Advance Concrete Technology
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Lecture – 12
Aggregates for concrete - Part 2

Good afternoon, everybody. In the last class, we were looking at different types of minerals that were present in rocks which were used as concrete aggregates. And some of the tests for identification of minerals you have already done in your lab classes like scratching the aggregates with steel, scratching the aggregates with glass. Looking at the streak that the aggregate makes on porcelain plate.

So, all these are regular test methods for identification of different types of minerals present within rocks. So there are different types of minerals that are found in different rocks which are used as concrete aggregates and because of the presence of these minerals you sometimes get unique properties from the aggregates when you use them in concrete.

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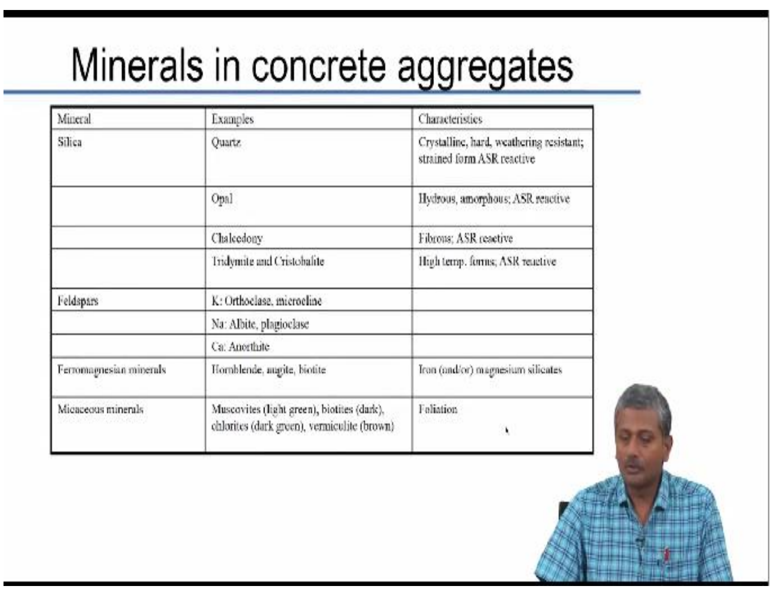

Mineral	Examples	Characteristics
Silica	Quartz	Crystalline, hard, weathering resistant; strained form ASR reactive
	Opal	Hydrous, amorphous; ASR reactive
	Chalcedony	Fibrous; ASR reactive
	Tridymite and Cristobalite	High temp. forms; ASR reactive
Feldspars	K: Orthoclase, microcline	
	Na: Albite, plagioclase	
	Ca: Anorthite	
Ferromagnesian minerals	Hornblende, augite, biotite	Iron (and/or) magnesium silicates
Micaceous minerals	Muscovites (light green), biotites (dark), chlorites (dark green), vermiculite (brown)	Foliation

So the silica based minerals that you find are Quartz, Opal, Chalcedony, Tridymite, and Cristobalite. So these are different forms of SiO_2. you all know very that quartz is a highly ordered form or highly properly arranged form of SiO_2. It is crystalline, it is hard, it is weathering resistant and in some cases if the quartz is gone through very high temperature and pressure it may result in having a strained form that means the bounds may get strained that may lead to the material getting some reactivity.

Typically, quartz is not reactive at all. It is highly inert. It is very hard and crystalline but you may get certain form which specially the ones in metamorphic rocks which may end up being quite reactive as far as alkali silica reactivity is concerned. Anyway we will talk about ASR specifically towards the end but in general quartz is known to be not reactive but then it can in certain types of rocks.

Opal is a hydrous form of silica it is SiO_2. It is written $SiO_2.nH_2O$ that means it is got some waters which are found within the structure of the silica. And because of the structure the ultimate structure of the opal becomes amorphous and that leads opal to have a very high reactivity with respect to alkali silica reaction. Chalcedony is a fibrous form of silica again. It has a high range of disorder which makes it more reactive.

And in cases of ASR you would do well to avoid Opal and Chalcedony minerals which are present in the aggregates. Sometimes these could be present as minority minerals in your aggregate, irrespective of what you are trying to use. So you have to be careful about your choice of aggregate and make a proper assessment as to how much of it could be made up with Opal or Chalcedony.

Tridymite and Cristobalite are high temperature forms of quartz especially when you are heat treated your material to around 800, 900 degree Celsius, you most likely would get other forms of Quartz like Tridymite and Cristobalite. Now these could be ASR reactive. So what happens now is you have Igneous and Sedimentary rocks that may have Quartz. But when these rocks undergo metamorphosis you can get extremely high temperatures and pressures exerted on these rocks.

And because of this your crystal structure will get strained, your forms of Quartz that are actually available may get transformed into Cristobalite or Tridymite. So ultimately the metamorphic rocks that end up from the same inert passive Igneous or Sedimentary rocks may actually end up being reactive. So very often although we see that Igneous and Sedimentary rocks may not have sufficient reactivity. The metamorphic forms of the rock have a lot of possibilities of reactivity.

I am talking about the types of rocks which are made up with this silica base mineral. However, having said I should also I should also add that Opal and Chalcedony are often found within Sedimentary rocks, which makes sedimentary rocks of certain types fairly reactive. Like for example I will talk later about rock called Greywacke. It is a Sedimentary rocks and that is known to be quite highly reactive. Feldspars are basically Sodium or Potassium silicoaluminate.

