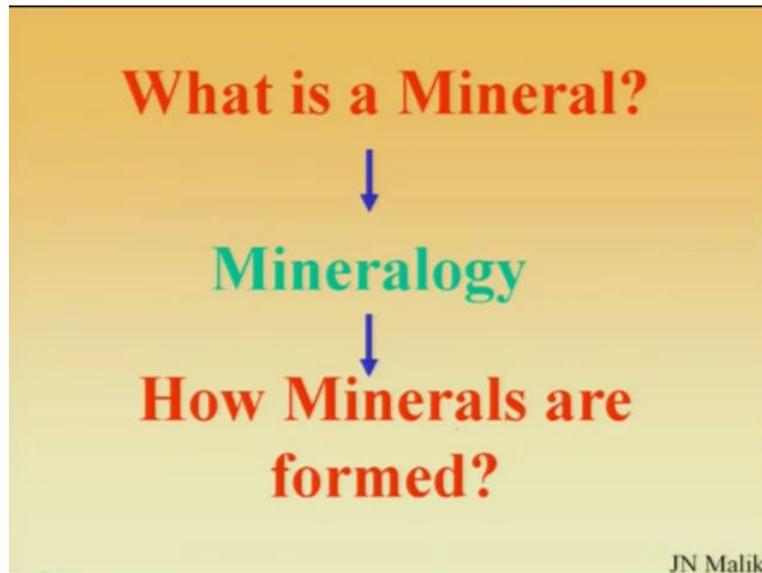


Earth Sciences for Civil Engineering
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Module 2
Lecture No 6
Rock-Forming Minerals and their Properties (Part-2)

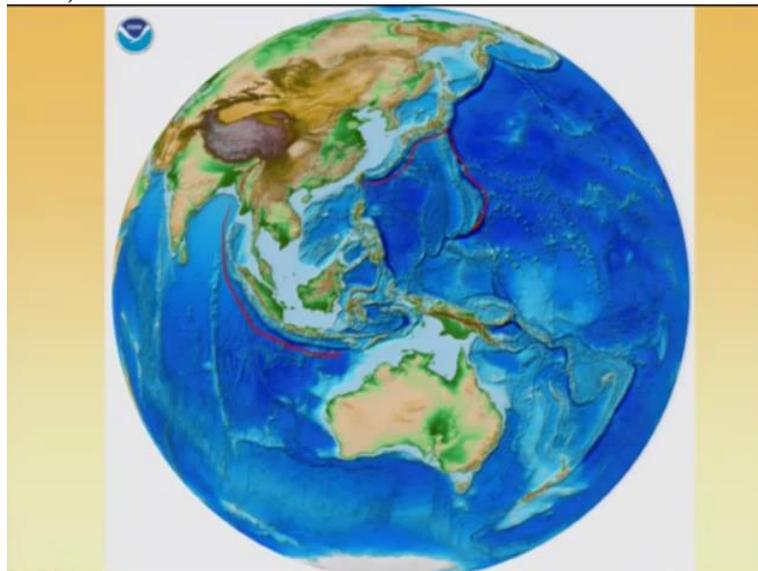
Hello everybody, welcome back. Now in this lecture we will talk we will talk about the minerals and how they are formed and valid they are formed.

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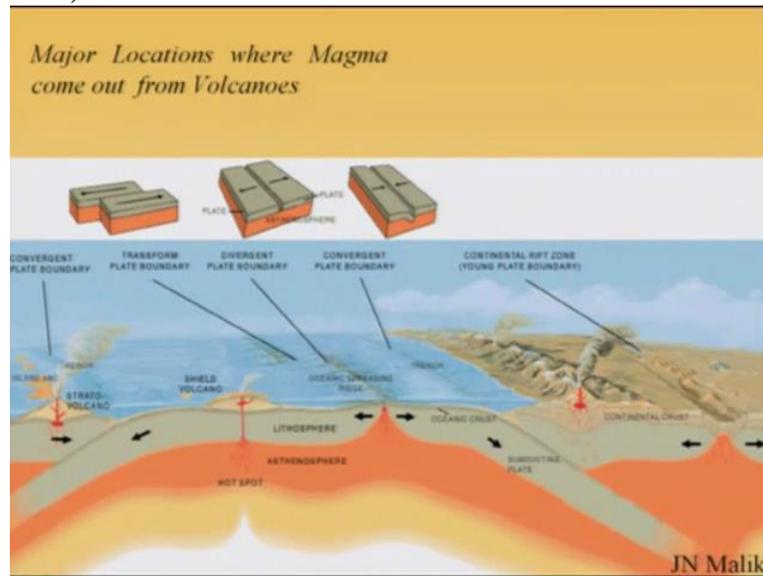
And the study of mineral the branch in geology is termed as mineralogy.

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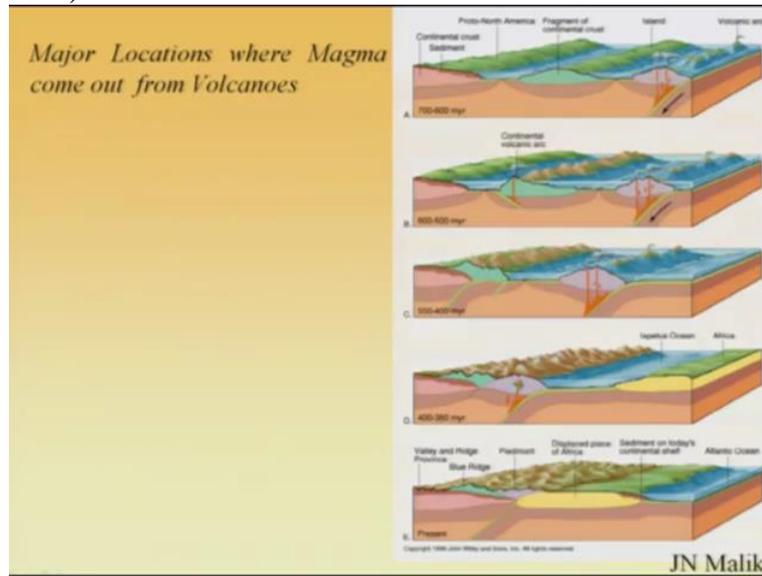
So as we discussed in the previous lecture, there are different type of plate boundaries. So most of the minerals are formed along the plate boundary. That is mostly along the subduction zones where we have the source of magma coming on the surface.

