2. This is a very, very qualitative schematic diagram just trying to highlight one simple concept the partial pressure of oxygen was low. So, you would expect most of the uranium to be in plus 4 state, because this is a surface operated process the formation of the sediments along with the uranium minerals will be carried as a mineral you all know that is u o two square the oxidation state is plus four this uranium oxide is uraninite.

So, this when the atmospheric oxygen is very low where the conditions is much more reducing there the uranium in uranium solubility will be very low and uranium will always be present in a solid detrital form. So, what we during that so this is exactly the time which is corresponding to the middle Proterozoic or a late Proterozoic time where the oxygen content of the atmosphere this is kind of a changeover which happened during the middle to late Proterozoic time where the oxygen content of the atmosphere rises with the distance of the photosynthetic plants. And what value we have is the present day value this is the present day value.

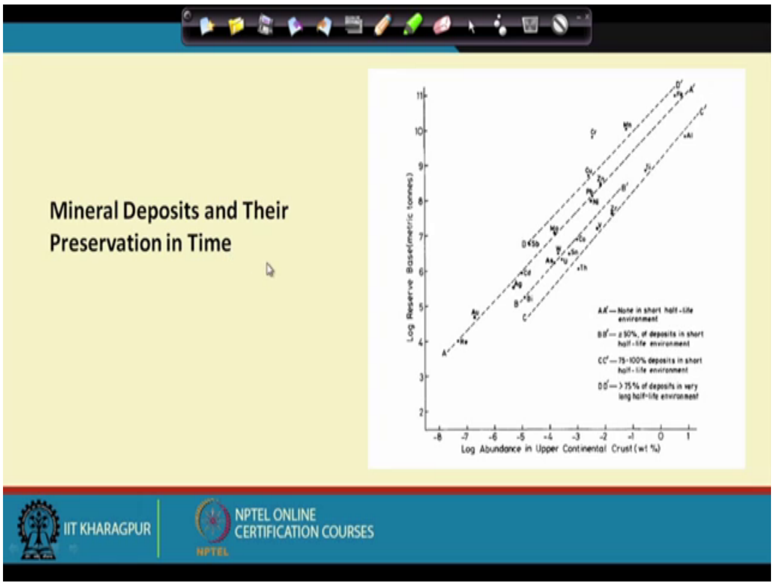
So, once the oxygen partial pressure of the atmosphere increased then we will mostly have uranium is soluble in plus 6 form. So, we will only be able to get the uranium 6 plus deposited in the form of a mineral solid mineral like uraninite only when we will be able to bring about a zone in which there will be reduction and u 6 will be converted to u 4. So, those will definitely in the present or a anytime in the later part of the geologic history wherever we need to have uranium deposited in the form of uraninite with plus 4, there the oxidation state has to be low that means, they have to be some kind of a localized environment where this will be favored.

Now, why so how the two could be correlated now. Now, we all know if we take the case of iron, iron is just the reverse. So, iron is soluble in plus 2 state and iron is insoluble in plus 2 state and insoluble in plus 3 state. So, if the initial conditions of the because as we will see later that the process is very much like an intimate interaction between the atmosphere and the hydrosphere..

So, if the atmospheric carbon dioxide was high, and it was very reducing in condition, then almost the fluid the surface the ocean water or whatever the hydrosphere is will be able to have a huge amount of iron dissolved in the form of iron 2 plus. And just about the time when the oxygen partial pressure of oxygen of the atmosphere would have started to increase and also similarly the hydrosphere. Then all the iron 2 plus would have got deposited in the form of iron 3 plus.

Now on this backdrop of this simple principle we will be able to explain why the banded iron formation is restricted in time and never occurred in the later part of the geologic history. Similarly, the pressure conglomerate will be maybe will be come back to this diagram later part of the lecture. So, this explains that this non occurrence of bended iron information in any time in the geologic history later part, and also non occurrence of the pacer conglomerate point to the fact that the present day value of the atmosphere vis-a-vis by the carbon dioxide. You cannot have so much of iron again held in solution anywhere any domain to give rise to precipitation of iron 2 plus into iron oxide minerals in such huge quantity to form their own resource.

(Refer Slide Time: 30:16)



So, just to conclude if we remember we plotted the abundance or the total quantity of the metals that is available in terms of metric tons with in a logarithmic scale versus their bulk crustal abundance. It is a diagram where the same has been plotted against their upper continental crust an average because upper continental crust is the repository of all the metals. Now, this diagram just serves one small purpose that when we talk about rocks older rocks older rocks get recycled, get destroyed.

So, deposits which form in older times also are likely to be destroyed. So, the deposits of these metals in any the quantity that is available to us we can think of that. They are what we get it is exactly what is survived after the earth's own recycling or the cannibalistic recycling destructive processes in which you see that some metals starting from here rhenium to here all these silver, cadmium, molybdenum lead and zinc. They fall on a line which we can take the reference lined call them the main train line. And some other metals like for example, on the C, C prime you see thorium and aluminum is plotted on the uppermost line is to get copper and the metal deposits of bismuth uranium tungsten etcetera they are forming somewhere in between.

So, this line which is above the line of A A prime which is the main trend line which is called m. So, there these deposits are in such environments that they would get they do not get destroyed that very quickly. And we can think of that they are present in some kind of a very long half life environment compared to the metals which fall on C, C prime they are in the geological environment where the rate of the destruction either by the cannibalistic recycling like the subduction process or normal weathering resume process they are much faster..

So, this diagram is very informative in that way that whatever quantity of the mineral resources that we have we are left with are basically after they survive the earth's own cannibalistic recycling process, so that is what that is all for today. And we will continue discussing in the next class.

Thank you.