Evolution of the Earth and Life
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Minerals and rock cycle

Welcome to the course Evolution of the Earth and Life. Today, we are going to talk about what do we learn from minerals and what are the factors that guide the abundance of specific minerals in the Earth.

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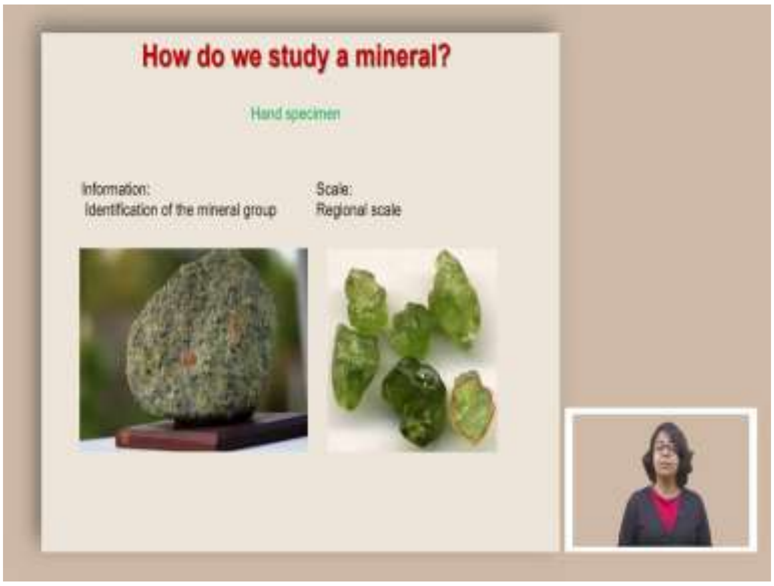

So, let us try to think how do we study minerals. So, everything starts from a hand specimen that means we go to the field, we collect specimens which are large enough and then we bring them back in the lab and then we try to study them. So, when we talk about hand specimens it is large and we can see it without a microscope and we can classify them based on the optical properties that we can see without a microscope as well as other information such as shape, hardness and things like that.

So, that gives us fairly good idea of which mineral group we are looking at. So, for example this is a rock that was collected in the field by someone and then we look at some of the green patches and if we crush this rock it will look like these minerals, these mineral grains which are also green in color. Now we can try to describe them using the set protocol of how to describe a mineral and what we will find that it is an example of Olivine.

Now Olivine is a large group and there are very specific aspects about Olivine that you can go deeper about and which are very important when it comes to understanding the processes of formation. However, just by looking at hand specimens you are not going to get any information about those.

So, the important aspect of studying hand specimen is because you are collecting it from the field you can actually cover a large region pick up some of the hand specimens, some of the hand specimens you can even study in the field without taking it out in the outcrop and therefore you can cover a really large region in terms of description just by identifying them at the large scale at the hand specimen level.

However, as I said that when you are trying to understand deeper in order to understand what is the relationship of this particular mineral with the surrounding mineral, when did it form, did they form earlier or after the formation of other minerals you need to see the relationship and often these relationships are hidden in very small scale studies and those small scale studies can only come if you are looking at a microscopic level.

So, when researchers try to study minerals they first go to field, they look at the overall distribution of the minerals that they can see without a microscope, then they collect all these hand specimens often amounting to a few kilos and then they bring it back to their labs, the next step is to cut them and make a thin section.

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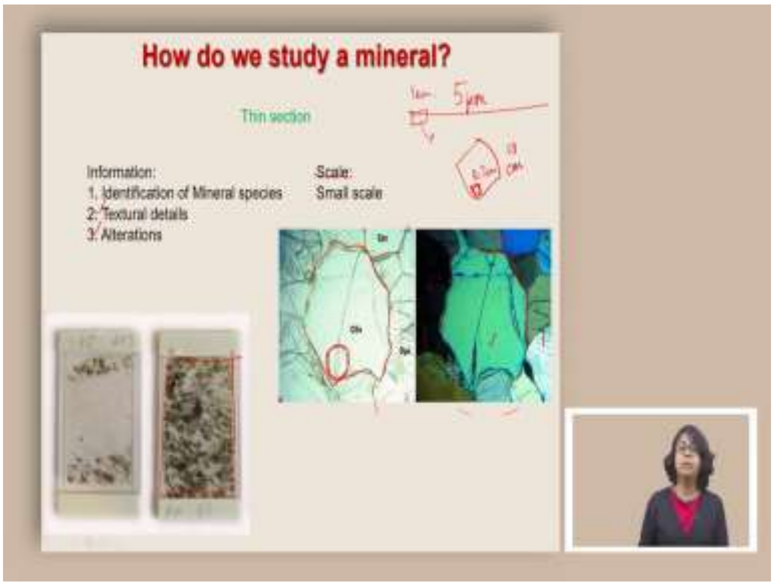

