Engineering Geology
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Lecture -12
Metamorphic Rocks

Hello everyone and welcome back. Today's lesson will be on metamorphic rocks. If you recall, we talked about 3 major classes of rocks; one was volcanic rock, then we talked about sedimentary rocks and today we are going to wrap up the discussion on rocks by talking about the origin and engineering issues and uses involved with, involving metamorphic rock masses and metamorphic rock terrains.

Before we get on with today's lesson, we are going to look at the questions that were given to you as part of the previous lesson; these are the questions.

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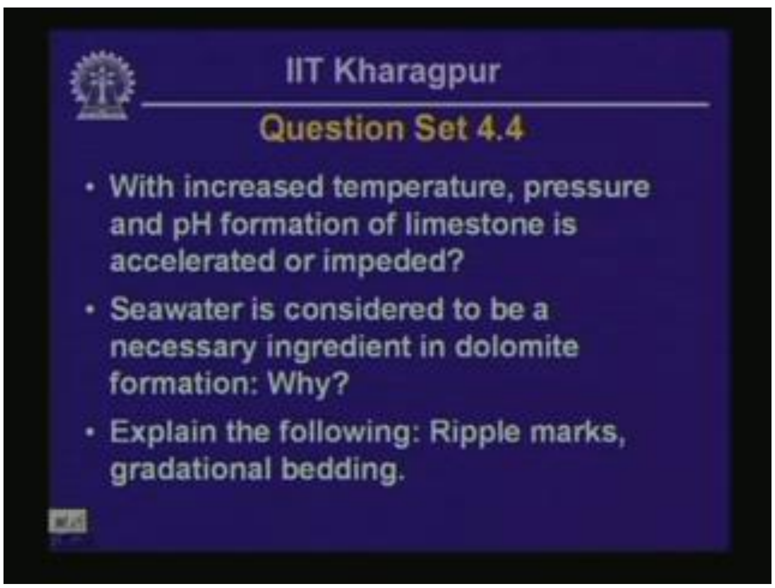

The first one was that with increased temperature, pressure and pH, formation of limestone is accelerated or impeded? In order to understand that we have to consider the chemical reactions involved in the formation of limestone; the basic chemical reactions are like this.

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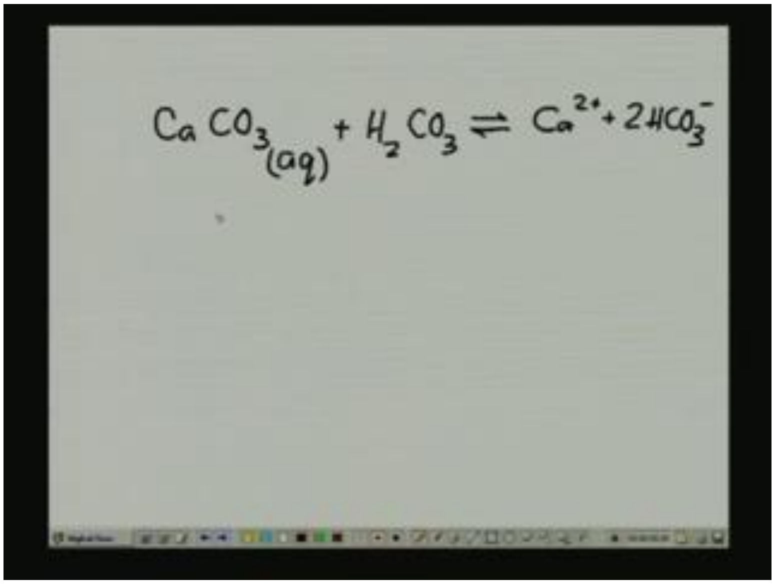

Let us consider a solution, aqueous solution of calcium carbonate, how that actually changes. So, we started with aqueous solution of calcium carbonate and that is going to be reacted upon by - we have got another mistake here - that is going to be reacted upon by carbonic acid and then what we are going to end up with in this process is release of calcium ion and another ion; both of these things is going to be in aqueous again.

Now, this carbonic acid actually is going to come from dissolution of carbon dioxide in water and the reaction involved in that process goes like this.

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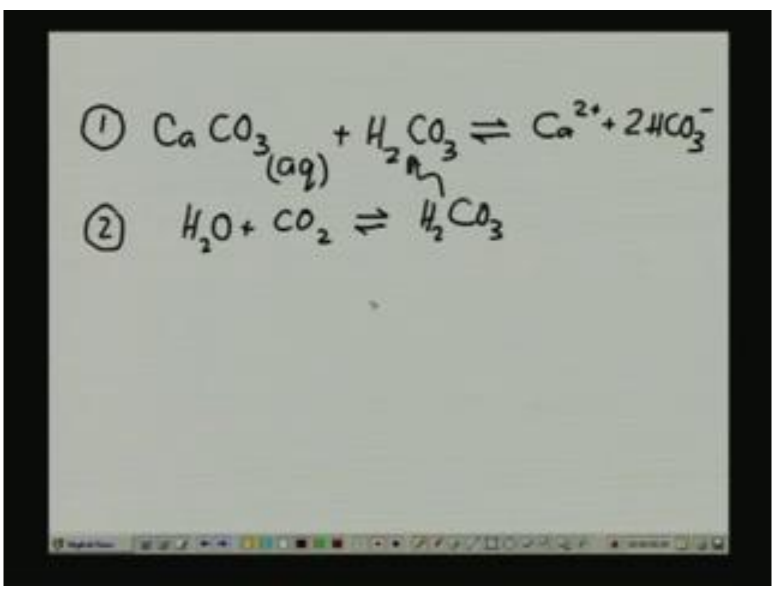

So, this carbonic acid and sub acting, reacting with calcium carbonate. Now, what happens actually? Let us consider the reaction 2, let us consider reaction 2; I mean how reaction 2, the forward rate of reaction 2 is actually accentuated and then we look at what is the impact of that particular rate on the precipitation or dissolution of calcium carbonate.

Now, the forward reaction of dissolution of carbon dioxide in water and formation of carbonic acid: that is actually accentuated by decrease in temperature. So, if temperature goes down, then the forward reaction is actually accentuated; then if pressure goes up, then more and more carbon dioxide gets dissolved in water and that leads to the formation of more and more carbonic acid. So, these are the two factors that lead to increased dissolution of CO_2 and thereby increased H_2CO_3 formation.

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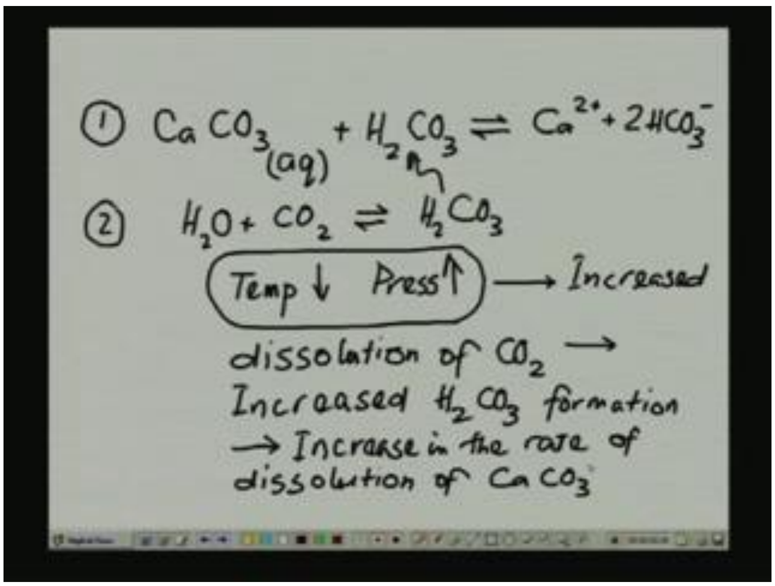

Now since, H_2CO_3 formation is going to actually trigger the forward reaction of dissolution of calcium carbonate, the forward reaction of chemical reaction 1 also is going to be accentuated capitalized by this particular process. So, this will also will lead to an increase in the rate of dissolution of calcium carbonate and the reverse is true if, and the reverse is also true. In other words, if we actually impede generation of carbonic acid by increase of temperature or decrease of pressure, then that is going to lead to the precipitation of calcium carbonate.

