Mineral Resources: Geology, Exploration, Economics and Environment
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Lecture - 16
Hydrothermal Processes

Welcome to today's lecture. In the previous classes, already we have discussed certain important type of ore deposits that result from magnetic processes and sedimentary processes for some time. Now we will be discussing on the hydrothermal processes, what exactly we observe or the hydrothermal deposits of a wide spectrum of them occurring in wide diversity of geological environments in different parts of the crust.

We have seen their distribution in space. So, we will try to look at the hydrothermal deposits and attempt to understand the hydrothermal processes.

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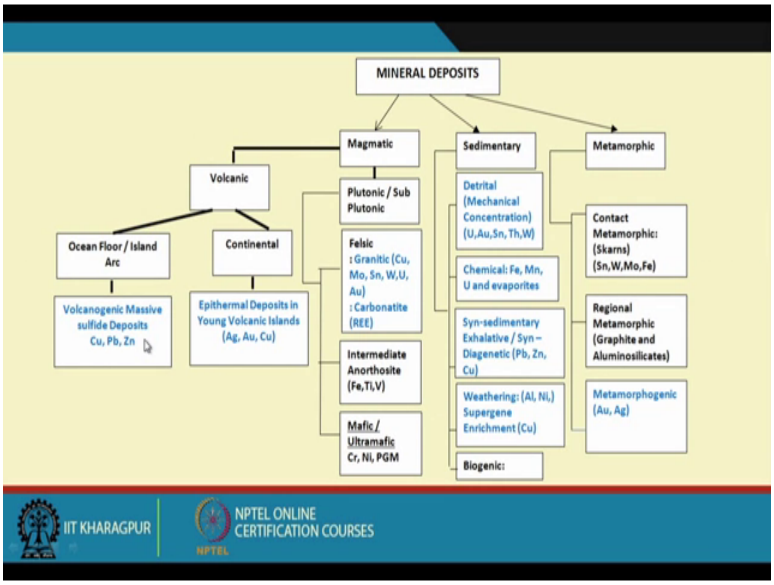

Just to recapitulate in the classification scheme that we proposed for mineral deposits, I here I would like to draw your attention to all these boxes in which the specific deposit types are in blue.

They have one thing in common that they owe their origin, through the activity of a fluid a hot aqueous fluid which we call as the hydrothermal fluid.

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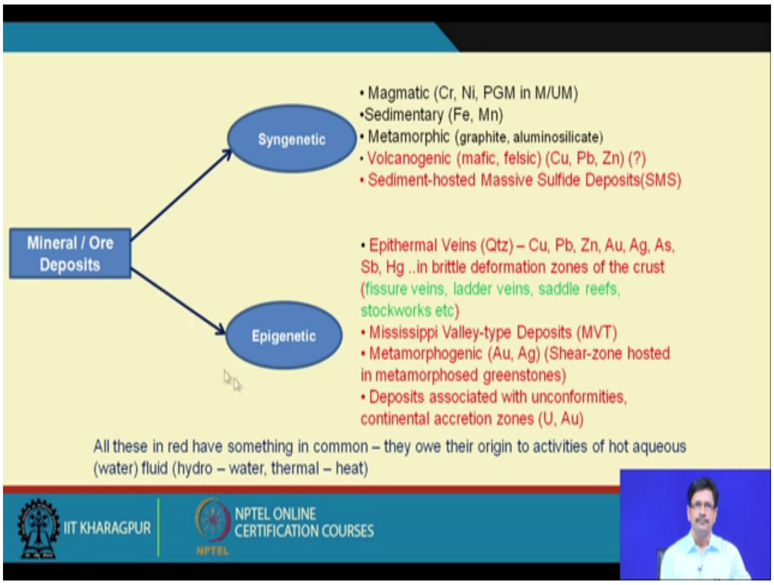

Similarly, in our classification to do deposits to syngenetic and epigenetic, here also all these that is marked in red the volcanoes in the graphic sulphide deposit the sediment hostel massive sulfide deposits, the epidermal deposits in volcanogenic irons, the mississippi valley type deposit, metamoorphogenic gold silver deposit and so on. So, all these in red have a commonality that they owe their origin to activities of a hot aqueous fluid which we call as the hydrothermal fluid.