So, what do we mean by rock thin section? We mean that the rock is often cut and glued to a glass slide and then polished to the level at which, it is so thin that the water, the light can pass through it and when light can pass through it, it actually reveals the optical properties of the minerals under microscope. And therefore studying minerals in thin section is very important.

Now the point is that if we are thinking about what we learn, what we can learn from the thin section studies, it is huge because we can now identify mineral species. So, it is not only Olivine group but exactly what kind of specific structures we are seeing, we can also know textural detail. So, for example the minerals that are around this particular Olivine when did they form, how did they form, all these information are possible to extract from the studying thin sections because it tells us the relative arrangement of the placement of the minerals.

It also tells us something about alteration that subsequent to the mineral formation what are the changes that took place, but we are compromising on the scale. Because imagine a field of 5 kilometers can be studied probably over a year or so and you can identify minerals in a broad scale that is what we were doing in the hand specimen level. However, when we are talking about thin section it means from each region you can collect maybe a few hand specimens and out of those hand specimens if a hand specimen is large enough let us say it is a few centimeters you are only taking part of it to make a thin section.

So, probably this entire region of one kilometer would be represented in your thin section which is a few centimeters long maybe 2 to 3 centimeter long and that is what these thin sections are but why do we still make thin sections first of all the idea is that the processes, that the large scale processes that are operating probably will impact at different scales and even if you are compromising on the scale you are taking only a small piece of the rock and the mineral, you are still going to find the same signatures that are operating at a large scale and therefore studying thin section is very important.

How do they look like, so when you look at it under microscope the light passes through it and that gives you a general idea of the mineral grain. So, in this case this is an Olivine mineral grain and it is surrounded by other minerals, these are pyroxene, different types of pyroxene, this is clinopyroxene, and this is orthopyroxene.

Now just looking at it under plane polarized light is not enough if you look at it under crossed polarized light, it also gives you additional Optical properties. For example it immediately gives you a characteristic color which unlike the color that you observe in the hand specimen, this particular color is extremely reliable and this is one of the ways of identifying a mineral.

There are other things such as what is the boundary like, these would also give you some understanding of how the other minerals have grown with respect to this one a careful consideration of the pattern of the outline and the relief will also tell you something about the hardness, how hard the mineral is with respect to or relative to the minerals which are surrounding it. So, the relief is also important.

Again at this scale, at this thin section level it is possible to identify the mineral the texture the alteration all of these things but still if one is interested in knowing more about the chemical composition one needs to study the chemical composition of the mineral they have to go for chemical analysis. Now how do we do chemical analysis well out of this entire slide all the minerals that you see you can pick may be part of this and powder it and then try to look at the chemical composition.

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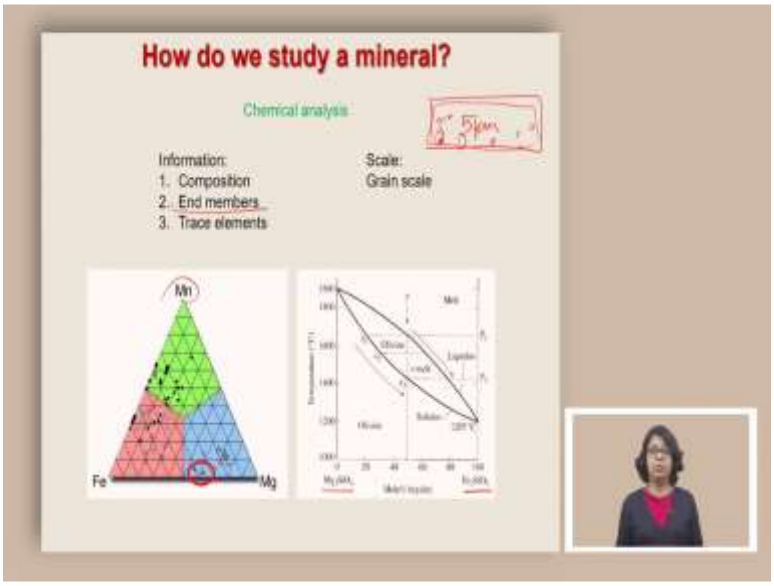

So, there are various ways of studying this chemical composition I am not going into the detail of the analysis analytical methods but there are different ways to understand and characterize the elemental concentration also. So, once you know the elemental concentration it is possible to know what are the n members that are creating this particular mineral and how much of these n members are present in this particular mineral in this particular section.

