Mineral Resources: Geology, Exploration, Economics and Environment
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Lecture – 28
Hydrothermal Processes and Resultant Mineralization

Welcome to today's lecture, today we will discuss about an important metal the deposits of an important metal; that is uranium. We all know that it is one of the important sources of generation of energy; nuclear energy and it is a most sought after metal. And we all know that the Indian scenario is not that very good as far as the resources of this particular metal is concerned and let us have a brief look on the important types of deposits of uranium in the global scenario.

We do have a lots of deposits; lots of types of deposits of uranium, we just discussed a few classes back about the Paleo pressure taking the witwatersrand example which has been a major source of uranium, the Olympic dam deposit which is belonging to the IOCG class and is a one of the major contributor of uranium.

And today's discussion will be on 3 important types of uranium deposit contributing another the major at the rich sources of uranium and contribute a major proportion of the total uranium production of the world. The first important category is the uranium mineralization associated with the unconformity.

So, that is how these deposits are included in this spectrum of hydrothermal mineralization. They are essentially hydrothermal, deposition is resulted by; resulted from hydrothermal fluid and we will see of what nature whether it is possible to ascertain the fluid characteristics.

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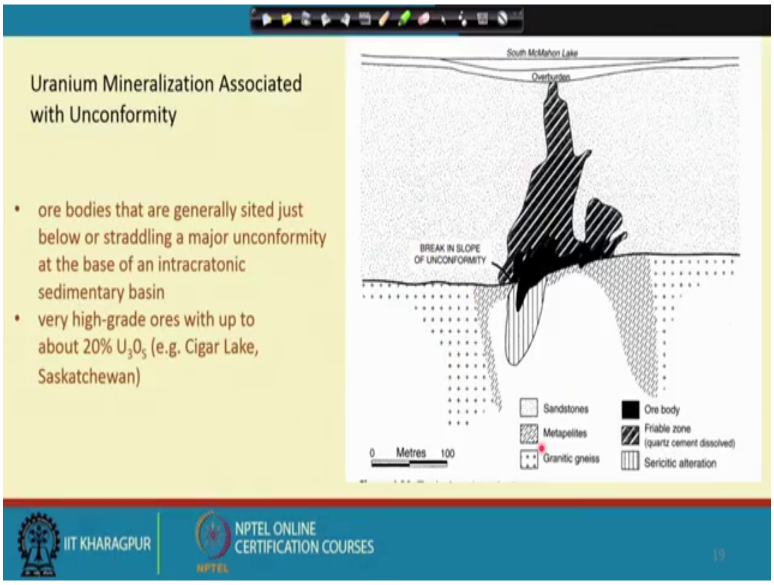

So, this uranium mineralization associated with unconformity constitute a very important and rich class of ore deposits; two important locations or two important deposits, the most rich ones are the Athabasca basin in Saskatchewan, Canada is the most prolific and the alligator river basin in Australia. The famous Cigar Lake deposit in Athabasca basin which is the one of the richest in the world and which go where the uranium this U 3; O S can go up to a percent of 20 compared to the kind of deposits that we work out in India, where the value can go to 0.4 percent.

So, compared to that these deposits are really rich deposits and these ore bodies are generally cited just below the; below are straddling a major unconformity at the base of the intracratonic sedimentary basin. So, they could be broadly classified as structurally controlled because unconformity we all know is provides the suitable structure; where they could act as a trap for the over fluid to encounter to change in environment in which the deposit could take place.

The diagram here is a idealized in morphology of the deposit, where this black part is actually the enriched part of the ore; constituting of the minerals mostly uranium (Refer Time: 04:10) of pitchblende, coffinnite type of mineralization associated with a friable zone this a quartz cement dissolved. So, it is also characterized by some alteration like this is a dominant of the very prominent sericitic alteration which is their observed and the immediate rock surrounding the ore body seems to be desilicified and the silica is deposited in the form of friable quartz cemented zone above the ore body.

And in this situation; it could be kinetic nice basement and the metabolites and this overland by sandstone with a prominent unconformity.

