Evolution of the Earth and Life

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What is a mineral?

Welcome to the course evolution of the earth and life. Today, we are going to talk about minerals.

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Minerals are defined as any naturally occurring inorganic solid that possesses an orderly crystalline structure and a well-defined chemical composition. Now, this definition has couple of components that we should pay attention to, the first one is, it is naturally occurring. So, even if we are able to produce a crystal exclusively in the laboratory condition that is not going to be called a mineral, simply because we do not find it naturally.

There are exceptions to this, we may find a mineral which we think is developing in near deeper in the mantle and can be produced in the lab, but we do not see those minerals in the nature, but we know of their existence in that case the thing that would be produced in the lab would be a proxy for these mineral and we will call it a mineral.

The second component of the definition is, it has to be a solid substrate even if we are finding something in a different state such as mercury, we are not going to call it a mineral because it is not a solid substance. The third component is, well-defined chemical composition what we have to keep in mind that this well-defined chemical composition can have a range, it does not have to be a single chemical composition that the mineral represents, it can be within a range and that is true for most of the naturally occurring minerals.

The last point which is important is generally inorganic. Now what do we mean by inorganic at this stage, there are a couple of minerals which are produced through organic processes through the involvement of biology. However, the substances which are being produced are inorganic in nature. So, that is what we meant by generally inorganic, there are examples where we find mineral like solid substance which are naturally occurring in parts in the coal, which sort of makes the difficult transition of an inorganic part of the mineral to an organic part.

So, coal actually carry certain types of chemical compounds which are closely resembling a mineral, however they are organic. So, at times they are also called bio minerals. Now using these components of the definition, let us see which of the following is not a mineral. So, table salt if you think about table salt, it is naturally occurring because if you go to the seaside the ocean carries a lot of salt in dissolved form and that is the reason if you taste the water of the ocean, you see it will taste salty.

And if you let it evaporate for quite some time you will also find that crystals are forming and those crystals are naturally occurring salt crystal and that is how the (ini) at the initial stage table salts were produced. And these are called halite crystals, these are minerals, it is called halite which has a composition in this case a pretty fixed composition which is sodium chloride. So, therefore by that definition, that it is naturally occurring, it is a solid substance, it has a well-defined chemical composition, and its generally inorganic, it does not really have any involvement of biology per se, and the elements that are creating this, they are inorganic in nature, hence we can call table salt a mineral.

How about ice? Now when we think about ice, we probably think about something that you make in the fridge but there are naturally occurring ice, if you think about glacial ice, they are absolutely naturally occurring. And very interestingly they have a very specific crystal structure and that crystal structure is a (())(5:27) sign of the glacial deposits in terms of how much compaction they have gone through, which stage of compaction they are in.

So, it is a naturally occurring material, it is a solid substance because we are not really talking about water, we are talking about ice which is part of the glacier which is solid in that condition, it has a well-defined chemical composition it is primarily H2O and it is inorganic. So, by that definition glacial ice is an example of a mineral. So, naturally occurring ice as part of the glaciers would be considered a mineral.

Now let us take a look at Sugar. So, when we think about sugar you can actually find it naturally, there are places where you can see plants producing sap, which finally crystallizes to make it to a sugar crystal. So, it is naturally occurring it is a solid substance, it has a well-defined chemical composition, however it is not really inorganic unless it is produced in a certain conditions in a controlled setup. So, therefore by this definition sugar would not be considered a mineral.

Now minerals are building blocks of rocks. So, before we try to understand the rocks and what they tell us it is very important that we identify the minerals and also understand a bit about how they form.

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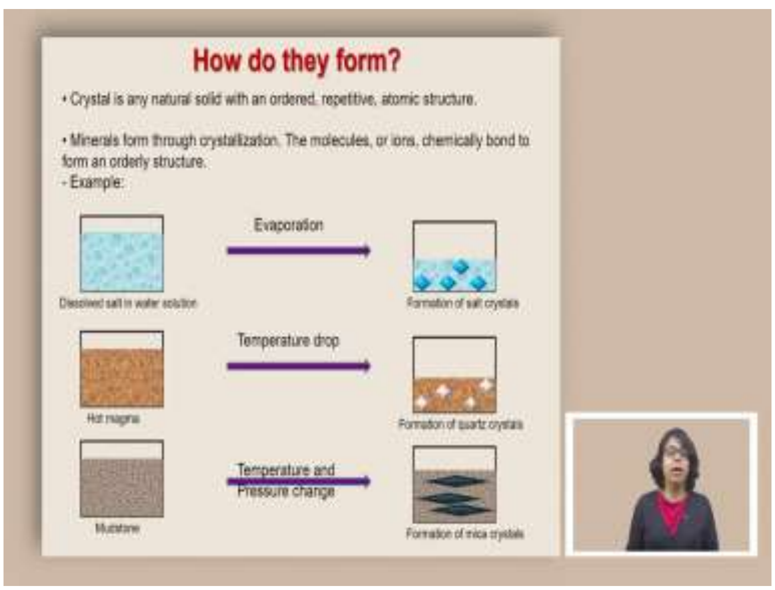