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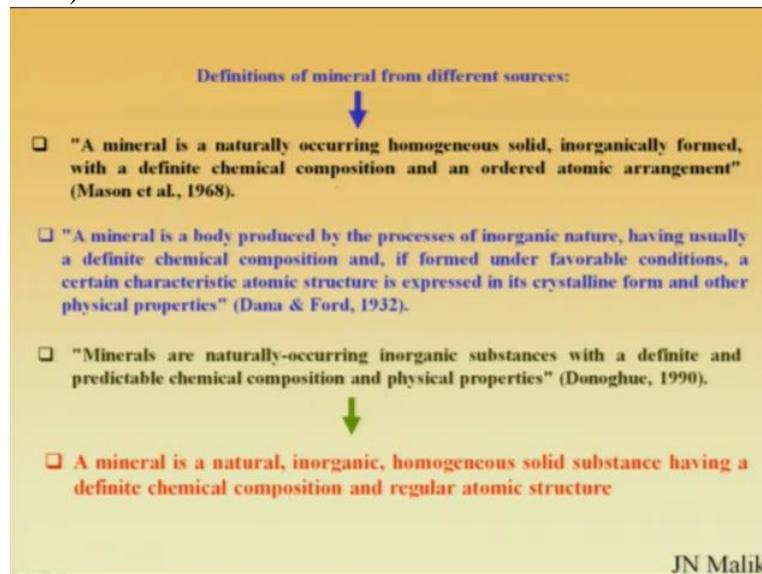
So if we broadly if we look at the major locations where the magma comes out from the volcanoes are the subduction zones. Either they are, that subduction zone is between the continental and oceanic plate or oceanic-oceanic plate. Or we are having the spreading centres. So these are the 3 major areas where we can look at and try to look at the magma which is coming out on the surface.

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So again just to quickly look at where are the sources, so as we have I have explained so we have the oceanic oceanic subduction. We are having oceanic-continental subductions. These are the locations where we will have the source of magma coming right up to the surface.

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Now in total if you look at the definition of mineral from different sources, what it says is that a mineral is a naturally occurring homogeneous solid inorganically formed with a definite chemical composition and an ordered atomic structure. So each mineral will have a typical chemical composition and atomic structure. And this is very important. We will study how we

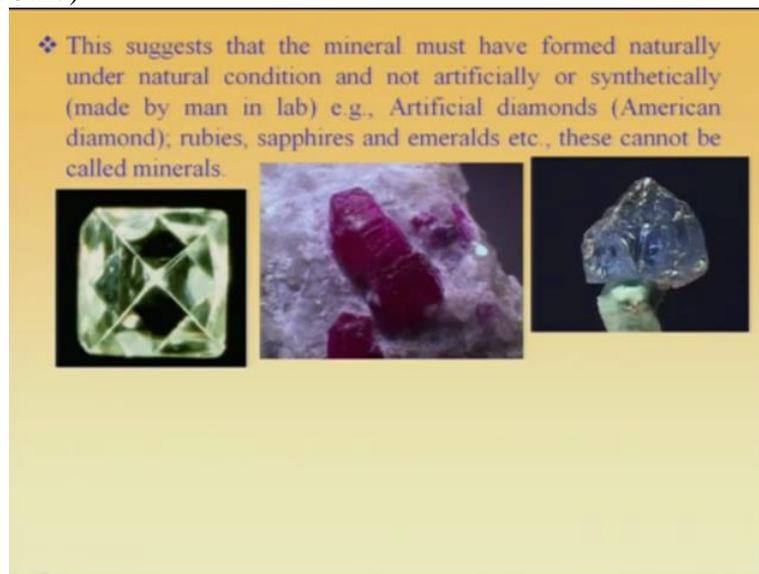
can identify based on the atomic structures also the different minerals and the chemical composition.

Another definition says it was given by Dana and Ford in 1932 that a mineral is a body produced by the processes of inorganic nature having usually a definite chemical composition and if formed under a favourable condition at certain characteristic atomic structure is expressed in its crystalline form. So we will look at the crystal structures also that what different and the crystal forms also. So these are the crystalline forms and other physical properties.

That is what is given. Again almost similar talking about the inorganically formed in having different chemical composition and the atomic structure. Then 3rd it came in 1990, it says minerals are actually occurring inorganic substance with definite and predictable chemical composition and physical properties.

And then it talks about finally if you take considering all these definitions, we can say that a mineral is a natural, inorganic, homogeneous, solid substance having a definite chemical composition and a regular atomic structure.

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So for example, these are some of the pictures which are being shown of diamond and then we are having Ruby and then we are having the quartz. So this suggests that the mineral must have formed naturally under natural conditions and not artificially. Of course in the market we have

certain artificial stones which also mimic the similar structures and all that but they are not the real one.

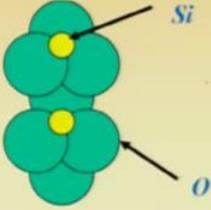
Like for example the artificial diamonds which we call the American diamonds, rubies, sapphires or emerald, etc, this cannot be considered if they are artificially formed crystals. So diamond is the hardest one amongst the all, having the hardness of around 10. So we will talk about this when we are talking about the hardness scale and all that. And then we are having Ruby which is also like in Sanskrit it is known as Raj Ratan which is again a very important mineral in terms of the gemstone.

Or it is a gem variety and variety of Curundum and then we are having the sapphires which is again a transparent or non-red variety of Curundum. Of course other than that, what we are having we talk about the fuel minerals. We have the coal, petroleum, natural gases, etc are organic substances which to strict sense are not minerals as per the definition. However they are considered as mineral and we call them as fuel minerals.

