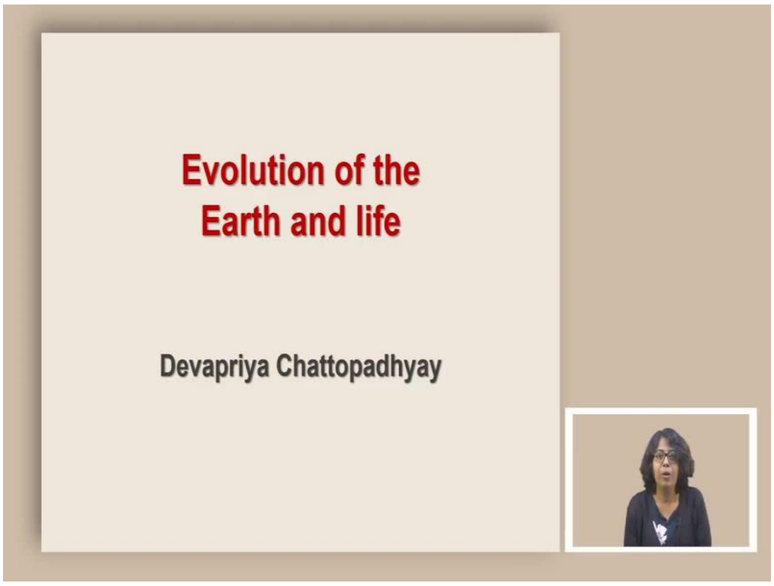
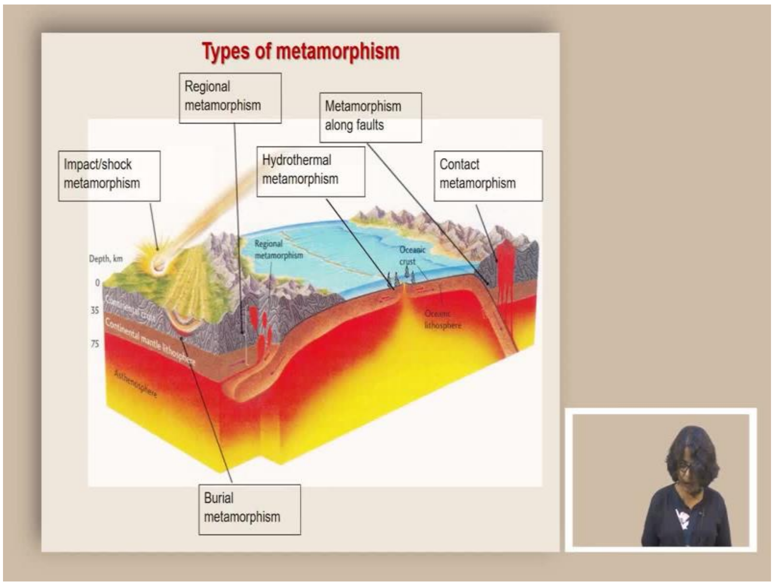
Evolution of the Earth and Life
Professor Dr. Devapriya Chattopadhya
Department of Earth and Climate Science
Indian Institute of Science Education and Research Pune
Types of Metamorphism

(Refer Slide Time: 0:17)