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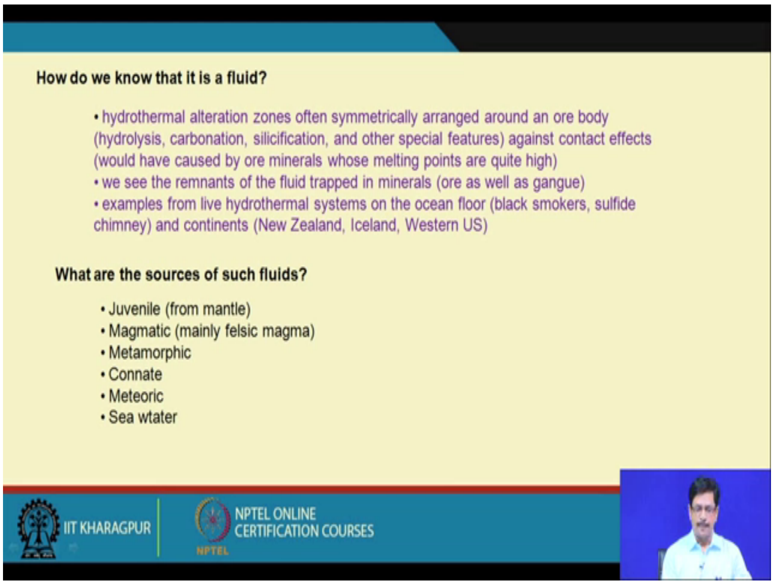

So, we can use we can break the break the term hydro thermal as hydro is for water and thermal is for heat.

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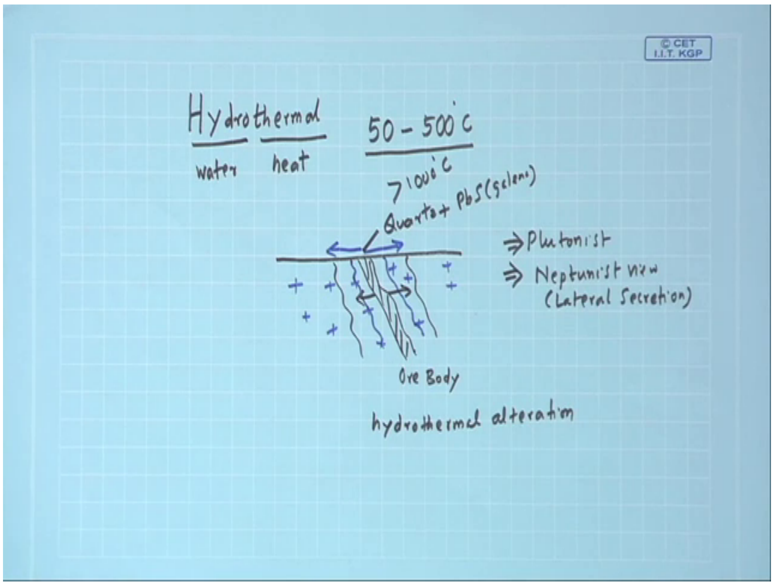

So, essentially it is a heated water, and this what is the temperature range in which we consider this hydrothermal fluid or call them as the hydrothermal fluid; is the temperature anything to start from 50 to 500 degree centigrade. So, once we fix the range or we know that the range temperature range of this fluid is anything between 50 to 500 degree centigrade, then it is obvious that these fluids could not be derived from only a single source, they have to be their source has to be multiple which we will see them.