Or even calcium silicoalumates which are found primarily in Igneous rocks like Granite for instance. So, the potassium based Feldspars are also otherwise called as orthoclase or microcline. Sodium based Feldspars are including Albite and plagioclase and calcium based feldspar is called anorthite. So different types of Silicoaluminate species exist within igneous rocks and these are essentially called as feldspar's.

You also have ferromagnesian minerals like hornblende, augite, biotite these are basically iron magnesium silicates. Micaceous minerals are the once which introduce very different kind of a characteristic as far as the mechanical properties of the aggregates are concerned so we have foliated properties because of the presence of micaceous minerals. Foliation means you have basically layered formation of the rock.

That is primarily because of the micaceous minerals which include muscovites, biotites, chlorites or vermiculite.

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Minerals…(contd.)

Clay minerals		Layered silicates < 1μm
	Kaolinite, illite, chlorite	Relatively stable, but absorptive
	Smectite, montmorillonite	Swelling, unstable
Zeolites		Hydrated alkali-aluminium silicates; soft and light colored; formed from hydrothermal alteration of feldspars; can contribute alkalis through cation exchange!
Carbonate minerals	Calcite and dolomite	Soft, acid soluble
Sulphate minerals	Gypsum, anhydrite	Sulphate attack
Iron sulphide minerals	Pyrite, marcasite, pyrrhotite	May oxidise to H_2SO_4, and form iron oxides/hydroxides that may stain concrete
Iron oxides	Magnetite, hematite, ilmenite, limonite	Hard; color providing

We also have clay minerals which are basically layered silicates extremely fine layered silicates. Clay minerals are extremely fine of course you know that less than 1 micron in size, the typical clay minerals includes kaolinite, illite and chlorite these quite stable but they could absorb to a large extent a lot of water. Kaolinite does not but illite and chlorite are known to absorb some moisture. Smectite and montmorillonite are highly swelling and unstable clays.

Of course you need to insure that if they are present in your the aggregate then you need to minimize their usages as much as possible. Zeolites are naturally occurring hydrated aluminium silicates which can be soft and light coloured and what happens is sometimes these Zeolites can also result from the transformation of the rock. Certain types of minerals within the rock can get transformed as zeolites.

These are essentially soft minerals we need to avoid aggregates which have too much or excess quantity of zeolite present in them. Carbonate minerals you all know very well include calcite and dolomite. Calcite is calcium carbonate and dolomite is calcium magnesium carbonate. These are again soft but then they also form very good aggregates for concrete apart from obviously being the primary raw material for the manufacture of cement.

And carbonate rocks are acid soluble as opposed to silicate rocks which are not acid soluble and this is something that you already done in your laboratory classes before. Iron sulphide minerals include pyrite, marcasite and pyrrhotite. Now the iron sulphite minerals although they form very hard aggregate the issue there is that the presence of sulphide in certain conditions that sulphide can actually transform to sulphuric acid.

It can give rise to sulphuric acid and this was actually found out by accident when pyrite based aggregates were used in concrete that the reactions with the alkaline medium of the concrete, lead to the formation of sulphuric acid from the pyrite aggregates and that lead to obviously the damage of cement paste by acid attack. So again you have this tendency to attack concrete and stain it because of the formation of this acid.

Iron oxides include magnetite, hematite, ilmenite, and limonite. Again most iron oxides are heavy in nature so they form mainly the components for high density concrete when we want to use high density aggregate we basically use iron based aggregates for concrete.

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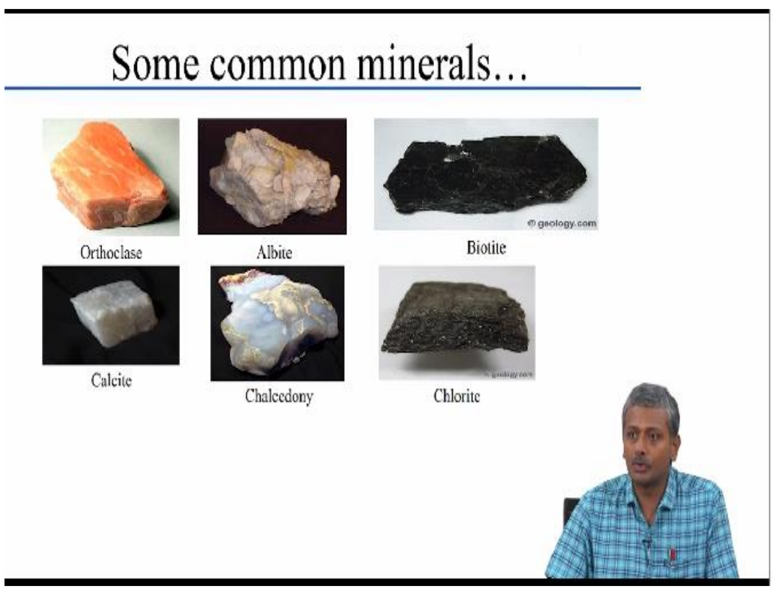

So some pictures of common minerals you have Orthoclase, Albite, Biotite. Orthoclase and Albite are basically feldspar minerals. Biotite is a micaceous mineral. Calcite of course you know calcium carbonate. Chalcedony you can see the irregular structure that it is showing and chlorite. So these are all different types of minerals that you can actually get in the natural environment.