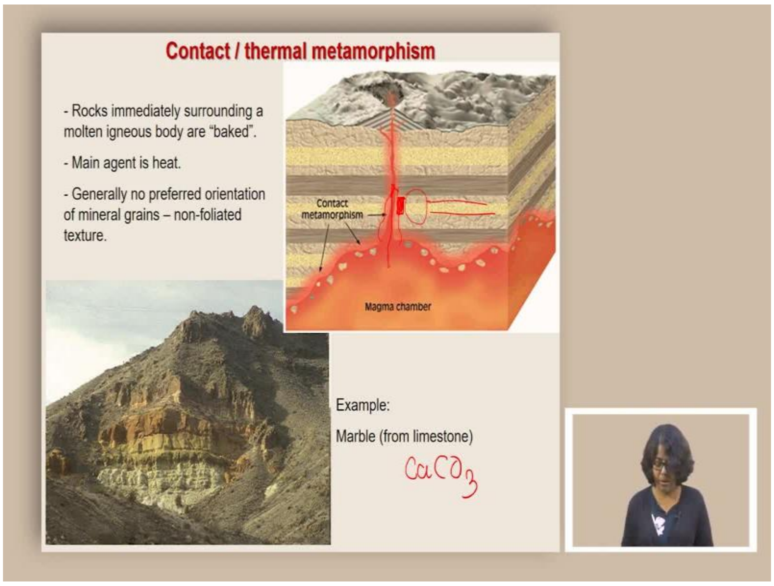
Welcome to evolution of the earth and life. Today we are going to talk about different kinds of metamorphic events and where they take place. And also what kind of metamorphic rocks can we expect out of those events.

(Refer Slide Time: 0:37)



So this is a summary slide of different types of metamorphism that are happening in different parts of the earth crust. And it is important to notice that all of the metamorphism that is happening are primarily restricted to the crust and bit of upper mantle but not any further. And therefore metamorphism is primarily a crustal phenomena rather than deep interior of the earth. So we are going to talk about all these different types of metamorphism and we are going to see that what are the agents of metamorphism that are most active in each of these situation.

(Refer Slide Time: 01:32)



So let us start with a type which is called contact or thermal metamorphism. In contact or thermal metamorphism rocks immediately surrounding molten igneous body are baked. So imagine a situation where from the magma chamber magma rises to the surficial level. So the surrounding rock right next to the magma chamber and the part of the magma, it is going to be depending on the composition, it can start to melt.

However, there would be rocks slightly away from this, which are not going to be affected by the heat. What about the rock which are right around here, which is not experiencing a temperature which is high enough to completely melt them, yet they can be high enough to impact them and metamorphose them. So these are the situations where rocks are going to encounter are type of metamorphism which is called thermal metamorphism or contact metamorphism. So clearly, the main agent is going to be heat.

Because it is primarily guided by heat and not any directional stress, we will find rocks resulting out of these contact or thermal metamorphism that will not show any foliation in terms of their texture, we will not see specific orientation of mineral grains, instead we are going to find non foliated structure, non-foliated texture of rocks.

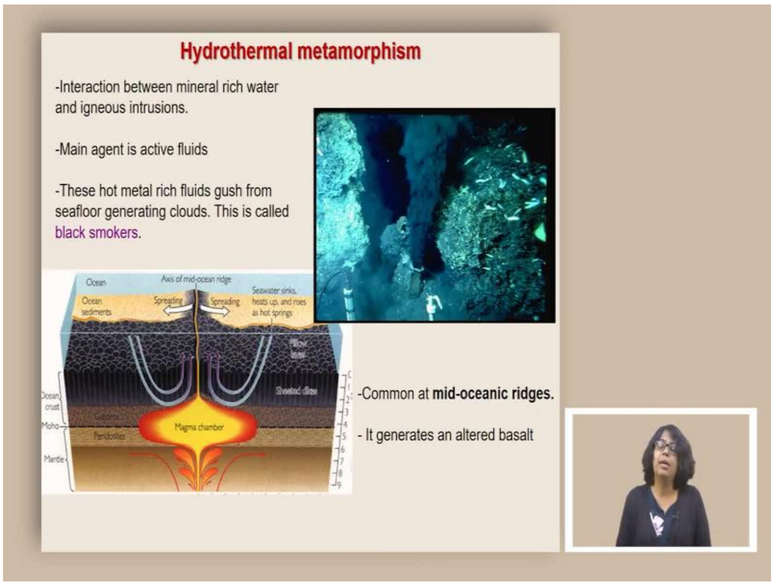
Examples are marble. So, marble starts with limestone, which is a sedimentary rock and the chemical composition is calcium carbonate. And when magma passes through a rock suit, which has calcium carbonate, let us say a limestone a bed often this limestone bed changes or metamorphosis to marble.