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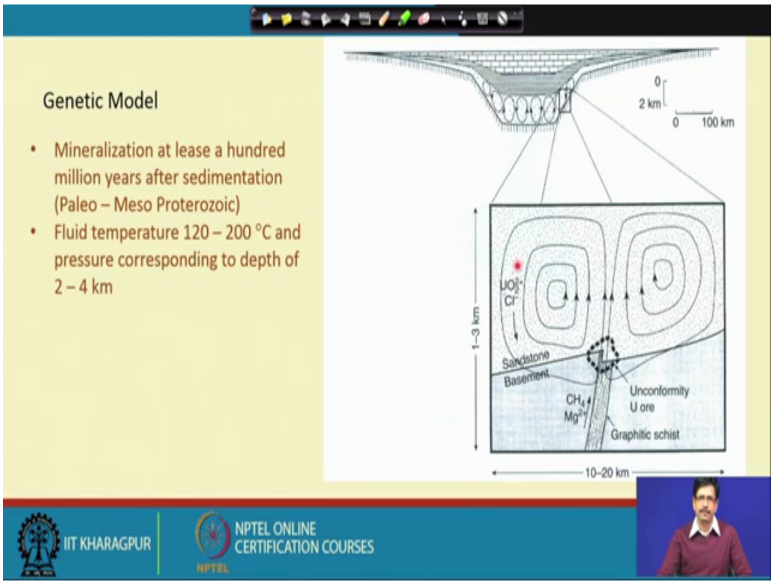

As far as the origin of such deposit is concerned before we; so, let us recall that uranium is a metal, where it is soluble in the oxidized plus 6 state and insoluble in the plus 4 state. So, the general idea is that wherever in whatever the situation if it has to be fluid assisted or the fluid operated, then the fluid needs to be an oxidizing fluid which will be able to dissolve substantial amount of uranium in any different kind of complexing at the urinal kind of complexes.

And then it has to encounter an environment, where it should; the fluids would I mean this would be zone of reduction where the fluid will be able to deposit the uranium in the plus 4 state is UO 2. So, if that is the general framework; the situation that generally prevails is believed to be prevailing in a unconformity related uranium mineralization; where this is the unconformity which is depicted here. And this part which is has been magnified in this switch source and this is the overlying sandstone layer, where there is a hydro thermal convection cell being generated; this hydro thermal convection cells, so this is the area where the condition is oxidizing.

So, its UO 2 plus chloride kind of complex; it could be must have been concluded on the basis of the fluid characteristic. And this convection in whichever way it is driven and in its way down; it is actually encounters a graph it exists its actually shown schematically. So, it has to be a zone which must be a reduce zone with carbonaceous material where the required reducing condition is encountered and the uranium is deposited in the form of the ores the (Refer Time: 07:04)

So, here the fluid temperature could be anything between 120 to 200 degree centigrade and pressure corresponding to a depth of about 2 to 4 kilometers. And the relative time of the mineralization and the sedimentation, these rocks are say this mineralization the unconformity type; associated mineralization exemplified by the Athabasca basin is generally Paleo to Meso proterozoic in age. And the mineralization is at least about 100 million years after the sedimentation; and this is; what is kind of a model, which is proposed for the origin of this kind of deposits.

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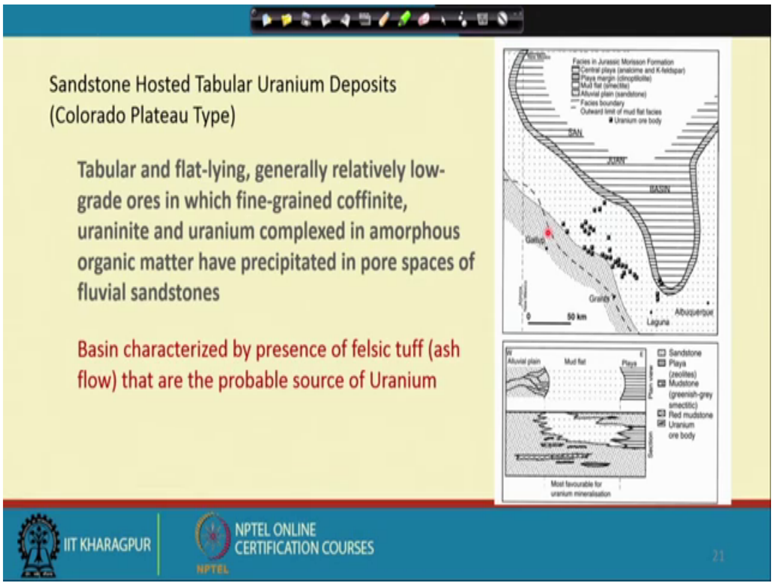