So, what is going to happen then is if we actually increase temperature and decrease pressure, then we are going to get more and more limestone and if we reverse these two influencing factors, then limestone is going to get dissolved in carbonic acid.

Now, we also talked about pH, now you notice that the reaction, the forward reaction, actually the forward reaction of chemical reaction 1 actually that is or the rate of that increases as the pH goes down, so if we actually increase pH, then that also is going to catalyze precipitation of limestone. So basically, these are the major factors that affect the precipitation of limestone or calcite mineral in the form of limestone.

In the second question that I asked was sea water is considered to be a necessary ingredient in dolomite formation; why that is so? Now, to understand that again we have to look at the chemical process involved in the formation of dolomite. Now, what happens there is this; we have got one reaction in which we end up in dissolution of calcium carbonate like what we had before.

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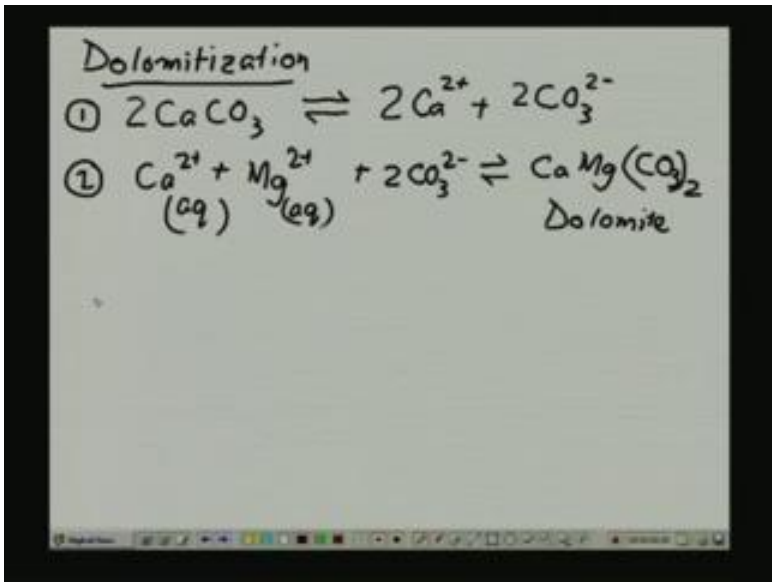

And then, what happens is this; this one here is your dolomite and basically these chemical reactions are clubbed together and I have given the name dolomitization. Now, the forward reaction, for the chemical reaction 2, forward reaction, forward rate of 2 is catalyzed by a few factors.

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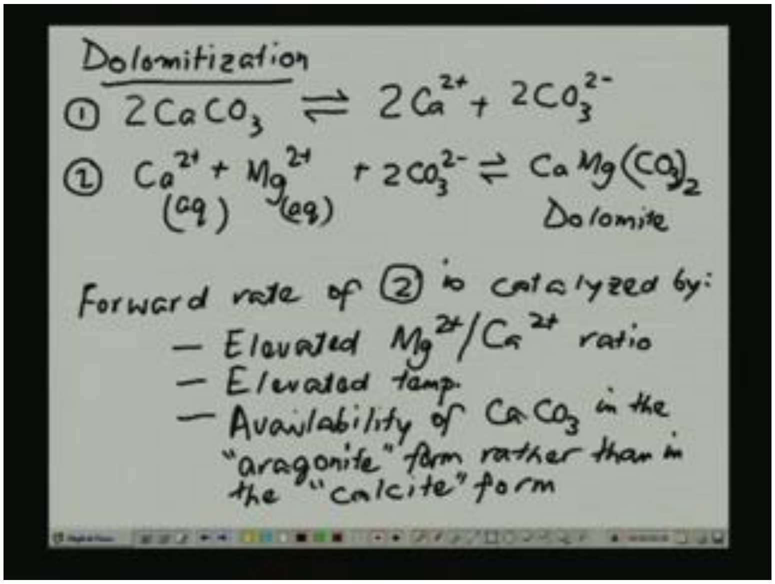

The major ones are elevated availability of magnesium as opposed to calcium ions, then elevated temperature as well and actually availability of calcium carbonate in the aragonite form rather than in the calcite form which we actually looked at earlier. Actually, what I am trying to say here is, calcite and aragonite, they are polymorphs; what we need in order to catalyze the formation of dolomite is availability of aragonite rather than calcite.

Now, all these things, particularly this one is met when sea water gets mixed up with fresh water, fresh ground water and the sea water itself acts as a source of magnesium ions. So, that is the reason why presence of sea water actually is considered a necessary ingredient for the formation of dolomite.

Reverting back to the third question; I asked to explain, I asked you to explain the terms ripple marks and gradational bedding and these things were discussed in the last lesson itself. So, ripple marks are the relic forms of wave actions that are readily visible in the texture of sedimentary rock as is shown in this sketch here.

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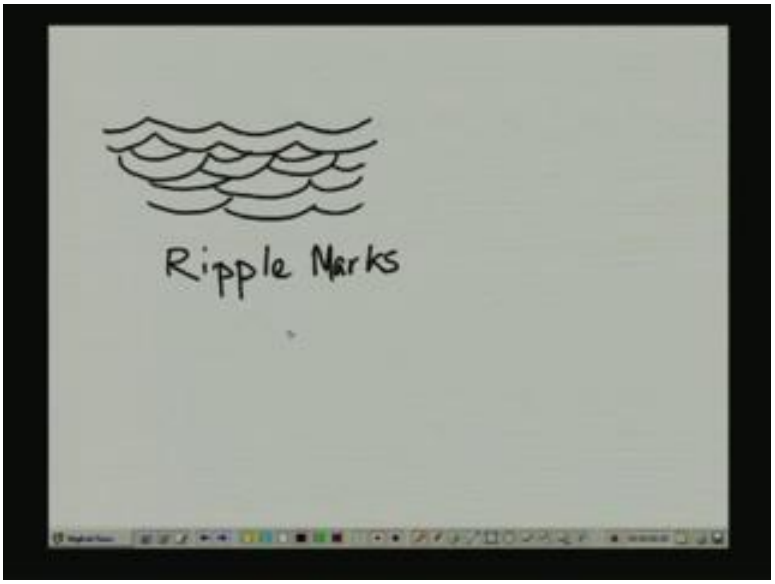

So, this is the appearance of ripple marks in a sedimentary rock structure. Gradational bedding on the other hand is going to be like this; you imagine that sedimentary rocks are often bedded in this form and each of these beds are going to be, going to become finer upward or finer downward as far as the particle size of the composing mineral grains are concerned.

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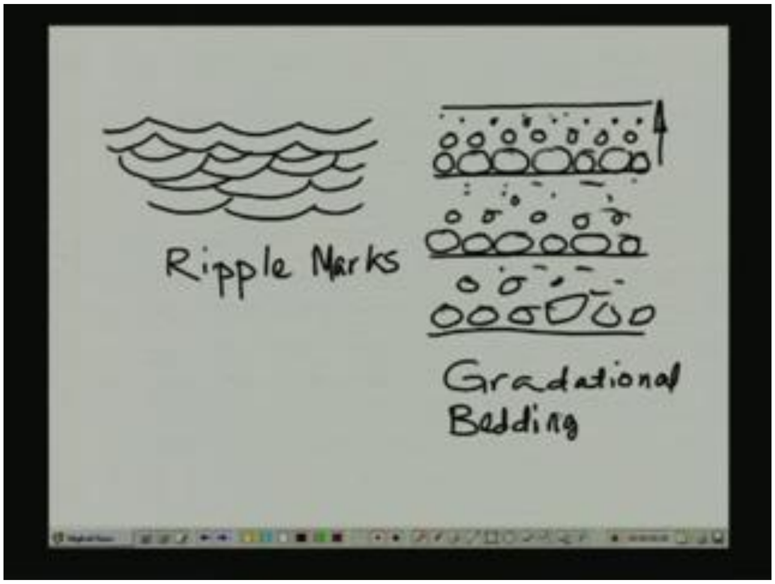

So, in this case, what I have shown is that the particle size is decreasing as you move upward and the same kind of feature is going to be repeated in other beds as well. So, this is called gradational bedding. Okay, all right. So, that kind of takes care of all the questions that were given to you in the previous class and now we hop on to today's lesson.