So, minerals are forming in different ways, crystals are important component of minerals because minerals are generally crystallized and these crystals are any naturally occurring solid with an ordered repetitive atomic structure. In fact, that is something that researchers use to grow larger crystals in the lab setup because they have a tendency of repeating themselves in the same ordered fashion. Minerals form through crystallization, the molecules or ions chemically bond to form an orderly structure. Now, how can it happen in nature?

So, we are going to talk about three processes and how they aid crystallization and finally formation of minerals. The first one is evaporation, so imagine bucket of water which has salt dissolved in it, normal table salt and now we know that normal table salt is an example of a mineral. So, it is already dissolved in water and then you let it evaporate. So, the water goes out through evaporation leaving the salt behind because in that evaporative face the water vapor does not carry any salt in it.

So, therefore with time as the evaporation progresses the remaining liquid water will have higher concentration of salt in it. So, with evaporation there would be a point where the amount of water remaining in the bucket would be very very low and the salt would eventually start crystallizing and that is how you get the salt crystals.

Now this entire process can be found in nature near the ocean. So, if there are places where the ocean water comes but does not return back and there are situations where it can happen if it is a closed embedment, where the ocean water comes but leaves a bit of water which does not go back. Then you will find a situation where water evaporates naturally and you see the growth of salt crystals in that case it is called a halite crystal.

The second way of forming minerals is by change in temperature and it often happens when we are looking at molten rocks, molten rocks or hot magma, when they cool down there would be some minerals which will form because they are not stable in that low temperature in the liquid form. So, they will start to develop crystals and those crystals because they are slightly denser, they will basically come out of the hot magma and deposit at the base, that is another way of forming crystals of different minerals. Quartz, which form often from hot magma forms this way.

The other way which of forming crystals of different minerals is through a change of temperature and pressure but in that case, it does not really go through a face transition in terms of going from liquid to solid or vapor to liquid something like that, it actually is a solid-solid transformation and that happens during metamorphism, where there can be materials such as common mud which if you subject it to very high temperature and pressure change often it forms crystals of different minerals.

And these crystals will have orderly arrangements and depending on the composition of the original material the minerals will also have specific mineral composition. But one thing is very important to recognize here, that this mudstone that I gave as an example will not go through any liquid face, it is not melting it is simply going through a transformation because of high temperature and pressure and creating different minerals.

So, these are some of the very commonly found processes operating in nature that produces minerals and different kinds of crystals of minerals. Now let us take a look at one particular mineral and how do they form.

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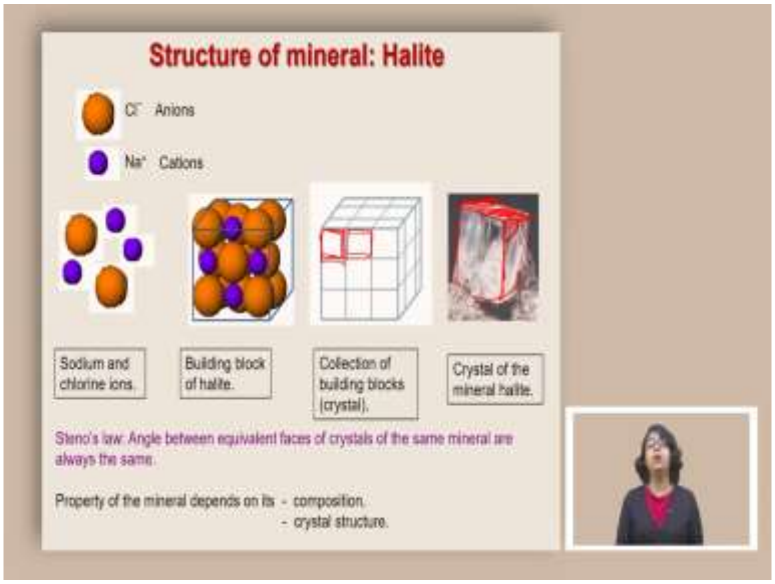