The another important and interesting class of deposits are the sandstone hosted tabular uranium deposits. These are mainly the example which could be given the important one is a Colorado Plateau type; they occur in the Colorado Plateau. So, the ore body is essentially tabular and flat line generally with relatively low grade ores, where fine grained coffinite uraninite and uranium complexed in amorphous amorphous organic matter have been precipitated in the pore spaces of fluvial sandstone. This is a general idea about the occurrence, where this is kind of a basin which could be exemplified by a saline lake kind of basin.

So, this region which is actually the sandstone; it is kind of a mudstone, a region and these locations are for the mineralization in the Colorado Plateau; you could see the scale, this represent it as a huge area in which the uranium ore bodies are shown. They are associated ethologies could be mud mudstone and there are alluvial plane sandstone.

So, this margin is essentially the margin which is essentially is this saline lake which is known as the Playa kind of lake. So, a cross section would make it clear here; so, this is the alluvial plane and this is the Playa, which is the saline lake and the region of mineralization is the mudflat. The basin characterized by presence of felsic to facias material as flow; that are probable source of uranium.

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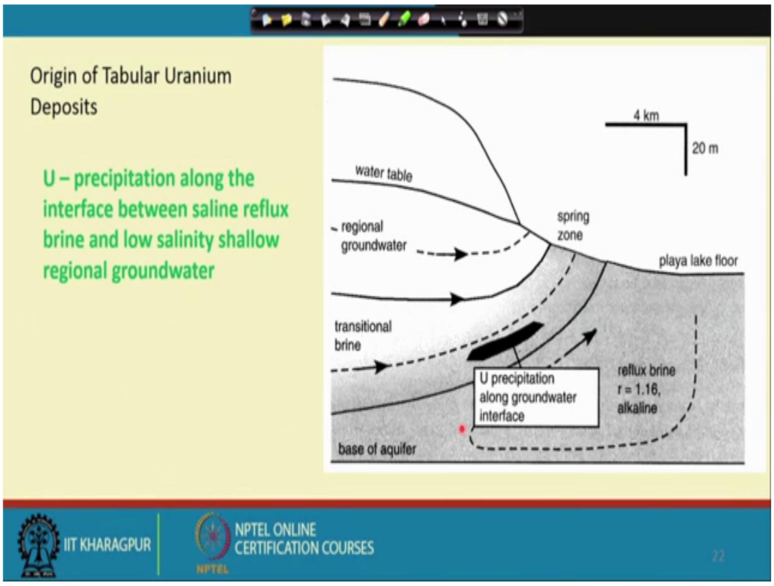

So, here these are only acting as the medium and you could see the way or with the visualized model for the origin of this kind of tubular deposits.

So, what we exactly saw here? So, this possibly is the boundary, this is the mudflat region, this is the Playa lake floor and this part is the delta is what was being shown here as this one this is the alluvial plane.

And this part is the Playa lake flow and what is the important here is that we do have kind of more than one flow path of the fluid; the one part which is there in the more oxidizing zone in the regional groundwater is shown here; this is a transitional brine this is the base of the aquifer. And the deposition takes place when there is a interaction of the reflux brine from the Playa lake, with brine which are and this brine is, this fluid is reducing in nature. And the fluid which is circulating here in this region is oxidizing and is supposed to have carried the uranium. And the uranium coming from the two process material which is present in this as shown here, in this horizon and the uranium is precipitated.