So, what we are going to learn from this particular lesson? We are going to look at the agents of metamorphism, the basic causes that lead to the development of metamorphic rocks, then we are going to classify metamorphic rocks, look at the grades of metamorphic rocks and we are going to consider basic engineering issues that are involved with metamorphic rocks and economic uses of metamorphic rocks.

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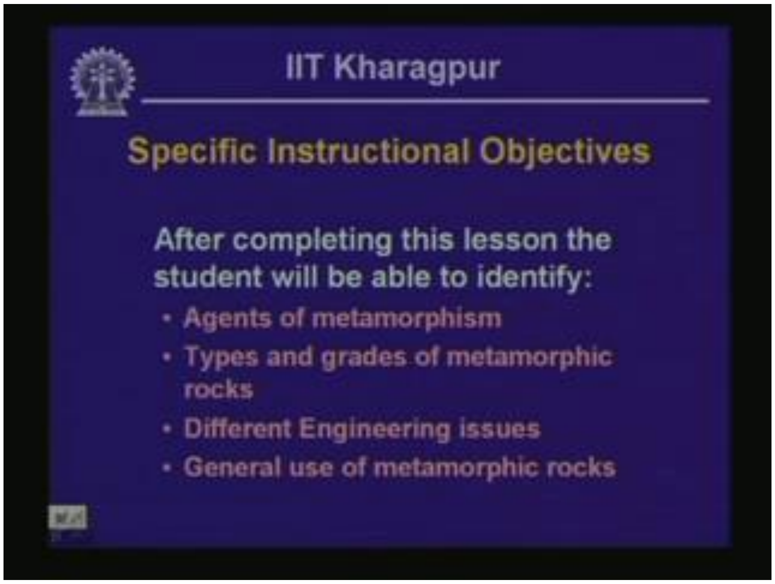

What is meant by metamorphic rock: that is the first question that comes into mind.

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Metamorphosis you know, you may have encountered this term elsewhere and what is meant by that is a process of change. Now, here what happens is what is meant by metamorphic rock? It essentially signifies the fact that these rocks develop by changing of preexisting rocks. These pre-existing rocks are often called photolytes and they could be composed of sedimentary or igneous parent rocks or infact, they could be even metamorphic rocks, preexisting metamorphic rocks.

What causes metamorphism? Metamorphism can be triggered typically by increased pressure, temperature and fluid action. We will see, we will see the details of these things as we continue with this presentation. Now, the effect of metamorphism leads to textural and mineralogical changes of the composition of the rock although in some cases what is going to happen, you will see that the relic forms of the preexisting rock is maintained. So, metamorphic rocks then originate from the action of different agents on metamorphism on preexisting rocks of primarily all the three varieties i.e, igneous rock, sedimentary rocks and metamorphic rocks.

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So, what are the agents that trigger metamorphism? The first one is temperature change and what is important here is the temperature radiant because you can imagine that as you go down deeper from the surface of the earth, then the temperature actually increases at a rate of approximately 35 degree Celsius per kilometer depth.

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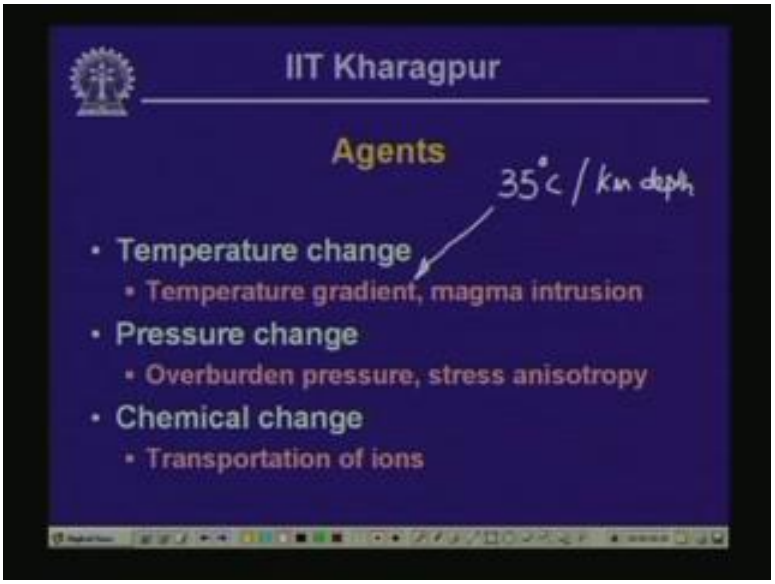

So, with deep burial, a preexisting rock mass; deep burial because of something, because of tectonic activity or because of mountain building or because of any other geologic process, the preexisting rock mass is going to be subjected to an elevated level of temperature. Magma intrusion of partially molten rock forming materials that also is going to elevate the temperature within the rock that surrounds the intruding magma.

Then another agent that actually triggers metamorphism is pressure change. As it happened in case of temperature with burial, preexisting rock will be subjected to an elevated level of pressure because it has to withstand the pressure of the rock or other materials that actually comes on top of it. Pressure change could also be directional and this particular situation happens when in the continental margin where one particular tectonic plate collides with another plate and as a result there are several different regimes of compressional and tensile stresses developed in the lateral direction.

Then chemical change could also be an agent of metamorphism and chemical change is often triggered by the temperature change and pressure change or it could be because of dissolution of rock minerals. Now, second thing what is important here is the grades of metamorphism. How do we classify grades of metamorphism? Now, in order to understand that, what we need to understand is what basically happens because of metamorphism.

Now primarily, what happens because of metamorphism is the minerals within the preexisting rock is if they are hydrous minerals, they are going to lose increasing proportion of water within the mineral structure and also they are going to lose gases such as carbon dioxide. Basically, metamorphism involves reduction of hydrous mineral percentage within the rock mass and also there will be reduction of carbon dioxide within the mineral structure. So, that actually leads to change of or it actually changes one mineral to another. Now, these two processes are triggered by increase in, primarily by increase of temperature and pressure.

So, as the process matures, in order to have a matured metamorphic process, we need to elevate the temperatures as well as we need to elevate the pressure. So, this particular chart here shows a plot where we look at different metamorphic grades.

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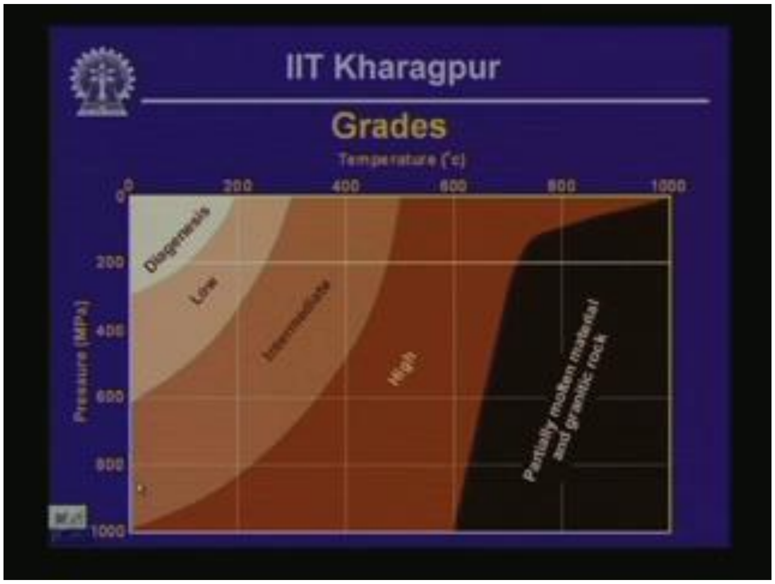

So, when there is not much of change of temperature and pressure, the processes involved in that case is diagenesis; we know what is meant by that term from our previous presentations and then we get into the zone where what is known as low grade metamorphism which actually takes place in the temperature range maybe 200 to 300 degrees Celsius and pressure range between 300 mega Pascals to about 600 mega Pascals.