Now we are going into much much detailed fashion. So, for example if we are talking about Olivine there can be n members that we already talked about in at some point of time that there can be forsterite and fayalite these are the n members of Olivine. But there cannot be a fixed proportion of fosterite and fayalite that you will find in all Olivins, every place every process that generates Olivine will be slightly different and therefore the ratio of fosterite and fayalite are going to be different.

Now, if you know the components in terms of n member from your chemical analysis you can actually have a very good understanding of what is the contribution of fosterite and fayalite in your specimen. Now we have come to the greatest depth in terms of our understanding, however please recognize that out of the 5 kilometer scale of your field area you are basically looking at one grain of hand specimen which can be let us say 3 centimeters long and then you have focused on a few micro meter level where you are collecting your chemical information.

Yes, it is true that probably all of these things are part of a larger process and hence will give you reliable answer which you can also generalize for the entire area but it is nonetheless from a very specific spot that you are taking this chemical information. So, to reduce some problems with this people do chemical analysis from different parts of the study area. So, that you can have a better understanding of the variability.

So, it is always a balance between how much scale or how big an area you can cover and how much information you can extract from a very small scale a combination of it gives you a deeper greater understanding but also over a large area. Now once we study the mineral and we have good understanding of how mineral variations are what can we say about the overall mineral assemblage on the earth.

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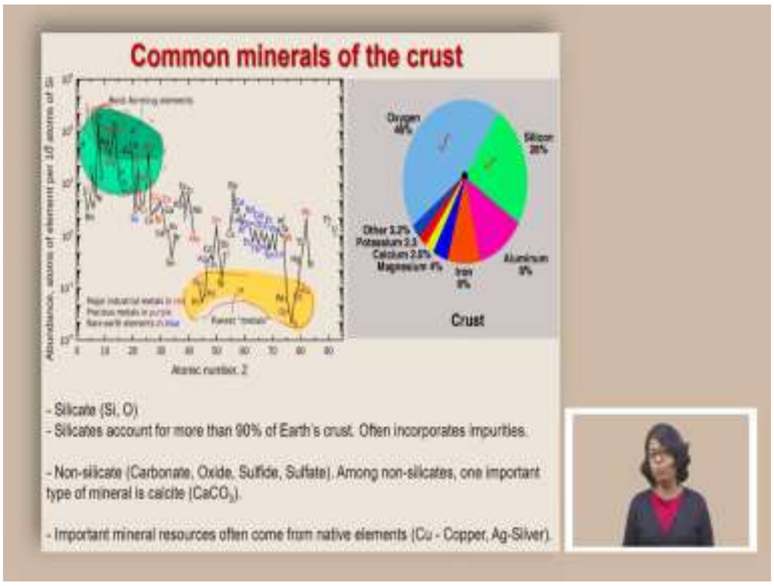

So, we are going to primarily look at the crust that what are the most common minerals that we can find. So, if you look at it, in terms of the overall abundance of elements which is normalized with silica simply because silica is really really abundant on the crust. And if we do that, we will find these variations of these rocks of these elements and these are generally called the rock forming elements which include oxygen, sodium, aluminum, silica, potassium, calcium, iron and so on and so forth because they are really really common in the crust.

They are also the most important rock forming minerals that we find on the crust and out of this these two things are the most abundant silica and oxygen no wonder that majority of the crustal rocks are primarily made of these two things oxygen and silica. So, they (())(14:09) and they create something which is SiO2 and we generally call them silicates. We should also pay attention to these elements which are relatively rare metals and we do not really find them much on the crust and therefore they are also some of the most valuable metals because they are so rare.

Apart from oxygen and silica we also find non-silicate minerals which includes carbonates, oxide, sulfide, sulfates again part of the reason is what you can find here in terms of its abundance and we do find high abundance and therefore it is natural that we find also corresponding minerals which are made by these elements. Silicates account for 90 percent of the earth's crust. So, all minerals that we can find from earth's crust 90 percent of them are silicate minerals and it often incorporates impurities and therefore we find a large variation in them.