So, abiding by the simple mechanism that if the fluid oxidizing here carrying the uranium and it has to encounter a region, where it should reducing and then the uranium will be deposited and that is how exactly it is visualized. So, it is an interface between the saline reflux brine and the low salinity shallow regional groundwater, which is oxidizing and is the potential uranium carrier.

So, this is one; although it is not and this deposit is not as rich as the unconformity related type, but they do contribute some proportion of the metal.

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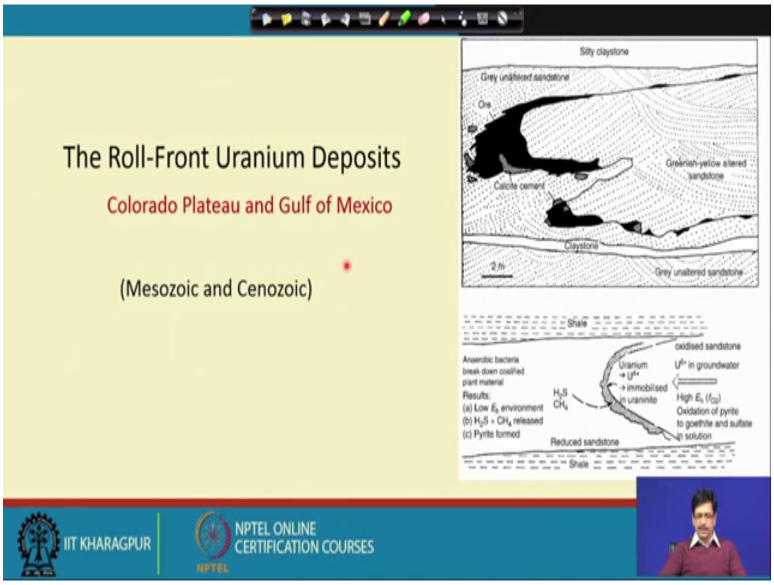

And the last type of uranium deposit which are a interesting class would deposit; which are the roll front type uranium deposit. The name actually derives from the very; way the ore body occurs the shape there is U shape type of the ore body takes; the name is derived from there.

And they are essentially Mesozoic and Cenozoic; this when they form pretty recent times, such kind of deposits in the archaean are not known as not expected even during the time of the Paleozoic and Mesozoic are also not known to be existing till so, far and they are also observed in the Colorado Plateau and the Gulf of Mexico.

Here the situation which could be abiding by the general framework of the chemistry of uranium; the solubility of the uranium species. Strictly speaking, this particular type of uranium deposit; does not qualify to be called as a hydrothermal deposit. Because this fluid, even the sand sandstone types sometimes the temperature of the fluid can go up to as high as 200 degree centigrade or so.

But the roll front type deposits which are mainly observed in sandstones; there the fluid is essentially the groundwater; shallow groundwater, shallow circulating groundwater. So, they do not fall in the temperature range that we have defined for hydrothermal deposit. So, this is an exception to the general class, but just for the sake of continuity; this deposit is included in this discussion.

And as you could see here this is the general morphology, this is the grey unaltered sandstone; here is the ore and the calcite cement what is more important here is that in such kind of situations; this is a large scale map which is been shown here on a plan view. This the control; the mineralized and the deposition of this (Refer Time: 14:32) seems to be controlled by presence of carbonaceous material sometimes some wood material, some plant material or some carbonaceous material which are present and sometimes the ore; even mimic the shape of such kind of fossil wood or materials which are present in this particular horizon.

So, a cross section which is shown here is the shale and the oxidized sandstone uranium 6 plus in groundwater; this is high E h fugacity of oxygen, oxidation of pyrite to (Refer Time: 15:07) and sulfate in solution. So, this particular solution is carrying the uranium in 6 plus state and is moving through the aquifer because in aquifer through which the water will flow; in either just by a hydraulic head or by some kind of process there.