Now, why we think that these deposits as we saw in the previous two slides, and why would we say that they do owe their origin to a fluid. Suppose I will show you a very common situation of occurrence, this is a, this represents a common crustal rock and now here I observed that there is a there is some there is an ore body of any particular metal any say let us copper gold, copper led zinc or gold whatever it could be. Suppose it is an ore body of a sulphide containing and this this contents suppose quartz is the gang plus any of our sulfide minerals there is a galena, which is Pbs. In up in the olden old days when these signs of ore geology the mineral deposit formation was at its infancy there were many views, that were proposed by many philosophers, scientists there was one view was that all these deposits like this one, they result from the by the activity of a magma a molten material that is being implied into the common crustal rock.

There was so; it was actually a view, which was more popularly known as the protonist view. The other opposing view which was proposed was that it was more commonly known as the theory of lateral secretion means it is all the activity of the water, which scavenges the metals from the surrounding rocks, and deposits them on a suitable location. So, that was the Neptunist view or the concept of lateral secretio.n Now let us try to find let us try to see the logic that had this particular material been of a much because we know that.

If we have to bring a quarts and a galena like sulfide into a molten state, the temperature has to be very high greater than 1000 degree centigrade at least. Now if such a material is emplaced within the common crustal rocks what would you expect? We would expect that this particular material would have some contact effect or we call them as a baking effect and we would be getting this immediate contact this rock to be baked or be affected by the high temperature. In most of the cases all the deposits that we classically put them under the category of hydrothermal and whenever they occur in such kind of forms as veins or as spaces occupying open spaces that are created in common rocks; we actually do observe that instead of having such kind of a contact effect of very high temperature contact effect; what exactly we see that this the material the rock in the immediate contact and when we move away to the fresh rock, this they all show the evidence of addition of fluid or their hydrolyzed or they are essentially we call them as hydro thermal alteration. So, this hydrothermal alteration may be occurring in zones maybe they are symmetrically arranged, they may be just about one or even multiple such zones, typically they are characterized by presence of some all hydrothermal alteration minerals, which we will discuss in details in the later classes, where we will be looking into the process . So, this gives us first-hand information that this particular process of mineralization or emplacement of this particular ore body is not in the form of a molten material or a magma rather it came in the form of fluid, and that is how it is hydrolyzed or has affected the rock surrounding immediate rock, which we call as a country rock by hydrolyzing them or altering them or became causing some alteration are characterized by hydrothermal alteration minerals.

Second is that. So, this kind of hydrothermal alterations could be hydrolysis carbonation silicification the addition of silica and any other kind of situations. And the second most direct evidence come from what I showed in the distributional peculiarities of mineral resources, by looking at the ocean floor hydrothermal systems and such land based geothermal systems, where we see that a hot acquiesced is election in giving rise to mineralization.

So, that gives us the most direct evidence in favour of a hydrothermal origin of any of these mineral deposits. And the other one is that when we examine such minerals from these deposits, we see fluid tiny fluid filled cavity is called fluid inclusions or they are supposed to be their elements of the fluid from which the mineral because it was formed.

So, since we have defined temperature range of 50 to 500 degree is celsius for this ore fluid, we call them as ore fluid, hydrothermal fluid, synonymously you can use the two terms. So, these are the different possible sources that we can propose for them. The first one it is of course, not in terms of importance, but the first one is if the juvenile fluid juvenile veins the fluid which is never been a part of the normal hydrologic cycle its supposedly from the mantle to the process of depolarization of the mantle.

Most in many of the ore deposits that we have studied, there is hardly any direct evidence of the direct indication of any of the rather it is the rare. So, this, but this is always possible candidate to be a fluid good fluid. Majority of them many of the deposits which we will be looking at in this particular in in subsequent topics here, the magnetically derived fluid and these magma is a generally the felsic magma which have a lots of volatiles dissolved in them when they get when they generate in the middle or the middle part of the crust; the metamorphic with the fluid which is liberated during the process of depolarization of rocks, which undergo metamorphism on in high temperature and pressure conditions.