And the rarest of the minerals are the native elements such as copper, silver, gold these often appear as ores but they are basically the native elements which we directly get rather than finding them in a compound. Now let us concentrate on the silicates. How many different types of silicates can we find and is there an ordered arrangement of silicates that we can expect.

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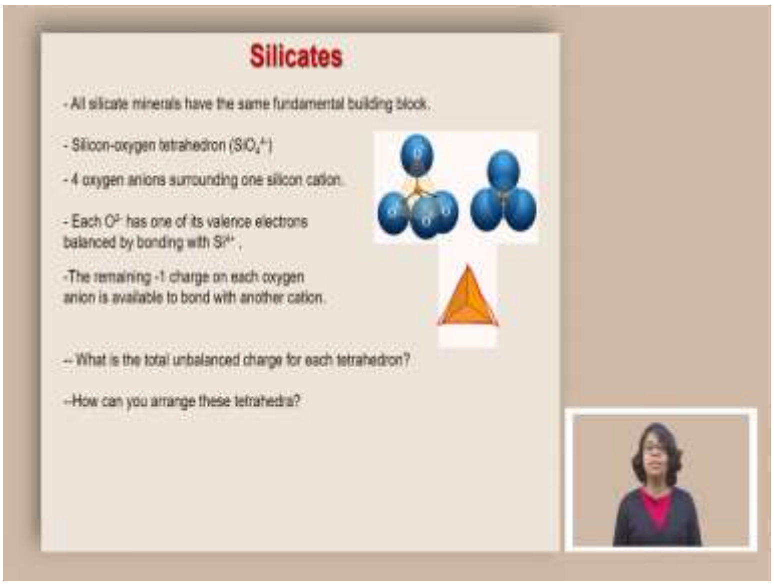

So, silicates are materials or minerals that have the same fundamental building block it is a silica oxygen tetrahedra. So, at the center you find these Si the silica and then there are four oxygen anions surrounding this one silicon cation. Now each of these oxygen has one of its valence electrons balanced by bonding with Si4 plus but that means the remaining minus 1 charge on each oxygen anion is available to bond with another cation and that is one of the most important thing to remember.

So, in a very simplistic way, we can think of the structure as a tetrahedra where at the center is sitting this silicon and at all four sides there are oxygen. But because these oxygens are not perfectly balanced in terms of its charge it will also try to bind with something else. So, it can either bind with other elements but it can also bind with other silica tetrahedra and that is the key to understand the overall mineral variability among silicates on the crust and that is what we are going to look at.

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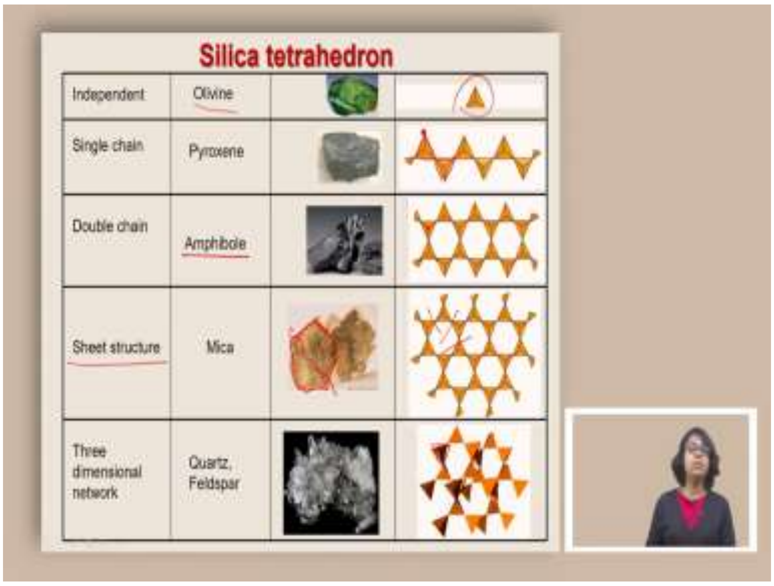

So, this is a structure of silica tetrahedral that we can find commonly in nature. So, let us start with the very top one which is a single independent silica tetrahedra, what it means that it still have this unbalanced charges which are being balanced by other metal ions, calcium, iron magnesium and that creates a mineral structure where we are going to find these independent silica tetrahedra balanced with metal ions and that is a common composition of Olivine and depending on which metal ions are attaching to any of one of these silica tetrahedra it will also give you the compositional variability of the Olivine.