But these are essentially low temperature situation; it is not driven by any kind of a thermal related; any convection or any kind of a flow. And then there is a falsie change from this oxidized sandstone to reduce sandstone. And the margin of the oxidized sandstone; reduce sandstone is the domain of deposition and this deposition takes a very characteristic U shape or the shape of a roll. So, that is how; and this particular zone is also by virtue of its carbonaceous content is methane and H 2 S bearing.

So, it is a low oxidation state low E h environment H 2 S plus C H 4 and the pyrite form; another bacteria will breakdown and some qualified plant material as I just mentioned. So, this provides the essential ground for a deposition of uranium to get it reduced to form its insoluble uranium oxide; so, that brings us to the close.

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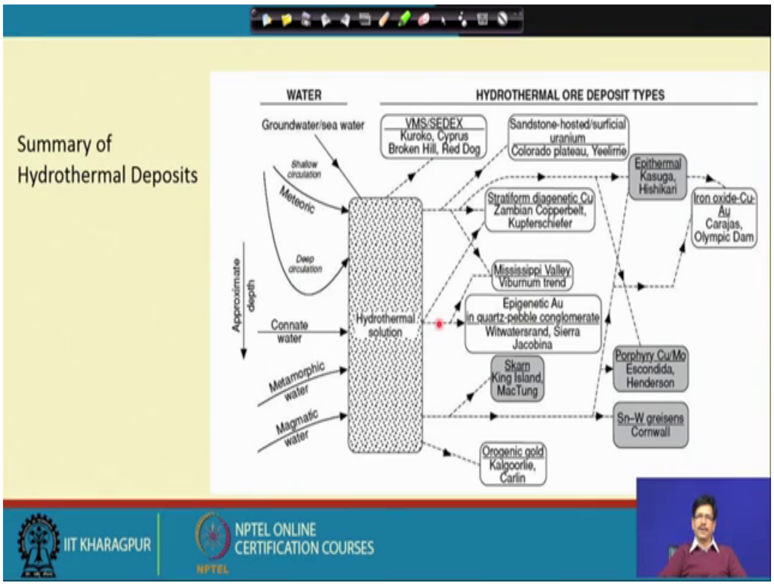

So, what we essentially have been going through it is kind of a journey through a whole spectrum of mineral deposits that result from the activity of a fluid and in almost all, but one case it is a hot aqueous fluid, water rich fluid and the fluid could have any source; could have a very high temperature, magmatic sources as we saw in case of the porphyry type deposits, this skarn deposit and the metamorphogenic deposit.

So, let us have another loop on this particular diagram from which where we started and we see whether we have; now with this kind of discussion, we could possibly review this diagram and see the different types of deposits that we have discussed. And keeping in mind that the hydrothermal systems; even though we classify them as magmatic, metamorphic or vicinal or meteoric.

They do the actual mineralization process is brought about in most of the cases by mixing of fluid of different sources; very common are the magmatic deposits which are the porphyry type deposit, where the mineralization is brought about by at; least by the some component by the cooling of the magmatic fluid by meteoric fluid and the alteration like the properlytic zone and the friable zone are generated with involvement of fluids of meteoric source.

So, mixing of magmatic fluid with mateoric fluid, metamorphic fluid with meteoric fluid are very commonly observed in many such deposits. So, we have seen some special type of deposits; the iron oxide deposit, IOCG; there is a epithermal deposits in young volcanic island; like this is the deposits which we discussed in terms of the high sulfidation and low sulfidation deposits. They Stratiform diagenetic deposit which are essentially coming from very low temperature connate water, Stratiform copper deposits Mississippi valley type deposits also coming from very low temperature connate water.