So, as I said about halite, that they are naturally producing salt that we find from the ocean. So, in terms of its basic framework, it has sodium plus as the cation and chlorine minus as the anion and sodium and chlorine they bind together to form the first building block of halite and it will have a structure. That is what, we meant by this second step that there would be multiple sodium and chlorine sort of balancing each other and eventually forming a structure.

And this structure repeats itself because these blocks basically adhere to one another creating larger and larger crystals. And these crystals eventually can grow depending on the condition of the initial liquid, how much salt is already dissolved in it, and how much it can precipitate out of it, that will determine what is going to be the size of the crystal.

Generally, if we see that the chemical reaction is operating for a very long time in a slow process we tend to get really large crystals. Now again because these crystals are basically repeating its structure again and again its properties are going to be scalable, what I mean by that, even if you look at a very small grain of it, the properties, the structural properties that is going to you are going to see is going to be identical to a very large crystal, so the size does not matter in terms of identification.

And what kind of structural properties are we talking about, one very common structural property is, that if you are looking at a particular crystal and if you are looking at these sides which are called faces the arrangement of these faces should be constant does not matter which size you are looking at. So, one such thing to check is the angle between the faces. So, if I am looking at this particular face and this particular face what is the angle behind between them that is one of the very important features to characterize this crystal.

And what researchers found that the angle between equivalent faces of crystals of the same mineral are always the same and this is known as Steno's law. So, that helps us a lot in terms of identifying crystals of a particular mineral because they are always going to give us the same property. So, if we know what kind of angle we are going to expect we can identify the mineral irrespective of their size, it can be identified at a micro scale, it can be identified at a mega scale.

So, the property of the mineral definitely depends on the composition as we have seen because it will eventually control the crystallization but it is also depend on the overall crystal structure. And with the same composition you can have different crystal structures giving you slightly different properties of the mineral and we are going to see those kind of variations.

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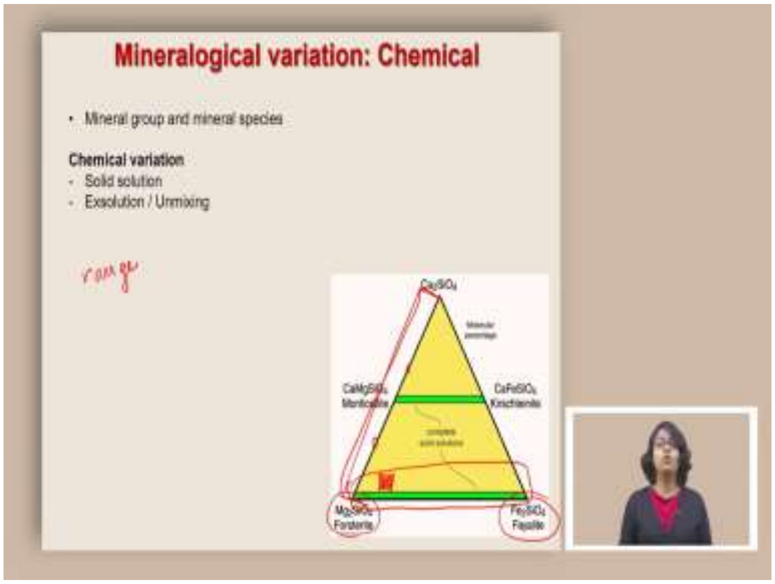

So, the first variation that we are going to talk about is a chemical variation. So, there are different mineral groups and mineral species, what we mean by that, that even though we may call something a single mineral as I mentioned that they may have a range of chemical composition and this range is very important because it tells you even more details about how they formed and where they formed.

So, I have given you an example of this particular ternary diagram where we have different n members. So, this one is called Forsterite its Mg2SiO4 and this one is called Fayalite Fe2SiO4. Now, these can vary these are n members and they can vary and the entire thing will represent one single mineral. However, the same mineral can have differing ratios of Fosterite and Fayalite.