There can be other possibilities where one silica tetrahedra is basically balanced by another silica tetrahedra, the other places can still have the other metal ions in those cases it is going to create a single chain structure and these are classical examples of pyroxine a mineral called pyroxene. This can be repeated where both the ends of the silica tetrahedra are balanced by other silica tetrahedra except the top part which can be taken up by other metal ions in that case it is called a double chain silica tetrahedra an example would be amphibole.

If all of these structures are basically extended in a plate-like fashion on a plane then it is going to create a sheet structure which we call a mica. So, the entire mica sheet or in one plane is made up of the silica tetrahedra but between subsequent silica tetrahedral sheets the attachment is very weak and it is bound together by a very weak bond and that is the reason when you are peeling off one sheet of mica you are basically taking off the entire sheet of silica tetrahedral plane but you are not breaking these joints.

And therefore if you are trying to basically break along this line it becomes very difficult. One of the most stable structures on the crust of the earth is quartz and feldspar structure which corresponds to the three-dimensional network which basically means that if you can imagine a silica tetrahedra in all the sides on all the silica tetrahedra are basically balanced by each other creating an extremely hard and stable form of a mineral.

Now this has also implications in terms of which mineral is going to stabilize at what temperature how easy it is to break, what is going to be their cleavage plane, how many sets of cleavages are going to be there, many of these are connected with the idea of this silica tetrahedra and what is their initial arrangement for a particular mineral.

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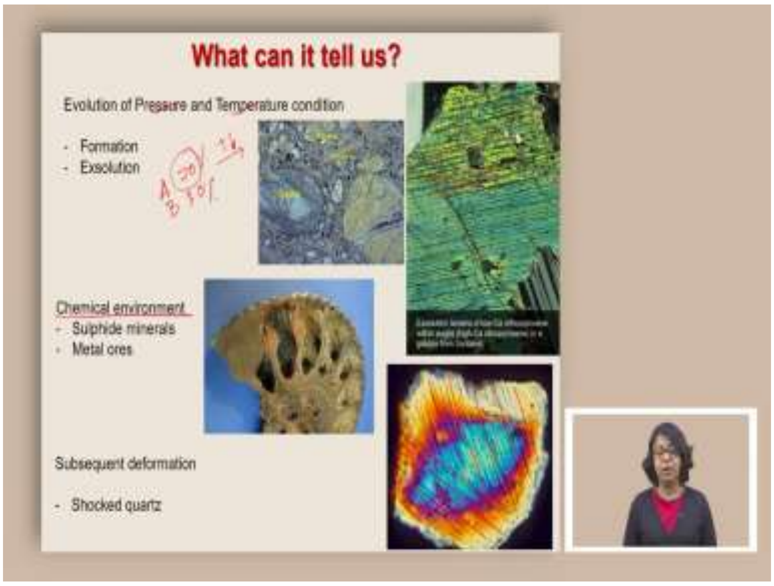

Now, let us try to think what the minerals can tell us. Apart from just the name of the mineral or which silica tetrahedra it represents, it actually tells us a lot about how they were formed and what are the subsequent processes they have gone through. So, for example it can tell us a lot about pressure and temperature condition as we know that certain minerals actually form at high temperature versus low temperature. And therefore if you find those minerals that immediately tells you about the temperature of crystallization, but it is not the end of it, in fact there are minerals which will have different n member contribution depending on the pressure and temperature especially temperature.

And if those n member compositions can be recognized through chemical composition or through optical properties, then it tells you very precisely about what that temperature might have been. More importantly, let us say n member A and B were their n, this proportion it is possible that the rock has gone through a phase which is a temperature drop and in a dropped temperature the proportion of 70 percent A is not stable. So, in that case A will try to come out of the mineral structure and that creates a pattern which is called an ex solution. And we will find some of the lines which are corresponding to these exalt material. And that tells us that the original temperature changed over time and therefore you are finding these ex solution patterns.

Change in chemical environment is also traced back to the minerals. So, for example this is a fossil and within the fossil you find some glittery material which shines these are pyrite. This means it is a sulfide mineral, now we know that sulfides are not really stable at high oxygen environment, they tend to convert into sulfate. The reason we are finding the sulfides in these particular place as a mineral form is because when they were formed the oxygen abundance was really low in that particular area.

