Hello everybody, welcome back. So this is the last portion in different type of rocks. So in the
previous lecture, we discussed about the sedimentary rocks and this one is the metamorphic
rocks.

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And as we discussed in the beginning that the metamorphic rocks are formed at the deeper part of
the crust or the interior of Earth. And it is because of the under high temperature and pressure. So
we will see again the different type of metamorphic rocks and what are the importance of
different rocks in CE, that is civil engineering.

Now before just I start what we did in the igneous rocks and the metamorphic rocks, we looked
at different minerals stages and we looked at whether colour of the rock is darker or brighter, or
maybe it is and that was basically based on the felsic and mafic minerals.
And then we looked at the grain size and the textual features of the rock. So in both the rocks that is sedimentary and igneous rocks, we looked at the different mineral composition as well as the grain size and the texture of the rocks. Now here also we will move ahead and different minerals which are ordered from one mineral to another one due to high temperatures and pressures, what different type of rocks we get, that is basically the metamorphic rocks and how the different textures are been formed in terms of when they are the rocks are subjected to high temperature and pressure.
So again starting with the so the previous slide if you look at, this is one of the, the most beautiful monument: this is from Taj Mahal. So you see the White Rock behind this one is all is the marble. So marble is a metamorphic rock.

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So with this I will start and then briefly we will talk about that what exactly we discussed regarding the rock cycle. So we reached up to this in the previous lecture. We talked about the formation of the sedimentary rock and when sedimentary rocks are subjected to high temperature and pressure because if you move in the deeper part of the earth, then you will have high temperature and pressure.

So if they are subjected to high temperature and pressure, they will deform, they will got buried and then result into the formation of different type of metamorphic rocks depending on what type of sedimentary rock is been metamorphosed. And further down, it will again melt, get into the magma chamber and it comes out on the surface in the form of again the extrusive igneous rock or it may remain an intrusive igneous rock.

So the cycle continues and we see the formation of the rocks, weathering of the rocks, solidification and again subjected to deep burial under high temperature and pressure.
So what is a metamorphism okay? So metamorphism is a change in form that happens in earth’s crustal rocks in response to changes in temperature and pressure. So this is the most important. So the temperature changes, change in the temperature and pressure will result into the metamorphism of different rocks. For example, I am giving one is this, sandstone if subjected to high temperature and pressure, will result into the formation of quartzite.

So similarly, the limestone if subjected to high temperature and pressure, it will result into the formation of marble. So the minerals got changed from mica to chlorite and all that. So this is the process in which we see the different type of metamorphic rocks.
If you look at that how these rocks, sedimentary rocks are subjected to deeper burial or they are subjected to high temperature and pressure at the deeper part of the earth interior is mainly because of the ongoing tectonic movements. So when the plate subducts it take the surfacial material in into the interior of Earth and which will be subjected to folding, shearing. So this folding and shearing also will result into the metamorphism.

And at deeper part of course it has an advantage having the high temperature and pressure. So these are some of the examples which are been given which says that deformed and intruded rocks in the mountain and then they are subjected to fracturing and metamorphism. For example limestone if it is subjected to metamorphism at the deeper, it will result into the formation of marble. And then shale which we talked about, these are all argillaceous rocks.

And these are we talked about the limestone are either from the dissolution or maybe formed because of the organic rich shales and all that. So limestone is that which will result into the formation of marble. And then we are having shale which will be converted to slate. Further metamorphism which result into the formation of phylites.

And then schist, this one is there, schist and then sillimanite schist and all that. These are minerals here. And mica and chlorite is again minerals we are looking at. And then we are having sandstone. If it is subjected to metamorphism, it will result into the formation of quartzites. And
then again if you are having the again crystalline rocks, for example, you are having granites then if they are subjected to metamorphism they will result into the formation of Gneiss.

We will see those rocks because again these rocks are having very typical characteristics and based on that what we say, the foliated and non-foliated metamorphic rocks, we will try to see that.

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So metamorphic rocks, when rocks are baked by heat of molten magma, that is the internal heat coming in or squeezed by movement of huge tectonic plates or by the pressure of overlying thick succession of rocks okay, so you are having one, the defamation going on, subduction which is resulting and then you are having the burial pressure from the top.