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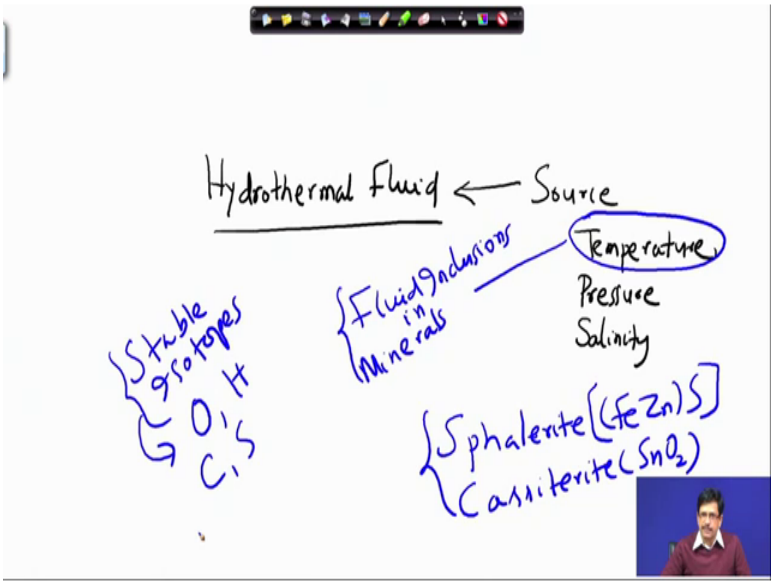

And so, this is the spectrum of the deposits that we saw. So, if we summarize; the important attributes of the hydrothermal fluid is basically the source. And the source of the fluid can only be characterized or can be the source can be traced only when we characterize the fluid completely.

So, the characterization will be in terms of temperature and also pressure which sometimes is significant. And then we have to characterize the fluid in terms of the salinity; in terms of the concentration of all the dissolve species; not only just the metal, but the other constituents which are essential for transportation of the metal in different types of; in forms of complexes.

So, we realized that it is important to understand the transport mechanism of transport of metals in the hydrothermal fluid and so, temperature can be measured from fluid inclusions; in minerals. These fluid inclusions in minerals could be studied in the ore minerals or the associated gang minerals; they could be the common silicate minerals; the commonly occurring gang minerals in hydrothermal mineralization is quartz. And quite often, we do the fluid inclusion studies and calcite on fluorite. And even the ore minerals themselves like we have seen this sphalerite and ore minerals like cassiterite, these ore minerals also can be a fluid inclusions; can also be studied in these ore minerals and the characteristic of the fluid can be very well constrained.

But majority of the fluid inclusion work is carried out in gang like quartz; where we generally find that the quartz is very intimately associated with the mineralization, with the sulfides. And they do represent the characteristics of the original hydrothermal fluid from which the mineralization has taken place.

Fluid inclusions, we used and we saw the methodology of the fluid or fluid inclusions studies by doing homogenization experiments; approximating the temperature of the fluid from the homogenization data. And then we also constrain temperature from stable isotopes, which is mainly oxygen and deuterium and also equally possible is also the isotopes of carbon and sulfur.

So, these light elements; their isotopic makeup they help in retrieving the temperature, we can combine the study of fluid inclusion and stable isotope to arrive at the data on the temperature of the fluid; which will be far more dependable; then getting this temperature, only depending only on one source such as fluid inclusions or stable isotope.

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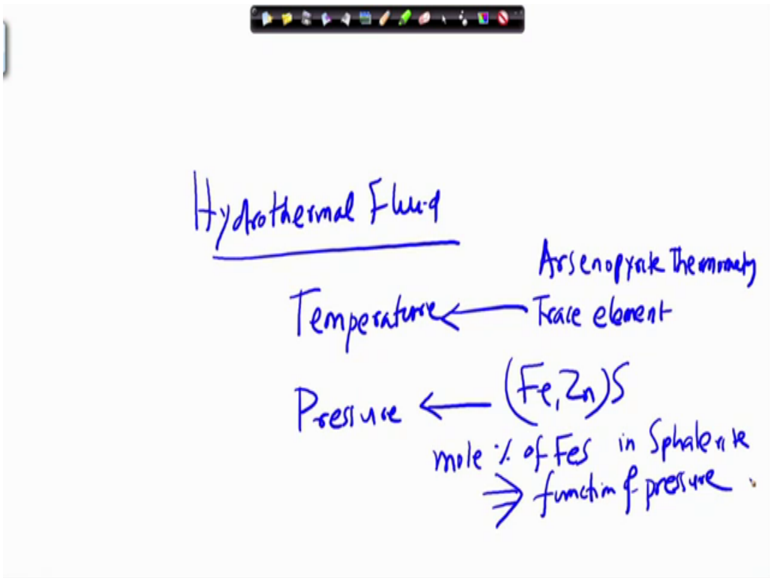