If we increase the temperature further and or all increase the pressure further, then we get into intermediate grade of metamorphic rocks and the temperature range for that is between 300 and 500 degrees Celsius typically and the pressure at which intermediate metamorphic rocks develop that actually varies typically between 600 and about 1000 mega Pascals.

If the temperature and pressure increases further, then we are going to get high grade metamorphic rocks and these rocks are going to be, going to contain least percentage of hydrous minerals such as different varieties of mica. And the zone, the ranges of temperature and pressure for high grade metamorphism is shown on the plot there; the temperature could vary anywhere between say 500 and say typically 800 to 900 degrees Celsius and the pressure range is typically more than 1000 mega Pascals and if you increase the temperature further and or all increase the pressure further, you are going to end up with melting the rock mineral partially.

So, what is happening here on this chart is that as we go down from top left to bottom right, we are losing more and more hydrous minerals and we are going to also loose gases such as carbon dioxide.

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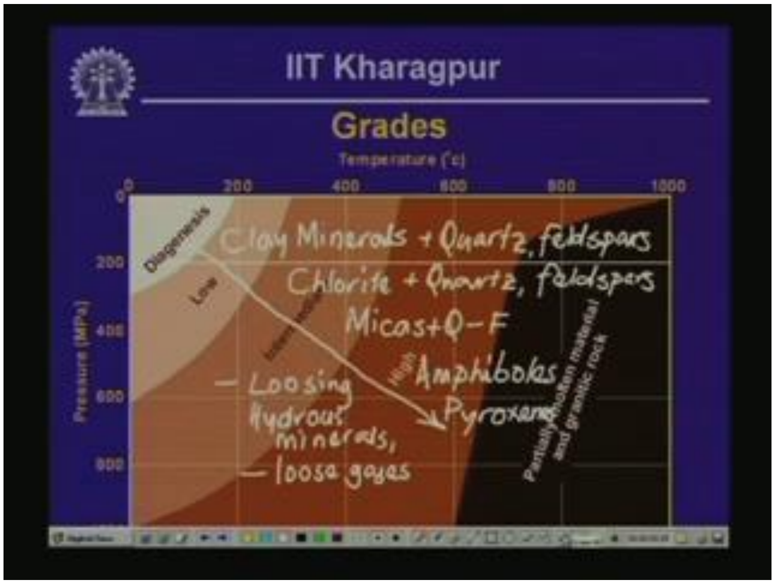

So, these are the two major features of these processes. And also, we will see later that in this particular direction, we will start typically from clay minerals, there may be some quartz and other stable minerals also in the rocks that we begin with but this clay minerals actually are going to be evolved into chlorides, then we are going to start getting more and more micas and then we are going to start getting more and more other mineral, there will quartz, quartz and feldspars in all the cases and here also you will get quartz and feldspars and we will get more and more minerals of other varieties as we proceed to the bottom right such as we are going to start getting amphiboles and pyroxenes as we move down to the right. So, that actually in a nut shell gives you what is meant by grades of metamorphism.

Now, there are different types of metamorphic rocks or metamorphism, the process of metamorphism depending on what are the or depending on what factor triggers the process; there will be several different types of metamorphism and those are listed here.

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The first one is called contact metamorphism; in this case, metamorphism is triggered by an intruding mass of molten magma. Then we can have regional metamorphism and this particular type of metamorphism is triggered by a large scale geologic process such as tectonic collision or other types of tectonic activities, mountain building process and so on and so forth.

The third type of metamorphism is called cataclastic metamorphism and this type of metamorphism is triggered near the vicinity of a fault; we know what is meant by fault from one of the earlier presentations and also there are other types of more rare forms of metamorphism such as hydrothermal metamorphism.

Actually I would not call hydrothermal metamorphism as a real one but this is actually triggered near the divergent boundaries; we will see actually what is meant by divergent boundaries when we get into play tectonics later on. These are essentially under sea vents from which molten magma comes to surface at the sea shore leading to the formation of basalts, basaltic rocks.

Hydrothermal metamorphism is triggered basically by convicting water at elevated temperature near surface actually and finally, we could also trigger metamorphism because of very heavy impact such as those encountered during the impact of meteorites.

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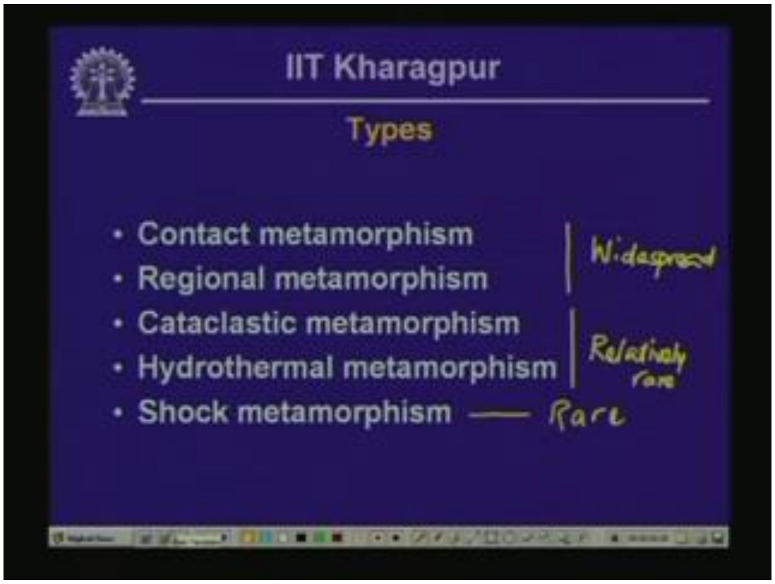

So, what I wanted to suggest here is that this one, this type of metamorphism is quite rare whereas these two are relatively rare and these two quite widespread, relatively speaking. We will get into the details of each one of these things in the next little bit and we will start with contact metamorphism.

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So, what drives contact metamorphism? Contact metamorphism is driven by or triggered by the fact that a large mass of molten magma intrudes into preexisting rock mass; that could be sedimentary rock or that could be other types of chemically formed rocks or volcanic rock or all kinds of rocks, in those it is intruded by molten magma. Then what happens is the rock mass that surrounds the molten magma is going to be subjected to elevated level of temperature, not so much on increased pressure and that temperature radiant actually triggers chemical changes, chemical and mineralogical changes and that is cause of contact metamorphism.

These things, these types of metamorphism typically takes place at shallow depth because at shallow depth only you are going to get a large temperature gradient; what we mean by temperature gradient is that the rate of change of temperature specially as we move from the surface of the intruding magma to the surrounding rock away from the intruding magma.

Now, what happens actually? As we go to deeper layers, then the surrounding rock around intruding magma is going to be also at an elevated temperature. As a result, we are going to have a larger rock mass around the intruding magma at a relatively larger temperature and the gradient, temperature gradient as a result is going to decrease quite a bit as we go down deeper.

Now, what we also have, what we also have in this case is the pressure gradient is relatively small and as a result, these particular type of metamorphism gives rise to rocks that are not foliated or layered. What we mean by foliation is essentially the foliated rocks, they are composed of layers inter layered structure as you will see in the next little bit.