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CRYSTAL: Greeks called *krystallos*; the Romans as *crystallum*

- è The word crystal can be applied to any solid substance that grows with planar surface or a naturally occurring solid body bounded by smooth and plain surface arranged in an geometrical pattern
- è This is an outer expression of internal atomic structure.



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So coming to that part what we are talking about, the crystalline forms. So what is crystal? What it has been defined as? It is again a great word called Krystallose. The Romans, they said crystallone. So the word crystal can be applied to a solid substance that grows with a planar

surfaces or a naturally occurring solid body bounded by a smooth and clean surface arranged in a geometric pattern. So it has an angle in between the 2 planes.

And you will see that most of the minerals are having very definite crystal forms and the crystal planes. This is another outer expression of the internal atomic structure. So if you are having the internal atomic structure for the quartz and all that where you are having silicon and oxygen. So if you are having a definite internal structure, it will be reflected in the form of crystal face, crystal surface.

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So this is an example of quartz which is a hexagonal prism which is definitely like very beautiful crystal faces you can see here very definite at definite angles. And then another example is of the Halite which is in the cubic form. So you see almost all faces are at right angle. So if you define the crystal face, the plane surface that bounds the crystal is called crystal face and the geometric arrangement of the crystal faces is termed as the crystal form.

So these are the crystal forms we are having, the isometric and the hexagonal system and all that. So we will talk about this in due course. So these are all the crystal face.

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Mineraloid

- Some naturally occurring solid compounds do not meet the definition of a mineral because they lack:
 - a definite composition, or
 - a characteristic crystal structure, or
 - both
- e.g., Opal: is amorphous in nature



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There are different minerals which are not having a different crystal face. And they are termed as mineraloids. Some naturally occurring minerals, solid compounds do not meet the definition of a mineral because they lack 1, a definite composition or a characteristic crystal structure or both. And they are termed as mineraloids. So example is Opal which is amorphous. It is very soft in nature.

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Polymorphs:

- Minerals having same chemical composition but different crystal structure:
- Calcite (CaCO_3 ; Hexagonal)
- Aragonite (CaCO_3 ; Orthorhombic)



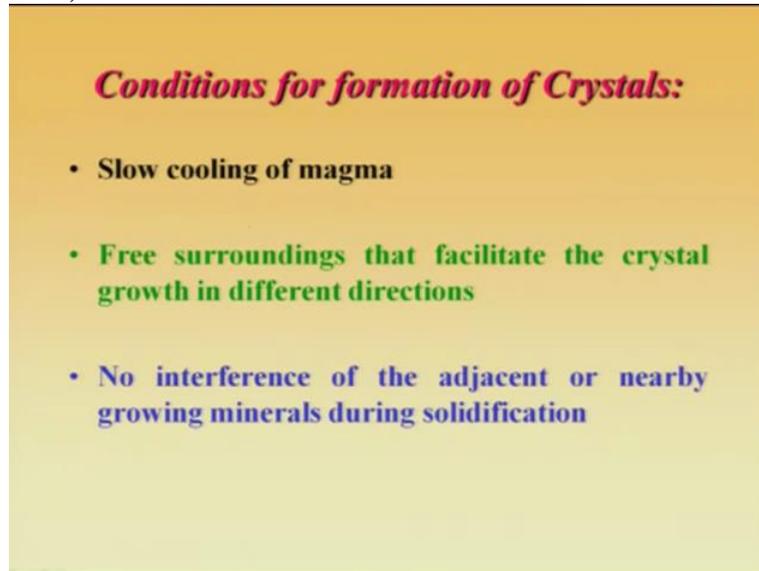
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And then we are having polymorphs. So we have crystal crystalline minerals. We have mineraloids and then we having polymorphs. Now polymorphs are the minerals having same

chemical composition but different crystal structure. So this is an example which talks about the calcite and having hexagonal crystal form and then we are having aragonite which is orthorhombic in nature.

But both are having same chemical composition. So the polymorphs are those minerals having same chemical composition and different crystal structures.

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Now the condition for formation of crystals. Again, slow cooling of magma and then 3 surroundings that facilitate the crystal growth in different directions. And 3rd is no interaction or no interference of the adjacent or nearby growing minerals during solidification. So these are the conditions for formation of the crystals.

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Mode of formation of minerals

There are three mode of mineral formation:

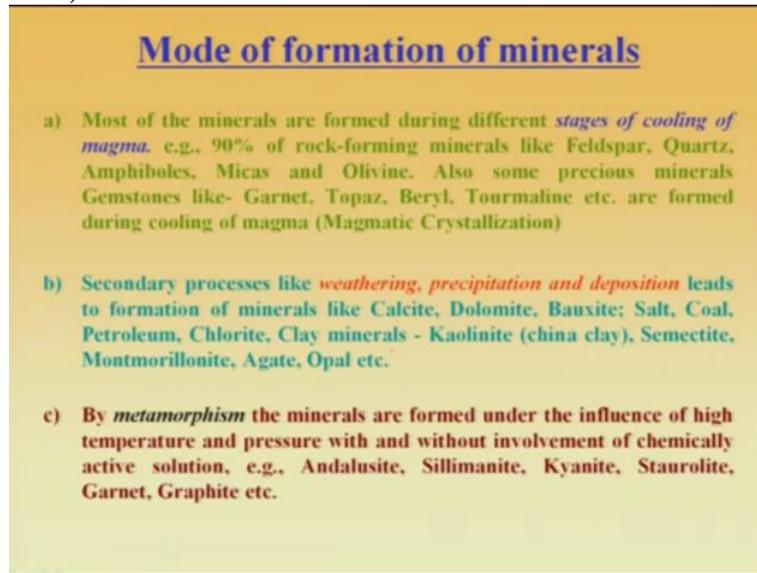
- (a) by cooling of Magma
- (b) by secondary processes
- (c) under metamorphism



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Now mode of formation of minerals if you take in total what we are having is, there are 3 modes of mineral formation. By cooling of magma, by secondary processes that is what we are talking about that if they are having a chemical process and all that. And the 3rd is, under metamorphism. So under great temperature and pressure beneath the Earth's surface, will result into the change in the or alteration of one mineral to another one.