They call it water with the water which remains trapped within the post business of sediments for a considerable period of time and by the process have changed their chemistry to certain extent depending on the kind of sediments that they are in, and the meteoric water is the water which basically is our rainwater which falls as precipitation on the surface, and many of the deposits we find a very big role of played by the meteoric three into the water and bringing about mineralization and the sea water which is a modified meteoric water, and we all know its chemistry is different from its salinity is higher about 3.5 about person and its very chemistry is pretty complicated. But then many a situations we find that if the sea water like situations ins how can we is the any massive sulfide deposits, they it is a is the important component.

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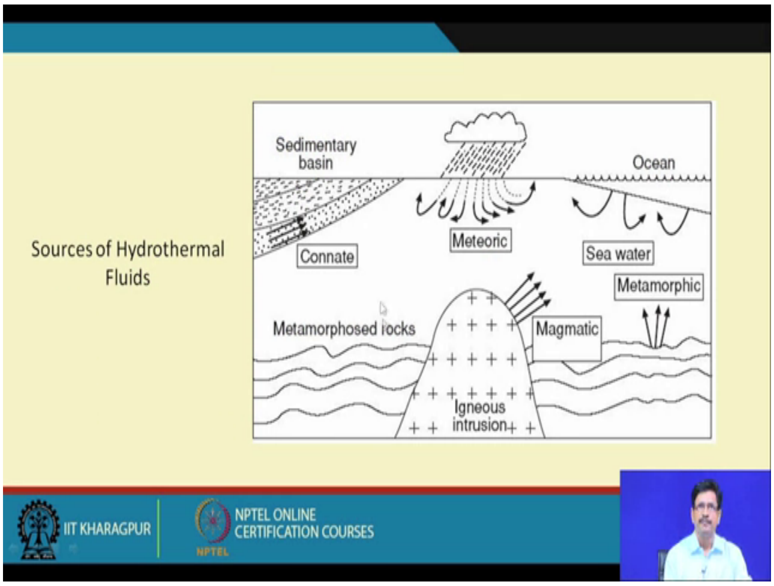

This is a schematic diagram taken from the book of Lawrence rob.

So, it suggests a cartoon you can say that showing them possible sources, here is a igneous intrusion it could give off the fluid during the time of its crystallization evolution to give magnetic fluid, these are the started which are being metamorphosed at high pressure and temperature conditions, they can release the fluid during the process of depolarization, maybe water carbon dioxide and many other species like sulphur bearing species charged with them, similarly in the case of the magnetic fluid which is dominantly water plus carbon dioxide plus.

Sulfur species like sulfur dioxide H 2 S depending on the oxidation state, sea water is a bit very water and call it water, this diagram is very self-explanatory, this was the sedimentary strata and the fluid being liberated from these sedimentary strata, which were trapped within the pore species of sediments for a long geological time change its composition and in response to some tectonic activity or just by some process through which the fluid could migrate and cause mineralization a different suitable locals.

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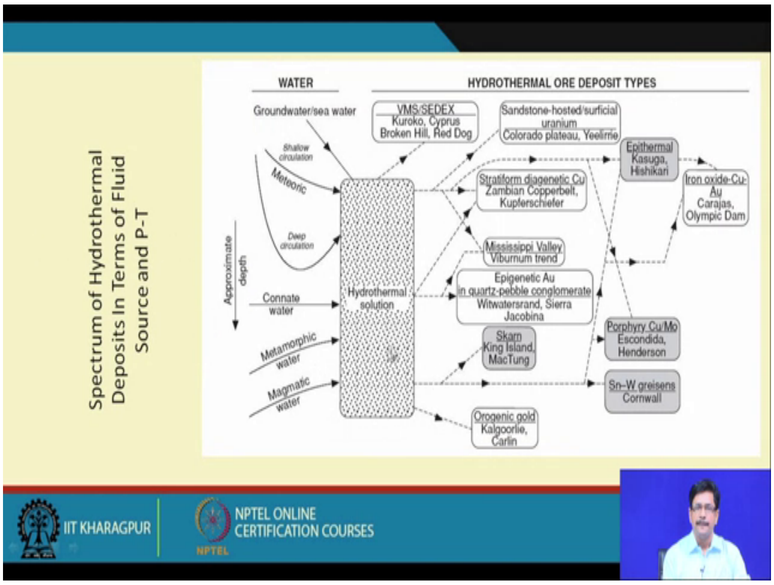