So, it also tells us something about the chemical environment. Then there are examples of minerals which has gone through a severe changes in condition maybe they were shocked by a large impact in those cases that also changes their optical property. This is an example of a quartz, quartz under microscope is generally gray in color the reason you are seeing all these bright colors and also some of these planes which look like weak planes are created because of this large shock wave because of an impact. Now these are things which gives you (())(24:54) signature of changes that happen later. Now we learned a little bit about minerals.

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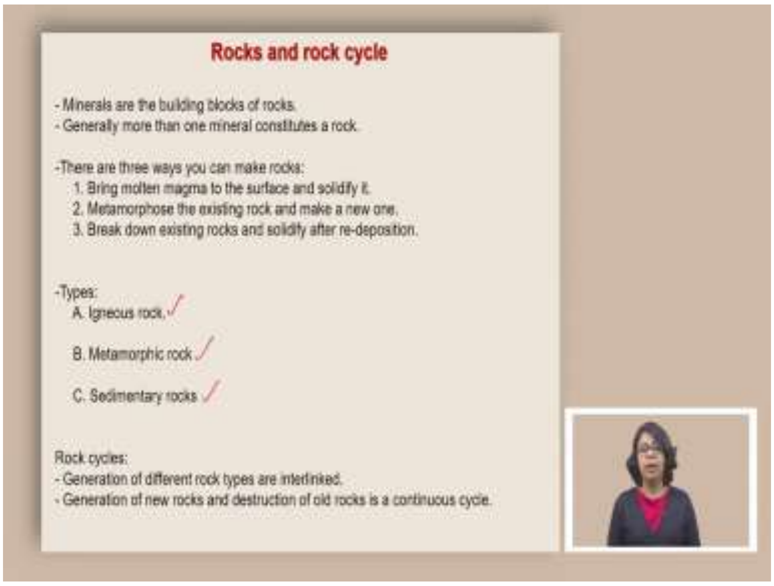

Minerals are the building blocks of rocks. Now generally more than one mineral constitutes a rock, if there is a rock which is made up of only one single mineral then it is called a mono mineralic rock but generally again, it is not always common, we find rocks where there are multiple minerals. Now there are three different ways one can make a rock, one is bring molten magma to the surface and solidify it by dropping the temperature. The second one is changing existing rocks by the effect of pressure and temperature but without melting it.

The third one is by breaking existing rocks and solidify it just by gluing them and therefore creating another type of rock depending on these processes, it can create three types of rocks igneous rock, metamorphic rock, and sedimentary rock, but these rocks on the surface of the earth and in the mantle they are sort of connected in terms of how they are being created and how they are converting from one rock to the other and that is what is meant by rock cycles.

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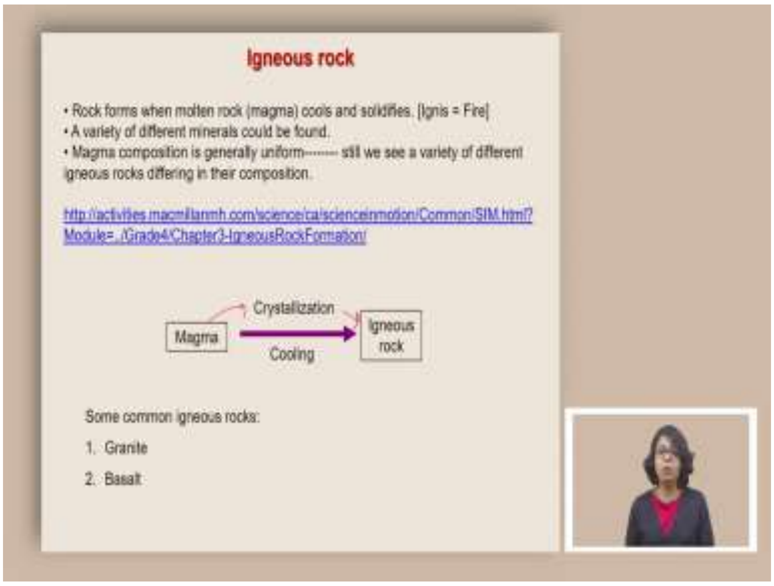

So, igneous rocks are rocks that are formed from molten rock which cools down and creates a rock and generally it is from the magma the crystallization produces the igneous rock some examples would be granite and basalt.