Now, the same is true when we are looking at this particular range that we can have a combination of Mg2SiO4 and Ca2SiO4, but there would be different ratios looking in different you know examples of minerals although the entire thing can represent a single mineral and that is what we mean by a range of chemical composition within the same mineral.

So, one very important aspect that we should keep in mind that especially this example that I talked about Fosterite and Fayalite, this is often called a solid solution. Because basically you get different proportion of each of these n members in a mineral, in the same mineral and often they behave as if they are in solution, however they are in solid state and therefore they are often called solid solution. And their stability of each of these n members are different in different temperature and pressure condition. And therefore once you change the temperature and pressure, it can so happen that one n member which was high in the mineral is no longer stable in the changed temperature and pressure.

And therefore it will try to come out of the mineral structure and form something which will look like unmixing and this is also called an ex solution, because it is coming, trying to come out of the solution, but everything is happening in a solid face.

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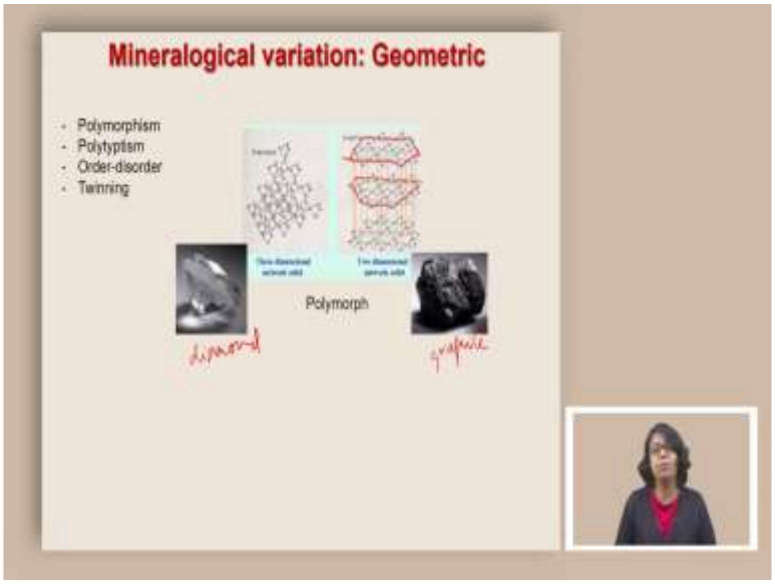

Other variations can be geometric, so within the same mineral composition we can have very different geometries representing different minerals. One classic example is a polymorphism, we know the difference between a diamond which is a mineral and a graphite, both of them are representing carbon, and it is pure carbon you can, if you in at high temperature if you burn them or you oxidize them you basically get carbon dioxide. So, both of them have the same exact chemical composition, in fact there is not even a range of chemical composition, it has a very very strict mineral composition per se the chemical composition and its only carbon.

However, we know that in terms of their properties they vary a lot, the diamond is extremely hard, extremely difficult to break down whereas graphite is so soft that even rubbing it against things as soft as a paper powders it, and that is why we can write with graphite. So, the difference lies not because of their chemical composition but because of their atomic structure, in the diamond we have these three dimensional network of the solid which binds it so well that it is very hard to break and there is no weak plane.

On the other hand, if we look at graphite there is a two dimensional networks of solids which creates a plane but between the planes the bond is really weak and therefore they will have a tendency of sort of sliding past each other and therefore grinding very easily, again these differences are being created simply because of their arrangement of elements and not so in terms of difference in chemical composition. So, there are such things like polytypism, order disorder, twinning all of these are variations in geometry of the minerals and therefore creating variations in minerals.

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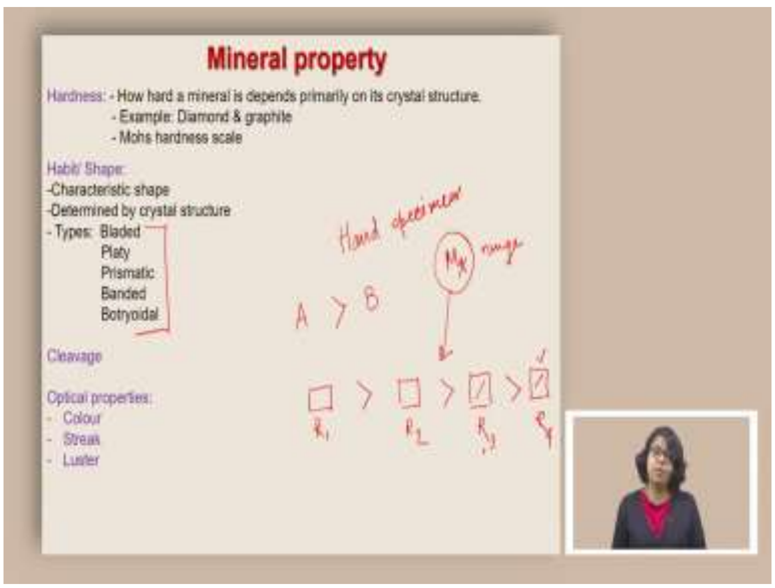