This is a diagram which gives a better overview; here is the depth fringe this also taken from the book of Lawrence Rob. This is hydrothermal fluid this is the depth condition. So, the ones which will be here will be definitely be the surface fluid, meteoric fluid or the low temperature fluid, which are the sedimentary decimal fluid and as we go deeper down. So, they will be magnetic or the metamorphic fluid; we see some of the deposits like four free copper deposit here cling tungsten or the power cling or cling tungsten deposits this Skam deposits and as we go to the more surficial region, we see the alternately the massive sulfide which is dominantly by the sea water, then the starting form copper because a the mississippi valley type deposit coming from the cornett water and this epithermal deposit like the ones which is associated with volcanic island like one in Japanese this is the iron oxide copper gold. So, this gives you a spectrum of deposits and these arrows essentially indicate that there this mineralization process in the hydrothermal system, it generally involves multiple sources of the fluid which are in action.

Sometimes the magnetic fluid could be could mixed with a meteoric field, a decimal fluid could mix with the meteoric fluid a madman the metamorphic fluid could mix with a meteoric fluid or a decimal fluid, and we try to retrieve the signatures of such conditions or chemistry as well as the thermal regime of the fluid through our systematic investigation of the ore minerals and the associated silicate and carbonate minerals associated with the with the ore.

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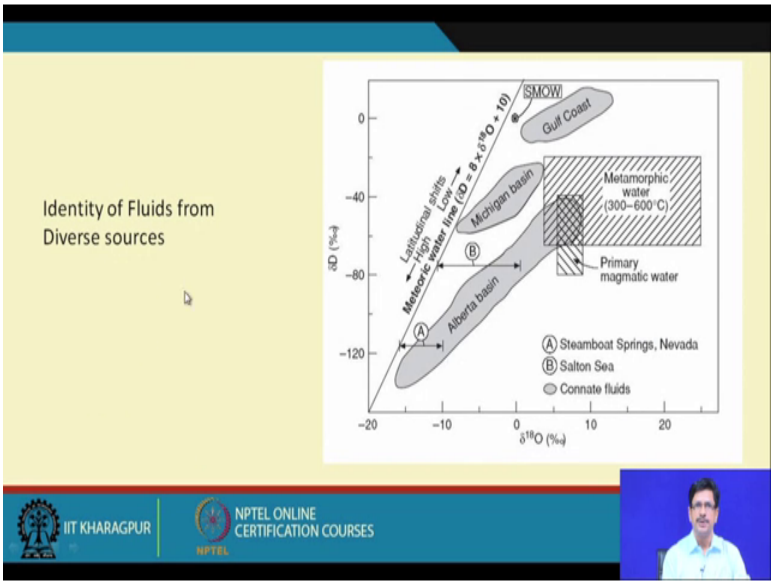

Now, since we are talking about the fluid sources coming from the meteoric source or magnetic or metamorphic or call it and so on. The question that we posed that do we have any identity for such deposits, the answer is yes. We do have if we are able to a sample the remnant of the particular fluid which is cause the mineralization, and we analyze the oxygen isotope ratio, then we would be possibly be able to point to identify the what kind of fluid actually gave rise to a hydrothermal deposit.