All will result into the formation of metamorphic rocks because of the conversion of one mineral to another mineral, that is what we call the diagenesis. Then they are altered. So minerals are altered or the rocks are altered in complete which results into the change in chemical composition also okay, texture and structure. So this is very extremely important part.

So under the internal heat, either they are squeezed or by the huge tectonic plate forces or by the pressure of the overlying successions, then the rocks are altered which may result into the change in the chemical composition, texture and structures. These are termed as metamorphic rocks.

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So factors controlling metamorphism, of course the simplest way to understand the metamorphism is to remind the cooking effect. So what you cook that is extremely important. So if say that I want to cook limestone and then have the quartzite, it is not possible. So you should know what you are cooking. So depending on that you will find the same is in the metamorphism process.

The end product will depend upon the initial composition and the pressure and temperature okay. So if you are at the shallow depths, you may not expect that you will have schist from directly or you may not have phylite, you may have schist. So from schist, further you go down, then you will have the phylites and all that. That we will see.

And then factors that controls or they influence metamorphism are one, the chemical composition of the initial rocks which have been put in. And then inter granular fluid which you are having. So what is the composition of the fluids and all that? And then we are
talking about the temperature and pressure at the greater depth and the time also ok fine.

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So type of metamorphism, this has been explained in a very simpler way. What we have? We say fine, if you say if you keep on increasing the depth, you are increasing the pressure, you are increasing the temperature. So if you are subjecting the different rocks at high temperature and high pressure, the process which leads to that is termed as prograde metamorphism and which goes up to C from A to point C.

Now this process is like is because of the subduction subducting plate or the material which has been subducted below the surface within the crust and then time will come, the tectonic movements stop here somewhere. But when and after that, if suppose you are having an uplift going on, in that process again the pressure decreases no doubt but there is some increase in the temperature over here but it slowly it decreases.

But it does not decreases very smoothly. So even the prograde metamorphism continues up to the C and then you are the having the uplifted is coming, the rocks are coming or exposed up to the towards the surface where we will have again the pressure decreases and the temperature also decreases, that is termed as the retrograde metamorphism.

So metamorphism, the metamorphic changes that occur while temperatures and pressures are rising with abundant inter granular fluids are termed as program metamorphism. And then metamorphic changes that occurs as temperature and pressure declines so this is the retrograde metamorphism.
So inter granular fluid plays an important role in process of metamorphism. And these fluids may include some amount of gases, salts and mineral constitution dissolves from the host rock. Now if the fluids are absent or available in very less quantity the process of metamorphism is very slow. So this also affect on that that I was talking about that the cooking process.

So if you have less fluid available, then the process may be a little bit slow and few changes in the mineral composition will take place. So alteration of one mineral to another mineral will be in a slow process. So this also is important.

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Now the temperature, the source of the temperature is either from magma or due to the depth factor. And this we have discussed in the beginning when we were talking about that how temperature and from where it comes. So internal heat is from the either the radioactive minerals or the radioactive material, elements within the Earth’s interior or from the magma chamber we are having at the depth.

So metamorphism usually results in into change in mineral composition and the texture of the rock. So textural features will also change and of igneous and metamorphic rocks which are subjected to temperature. So the temperature is as high as almost like you can say greater than 100 degree centigrade and pressure will be more than 1000s of mega pascal. So low-grade metamorphism, we have to look at the temperature occurs at about 100 to 500 degree centigrade.
Whereas the high-grade metamorphism, you are having the temperatures which are greater than 500 degree centigrade. So these are the 2 types of metamorphism we termed as low-grade and high-grade metamorphism. So depending on this, we will have different type of rocks which are been formed.

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So for example, if you look at this section, it shows that this is an increase in pressure you are having and here you are having increase in temperature. So this area that is the region of diagenesis where the process starts changing the mineral composition. So region of low-grade metamorphism and this is a region of high-grade metamorphism. Finally, you are getting into the region where the melting starts. So melting starts somewhere at around 800 degree centigrade.
So pressure is extremely important and if you look at that if you are having Sigma 1, Sigma 2, Sigma 3, all are same, then what will have is the uniform deformation. But suppose you are having so this is under the uniform stresses and suppose you are having difference in the Sigma 1, Sigma 2, so you are having high or maximum, minimum and intermediate, then you will have directional deformation or we can say differential stress.