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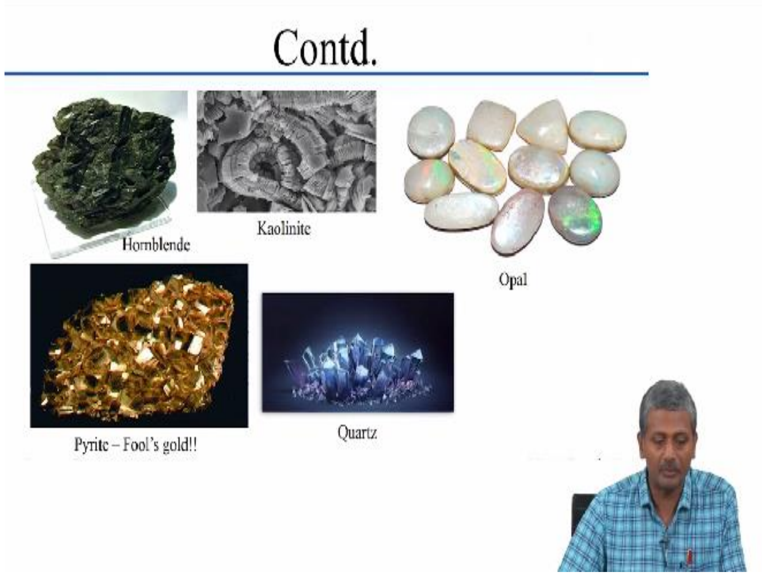

Hornblend, now look at Pyrite it looks almost like gold so it is called fool's gold, that is the material which is copper iron sulphide base material. Quartz you can find fascinating pictures of Quartz on the internet of course. This is one of those pictures that I picked up from Wikipedia. Quartz is a very hard mineral that is very inert, mostly inert mineral. And Opal of course you know that Opal is also used a lot for manufacturing jewellery.

But Opal is essentially a form of silica and, Kaolinite, this is a microscopic picture of Kaolinite which shows you the very fine texture of Kaolinite and also several layered aluminosilicate sheets which are connected to each other with some water of hydration inside. So, Kaolinite of course you know also when you heat up Kaolinite to beyond 700 to 750 degree celsius. The water between the sheets gets removed and the sheets get activated.

So, in another words the clay becomes activated clay or calcined clay which is quite useful as a pozzolanic material and you can replace 25%, 30% of your cement with calcined clay specially the Kaolinitic clays. We talk about that of course in more detail in the mineral admixture chapter.

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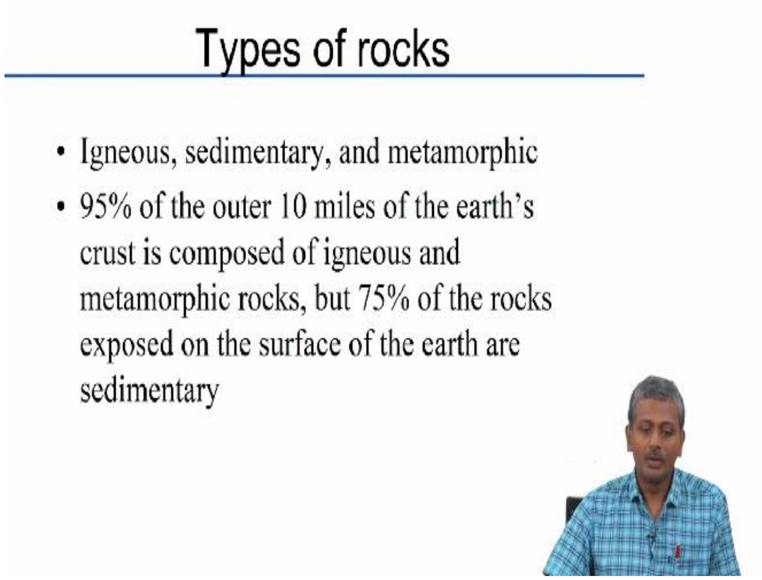

So, these minerals make up the rocks. So rock is composed of either one type of mineral or several types of minerals. So rocks you know are of three different types you have igneous, sedimentary and metamorphic. 95% of the outer 10 miles of the earth crust is composed of igneous and metamorphic rocks. But 75% of the rocks on the earth surface are sedimentary rocks so you can imagine that when you are actually extracting from close to the earth surface.

You are mostly going to get sedimentary rocks. If you want igneous and metamorphic you need to actually dig down deeper for example granite for instance you need to have a quarry that goes fairy deep to actually extract granite. Limestone you may be actually getting surface limestone mostly because mostly what happed is limestone and dolomite formations where? From sea floors, ocean floors.

And essentially the shelled organism basically started depositing there, calcitic sediments and under the action of the pressure of the sea water and with the passage of several years these shelled organism got compacted into what we know today as calcite or limestone. So essentially we are looking at prehistoric shelled organisms which are actually transformed into this or which are lithified into stone.