This is a diagram on which you could see that the line here is the line for the meteoric water which is only the meteoric water line, which follows a an question could be fit to this particular metallic water line, which is del d is equal to 8 into 10 to the power of 18sorry they 8 into tale 18 ore into 10, and this is shown is the standard that this standard minerals like water now here what basically you see that these are the areas where the gray areas they indicate the three different basins the Alberta basin, Michigan basin and the gulf coast these are the areas where you get mineralization of base metals magnet and zinc and it gives.

An region in which there is variation of both the oxygen isotope delta it in ore and del d and this area we could see that the metamorphic fluid region is defined by a by this box and the magmatic fluid is defined by a box and they do have an overlapping area, because we all know that magnetism about the melting is the regime of melting of crustal rocks.

So, overlaps with the conditions of highest conditions of metamorphism, it increasing temperature and pressure condition. So, we do get an overlapping area. And many of the geothermal systems they show a variation in the horizontal direction without involve without any variation in the hydrogen, through that in an isotope and so this is this gives us a broad idea that the fluid sources could be identifiable.

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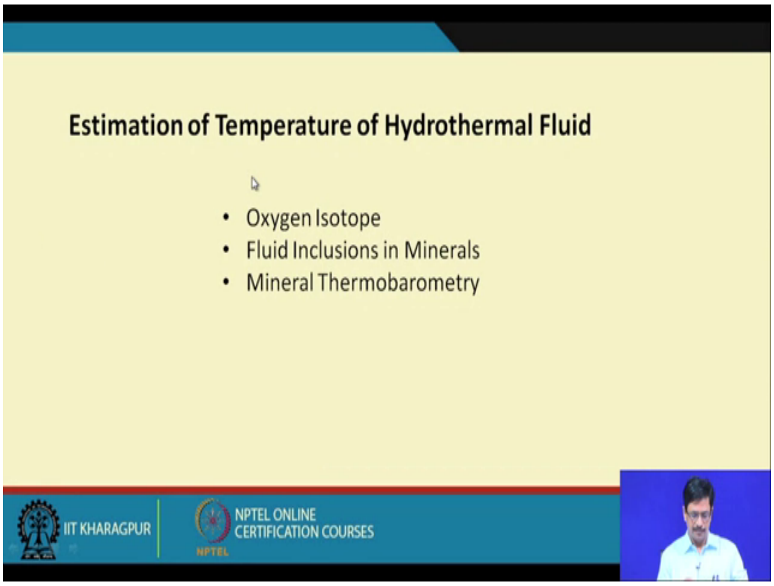

Just for your recapitulation we all know that the parameter, that we are representing as del 8 in o.

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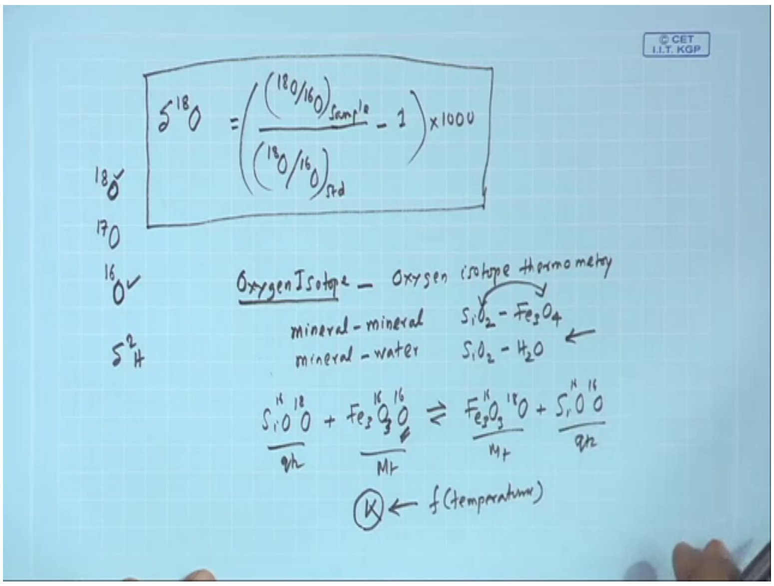

Because we know that oxygen occurs since 3 isotopes 18 O, 17 O and 16 O and we consider only these two isotopes, whose abundance is more and they can be analyzed their ratio can be analyzed in by standard techniques . So, del 18O of any particular the mineral or a fluid I can represent as the ratio of 18 O by 16 O in the sample, divided by 18 O by 16 O a standard that is a one which I showed on the diagram is the standard made of selling water is a standard minus 1 into 1000.