So the composition does not change, the composition is still the same, it is still calcium carbonate. However, what you are going to see that the texture has changed, clearly the mineral grains or the sedimentary particles that were making the limestone have become much more condensed, the crystals have become larger and they have been brought together and the grains and the gaps are nonexistent between the grains and there is no grain structure all you see is the development of the crystals recrystallization of calcium carbonate.

The reason I am saying that it did not change its chemical composition is because if you drop if you pour a drop of acid on a limestone, it will emit carbon dioxide so it will fizz out, it will do the same thing if you do it on marble.

There can be development of other minerals in a low proportion depending on the surrounding environment for a marble, but primarily it will still have calcium carbonate and calcium carbonate and or if you will when we are looking at the marble, it does not really have any foliation planes or it is not going to give you a preferential direction of the arrangement of the crystals, it is going to be more like a grano-plastic pattern.

(Refer Slide Time: 05:34)



The second type is a hydrothermal metamorphism. So let us try to understand where we can expect them. These are going to be places where high temperature fluids are coming out from the deeper part of the earth and hence influencing the rocks surrounding to those events. They are these hydrothermal metamorphism is observed near the mid oceanic ridges. This is an interaction between mineral rich water and igneous intrusions.

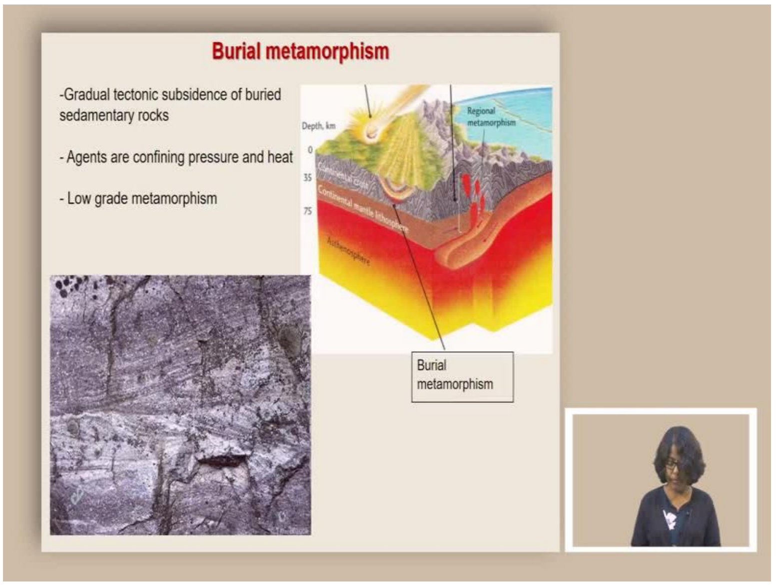
So if you recall the mid oceanic ridges, these are the places representing the divergent boundary. And hot magma is coming out at the surface and interacting with the ocean water, because it is quite hot, and also there is a high overburdening pressure because of the water column at this high pressure as well as high temperature many of the minerals especially the metal ions are dissolved in the water, which is an which otherwise would not be dissolved in that water.

So there are there would be water here which is much-much higher, which has a much higher temperature, then the boiling point, because of the high pressure, it can still be stable, it can still be a boiling water at that particular temperature and it is going to dissolve many of the metal lines. And therefore these active fluids are going to change the composition of the nearby rocks. And these nearby rocks, by definition would be basalt.

So the basalts are going to be completely metamorphosed by these events of hydrothermal metamorphism. These particular features are called black smokers, these are hot these are pipes through which hot metal rich fluids gush from the seafloor generating clouds. And there can be black smokers there can be white smokers depending on what is the chemical composition of these fluids that are emanating from these vents.