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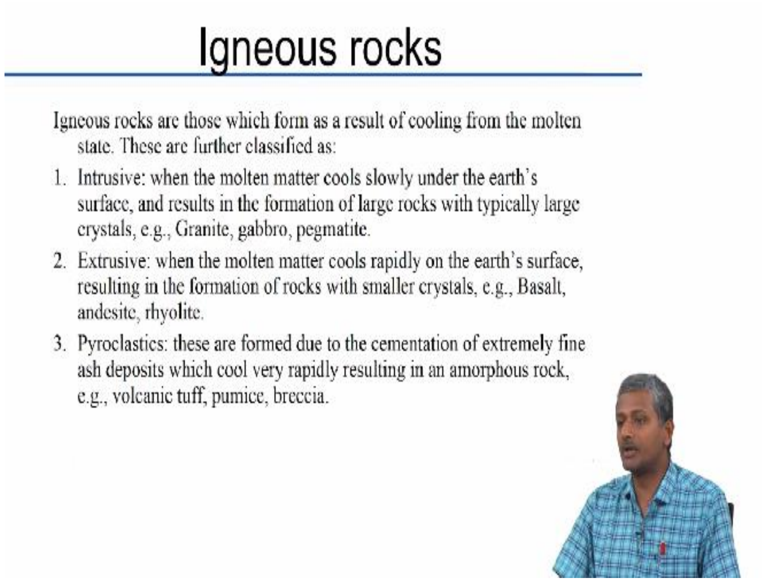

So Igneous rocks we know very well are those which are formed from the molten lava. So molten lava cools and forms different types of igneous rocks depending upon the rate at which the cooling occurs you get different types of Igneous rocks if the cooling occurs within the earth's crust it occurs slowly and so you have the change to form very large crystals that is typical of the intrusive igneous rock which include granite, gabbro and pegmatite.

Granite is the rock which is found in abundance in the southern part of our county and this is where we see that the granite has actually very nice and big crystals. You can actually see a nice crystalline materials in granite and granite is also a very hard material useful for concrete application obviously. But also useful as roadway material for asphalt concrete. Pegmatite is a material which has extremely large crystals much larger then granite.

And that may often turn out to be a disadvantage with respect to intrusive igneous rocks that if you have very large crystals and you are using it for applications which involves abrasion. You can imagine that these large crystals can get dislodged quite easily when you abrade them, So pegmatite is not suitable for applications such as highway construction. Extrusive igneous rocks when the same molten lava cools on the earth surface.

Air cooling that happens is much faster so because the cooling is faster, result in the formation of much finer crystals like in the case of basalt, andesite and so on. So these are smaller crystals but they are not yet at the level which could be reactive. However, some forms of these extrusive igneous rocks some forms of rhyolite and andesite could be reactive because the cooling may have been fast enough to result in some degree of reactivity in these materials.

Of course the most reactive are the pyroclastics which are essentially the cementation of the ashes that gets spill out during the volcano. So mostly we know these to be producing very good light weight aggregates like volcanic tuff or pumice or breccia. But these are also composed of amorphous silica which may lead to a very high degree of reactivity if you use them as aggregates inside concrete.

So alkali silica reactivity will be very high in the pyroclastics but for the most part we are concerned about the andesite and rhyolite rocks which may have high alkali silica reactivity owning to the fact that they have very small crystal sizes.

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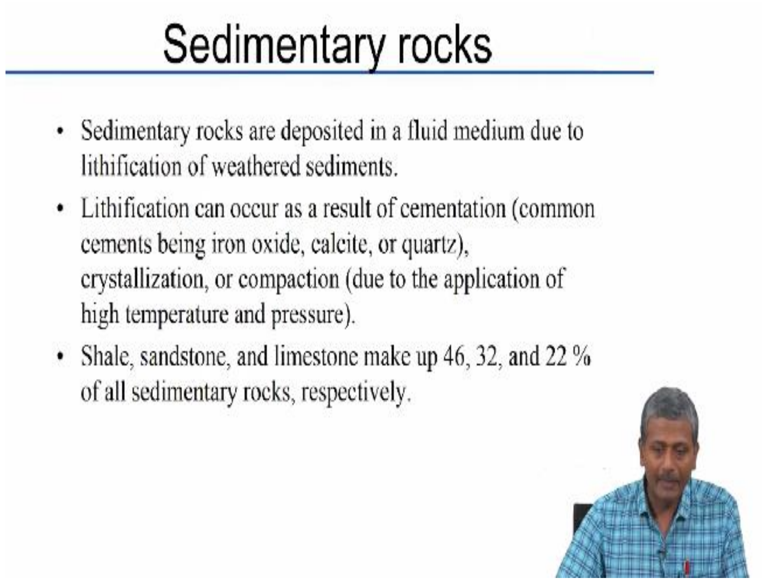

Sedimentary rocks of course are deposited in fluid medium due to lithification of weathered sediments. So any sediments that gets weathered and gets compounded together either by the action of pressure or by the action of additional cementing materials like iron oxide or calcium carbonate can form a sedimentary rock. So lithification get occurred because of cementation, common cements being iron oxide, quartz and calcite.

And the other reasons could be crystallization from like deposition of the crystals in one location or compaction because of high temperature and pressure. Typical sedimentary rocks are shale, sandstone and limestone which make up nearly of course if you add this up it becomes 100% but close to 100% rocks which are found are belonging to the shale, sandstone and limestone category.

So you have sandstone of course is used a lot in monuments in northern part of India you have different coloured variations of course. The pink ones or the red ones are the one's which contact iron oxide as a cementing agent. The white or yellow sandstone are the once which contain calcium carbonate or calcite as a cementing agent.