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So mode of formation of minerals, so that was the mode of formation of minerals we are talking about in terms of cooling of magma, secondary processes and under metamorphic.

Now here mode of formation of minerals if we take, most of the minerals are formed at different stages of cooling of magma. So as magma is erupted at the surface, it cools down, it solidifies. So that is the process along which the different minerals will form and we will see that reaction series, how different minerals are formed. And almost 90% of rock forming minerals like feldspar, quartz, amphiboles, mica, olivine are formed during that process of cooling of magma.

Also some precious metals, gemstones like Garnet, Topaz, Beryl, Tourmaline. etc are formed during the cooling of magma and that process is termed as magmatic crystallisation. Secondary processes if we take is weathering, precipitation or deposition leads to the formation of minerals like calcite, Dolomite, bauxite, salt, coal, petroleum and this is because of the mainly because of the weathering.

And then we are having more of clay minerals like Kaolinite, Semectite, Montmorillonite, Agate, etc are the are the reasons for the how they are formed in the secondary processes. Then finally we are having 3rd one, is the office of the minerals that are soft. So under the influence of high temperature and pressure with and without involvement of the chemical active solution we see an example for formation of minerals or alteration of minerals from one to another. So we see

Andalusite , Sillimanite, Kyanite, Staurolite and all that. And the major locations as we have already discussed, I will just move ahead.

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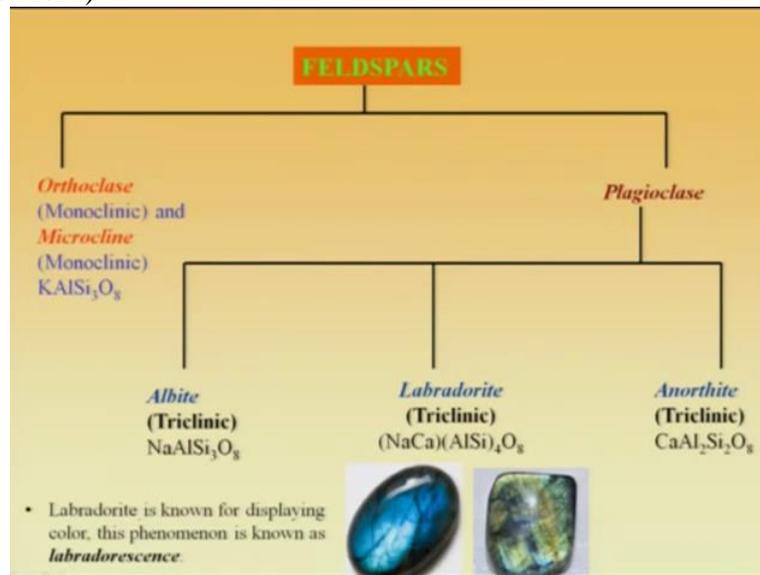


So important rock forming minerals if we take, so what we are having? More than 70% of the Earth's crust is made up of elements like oxygen and silicon. And in order of abundance if you take, silicates are the most abundant ones, most abundant rock forming minerals followed by oxides, carbonates, phosphates and sulphates. So we are having silicates are the minerals which comprises silicate tetrahedron or silicate anions.

And examples of these minerals are commonly seen which are feldspar, pyroxene, amphiboles, olivine, Garnet, quartz, clay and mica. And whereas we, if we look at the non-silicate minerals, we are having oxides. Mainly the haematite, magnetite and then we are having sulphides which we are having chalcopyrite which is rich in copper or we are having lead that is Galena. And then we are having carbonates, mostly the calcite.

We are having sulphates, we are having gypsum and then phosphates, we are having appatite. So these are the non-silicate minerals and we are having the silicate minerals and silicate minerals are most abundant in nature.

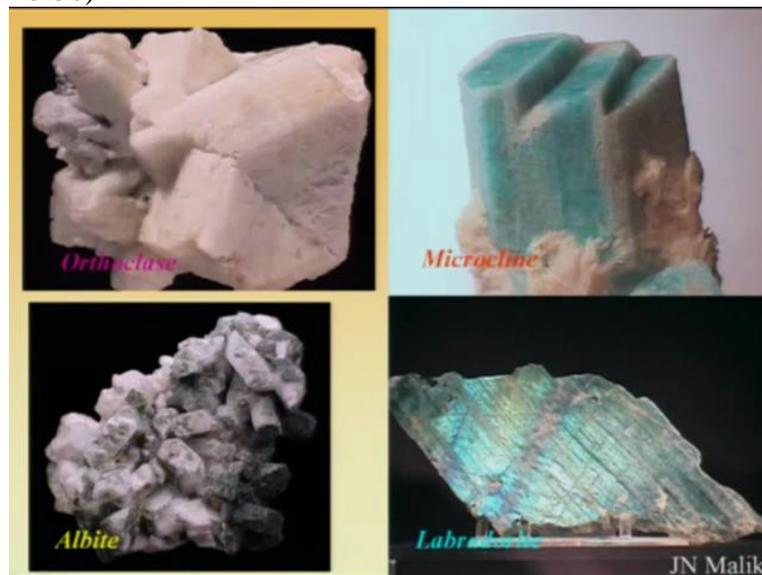
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Now coming to the feldspar particularly, this is the form of the silicate minerals. We have again different types of feldspar. And mostly what we have is the plagioclase feldspar and we are having the orthoclase feldspar. So what we see, the potash feldspar mainly. And then further plagioclase feldspars are being divided into 3 which starts from sodium and we are having right up to the calcium.

So we are having the Albite, we are having Labradorite and we are having Anorthite. And Labradorite is one of the minerals which is also being used by many people as a gem variety which has the characteristic of play of colours and this has been termed as Labradorescence. So labradorite is known as known for its displaying different colours. And this phenomena is very much commonly seen in the plagioclase feldspar.