So all along the mid oceanic ridges, we are going to see signature of hydrothermal metamorphism in the form of altered basalt. It is also important to recognize that these signatures can be traced back even at ancient rock record, where we can find the development of pillo-basalt, which happens because of the underwater move underwater release of magma, and then it will eventually be metamorphosed because of these hydrothermal metamorphism.

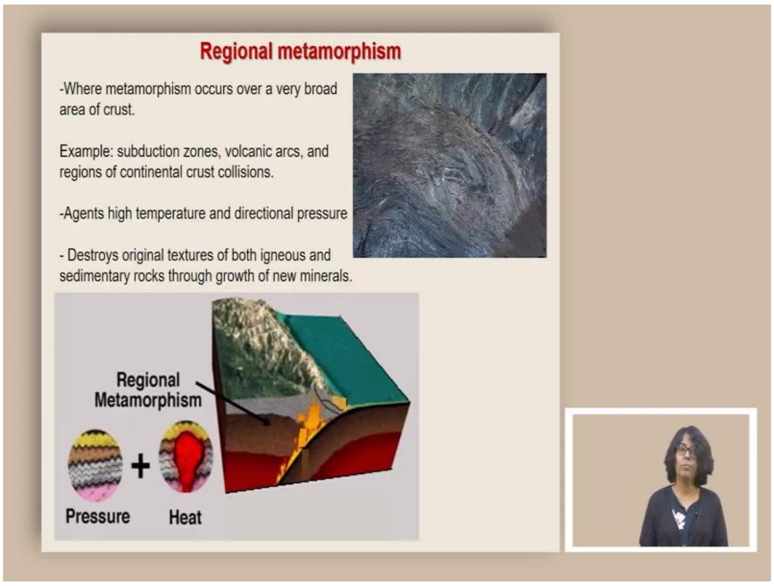
(Refer Slide Time: 08:48)



The other type of metamorphism is burial metamorphism, this is a gradual tectonic subsidence of buries sedimentary rocks. And because we are talking about burial, the primary agent is the confining pressure and heat. It is important to understand that we are not talking about directional pressure and therefore, you are not going to expect major changes in terms of shape, we are primarily going to find compressive pattern sometimes we are going to find development of foliation but not so much which we can expect in areas where we find tensional stresses or shear stresses.

They are generally low grade metamorphism and the places where we can expect such burial metamorphism are associated, they do not have to be associated with a specific tectonic boundary setting, it can be any intra-plate part two where part of the rocks or sediments are synced down because of the overburdening pressure and experiencing high pressure and relatively high temperature. And a combination of that is going to produce these burial metamorphism.

(Refer Slide Time: 10:26)



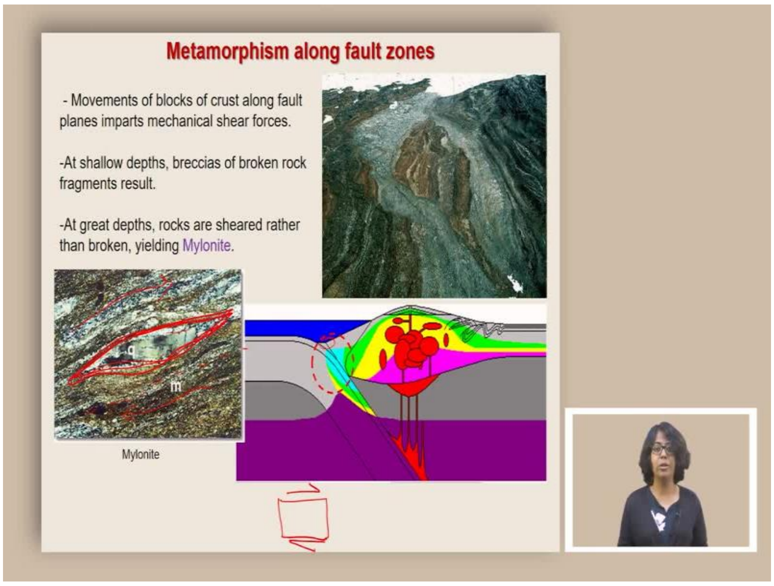
Regional metamorphism is probably one of the most wide scaled feature on the Earth, where the metamorphism occurs on a very large scale or large area of the crust and they are often associated with specific plate tectonic boundary. Because these plate tectonic boundaries have continuity and along those continuation of those plate boundaries, we are going to see the same process of regional metamorphism. One example would be the subduction zones or volcanic arcs or regions of continental crust coalition. So, all kinds of convergent plate tectonic boundaries finally lead to development of regional metamorphism.