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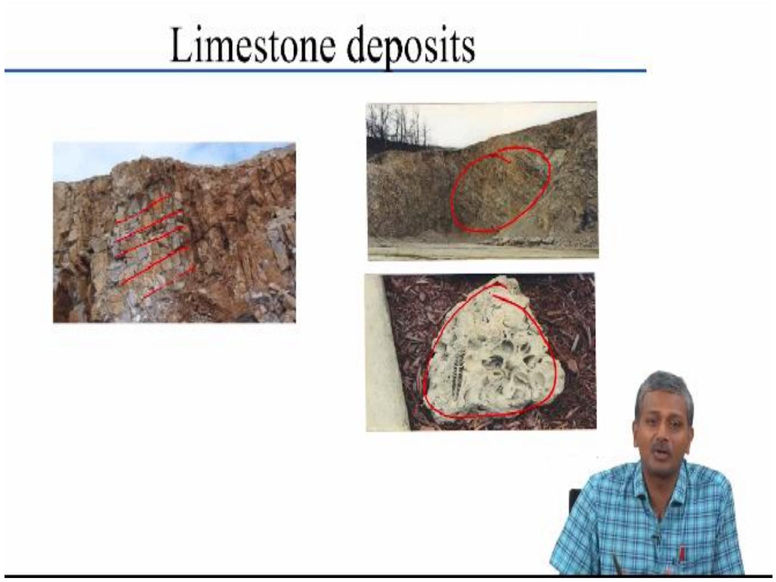

So this is a picture of a quarry where they have actually extracted limestone what is interesting to see is the, you can see the bed is actually inclined. The deposition of limestone is happening in an inclined bed you can see those much clearly here. So, essentially limestone deposits are formed because of the decay and redeposition of calcite from the shelled organisms that happens over many millions of years.

We are not talking about 10 or 1,000 or 100 of years here we are talking about millions of years. And over this time there is lot pressure that is exerted by the weight of the sea water above that lead to the compaction of these calcite crystals into limestone deposits. And interestingly you can also find fossilized remains of the shelled organisms within the limestone deposits. So it is quite interesting to see this because if you visit a quarry you can also be doing some archeology.

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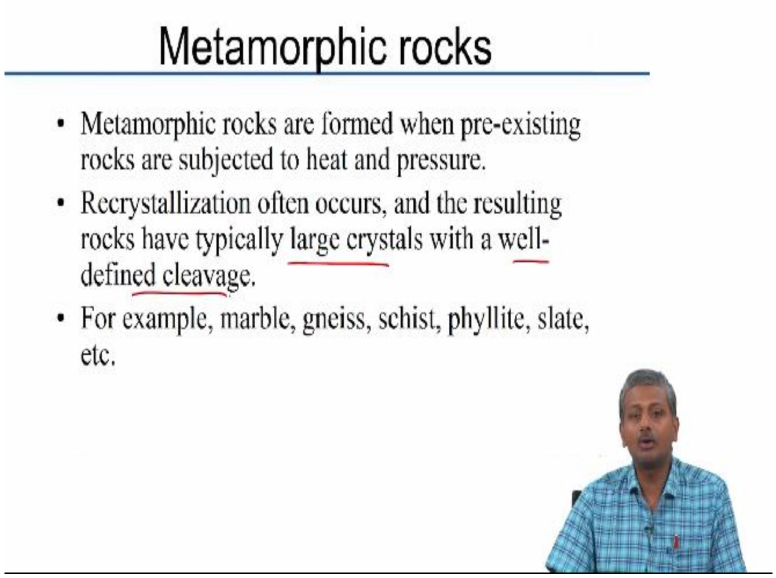

Metamorphic rocks are formed when pre-existing rocks are modified because of the application of temperature and pressure and the important part for us to understand is when very high temperature and pressure act upon the originally pre-existing rocks which are igneous or sedimentary. These can lead to a recrystallization and form a completely different structure compared to what was originally present.

And that is the reason, why metamorphic rocks are quite difficult are ascertain whether they are going to be useful as aggregate or not or whether they are going to cause any problems like alkali silica reactivity or not. So example of metamorphic rocks you know marble which is metamorphic form of what? It is lime stone basically. A limestone which gets metamorphosed to marble you have gneiss which is granite.

Schist is usually from micaceous rocks. Phyllite, slate, slate is basically the metamorphic from shale. So these are all different types of metamorphic rocks that can be found on the earth surface and again because of the recrystallization you end up usually with very large crystals and with a well -defined cleavage that means that these rocks could have definite boundaries of failure or fracture because of the formation of the large crystals with well-defined cleavage.

So, what you need to insure is, you minimize the usages of rocks which can have these kind of properties because then they would present very weak or layered rocks which may not be suitable one as aggregates.