Now, there are couple of definitions in this connection; the intruding rock mass, the rock that surrounds the intruding rock mass where metamorphism is taking place that particular layer around the intruding magma is called aureole and examples of rocks that arise because of contact metamorphism include hornfels primarily and you could also get quartzite and marble.

Now, we want to have a look at different grades of contact metamorphism and as we have stated, as we have learned earlier that pressure increase in this case is going to be relatively modest. So, we are going to look at, we are going to look at depths typically less than 10 kilometers and pressures typically less than say 300 MPa and in this case we are considering the grades of metamorphism that arises because of metamorphism of pelitic, quartz, feldspar and mafic rocks.

The term pelitic is new to you actually and what is meant by that is rocks that are composed of primarily of clay minerals that actually arise from diagenesis and cementation of clay layer, layers of clay. Examples of this type of rock includes clay stone, shell and so on and so forth and slates also; although slate is a little bit far the down on the grade of metamorphism compared to shale rock.

Now, we can see the different types of metamorphic rocks that arises because of contact metamorphism and that is shown here on this particular chart. This is actually a section of the plot that we have already seen.

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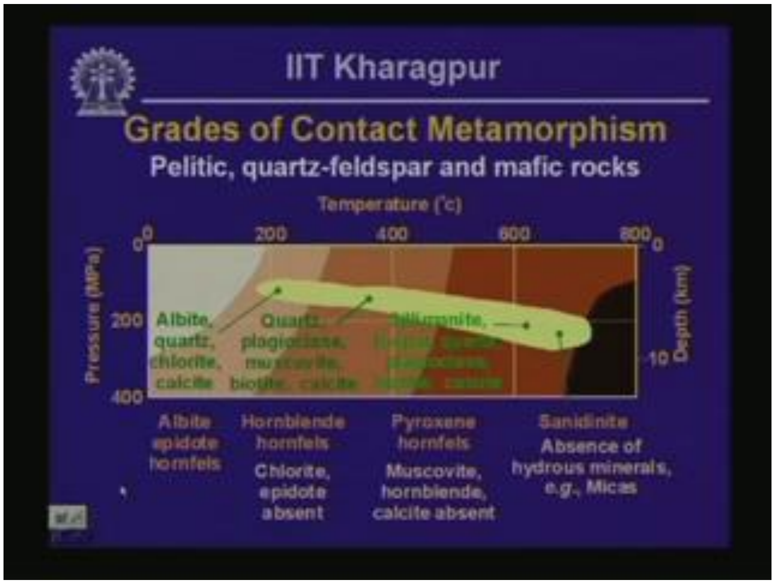

Here, what we are interested is the range shown as, range that is shown as yellow shade. So, what we are looking at is this particular area, this particular area, this particular range of temperature and pressure.

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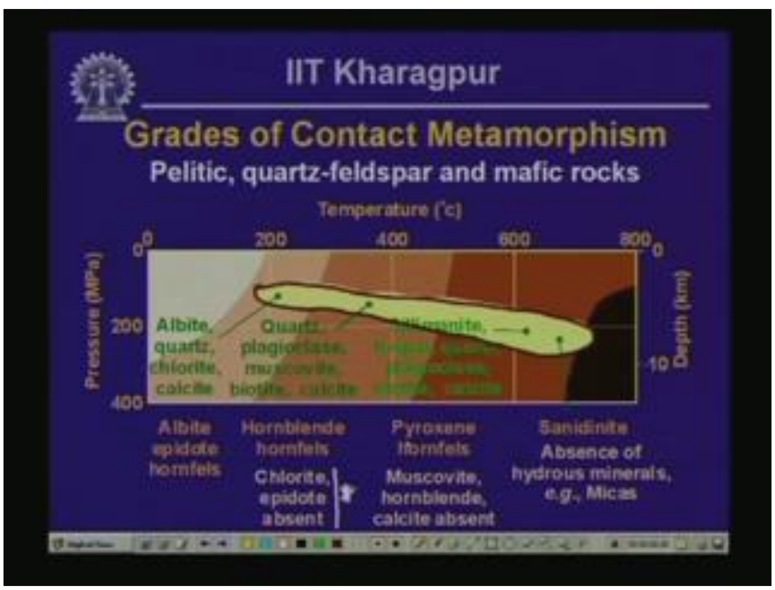

And here, as it is evident, we begin typically from rocks that contain a large proportion of clay minerals. Then we move on to a particular class of rock which is known as the albite epidote hornfels species which is to the left which is near the left end of the range of pressure temperature that we are considering here; that contains predominantly albite mineral, quartz chlorite and calcite.

Then we move on the hornblende hornfels species. In this case, we have got primarily chlorite, we have got primarily quartz, plagioclase, muscovite and biotite and mica and calcite and what you should notice here is that from these species, chlorite and epidote minerals are going to be absent typically and then as the grades of metamorphic rocks becomes higher, then we are going to get into pyroxene hornfels which contain a large proportion of pyroxene minerals.

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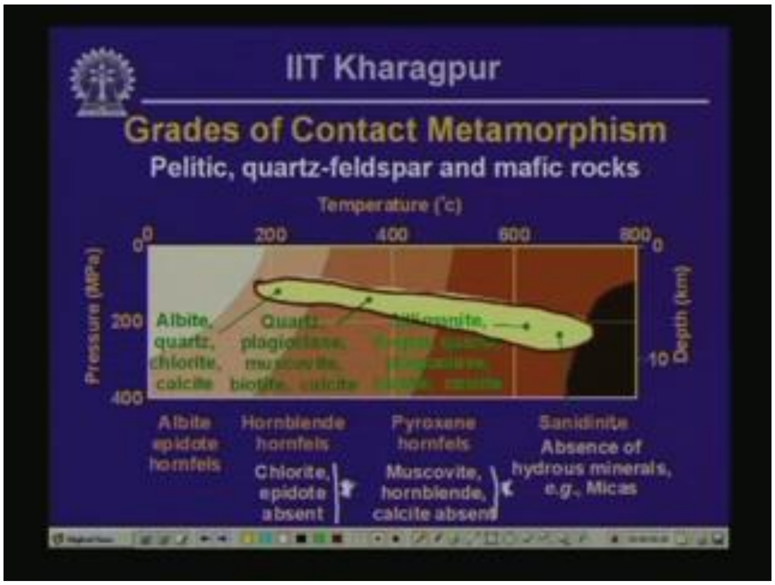

What you are going to get here is absence of muscovite, hornblende and calcite and finally at the highest grade where we are very near to the intruding magma, you end up with a class of rock which is called sanidinite species and here you are going to have a total absence of hydrous minerals such as micas and abundance of pyroxene minerals.

In other words, you must have noticed, if you recall from what we have said when we were talking about chemical composition of silicate minerals; the pyroxene minerals are essentially single chain minerals. So, as the grade of metamorphism matures, what we are getting is a reduction of the proportion of hydrous minerals, a reduction of double chain minerals and an increase of single chain minerals. So that is the major process that you should take a notice here.

Now, contact metamorphism also leads to the formation of another type of, another class of metamorphic rocks which originates when magma intrudes into preexisting carbonate rocks such as limestone and dollarstone.

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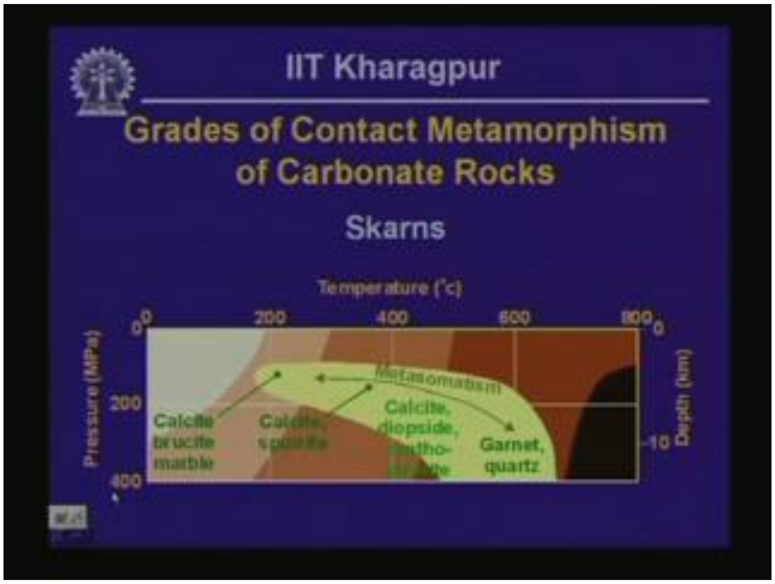

Now, the type of terrain that actually develops in this process is called Skarns. Now, here what happens? In this particular case, we start from calcite brucite minerals. If you recall what is meant by brucite from your chemistry, from the discussion we may already know actually, this one; so what we mean by brucite is essentially this particular chemical.