Now along with these chemical composition as well as geometric differences, it is important to identify minerals. Because every mineral tells you something about how they were formed and how they have gone through in subsequent processes. So, therefore we need to have some criteria to identify minerals. Now the question is, which criteria should we follow and how deep should we go in terms of identifying a mineral. So, today we are going to focus on identification which is primarily done on hand specimen.

So, that means that you are going to look at specimen of the mineral, which is large enough that you can see without the aid of a microscope and still you can tell something about the mineral and in those cases we are going to look at properties which can be observed without the aid of a microscope. The first thing that we are going to talk about is the hardness, how hard a mineral is and it depends primarily on the crystal structure, we already saw the example of diamond and graphite.

And in order to identify the hardness, people have designed something which is called Mohs hardness scale. What it means, it operates on the simple principle that if mineral A is harder than mineral B, then mineral A can scratch mineral B. And because we know some of the things that how hard things are you can create some reference materials with hardness and every time you get a material, every time you get a mineral you basically check with these reference materials and see whether something actually scratches it.

So, let us say we are taking an example, where R1 has the maximum hardness, R2 has lesser hardness than that, R3 has even lesser hardness, R4 is very soft. So, when you have an unknown mineral, let us say mineral X, which you really do not know what it is, you first scratch it on R4. Now if you see that mineral X actually scratches it, that means mineral X is harder than R4.

Let us say you scratch it on R3 and you find that mineral X can scratch R3. Then you go to R2 but you actually find that mineral X cannot scratch R2, that tells you that the hardness of this mineral is between the hardness of R2 and R3. And because these are already standard hardness scales, we know the hardness, it is important that we can, we can actually specify the range of the hardness for this unknown mineral.

Now, how, what kind of reference scales are we talking about? So, there can be porcelain, unglazed porcelain, there can be glass, there can be metal plates of different hardnesses, so all of these are giving you different hardness scale with known hardness, and then by comparing them with your unknown mineral, it is possible to put those minerals in the with respect to the relative hardness, and that is how the Mohs hardness scale works.

The second observational pattern of that we are going to talk about, that gives us very good understanding of minerals is the habit or shape. It basically tells us that, what is the characteristic shape? It has something to do with their crystal property and therefore it is important that we identify it correctly. Now there are various types of mineral shapes and when we are trying to identify it we have to use specific adjectives describing them.

We can definitely use our imagination to describing something, let us say something is more round than the other, something is more flat than the other, but unless we use the same adjectives every time, it becomes difficult to compare and that is the primary reason to come up with these set of descriptions that describe a specific shape. So, we are going to look at some of the shape characters.

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So, these are some of the examples of shape. So, let us take a look at kyanite, it is a mineral and generally they are described as a bladed shape. So, it has a structure which is elongated which has a very low thickness and relatively low width compared to its length and that is the character how we what we describe as blade.

On the other hand, if you look at quartz crystal in this case, it is called a prismatic shape because of its three dimensional structure and where you have the width and the thickness sort of comparable but one axis is quite long. Then there are examples of fibrous, so this one is a mineral which is primarily component is asbestos and you see these fibers coming out again the dimensions are very very similar when we are comparing width and depth but not the height, height is very high. Then there are shapes which are pretty hard to describe in terms of more quantitative manner but visually we can describe them in more irregular terms.

One example is botryoidal, so this is an iron ore hematite. So, the example that I am showing it has grape-like structure and they are generally described as botryoidal shape. Then we have banded structures, things which are replicating itself again and again creating these layers, and then in those cases we are calling it banded.