So you will have preferred orientations of the minerals which will be aligned almost perpendicular to the maximum stress okay. So pressure what we call we take as an stress here resulting into change in the textural parameters. So textures will change of the original rocks. Rocks are solid we know that which can be squeezed more strongly in one direction if you are having differential stress.

But at the greater depth, you will always see that the stress is uniform. So at the greater depth of, within the Earth, you will find that they are very much uniform. But close to the surface of the crust, you will have differential stress. So you will find the rocks which are formed are having very preferred orientation of minerals and we will see the examples of that in the next slide.

So texture in metamorphic rocks are the result of differential stress. Whereas the texture resulted from uniform stress are commonly seen in igneous rocks because igneous rocks crystallize from Liquid magma.
So now for example, development of different textures in the rocks of the same composition, and if you subject those rocks to differential stress and example here is the at the uniform stress if you are having you will find deformation of granite. Again, the granite is not an extrusive rock. It is an intrusive rock. Hence you see the minerals are uniformly formed. They are not showing any preferred orientation. I want to say that here.

But if they are subjected to differential stress, then the minerals will get oriented parallel to the or perpendicular to the high stress direction. So you have what we call as an granite gneiss. So this gets converted into the metamorphic rocks and they are termed as granite gneiss. The composition more or less remains similar here.

So under differential stress, major as well as the mica grain, so the major is quartzite and all that will be oriented parallel to the maximum stress direction giving rise to distinctive this thing. So this you will find that a preferred orientation has been seen.
This is an example of granite whereas this is an example of your gneiss they are subjected to differential stress. This is again very much preferred orientation you can see here. The clast here are oriented. So the stress direction if you want to see, is something like this. They are compressed in this direction.

And we are having the all this foliations which are formed here. These are all what we call the foliated rocks. And this is we term this as a budines.
So type of metamorphic rock if we have to classify based on the textures, we say either they are foliated rocks. So foliated again, we will have very definite, cleavable planes okay. As we have learnt in the minerals, the different type of cleavages, here also we will have cleavages or the cleavage planes which are being seen here. So these are all foliations or the foliated rocks. But in terms of the non-foliated rocks, you will not be able to see such type of plains. So they are all massive rocks. So they are non-foliated. So we have foliated and non-foliated metamorphic rocks which are classified based on the textures.

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So this figure if you look at, on the left-hand side, you are having all the sedimentary rocks, on the right-hand side you are having the metamorphic rocks comparatively what we have here. So for example we are having clay here, which if they are subjected to metamorphism, we will have like foliations because the clay minerals will again have the sheet like features and then on the deformation, we will have the foliated rocks here.

So we can have the deformation of slates. So mudstones if they are subjected to metamorphism so then we will see the development of cleavable surfaces and those cleavable surfaces will be easily break you can break easily along that plain. So the beddings will created and the clay minerals will change to chlorite and Muscovite micas.

So this will provide the weak foliations and align preferred orientation of the bedding plain. So we have the suppose this is an outcrop here of the sedimentary succession. When it is subjected
to the regional metamorphism on the large-scale because of the ongoing deformation, the material will get folded and will get lined okay.

So you are having the, these are the bedding planes. These are the bedding planes here. But you have this preferred orientation what we call the cleavage edges. So this will be seen when you look at the sample and hand specimen. And then further if you are having the sedimentary rocks like for example sandstone, and you are having the grains, sand grains, or main records or other minerals and you are having inter grain space what we call the pore space, when they are metamorphosed, they will try to squeeze.

No pore spaces found any more in that rock and then we what we see is the very beautiful locking between one grain and another grain and result into the formation of massive rock without seeing, we do not see any structure, sorry texture in this and these are all non-foliated rocks. Whereas this one which were looking at the, they are all foliated rocks.

These are non-foliated rocks. So in foliated rocks, you will have very definite, cleavable plains of weakness. So foliated and non-foliated rocks. So we will see different type of foliated and non-foliated rocks in coming slides okay.