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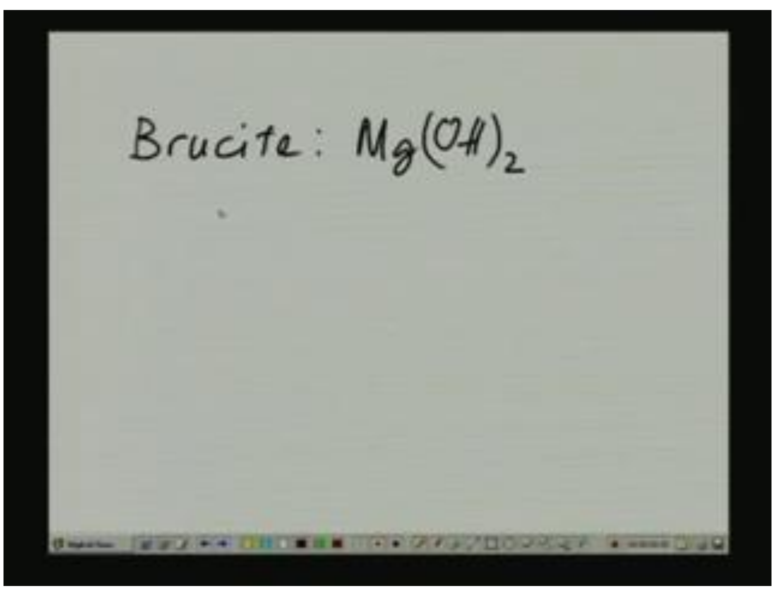

So here, we start with calcite Brucite. Calcite as you know already that it is simply calcium carbonate and then at the low grade, lowest grade of metamorphism, we get marbles in this case, essentially calcite, this arises because of recrystalization of calcite and brucite and then as the metamorphic grade increases, then we will get minerals such as spurite, calcite is also present.

Then, we will end up with minerals that have a larger proportion of pyroxene minerals such as diopside.

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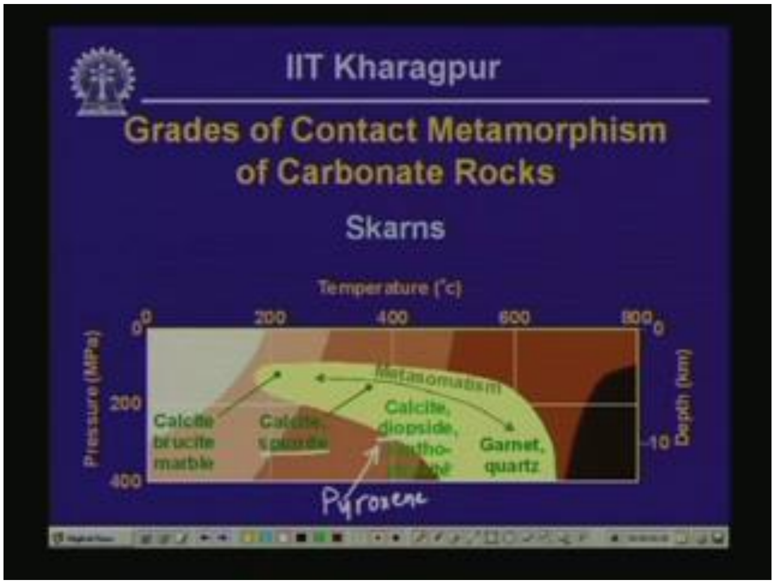

So essentially and finally as the grade as the metamorphism matures even more, then we are going to get granites and quartz to an increasing extent and here, also you should know that as the metamorphic grade increases, then we also get more and more, more and more mineral ores such ores of gold and limonite, tungsten so on and so forth.

So, the metamorphic rocks species which is near the contact of the intruding magma and the surrounding preexisting rock are often rich sources of those kinds of mineral ores and we will see this thing later on as we continue with this particular presentation.

The second type of metamorphism that we want to consider is regional metamorphism. So, as I mentioned earlier that this particular type of metamorphism takes place because of large geological processes such as near subduction zones or mountain buildings.

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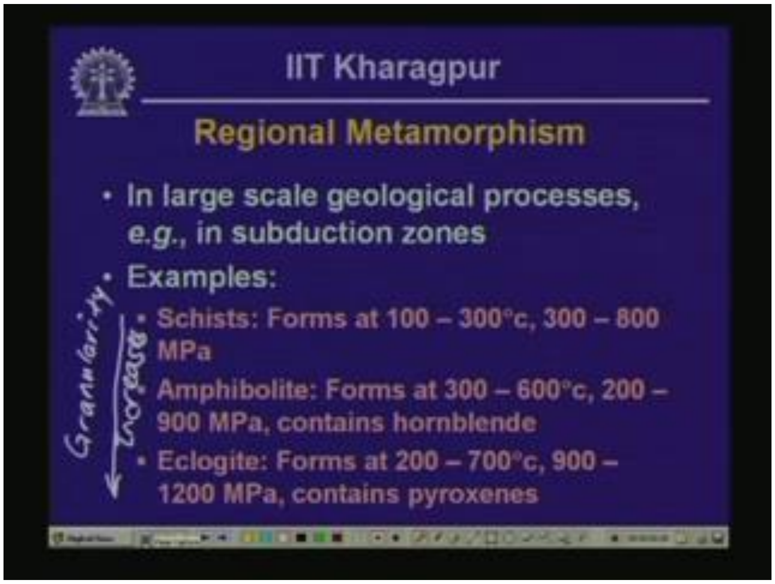

Examples of rocks, metamorphic rocks that arise because of regional metamorphism include Schists. The formation temperature in this case is between 100 and 300 degree Celsius typically and formation pressure is between 300 and 800 MPa, amphibolite at larger temperature at 300 to 600 degree Celsius 200 to 900 MPa pressure; these things actually contain double chain silicate minerals and eclogite and much higher temperature and pressure as is indicated at the bottom of the slide here, 200 to 700 degree Celsius and pressure of 900 to 1200 MPa and these things, these particular class of rock is rich in pyroxene minerals.

And also, another thing you should notice in this case is that as you go down, as actually the grade of metamorphism increases; the grain size - the granularity of these rocks also increase, granularity increases with grades of metamorphism in this case. These or this particular cartoon actually shows the grades of different metamorphic rocks that we already have discussed.