And we also have seen that the temperature of the hydrothermal fluid can also be constrained from the minerals themselves. And we discussed the case of the Arsenopyrite thermometry, we discussed trace element as indicator of temperature. And we also come from the mineral themselves; one although most of the sulfide minerals that we see in the sulfide ore bodies, they do not preserve, they do not freeze their chemical composition, but there are some minerals like sphalerite; whose composition in terms of the mole percent of Fe S is a function of pressure.

And we can determine the temperature and pressure of the fluid from such multiple methodologies, fluid inclusion micro thermometry, mineral thermometry like Arsenopyrite and trace element distribution, pressure determination from using minerals which have been calibrated as the composition being dependent with pressure and formulation a very standard equation, where a pressure could be written as a function of the mole percent of sphalerite. And with some little bit of an uncertainty in the formulation, one can determine the pressure in the hydrothermal fluid.

So, these are the important attributes by which we can characterize the hydrothermal fluid.

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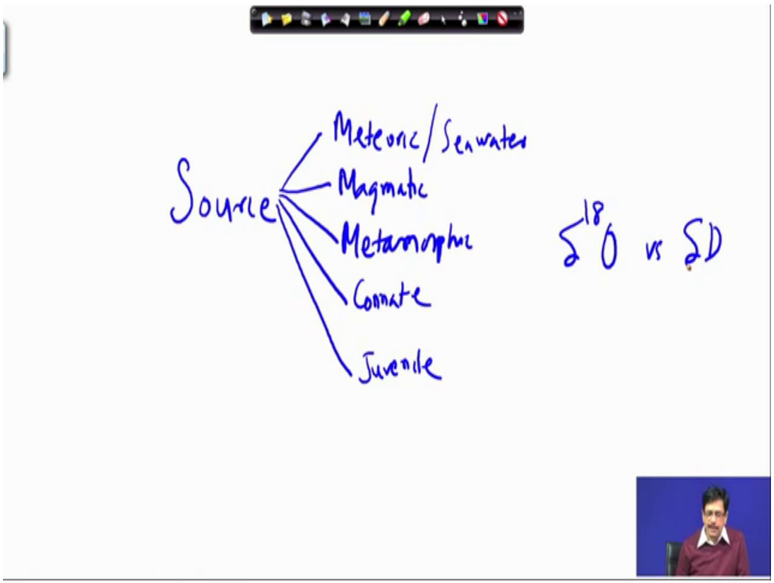

And the other one which we saw as the source of hydrothermal fluid as meteoric, magmatic, metamorphic; these four being the most important ones and the juvenile being very insignificant and I could always include sea water here; because there is nothing, but a modified meteoric water.

And we know that this source could be identified on the basis of the del 18 O; versus del D plot; which we saw the different fields on this particular diagram then the areas or the fields or could be very well delineated and so, if we have the oxygen and deuter hydros isotope data, we could conclusively talk about the source of the fluid.