So, this is the value similarly, you also do define del d which is actually del of 2 H, it can be defined also with respect to that standard. Now these we go to the to ask the question as to whether we do have any fluids, which when we are talking about the thermal region of 50 to 500 degree centigrade, you have defined for the range of the hydrothermal fluid. Is there a way that we could also estimate the temperature of the ore fluid; the answer is yes we do have two important techniques to retrieve the thermal regime or the temperature of the ore fluid during the formation of the mineral deposit of interest.

So, we can one of the method is our oxygen isotope; we do have something as a oxygen isotope thermometry. This oxygen isotope thermometry can be considered in the context of a mineral versus mineral, or it can be considered in case of a mineral and fluid say for example, mineral water, say it could be a quartz and a mineral like say magnetite, and it could be a situation like a mineral quartz and water because we know that these two can always exchange. So, this actually the basic principles of it even though we do not have a scope into getting into the detail of it these isotopes this heavy isotope is 18 ore, fraction its between the different reserve waves like we know that when water evaporates from the surface of the ocean, the water vapour becomes less in its 18 O concentration or we mean by saying that it is depleted with respect to the heavy isotope. Similarly when different reservoirs or different minerals and fluid, they react in those kind of scales they do fractionate the heavy isotope the 18 O, which can be very well utilized to determine the temperature I will just try to explain it a very simplified way if I put SiO O s 18 plus F e 3 O 3, O as 16 I could write F e 3 O 3 these are also this this also a 16, and as 18 plus SiO 16 and O is also 16; that means, one exchange there has been one exchange of the one site the exchange has taken place in one 16 O site in magnetite from the 18 O site of silica and this magnetite has become enriched with respect to the heavier isotope.

So, this is quartz, this is magnetite this is also magnetite, this is quartz since this is being written in the form of an equation this equation will have an equilibrium constant K and this equilibrium constant K will always be a function of temperature. So, if we can build up or you can develop the relationship between this equilibrium constant K and this kind of a fractionation which is going on between two entities, like a like here in this case two minerals as quartz and magnetite. And if we are able to analyze the ratio in them then we will be able to formulate the thermometry.

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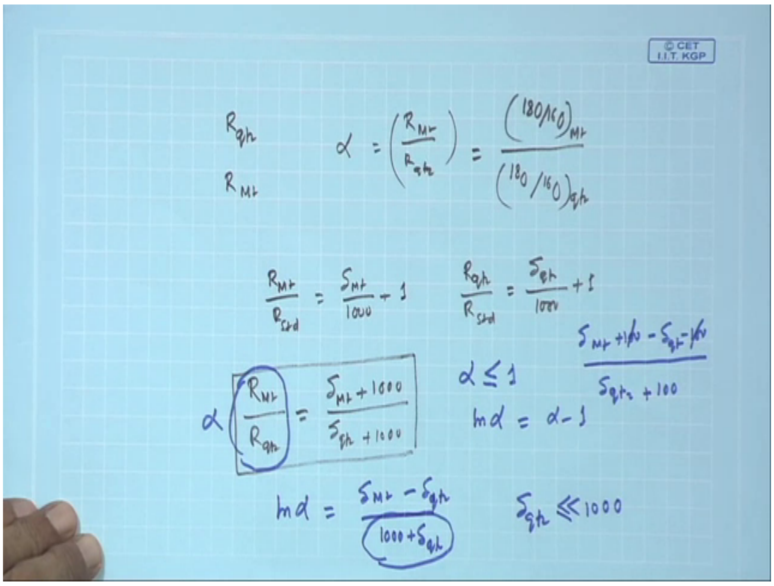

For example, I will represent R quartz and R magnetite and define a parameter alpha as R does not depend what the way I am writing may be R magnetite by R quartz. So, this particular. So, R is essentially the ratio that is the 18 O by 16 O in the magnetite divided by 18 O 16 O in quartz, and from the fundamental relationship that we have developed or we have defined the way the del 18 is being put.