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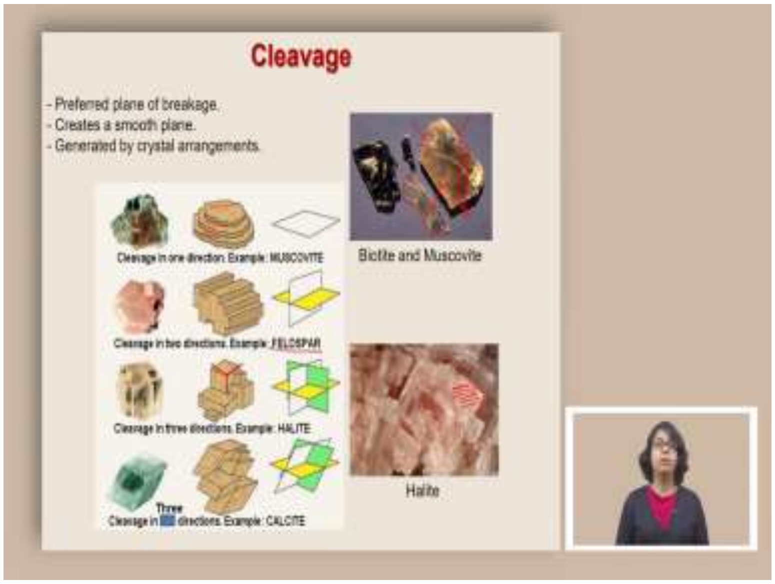

Apart from shape, another important aspect of mineral is the cleavage. It is the weak plane, it is the preferred plane of breakage for a mineral. Again it is controlled by the crystal arrangement of the mineral and once it breaks along those planes it creates a smooth surface. This is because, this is related to the crystal arrangement, it can be seen in microscopic structure as well as hand specimens. And therefore cleavage is one of the very important properties of the mineral and mineral identification.

So, these are some of the examples how it actually looks like. So, for example there can be one cleavage mica's are examples where each of the layers can be cleaved apart by one plane. So, if you look at this particular mica, example this is a muscovite, you can basically peel off the first layer and it will look something like this.

So, this came from here, if you peel off the next layer, it will again look something somewhat similar. But if you are trying to break it along this line down below, you are going to find it very difficult, because that there is no cleavage plane along that direction whereas this entire portion is cleaved apart in planes which are in this direction.

So, you can, it is almost like a leaf of the book and you can turn the pages you can take out the pages. Because it has only one cleavage direction, but there can be examples where there are two directions of cleavage Feldspar is an example and it is perpendicular to each other, there can be examples of halite, where there are three cleavage planes. So, if I look at this picture, you will see that there is one cleavage plane like this, another cleavage plane like this, another cleavage plane like this, which basically means it can be cleaved apart in along any of these directions.

Let us take a look at halite in a larger crystal, where we can see it and here also we basically see smooth planes all along the cleavage plane and this is another plane. So, we find all these three cleavage planes creating this step-like fashion, there can be other examples where three directions of cleavages they do not have to be perpendicular to each other calcite is one such example. So, all of these are important clues to identify minerals. So, when you get a mineral, first step is to talk about the shape, the cleavage, and then go into the optical properties.

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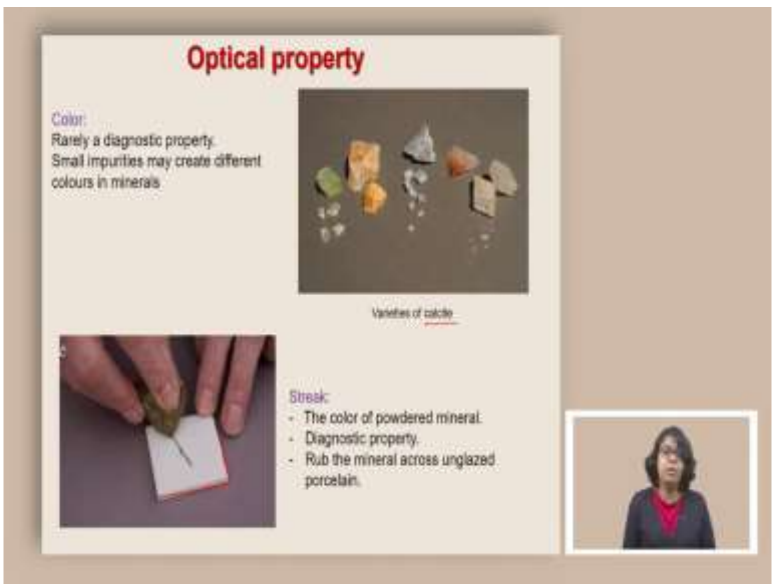

The optical properties, in general means how they are behaving in color in terms of the light. So, things that are included in optical properties are color streak things like that. Now color unlike what we think about them are not very good optical properties, when it comes to mineral identification. The reason behind is minerals change colors a lot depending on very small impurities in their chemical structure. And as I said because minerals can have a range of chemical composition, the same mineral can have a range of chemical composition the colors can vary a lot especially the color that you see in a hand specimen.