The agents of such metamorphism include very high temperature and directional pressure, primarily in the form of compression. So if we are thinking about these subduction zone metamorphism, a block of the crust is going down and underneath another block and before it reaches the depth and temperature composition where it starts to melt before that it is actually experiencing very high pressure and temperature and that pressure is not confining pressure, it is actually a directional pressure, a directional stress.

Primarily we are going to expect a compressional pressure somewhere around here, you are going to see that rocks are basically changing its shape, they are often buckling something which is signature of a ductile deformation.

And because of these all these factors, it destroys the original texture of both igneous as well as sedimentary rocks through growth of new minerals. So it does not really allow us to identify the original composition or its original parent rock, but it is a very good indicator of the temperature and pressure combination. Because depending on the temperature and pressure, newer minerals, newer metamorphic minerals are appearing as a result those minerals and the resulting texture become the proxy for a particular temperature pressure condition.

(Refer Slide Time: 13:07)

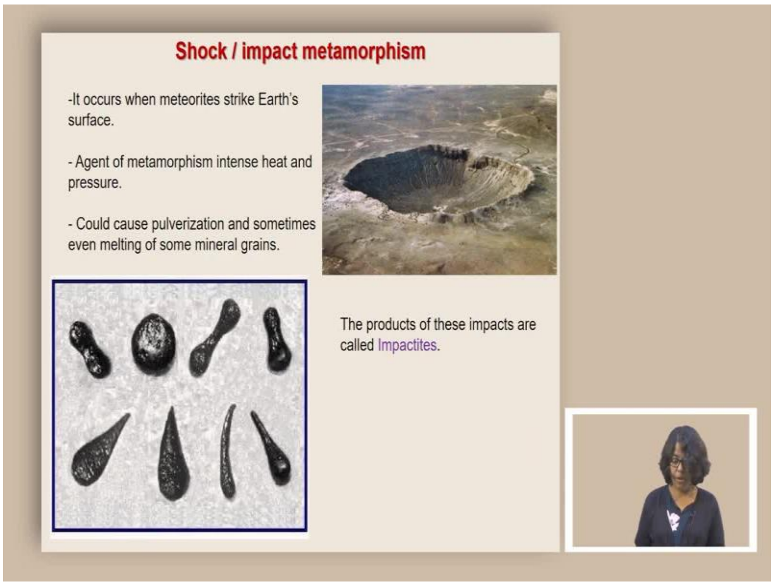


Another type of metamorphism is the metamorphism that happens along the fault zones. So if you think about the fault zones, it is a place of a relative weakness along the crust somewhere along the crust where the rocks can move. So movement of blocks of crust along fault planes imparts mechanical shear force. So we already talked about the shear stress and the shear stress is somewhere where the directions are differing in different directions. So and the stress vectors are basically differing in their direction and things tend to change their shapes and these are happening along the fault zones.

These are generally features at shallow depths, breccias of broken rocks fragments are resulting. So breccias are basically small crushed rocks with some of the original fragments present. Sometimes at greater depth, rocks can be sheared rather than broken and that can form a particular type of rock, which is called Mylonites. So this is an example of a Mylonite where these are Mica. And if you look at the direction pattern of it, it looks something like this and then there are minerals, which are quartz. So the quartz cannot really form a play T pattern it does not really have any cleavage.