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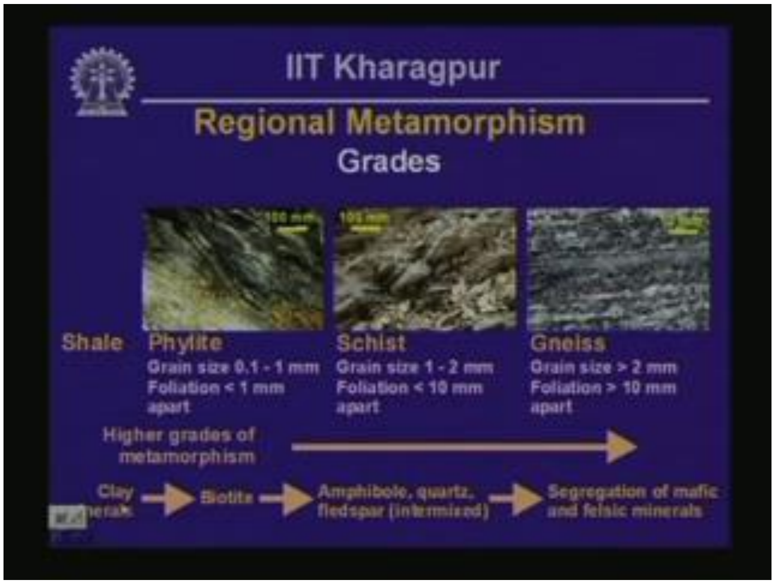

So, we begin with the relative rocks such as shales and then we move on to phylite, schist and gneiss with increased grade of metamorphism and the chemical changes as we have already discussed involves change of clay minerals first into biotite, then double chain silicates quartz and feldspar and finally what happens actually because of directional pressure in this case and that is a very major difference between regional metamorphism and contact metamorphism; these particular type of metamorphism involves application of directional pressure and that directional pressure application leads to the segregation of mafic and felsic minerals leading often to a foliated structure like what is seen on the pictures of phylite, schist and gneiss. All of them are examples really of foliated rocks or which involves, which is actually a composition of plate like entities.

So, this particular type of structure develops because of application of directional, directional application of pressure and this particular aspect was absent when we were discussing contact metamorphism. So, contact metamorphic rocks, they do not show typically foliated structure, whereas rocks that arise out of regional metamorphism processes show often foliated structures.

The other type of metamorphism is cataclastic metamorphism. This particular type of metamorphism occurs near the fault zones and that is because of the deformation breakage because of friction and welding because of elevated heat that is generated because of the movement of fault.

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The processes involved here includes heat and pulverization of the rock mass, preexisting rocks that are very near the fault zone and the two examples, the two best examples perhaps of rocks that arise because of cataclastic metamorphism include mylonite and fault breccia. Now, there is a fundamental difference in the environment in which mylonites and fault breccia arise and that has something to do with the depth at which the fault movement is taking place, depth below the surface.

So, at greater depths, the rocks are at elevated temperature and they behave in a much more ductile manner and in this case, the type of metamorphic rocks that arises is mylonite; whereas fault breccia is typical of brittle failure of the rock masses along the fault zone and this includes classes of previously existing rock masses around the fault and they often times get welded because of heat and that leads to the development of fault breccia.

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Then the other type of or next class of metamorphism is hydrothermal metamorphism and this is really because of the interaction between the rock and hot water and a very good source of hot water is near mid-oceanic ridges and those hot water near hydrothermal vents, they are called, they are rich in many different types of minerals that come out from deep underground and this type of metamorphism is common in case of basaltic rocks which lack hydrous minerals and an example of this class of metamorphism is or the type of rock that develops from this type of metamorphism is soapstone which involves the chemical change of pyroxene mineral to talc mineral and also zualite rocks, they also to a large extent develop from hydrothermal metamorphism.

Shock metamorphism on the other hand is caused when tremendous increase of pressure takes place, not so much increase of temperature, tremendous increase of pressure results because say of meteorite impact or volcanic eruption and the pressure that you are looking at is very very high of the order of 2400 MPa. If that happens, then exotic rock minerals actually develop, they are not very widely or they do not occur very widely on the surface of the earth because they are unstable at ambient temperature pressure conditions.

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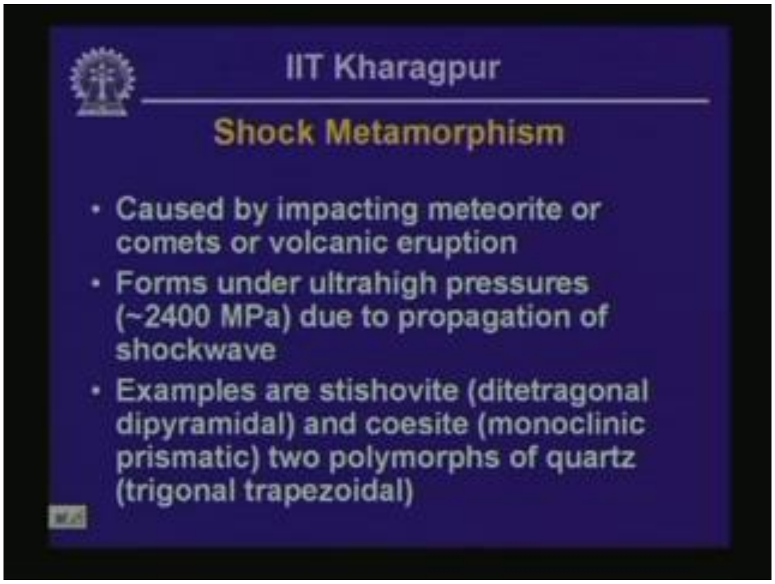

Examples of that is stishovite which is actually, stishovite and coesite; they are both polymorphs of quartz. All of them has got the chemical formula of SiO_2, all of them has got chemical formula of SiO_2, so SiO_2 is the chemical formula of quartz, stishovite and coesite but you can see the crystal structure of these three types of minerals are quite different from each other.

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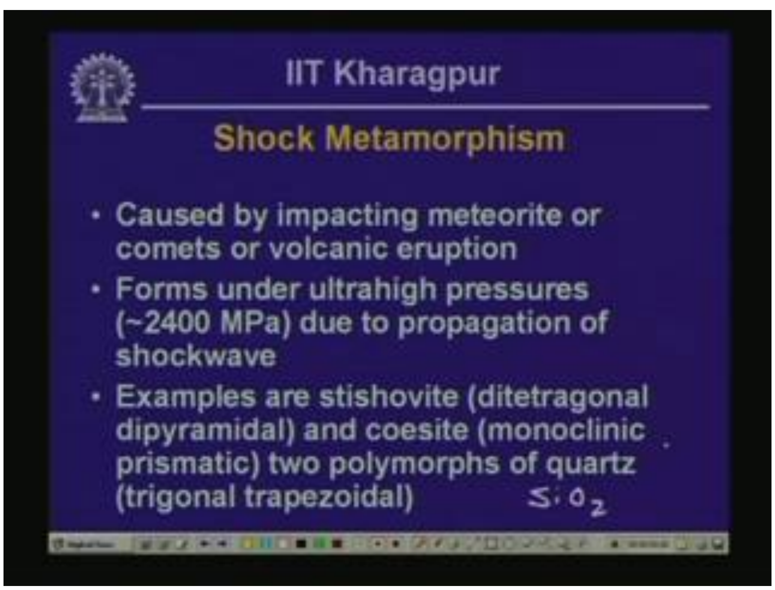

Now, textures of sedimentary rocks.

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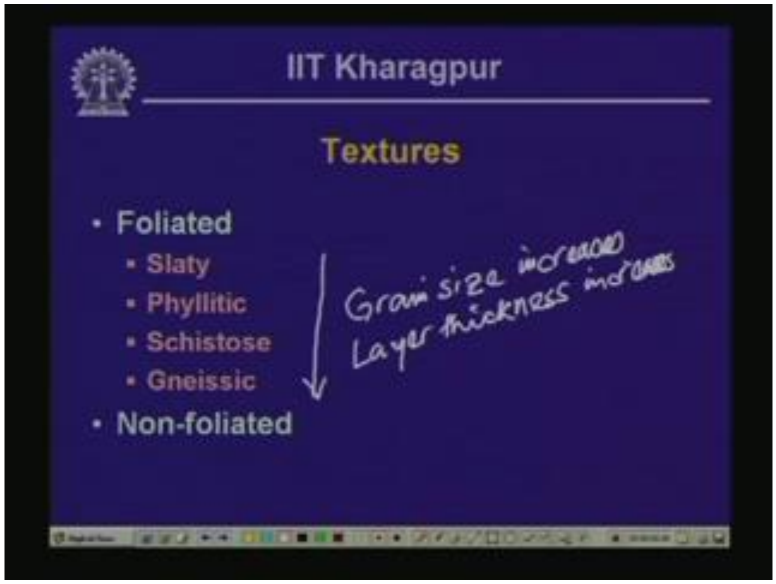

So, we have already mentioned that sedimentary rocks could be foliated or non-foliated. Foliated, if they actually have got layered structure or otherwise they are called non-foliated. Now, there are different types of foliated structure like slaty. Slaty is typically what is meant by that is it is composed of, it has got slate like, slate like layers which are quite slippery, slippery and soapy appearance or soapy feel.