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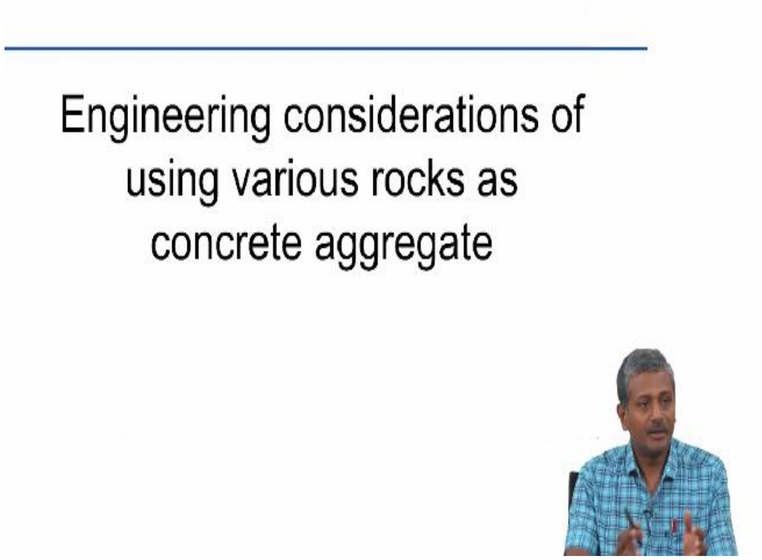

So let us again put whatever we have discussed into specific understanding about how concrete properties can get affected by the geological nature of the rock.

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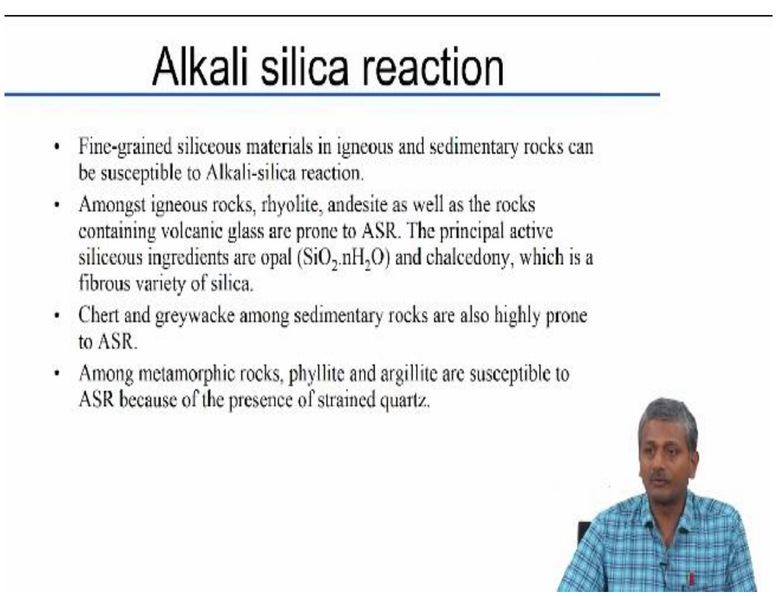

So Alkali-silica reaction obviously is the most important consideration when choosing a certain type of rock for your concrete aggregate. You know that we have a pour solution in cement paste which is highly reach in alkalis and these alkalis are available to react with reactive silica that can be present in certain types of aggregate. The entire mechanism of ASR we will discuss in a later chapter.

But essentially fine grained silicious minerals in igneous and sedimentary rocks are susceptible to reaction with alkalis which are released from the cement mostly. So amongst igneous rocks, the ones which we need to look out for are rhyolite, andesite and also the rocks obviously which contains the pyroclastic minerals or the volcanic glass. And in these cases the principle reactive minerals which might be forming are the opal and the chalcedony. So opal is the hydrous form of silica and chalcedony is the fibrous form of silica.

These are highly amorphous very reactive and these can lead to extremely high levels of expansions in your concrete when you have a high alkaline environment. Amongst sedimentary rocks the once which are most reactive are chert and greywacke. Again chert and greywacke can also contain opal and chalcedony as minerals. Please remember these are rocks, chert and greywacke are rocks which contain alkali reactive minerals in them.

It is the minerals which make the rock reactive. Among metamorphic rocks the ones which we are most careful about are phyllite and argillite. This is because of the presence of strained quartz. So as I talked about earlier quartz is a highly crystalline material, hard and inert, crystalline material. But the problem is when high temperature and pressure act upon quartz you can strain the structure and that strains can induce actually some reactivity to quartz.

So, because of that metamorphic rocks may have lot of susceptibility to alkali-silica reaction.

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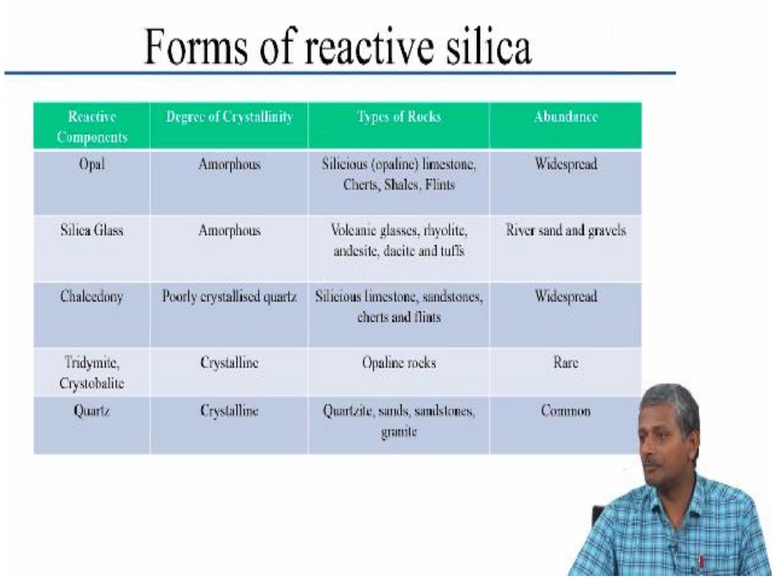