So this tends to become larger part tends to take up a larger part, it has still become a slightly play T fashion, but the mica has this interesting character where they can form sheet like structure and they can basically orient themselves to accommodate the stress. So therefore, we find these small micro grains all around these quartz crystal showing a flow and these are typical patterns of Mylonites that we find in fault zones. So in relation to the subduction zones, we can find Mylonites somewhere around here and crustal place where the rocks are basically sliding past each other, and showing some level of shearing.

(Refer Slide Time: 15:53)



And other very interesting type of metamorphism is called shock or impact metamorphism. It occurs when meteorite strikes the Earth's surface. When the meteorite strikes the Earth's surface, it generally creates a crater, but that is not all it also impacts the rocks that are already there when it is hitting the rock.

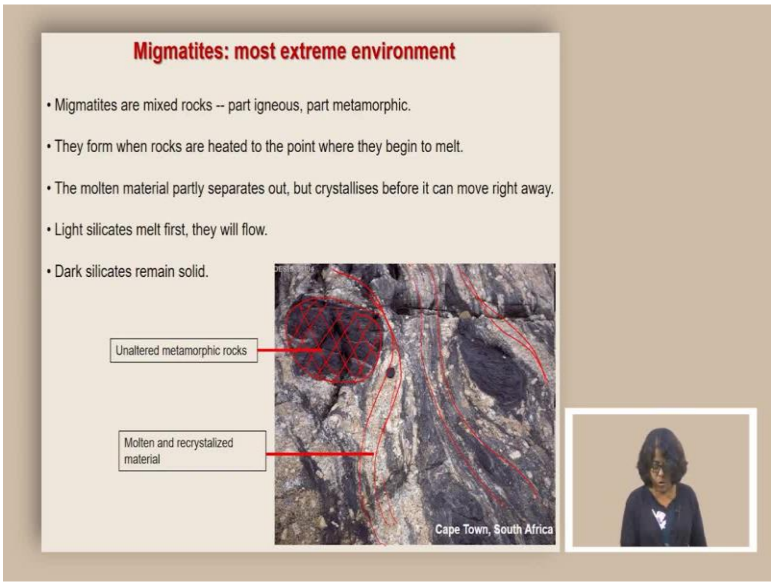
And the agent of metamorphism is intense heat and pressure. Now, this is the point which is important to recognize that this point is also subjected to heat and pressure and when we talk about let us say regional metamorphism those rocks are also getting subjected to high heat and pressure yet, the response is going to be completely different, simply because that time is different.

So, shock or impact metamorphism basically subjects the preexisting rocks to high heat and pressure within a split of a second. So within a very short time the temperature and pressure rises very quickly, sometimes there are shock waves which impact. On the other hand, if you think about the regional metamorphism they are the increase in the temperature as well as pressure happens over a very long timescale over millions of years. Hence, the response of the rocks the metamorphism resulting out of those are quite different.

So shock or impact metamorphism could cause pulverization that means breaking into tiny pieces, and sometimes even melting of some of the mineral grains. And a combination of these things produces a feature which is called impactities. So parts of the minerals which are being hit by the meteorite will evaporate it will melt at very high temperature, but at the same time will start to cooled down fast. Because of this cooling down as they are falling from the atmosphere they will form these teardrop shaped and these are called impactities.

So these are going to be very important signature to identify such shock or impact metamorphism or any event of meteorite impact. Because in geologic record, craters are not always easy to find they get filled up by sediments through subsequent geologic events and hence, it is not easy to identify the craters that were formed, let us say a few million years ago. However, these impactities can be there in the rock record, and therefore they are very useful to identify meteorite events in the deep past of the earth.