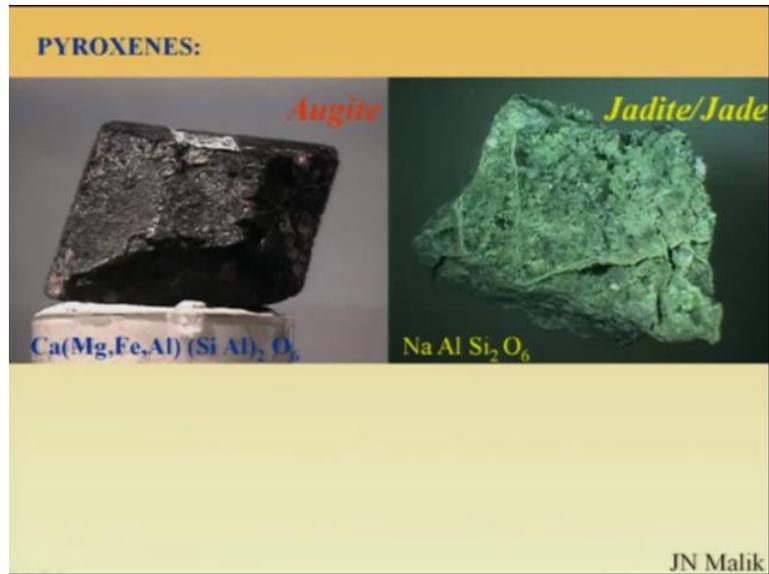
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Then we have other minerals like orthoclase, Microcline, that is again potash feldspar we are talking about. And then again we are having albite and that is plagioclase part. So this is how it looks like in a hand specimen.

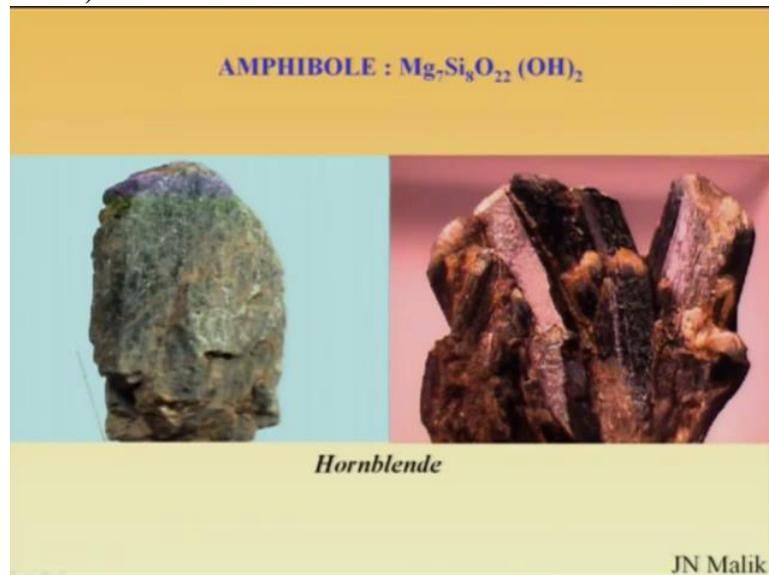
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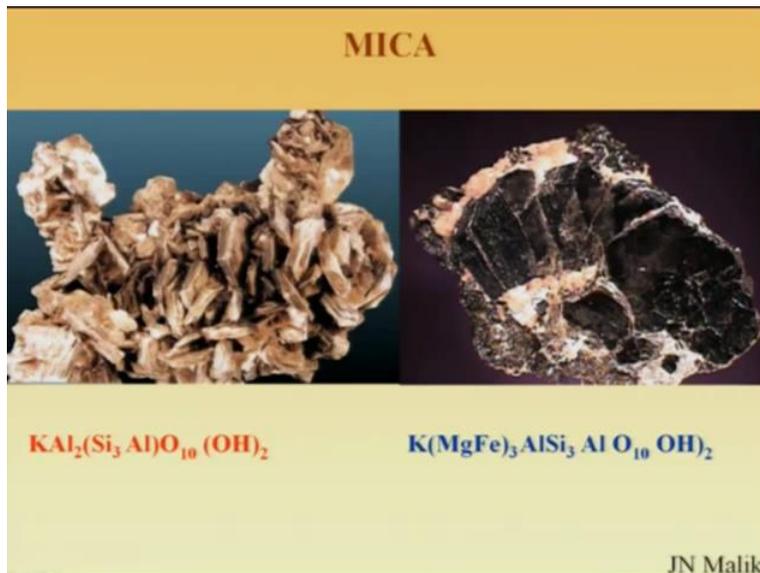




Then we are having anorthite. And we are having again pyroxenes. So mainly these are the, pyroxenes are rich in mafic magnesium and iron. And another one we are having, this is Augite and this is Jadite also. This is aluminium silicate minerals.

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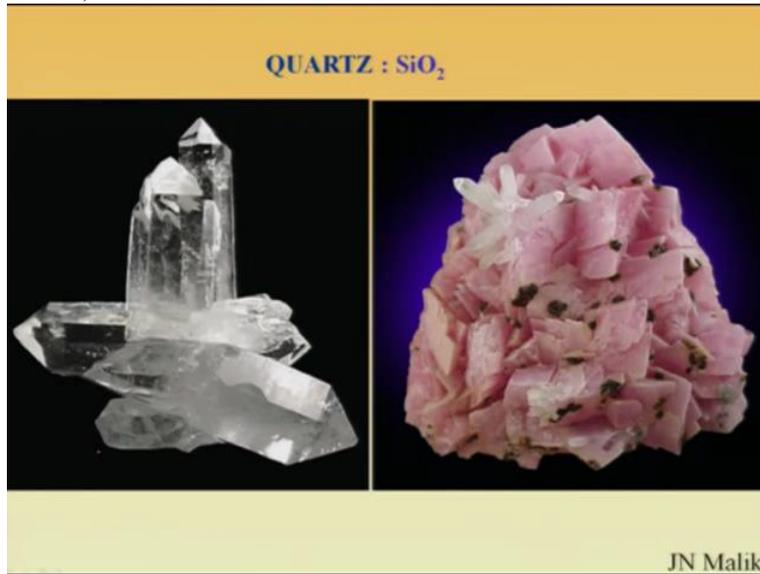


And then we are having amphiboles again rich in magnesium. We are having hornblende. Now these all minerals are been seen in different types of rocks and based on the composition different types of rocks are also been classified. We will see when we talk about the rocks and all that. And then we are having olivine which is again rich in magnesium and iron. And we are having mica which is again silica and magnesium and iron.