Forms of reactive silica

Reactive Components	Degree of Crystallinity	Types of Rocks	Abundance
Opal	Amorphous	Silicious (opaline) limestone, Cherts, Shales, Flints	Widespread
Silica Glass	Amorphous	Volcanic glasses, rhyolite, andesite, dacite and tuffs	River sand and gravels
Chalcedony	Poorly crystallised quartz	Silicious limestone, sandstones, cherts and flints	Widespread
Tridymite, Crystobalite	Crystalline	Opaline rocks	Rare
Quartz	Crystalline	Quartzite, sands, sandstones, granite	Common

So again this table actually captures the different forms of or reactive components present in different types of aggregates and their relative abundance around the world. So, abundance is important because we know that we have to use aggregates which is locally available and based on that we need to understand whether the aggregate that we have can contain some of these reactive metals. So, the first column shows you the reactive components.

Of course you have opal which is the hydrous form of silica. You have silica glass, amorphous silica basically. Chalcedony which is fibrous form of silica, Tridymite and cristobalite which are high temperature forms of quartz and quartz itself when it is present in the strained form. So, degree of crystallinity is also represented here. Opal, silica glass and chalcedony are almost amorphous.

So chalcedony is not entirely classified as amorphous but its poorly crystalized form of quartz. These forms: tridymite, cristobalite and quartz are all highly crystalline. But the fact that you have a strained structure because of very high temperatures leads to the alkali silica reactivity. The types of rocks on which these types of minerals are found of course the opal is found in limestone, cherts, shales and flints.

Silica Glass can be found in rhyolite, andesite, volcanic glasses and so on. Again chalcedony mostly in sedimentary rocks and tridymite in opaline rocks and quartz can be found in quartzite, sandstone, sometimes even granite may have quartz that is actually reactive depending upon the extent to which the granite has been modified by high temperature and pressure. So if you use the metamorphic form of granite like gabbro or gneiss you might actually end up having some reactivity in it.

Abundance, wide spread as far as opal is concerned, now of course abundance of silica glass is mostly in river sand and gravels. Chalcedony is wide spread. High temperature forms of quartz like tridymite and cristobalite could be there. So that is something we not worry about that much. Strained quartz is quite common in most metamorphic aggregates. So again these are present all across the word.

So aggregates have to be screened very carefully for their potential reactivity before we can consider them suitable for use in concrete.

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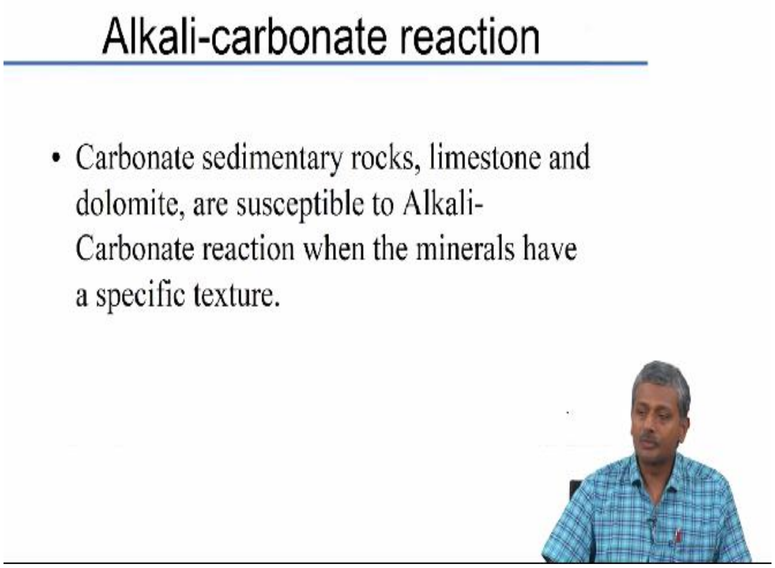

Now, sometimes these alkali–silica reactions could have a carbonate counterpart in alkali carbonate reaction. So this is a reaction which happens when you have carbonate rocks like limestone and dolomite which could react especially when they have very large amount clay bearing minerals. Now this is a little bit of a difficult problem to understand because the reactions are not very well understood in terms of how they actually lead to expansion and formation of cracking in concrete

But for the most part we know that there are certain types of textures which are exhibited by carbonate rocks which can lead to high degree of reactivity in an alkaline medium. So we will not talk about this in more detail.

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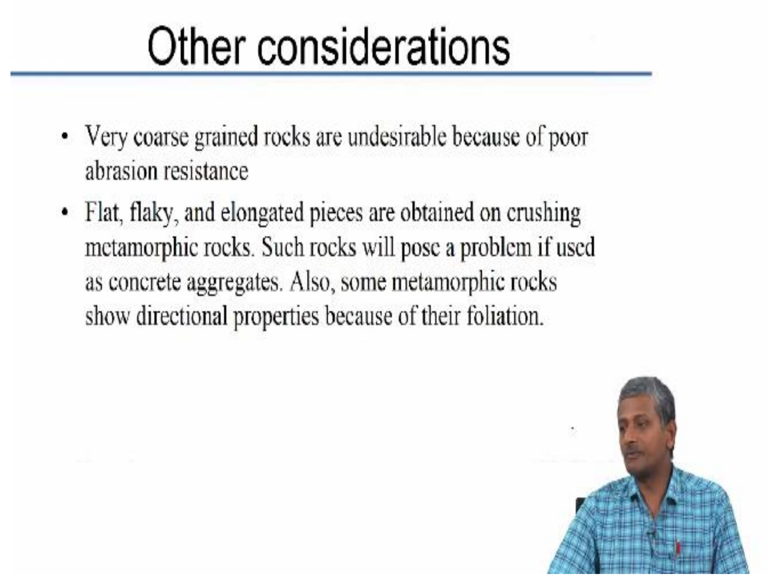