Then you have got phyllitic texture, schistose texture and gneissic texture. So, what happens in this case actually is the grain size grain size increases and also the layer thickness or the foliation thickness increases. Typical grain sizes that are connected with these different types of textures were indicated when we were talking about the textures of regional or grades of regional metamorphism. So, you should refer back to that particular slide to get a feel for what kind of grain sizes and layer thickness we are looking at. Non-foliated rocks on the other hand will not exhibit any layered structures and examples of this type of rocks are limestone and granulite.

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So, this actually explains what is meant by foliated rocks which we have already discussed; the texture is layered or foliated and minerals have got a preferred orientation and this arises because of directional stress application and we have seen that examples include slate and schist.

Non-foliated rocks on the other hand, we have seen that already, that forms by recrystallization of preexisting rock.

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Examples include marble and quartzite. In this case, you have got typically a structure that is composed of interlocked mineral grains.

How do you name different types of, different types of metamorphic rocks is explained here. Textural classification could be of three different or we could do textural classification in three different ways.

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We could look at the mineralogy of rock and in this case, we use two most abundant minerals as prefix to the type of texture of that particular rock. Example of that for instance is quartzo-feldspathic schist which is essentially schist and two of the most abundant mineral in that kind of schist is quartzite and feldspars. Then we could have chemical textures, chemical textural classification; example of that is talc-magnesian schist.

In some cases, classification of metamorphic rock includes which actually do not change much from protolith, from the texture of protolith; in that case, we use the prefix meta to the type of rock that composes the protolith and example of this type of rock is, this type of classification is metagranite in which the protolith was of granitic rock and there was slight alteration because of the metamorphic process and what we end up with is metagranite.

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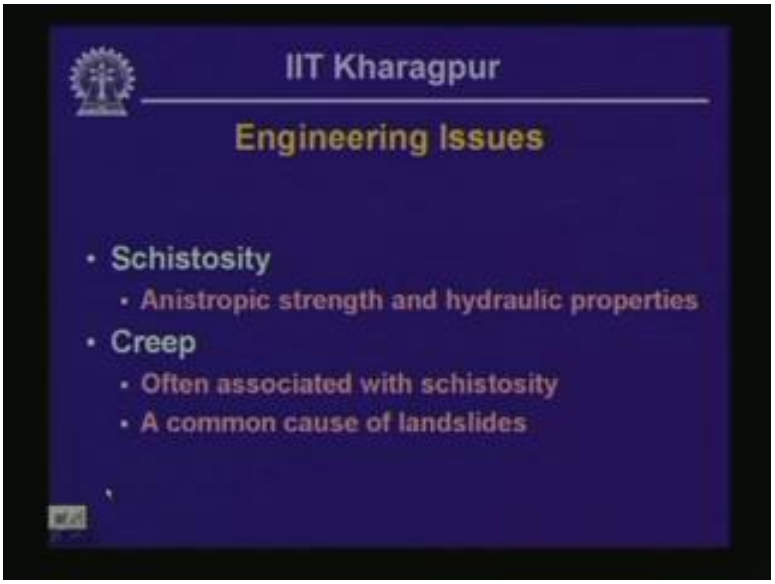

Engineering issues of metamorphic rocks includes schistosity and or foliation really and that leads to anisotropic strength development and hydraulic properties and often this type of rock exhibit creep behaviour and this actually leads to many landslide events.

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Economic use of metamorphic rocks: metamorphic rocks is a very major source of rare metal ores such as tungsten and gold which we have already discussed a little bit, it also a rich source of precious and semi-precious stones, schist and marble are used as building material and gneiss is also used as building material.

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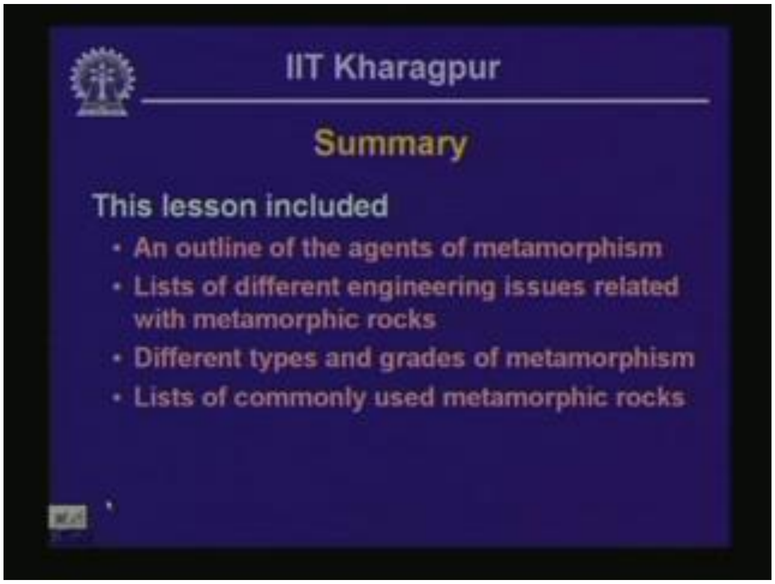

To summarize this lesson, we looked at the different types of metamorphism, what are the agents that causes metamorphism, list of different types of engineering issues we considered involving metamorphic rocks, we looked at different types and grades of metamorphism and what are the economic uses of different types of metamorphic rocks that also were considered in this lesson.

We finally wrap this lesson up by a question set.

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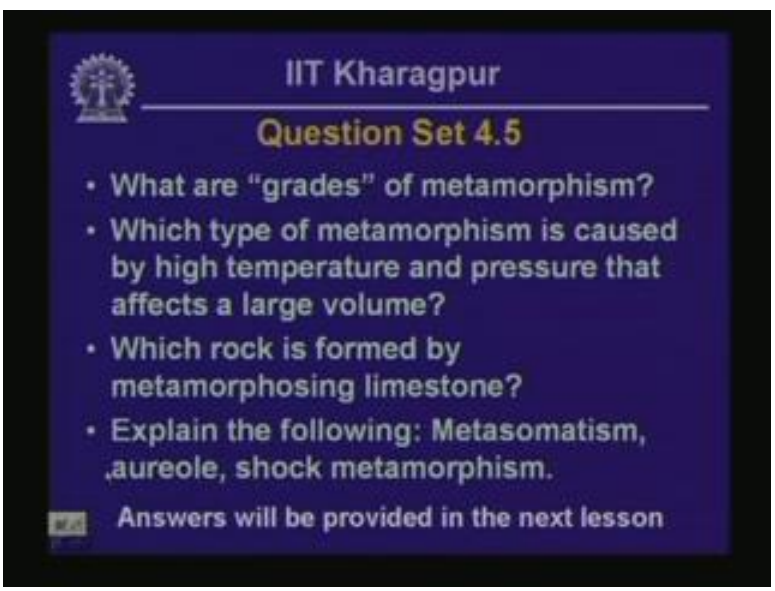

The first question is what are grades of metamorphism? The second one is which type of metamorphism is caused by high temperature and pressure that affects a very large volume of rock preexisting rock? The third question that I asked is which rock is formed by metamorphosing limestone? And, the fourth one I ask you to explain a few terms; metasomatism, aureole and shock metamorphism. You try to answer these questions at your leisure and when we meet in the next lesson, I am going to provide you with the answers.