So, I can write say R magnetite by R standard will be equal to delta of magnetite divided by a 1000 plus 1. Similarly I can also write R of quartz divided by R of standard is equal to delta of quartz delta means I means delta 18 O of quartz divided by 1000 plus 1. So, this will lead me to write as R magnetite by R quartz as something in the form of delta magnetite plus 1000 divided by delta quartz plus 1000. So, I know that this is essentially as alpha.

Now, if alpha is much less than 1, then an approximation used that ln of alpha will be equal to alpha minus 1. So, then here the ln of alpha can be put as delta magnetite minus delta quartz, here because this will be if I put alpha minus 1. So, the 1000 thousand will get cancelled and this will give me. So, now this becomes alpha as delta of magnetite 1000 get cancelled. So, this becomes delta of magnetite minus delta of quartz divided by 1000 plus delta of quartz. Here again I will take at approximation that if delta of quartz which is much much less than 1000. So, this can be reduced to just as 1000.

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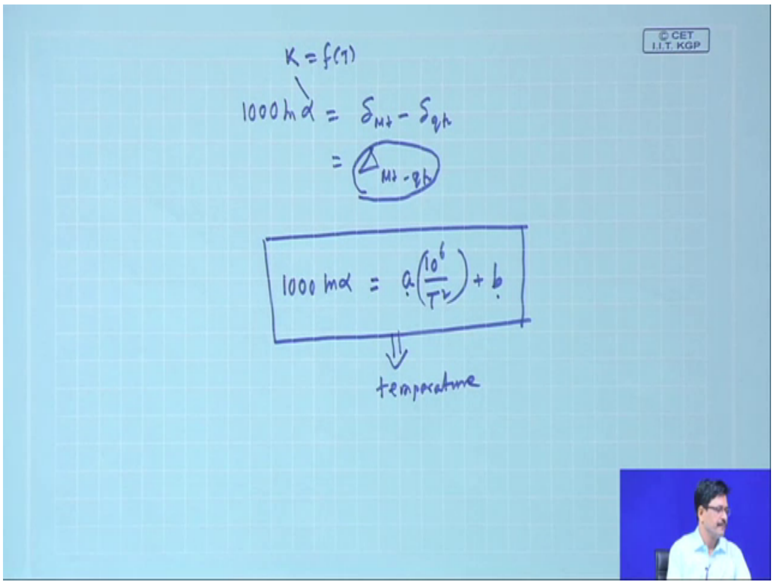

So, this becomes 1000 ln alpha will be equal to delta of magnetite minus delta of quartz, which I can represent as a symbol delta magnetite quartz. So, now as I have already told that alpha is related to K and which is a function of temperature. So, this quantity which is the delta of magnetite and quartz is nothing, but the difference in the ratio of the del 18 O in magnetite and del 18 by quartz, which is measurable and this. So, from that we will be able to once we know the relationship between this K and the temperature, we can always formulate a thermoelectric equation and something like 1000 ln alpha will be equal to say.

Something say a into 10 to the power of 6 divided by temperature square plus say b. And there are several such pairs for which these a and b terms are evaluated several mineral water and mineral pairs for which such kind of things are formulated and this gives us the way the direct means of estimating the temperature, assuming that the we represented same equilibrium state in which they form to retrieve the temperature of the ore fluid. So, we stop here today and we will continue in the next class.