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So coming to the foliated rocks, when platy, lamellar or flaky minerals, sheet silicate minerals, the micas like for example the biotite, Muscovite, chlorite, etc occurring in the rock oriented
themselves parallel to one another. So they will orient themselves parallel to one another, perpendicular to the direction of maximum stress.

That will result into the form, by the alignment of the minerals almost perpendicular to the or we can say we will have the preferred orientation of the minerals. So these are un-preferred minerals. Like for example we are having granite here but then got preferred along the definite plane or the perpendicular direction of the maximum stress. So we are having randomly orientation of minerals and we see preferred orientation of minerals due to metamorphism.

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Same example but this is because of the burial we can say. The sedimentary rocks here what we are having, this we are having slate which are formed because of the burial of the overburden. So we are having the compression here and then these beds are when having the greater depth will have preferred orientation.
another example of the slate if you look at in the close up you will find the edges are having very typical, cleavable or the cleavage along which the rock prefers to break out of multiple cleavages. So this is a typical characteristic of slate. So slate is again fine grain, foliated metamorphic rocks formed under low-grade metamorphism.

So they are not high-grade metamorphism. You will see. And they are formed from mudstone, shales or Clay Stones. These are sedimentary rocks. Mudstone, shales, and Clay Stones and we termed this as an argillaceous rocks. So these are the plane of weakness.
Then further deformation of slate if we take then what will happen okay? It will result into the further deformation and we see more weak zones and then you can the wavy structure here and this is typical of what we say phylites. So these are the phylites. So when the slates when metamorphosed further will give rise to more foliated rocks known as phylites. So first we are having shale that is sedimentary rock subjected to low-grade metamorphism will result into formation of slate.

And slate further metamorphosed will result in the formation of phylite. So it is characterised by wavy texture of the foliation. So this is typical of the phylite, phylitic rocks. So you will see this wavy structures if you look at in the hand specimen. Formed under low-grade metamorphism again, still we have not reached to the high-grade metamorphism. So slates shales, slate and phylites.

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So in thin section if you have to see, then what you will be able to look at, a very colourful picture and we are having the colourful preferred, oriented minerals which are mica and the darker ones are here quartz.
So schist again another metamorphic rock is formed under intermediate to high-grade metamorphism when phylites are subjected to the higher pressure and temperature. They will result into the formation of schists. And schists again we have the what we call the texture is termed as schistocity.

We will see the preferred oriented sheet of silicates and the minerals surrounded by that. So you will have from phylite to schist we have, so we have slightly larger grains and again, we will be able to see a very similar a typical wavy structures here also but not very much prominent as we have been looking at the in phylites.
So these are the Gneiss as we have seen we are talking about the from granite to granitic Gneiss. So parallel foliations, medium to coarse-grained, quartz, feldspar, mainly marked by lighter layers and the darkers are the ferro-magnesium minerals here. So these are Gneissic rocks. So you will have some very typical dark layers which are been found in the Gneiss. So non-foliated rocks, these rocks lack foliation.

And the best examples are quartzite and marble.
So quartzites, they are extremely massive, no cleavable plane you will find in this and whenever you break this, it will be a difficult, very hard. Of course it will break but it is tougher than the other rocks. So if you break it, it will break with very irregular surfaces. You can see this one here. And this one here. They are absolutely not along the preferred plane as we see in the foliated rocks.

Medium to coarse-grained, made up of fused quartz grains. So they are having fused quartz grains and the texture of this we termed as granulose texture okay. So and they are very well interlocked. So if you see this in thin sections you can see the contacts between the different grains very much preferred contact and a very prominent one.
Similarly like marble again if you look at, this is a close up of marble metamorphosed from limestone. I was talking about that limestone to marble and that was sandstone to quartzite we are having. So we have medium to coarse-grained grain size mostly. Crystalline texture. Shows tight interlocking of calcite grains. So that was the we are having quartz mainly.

Here we are having most of what we see is the calcite grains. Formed under intermediate to high grade metamorphism. This is the best example of that. So two non-foliated rocks we have seen.

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And the best example in terms of the monuments if you look at is the Taj Mahal okay. So thank you so much. I will stop here and will continue in the next lecture.