So this is termed as Muscovite and then we are having biotite. Biotite is a bit darker in colour because of the magnesium and iron. Whereas this is lighter because of the silica and aluminium. These are also one of the characteristic parameters we are using while identifying the Mafic

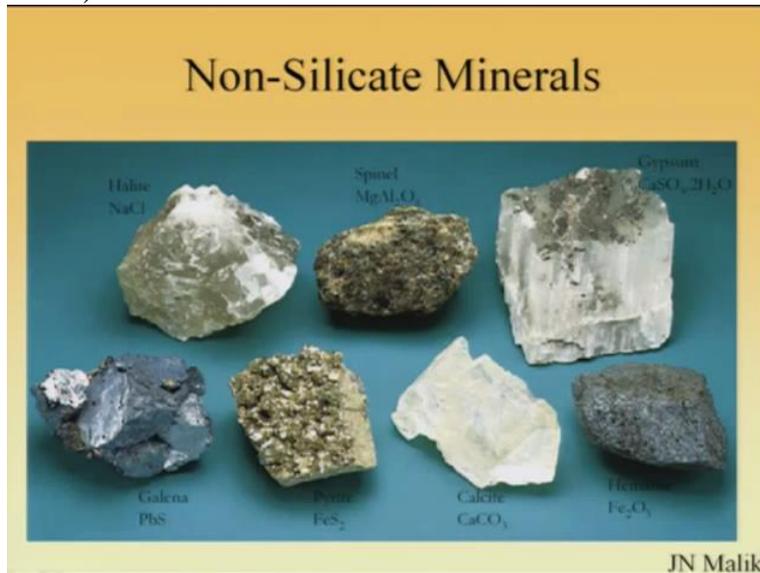
rocks or felsic rocks or the rocks which are rich in silica and all that. They will be lighter as compared to others. So they are having, these are the darker ones where we are having magnesium and iron.

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Then we are having quartz. Mostly silica, silicon oxide we are having. We have the crystal structures which are very definite. This is a rock crystal and this is what we see is the pink variety of quartz.

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Then we are having, we have seen discussed little bit about the non-silicate minerals mostly are formed because of the precipitation or the solution activities. We have Halite, we have Galena, we have pyrite, calcite, etc.

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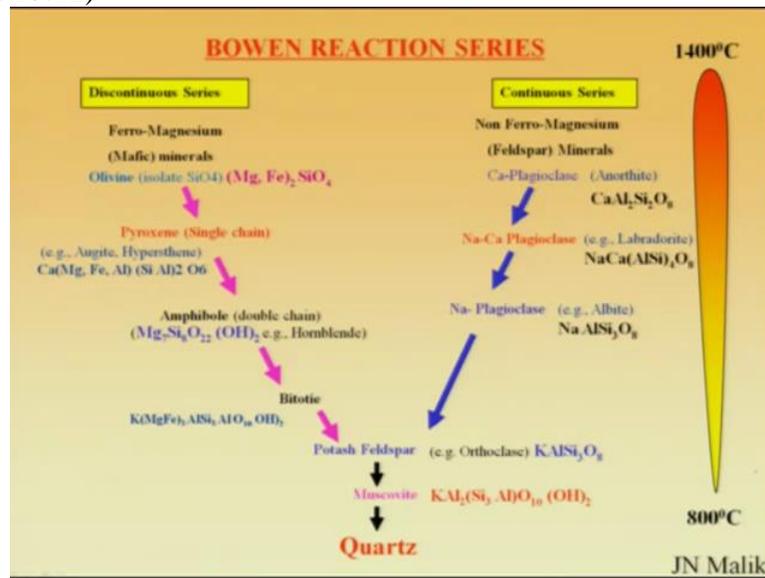
- Bowen in (1922) identified two series of mineral formation/crystallization. He suggested that Minerals crystallize in a particular manner with varying temperature ranging from 1400°C to 800°C
- *Discontinuous Series*
 - Mineral crystallize in sequence with decreasing temperature, mainly Ferro-Magnesium minerals e.g., Olivine, Pyroxene, Amphibole, Biotite.
 - If one mineral becomes chemically unstable, another mineral begins to form
- *Continuous Series*
 - Plagioclase feldspar forms with a chemical composition that evolves from Ca-rich to Na-rich with decreasing temperature

Now, in 1922, Bowen identified 2 series of mineral forming formations. The process of the crystallisation of minerals. He suggested that the minerals crystallise in a particular manner with a varying temperature which is ranging from 14000 degrees to 800 degrees. That is the, when the magma comes out, it is extremely hot and it slowly cools down. So in this process of cooling down different minerals will crystallise and different crystal forms will be seen.

So he identified and suggested 2 series. One is discontinuous series environment and crystallise in sequence with decreasing temperature. Mainly ferro-magnesium minerals. Example olivine, pyroxene, amphiboles and biotite. And then if one mineral becomes chemically unstable another mineral begins to form. And that continues in the form of the cooling process also. And another was the continuous series.

Now here, plagioclase feldspar forms with a chemical composition that evolves from calcium to sodium rich minerals with decreasing temperature. So one is the continuous. Another is discontinuous series he identified.

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Now if we look at the Bowen reaction series what it shows? Discontinuous series and continuous series with a different type of minerals forms in a process where we are looking at the decrease in temperature. So we have Mafic minerals, we have minerals which are rich in feldspar. That is ferro-magnesium and non ferro-magnesium minerals we are having. So mostly olivine ferro-magnesium mineral. Then goes with the pyroxene.

This is how the stages are there where different type of minerals will form. 1st olivine will come. Then pyroxene will form. Then we are having the amphiboles and then we are having the biotite. These are all the part of the discontinuous series and which are rich in ferro-magnesium. And then finally what we see in the continuous one, we are having calc plagioclase, anorthite, then we are having labradorite which has sodium, calcium both.