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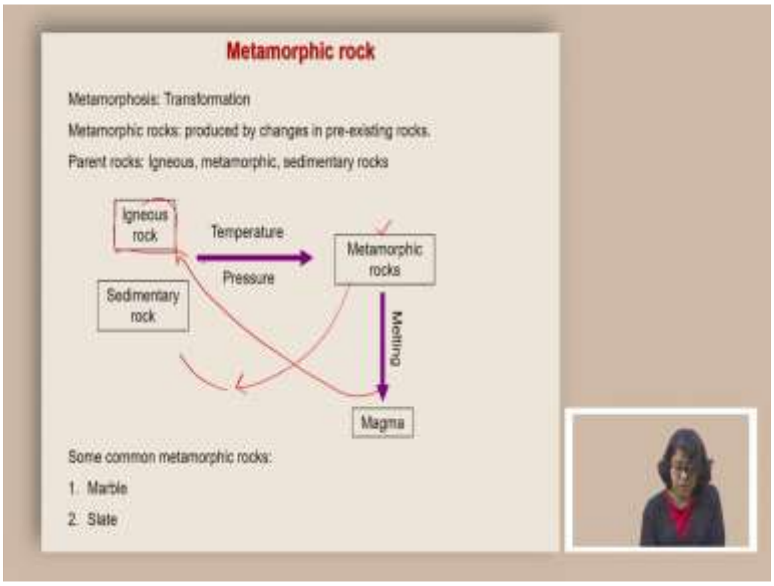

The second type of rock is a metamorphic rock. Now this rock can be produced either from igneous rock, where temperature and pressure make some metamorphic rock, but it will not melt it because if it melts again, it will again create an igneous rock. So, if it does not melt but still produces a different type of chemical composition, different type of mineral then it is going to be a metamorphic rock.

The metamorphic rock can still be produced from sedimentary rocks too. Metamorphic rocks can be produced from other metamorphic rocks too. And this metamorphic rock once it goes through melting, it can again produce an igneous rock. If metamorphic rocks are broken down into pieces and create sediments and then after compacting them they can produce sedimentary rocks.

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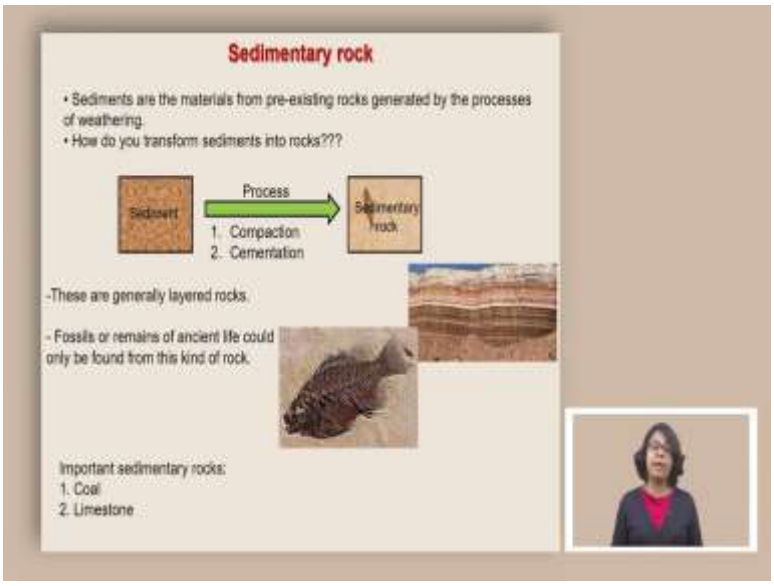