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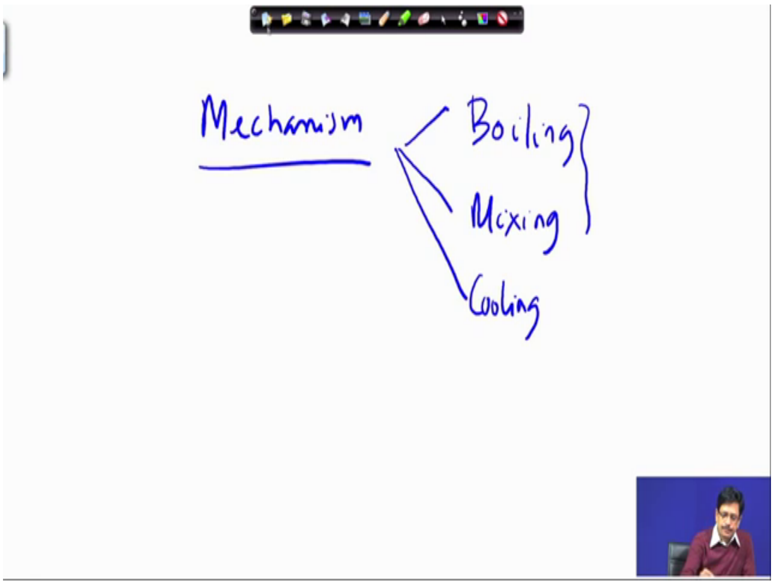

And then the mechanism or the process which was operated during the hydrothermal mineralization mechanism; which also could be very well constrained from fluid inclusion data and combined with isotope data, that boiling of the fluid, mixing of the fluid these two being the most important; other being cooling is also at times could be a good mechanism.

So, these processes also could be identified through a systematic and thorough study of the fluid inclusion characteristics in the ore minerals and the associated silicate gang minerals or other gang minerals. And then that is how we could; so, whenever we are talking about a hydrothermal deposit then we have to answer essentially to the basic question as source of metal.

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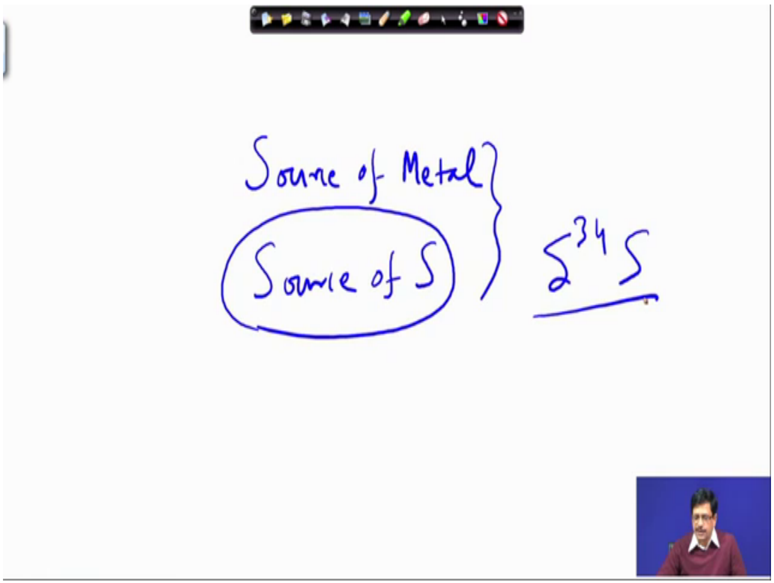

And source of sulfur when the deposit is a dominantly a sulfide deposit like the deposits we have been discussing; may it be a porphyry copper deposit or a skarn deposit or a VMS, SMS or SSC or MET deposit or it is a. So, the source of sulfur is also important and we know that in most cases whenever the deposits are at least Paleozoic, post Paleozoic or. So, we generally get a very significant sea water signature; the sea water is evolved in terms of its delta 34 S; as far as the delta 34 S signature is concerned; it is generally identifiable on the basis of the analysis of the ore minerals for their delta 34 S values.

And; so, these are the aspects which can be collated, combined to build up the hypothesis on genesis of any of the hydrothermal deposit. But through our journey or through the overview that we have made of all the entire spectrum of hydrothermal deposits, covering most of them possibly; we see that it has not been possible to get very definitive answers to these basic queries about the source of metal and source of sulfur in all these deposits.

And also one of the aspects which also remain conjectural in many of these situations are the tectonic setting of these old deposits. Although we see that the modern day hydrothermal systems, we can understand the process very well, but there are always some amount of gaps that remain here and there. So, we will continue discussing on this.

Thank you.