There are other considerations obviously when we choose aggregate for concrete purposes. Again we talked about the fact that certain types of intrusive ingenious rock may have very large crystal sizes which may render them having a very poor abrasion resistance because these large crystals can get dislodged quite easily especially when you have pegmatite based aggregate. Metamorphic rocks may end up having micaceous or flaky and elongated pieces.

If you crush metamorphic rocks, you will end up with lot of flaky and elongated pieces. Obviously you know that flaky and elongated pieces will lead to reduction in the workability and strength of the concrete. So these flat pieces will trap water inside because of which workability will be lost and secondly because if a fracture goes through the concrete if you have a flat and elongated piece it will easily fracture and crack.

Which will lead to reduced strength also of the concrete. And foliation is another problem which you find in metamorphic rocks because you have this directional or rather layered arrangement of several types of minerals that leads to again weaknesses. Some directions are weaker as compared to the others.

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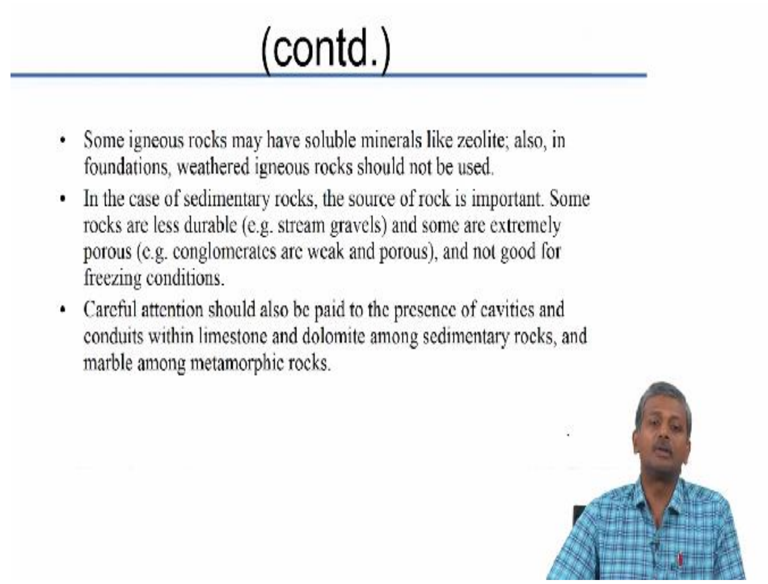

Again soluable and soft minerals like zeolite could be present in igneous rocks so we need to be careful. The other aspect is the presence of clay. Sometimes when the sedimentary rocks are chosen for concrete aggregate you may get lot of clay inside and the clay is obviously are to be avoided because first of all they are swelling. Some of the clays are swelling type. The other can actually coat the surface of the aggregates reducing the paste aggregated bond.

So again there is several reasons why you want to avoid a lot of clay inside the system. And sometimes when you collect from sedimentary sources like river bed you may actually get a mixture of different types of minerals. And some of these minerals could be highly porous, low density materials that may again reduce the strength of your aggregate. So we need to do a proper screening.

Now interestingly the way that the aggregate is screened from a river bed is quite interesting, you have to collect a sample of nearly 200 pieces of aggregates. You have to go through each one megascopically that means you have to evaluate each aggregate piece visually and then of course do the kind of mineral test that we already talked about previously. You need to then fraction it into the components that is regular density that means what do you expect the density of aggregate to be typically about 2.7 to 2.8 around that would be the density of most aggregate.

So you have to remove from these aggregates the pieces that you consider to be a low density. And your ASTM or IS, they tell you that the extent of deleterious materials or poor quality materials in your aggregate should be limited to a certain fraction typically 5%. So from these 200 pieces of aggregates you need to remove those which are of poorer quality.

Then you have to do further test on them to identify what are the problems with them. Do they contain clay? Do they contain high porosity? Are they likely to be alkali reactive? So it is a procedure that is quite highly involved and there are people who are trained to do this kind of petrographic evaluation of aggregates. Now again in certain types of sedimentary rocks you have cavities or conduits especially when limestone and dolomite are used.

So you again want to avoid them because they will give you pathways for water to penetrate and secondly they will also make the aggregate quite weak. So choice of aggregate has to be done carefully based upon first of all presence of reactive minerals then secondly the engineering characteristics exhibited by the aggregate. Most of these you will be able to pick out when you do the regular aggregate tests like specific gravity.

You also do the aggregate test which involves the measurement of the crushing strength and also the impact value, the aggregate impact value. So all those will tell you the extent of hardness that the aggregate has. Los Angeles abrasion test is another common test for aggregate where you put it in a drum and rotate for several revolutions. The idea is upon abrasion with each other and also with the charge that you put inside in form of steel balls.

You start losing some material from the aggregate. If the aggregate loses a lot of its mass, then obviously it is not a very durable aggregate in the system. So with that we come to the end of the chapter on aggregates.