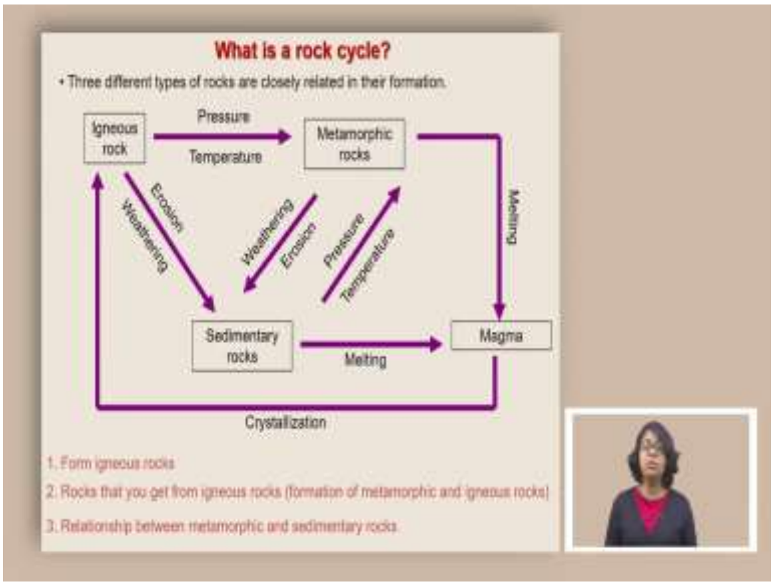

Sedimentary rocks are primarily derived from materials from pre-existing rocks that are generated by processes of weathering. Now the sediments can be compacted into rocks either by compaction or cementation. So, that means either you are pressing it too hard to hold a specific shape or you are gluing it and these are taking place in nature and creating a sedimentary rock. These are generally layered rocks and there can be fossil or remains of ancient life in those rocks and this is a very important point for sedimentary rocks because it does not go through very high temperature and pressure and it retains all these signatures.

So, if you want to know more about how the part of the crust interacted with other spheres such as biosphere, hydrosphere, atmosphere these are the rocks which are going to give us very important information, examples will include coal and limestone. Now if we look at all these three rocks and how they basically interact, we will see a quite complicated diagram. It will all start at some level from the magma, from the magma through crystallization it will develop igneous rocks, from igneous rocks through pressure temperature it can produce metamorphic rocks, igneous rocks when eroded and weathered can produce sedimentary rocks.

Metamorphic rocks when weathered and eroded can produce sedimentary rocks and sedimentary rocks on the other hand when they go under high pressure and temperature without melting it can create a metamorphic rock, both metamorphic rock as well as sedimentary rocks through melting can create magma.

So, it is an interlinked process through which we find development of different kinds of rock and which represent different ages of formation and this cycle is active today. This cycle was active deep in the past and because of these changes we often find very important clues of the earth's history through the rocks. So, it is important to recognize that none of these rocks are permanent they always will go through changes and one of the challenges of earth science is to recognize the different events of history using these rock record.

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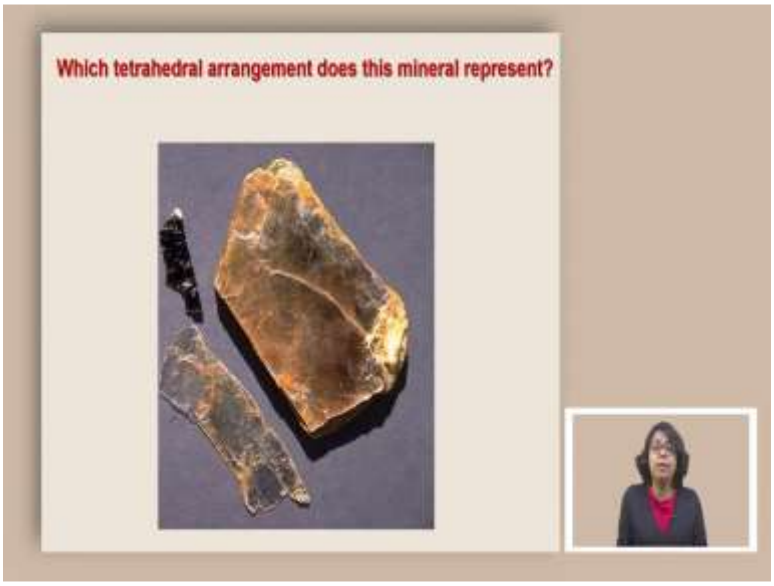

So, in summary in today's class we learned, how to study a mineral and at which scale should we study a mineral, we also learned that in different scales we learn different detailed information about the mineral but at the same time we lose a bit of information about the large spatial scale. Then we learned the different types of minerals that we can get on the earth's crust and their relative abundance. We talked about silica tetrahedra and their arrangement how that creates a variety of minerals on the earth's crust.

Finally, minerals are the building blocks of rock and we learned different types of rocks and how they are connected through the rock cycle. Here are some of the resources that I used for the content and here is a question for you to think about. Thank you.