And then we are having the sodium plagioclase that is an albite. And then finally what we see out of both the series is a potash feldspar and we are having finally the formation of Muscovite and quartz. So this all happens with the decrease in temperature from 1400 degrees to 800 degrees or further. So this is this you can remember and try to understand how different discontinuous and the continuous series leads to the formation of minerals with respect to the decreasing temperature from 1400 to 800 degrees.

This was been given by Bowen and this series has been termed as Bowen reaction series comprising discontinuous and continuous series of ferro-magnesium and non-ferro-magnesium minerals.

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CRITERIA FOR IDENTIFICATION OF MINERALS

- 1) **CRYSTAL SYMMETRY:** Most of the minerals occur in nature are in crystalline form, which is a reflection of their respective *Internal Atomic Arrangement*.
- 2) This geometrical arrangement of atoms result into different shapes of crystal e.g. Cubic; Prism; Hexagonal etc.
- 3) On the basis of symmetry and crystal form, these forms are *subdivided into six systems:*

The Six Crystal Systems

- **Cubic:** $a = b = c$; $\alpha = \beta = \gamma = 90^\circ$.
- **Tetragonal:** $a = b \neq c$; $\alpha = \beta = \gamma = 90^\circ$.
- **Hexagonal:** $a = b \neq c$; $\alpha = \beta = 120^\circ$; $\gamma = 90^\circ$.
- **Orthorhombic:** $a \neq b \neq c$; $\alpha = \beta = \gamma = 90^\circ$.
- **Monoclinic:** $a \neq b \neq c$; $\alpha = \gamma = 90^\circ$; $\beta > 90^\circ$.
- **Triclinic:** $a \neq b \neq c$; α and $\beta > 90^\circ$; γ .

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Now criteria for identifying minerals. This is again a very important aspect which we should know and we can use this criteria while, in the field also one we can where we can identify the different minerals based on the understanding that what different properties the respective minerals will have. So crystal systems, one is the 1st is the crystal. So we look at the crystal system and we try to identify or classify the different minerals.

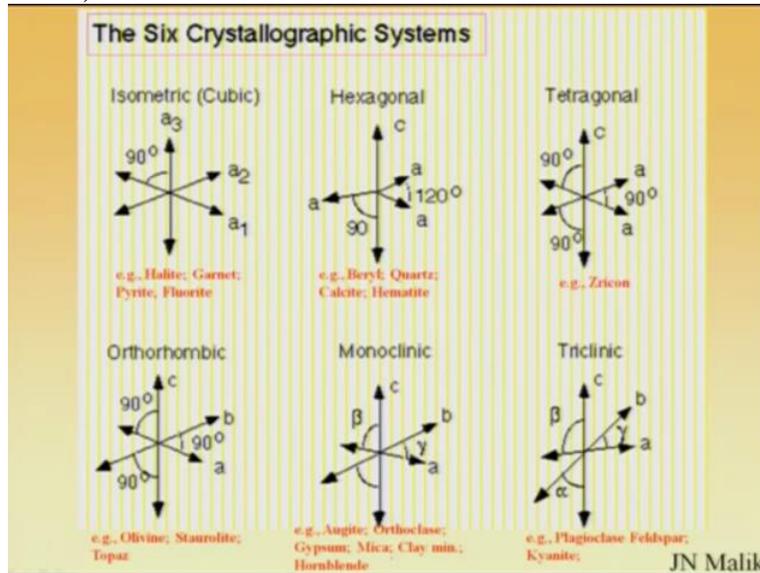
So most of the minerals occur in nature are having crystalline forms which is a reflection of the internal atomic arrangement that we were talking about. So this geometric arrangement of atoms results into different shapes of crystals. So for example, cubic either it is prism or it is hexagonal or it is Tetragonal. So on the basis of the system symmetry of the Crystal forms, these forms are subdivided into 6 different systems where we are having cubic, we have Tetragonal, we have hexagonal, we have orthorhombic, monoclinic, triclinic.

So we are having six crystal systems and these are the axis which talks about how they are, all 3 are equal and then angle between them are also almost at right angle. And then Tetragonal, 2 are equal, one is unequal and the angle is almost like 90 degree between them.

Hexagonal 3 axis are equal in the same plain and the 3rd one which is the larger one axis which is not equal to one another and the angle also varies most of them are having 90 but one is almost 120 degrees with respect to other 3 and all that.

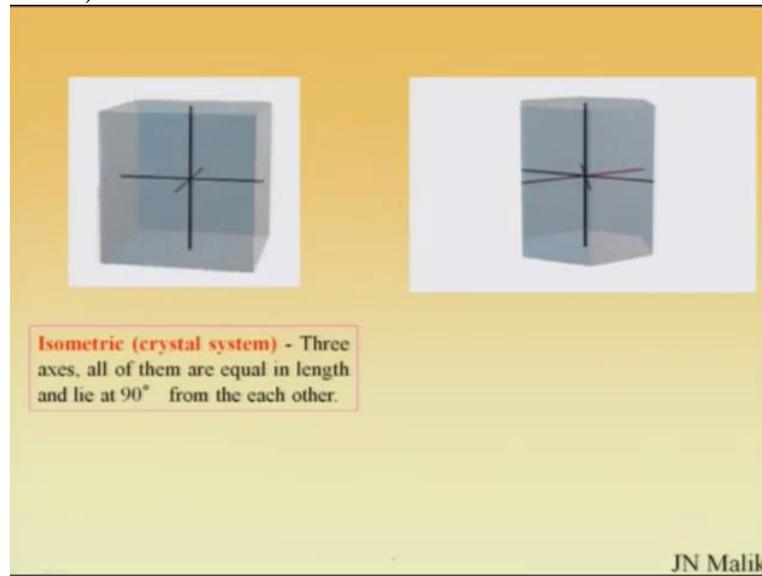
Similarly other relationship of the axis is also given. So based of this crystal system, you can also try to understand the minerals.