(Refer Slide Time: 19:01)



The final type that we are going to discuss is the most extreme environment of the metamorphism spectrum and these are called Migmatites. So Migmatites are basically mixed rock, it is partly igneous, partly metamorphic.

So if you recall, we define the metamorphic rocks as the rocks which will undergo solid state change and it will not completely melt, if it completely melts we will not call it a metamorphic rock instead, it will be called an igneous rock however Migmatites show at least partial melting. So therefore, when the rocks are heated to the point where they begin to melt, however, the temperature is not high enough to melt the entire rock.

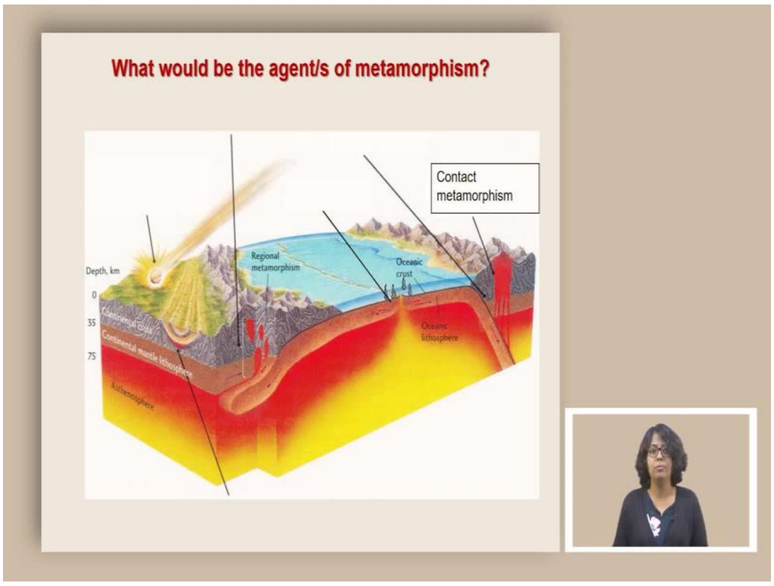
So let us try I do understand that how it can happen. So let us look at this rock, where we see interesting structure, we see these dark blobs, which are solid and which shows a more regular structure. On the other hand, there are parts which are mostly lighter in color and they show flowy pattern, all of these light color things are showing flowy patterns. So if we have to interpret this rock, the first thing that we will interpret is that these white parts must have flown and the way they can flow is if they are started melting, and they have this low viscosity pattern, which allows them to flow.

On the other hand, these ones must have been solid and therefore, they did not move or they did not flow. And that is exactly what happens that as we know from our discussion in igneous rocks, that all the parts of the rock do not melt at the same time. According to the Bowon's reactions series if you have a rock with both felsic as well as mafic minerals, the felsic minerals as the temperature increases, the felsic mineral will start to melt first.

And this is exactly what we see here that the felsic minerals which are lighter colored at a specific temperature, they will start to melt where the temperature is not big enough or high enough to melt the mafic rocks. And therefore, the mafic component of the metamorphic rock will remain constant, it will not melt it will retain its metamorphic character and the felsic part of it will start to melt and therefore flow and form these kind of structures.

So these kinds of combination of light and dark contrast in the metamorphic rock where the mafic minerals are going to be unmetamorphosed or unaltered, whereas the felsic minerals will show you signatures of flow due to melting are called Migmatites, they are often representing very high temperature, and therefore the main agent of metamorphism forming Migmatites primarily heat. And this is one of the end of the spectra of metamorphic rocks, beyond which it will go into the igneous rock terrain where the entire rock will start to melt.

(Refer Slide Time: 23:02)



So to recapitulate, what we learned today was different types of metamorphic types of metamorphic development metamorphic rocks, and situations where metamorphism can happen. We also discussed some of the agents of metamorphism associated with each of these types and how we can use those to identify ancient metamorphic events looking at the rock record. Here are some of the resources and here is a question for you to think. Thank you.