And therefore we do not pay much attention to overall color, we definitely note it, but we do not really use it as an identifying character. For example, if you look at this mineral calcite, you will see all kinds of colors appearing simply because of slight difference in the composition of the mineral just small impurities replacement of one Ion by the other will change the color and therefore color overall color of the hand specimen is not one of the most important identifying properties.

Let us talk about the streak, streak is the color of the powdered mineral that is more important than the overall color. Now what do we mean by that, we mean that if we crush the mineral into powder what is the color of that powder, because often the powder represents a color which is irrespective, which is not going to change because of smaller impurities and therefore it is much more reliable.

So, the way we recognize the streak is we have an unglazed porcelain plate on which we basically rub this mineral and it gives a characteristic line and a color and we call that as a streak and it is a diagnostic property. Obviously, if a mineral is very hard and it will if it does not produce enough powders by making something on this, then it would be difficult to identify the streak.

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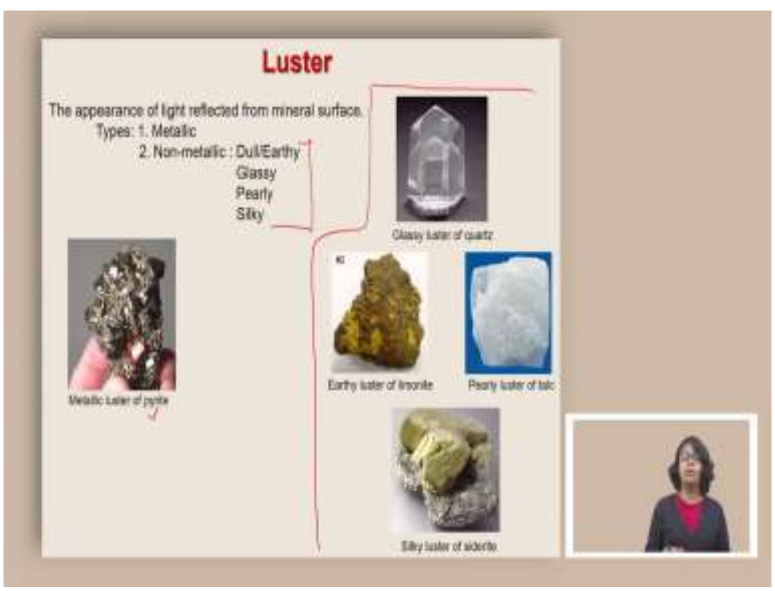

The other optical property which is very characteristic of minerals is the luster, it is the appearance of light reflected from mineral surface clearly it will primarily depend on the crystal structure but also on the composition. So, there are two major types of luster, one is called metallic luster, where the surface shines like a metal and then it is called a metallic luster. The non metallic lusters are difficult to describe and therefore we again go with a prescribed pattern of how to describe a particular luster.

So, this is an example of pyrite, which is FeS2 and this shows you the metallic luster which literally shines like a metal looks like a mirror, it is a perfect reflection and therefore you call it a metallic luster. The other set of non metallic lusters also give you some reflection but the reflections differ. For example, if you look at quartz, it reflects but it is quite different from the metallic luster, it looks more like glass and hence it is called a glassy luster.

The second one that we are going to talk about is, the siderite it has this silky smooth luster which reminds us about a cloth, which is silk and it has a reflection and that is called a silky luster. Similarly, pearly luster of talc, and then earthy luster of limonite. So, these are different ways of describing different luster patterns.

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Let us summarize, what we learned today. So, we learned how to define a mineral, second is how the variation in minerals can be created, and then what are the natural processes that can lead to development of crystals, and therefore minerals, the final thing that we learned is how to identify minerals and how to describe them in order to identify them, there are some resources that I used for this content, and here is a question for you to think. Thank you.