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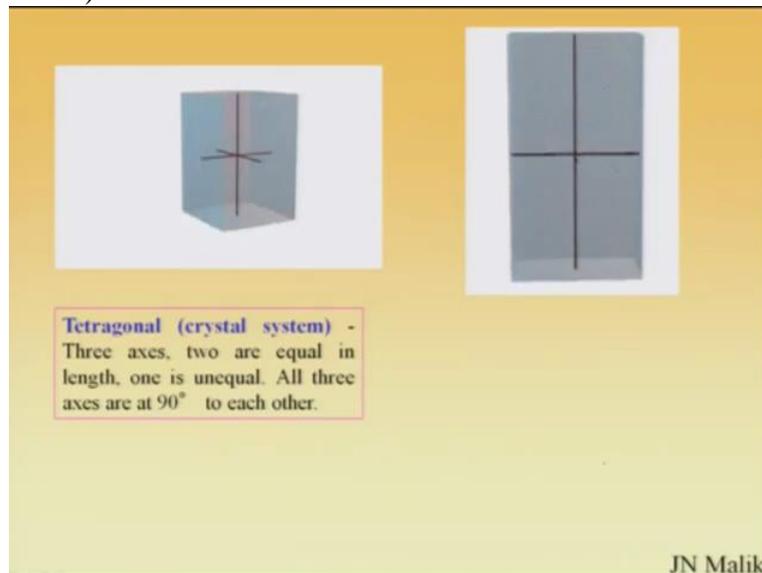
So there is again, that has been given that how three six crystallographic systems exist and which can help and these are different examples which have been given. For example, for cubic, we are having Halite, Garnet, pyrite, fluorite. Hexagonal we are having quartz, calcite, haematite and then so on and then we are having triclinic we are having plagioclase, feldspar and kyanite. So Zircon is in tetragonal and mica what we see is a monoclinic system.

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So these are the different crystals and the axis which are been shown here. And the means this videos. So isometric, 3 axis, all of them are equal in length and lies at 90 degree from each other. Then we are having hexagonal 4 axis where 3 axis are equal in length, lies in the same plane as you feel here. And then of of 120 degrees from each other and the 4th one is either longer or shorter, this one. This is either longer or shorter and it will be at right angles towards the other corners.

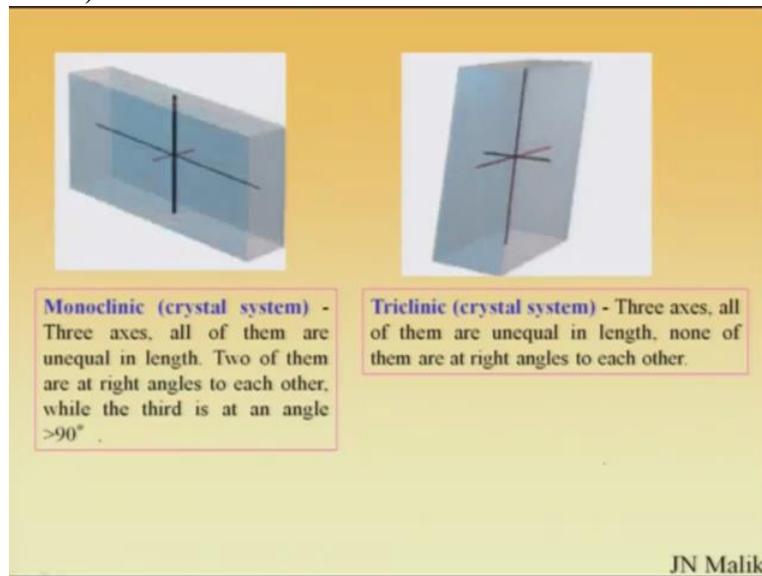
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Then we are having the tetragonal, 3 axis, 2 are equal in length. One is unequal. All 3 are at right angle to each other.

Then we are having orthorhombic, 3 axis, all 3 unequal in length, all 3 axis are at right angle to each other.

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Then we are having monoclinic. 3 axis, all of them are unequal in length. 2 of them are right angles to each other. While the 3rd one is having greater than 90 degree of angle. And then we are having triclinic. All 3 axis of them are unequal in length. None of them are at right angle to each other.

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- The simpler terms used to describe cleavage are: *Perfect, imperfect, good, distinct, indistinct, and poor.*
 - Cleavage is said to be **BASAL** when it occurs perpendicular to the major axis of the mineral and
 - **PRISMATIC** when it occurs parallel to the major axis.
 - Multiple cleavages that produce geometric *polygons* are referred as **OCTAHEDRAL** cleavage in the mineral fluorite,
 - **CUBIC** cleavage in the mineral halite or
 - **RHOMBOHEDRAL** cleavage in calcite
 - One Set of cleavage- Mica, Chlorite, Talc
 - Two sets- Feldspars, Pyroxenes, Amphiboles
 - Three sets- Calcite, Dolomite, Galena or
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Then we come to the other part is this simpler term used to describe the cleavage. So we can we can have cleavage, either it is perfect, either it is imperfect, good, distinct, these are the terms which are being used to identify or pinpoint the different types of cleavage in the minerals and we can say also either it is distinct, indistinct, or poor cleavage.

Now cleavage is said to be basal when it occurs perpendicular to the major axis of the minerals and prismatic when it occurs parallel to the major axis. So this is the crystallographic axis that we are talking about. Multiple cleavage that produces geometry. Either it is polygons, are referred as octahedral cleavage. And the minerals of like example is fluorite.

And cubic cleavage. And like example is halite. And we are having rhombohedral in terms of calcite and we are having one set of cleavage which has been seen in mica, chlorite and talc. Two sets mostly in feldspar, pyroxenes and amphiboles. So this is another property which is very much important to identify or differentiate one mineral from the another one apart from the crystal shape and crystal form.

And then we are having calcite, Galena, we will have 3 sets of cleavage. So the cleavage is the plane along which the mineral will break actually. And then we are having fluorite, we are having 4 sets. So thank you very much. We will continue in the next lecture.