Geomorphology
Prof. Pitambar Pati
Department of Earth Sciences
Indian Institute of Technology – Roorkee

Lecture – 11
Weathering and Soil Formation (Mechanical & Chemical Weathering)

Okay friends. Good morning and welcome to this lecture series of geomorphology. And today we are going to discuss different factors and different reasons for weathering and erosion. If you remember your last class, we were talking about this mechanical weathering or physical weathering and the reason was the pressure unloading as well as growth of foreign crystals. So if we resume it within 2 minutes or so.

Pressure unloading that was mostly responsible for exfoliations that means if you are removing the overburden pressure the rocks in the depth which was formed, they are unpressurized or depressurized and finally spalls of rocks comes out at layers and those layers are mostly parallel to the topography. These were the main reason for weathering of granite and massive quartzite. And similarly there are foreign crystal growth. Foreign crystals mostly we are talking about the growth of ice crystals and growth of pyrite.

So if we remember precisely the permafrost region the higher reaches and higher altitudes mostly the rocks are eroded by the growth of the ice sheets or this ice crystals within these rock fractures. Similarly in shales and other types of rocks. The growth of pyrite it is an exothermic reaction and finally it reacts with the oxygen and forms smokes. So that is why smoking hills that we are discussing in the last class. In the present class we will discuss on other factors which are mostly responsible for this physical weathering and some of this chemical weathering also. So here the prominent factor we are going to discuss about the thermal expansion and contraction.

Generally this thermal expansion and contraction these are mostly active in the high temperate regions like in deserts and if you believe me it is in moon too, moon (lunar) erosion. So boulders and cobbles exposed to hot desert sun and are found broken somewhat orange slices. This is due to thermal expansion.

So it is very interesting fact to note here that desert travelers Sahara's they were listening the rifle shot sound during the evening time when they were moving through this desert. This is due to this expansion and contraction of these rocks and boulders in the Sahara where the daytime temperature was very high, and this nighttime temperature also reduces. So that this thermal expansion during the daytime and contraction in the evening time there were creating stress that means expansion and contraction of these boulders in the upper surface.

And if you analyze it very precisely that this expansion and contraction is not uniform throughout. If you remain yourself on this surface of a boulder. So here the temperature effect is more as compared to the inner part. So that is why the upper surface of the boulder it expands at higher rate as compared to the inner side of this boulder. Similarly at the evening time due to fall of temperature this it contracts, and alternative expansion and contraction creates minute cracks and those cracks are responsible for weathering or physical breaking down of those boulders in the Sahara deserts.

Generally differential expansion also in the some rocks or even if every rocks there are differential expansion occurs due to heating and thawing. How would happen so? We know that these rocks that is mostly composed of minerals of different kind there are also monomineralic rocks like dunite, peridotite these are the monomineralic rock how? Once we say it is monomineralic that does not mean it is 100% composed of that mineral but it still matters.

We are here we are talking about these rocks which are composed of different types of minerals. For example take granite, Granite it is composed of mostly quartz and feldspar? So if you put this granite block in a temperate environment the quartz expansion and the contraction will be different as compared to the feldspar.

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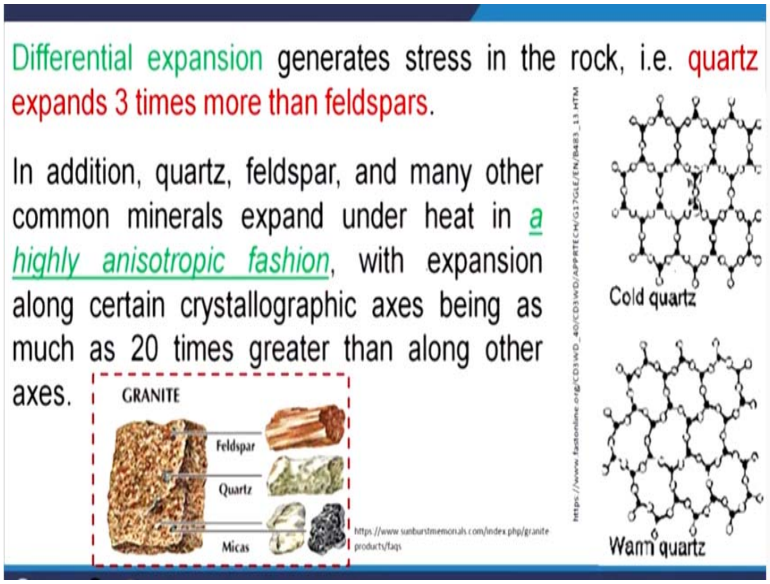

So some of this minerals like quartz it expands 3 times more than the feldspar. So now imagine a block is composed of granite. We have quartz and we have feldspar and we hit it. So the quartz will expand however as compared to the feldspar the quartz is expanding at a higher rate as compared to the feldspar. So that what happens within that mineral within that quartz suppose this is a quartz crystal within that quartz crystal their expansion will be different.

Similarly once it expands and feldspar is here so there will be friction between this quartz and feldspar boundary. So that means within a mineral there will be differential expansion there will be stress within the mineral. There will be stress inter-mineral space like the quartz and feldspar along this walls that will be differential stresses. In addition quartz and feldspar many other common minerals also expand under heat and highly anisotropic fashions.

So these type of differential expansion relates to development of cracks in the rock. In this figure given here if you see here confined yourself this cold quartz if you see this axis is this much. However if it is one quartz if you see this axis is different. And if you take a cross section here you will see this quartz crystals this atoms they are arranged in this fashion. However this is in elliptical fashion why?

This is due to expansion due to heating. So that means these type of differential expansion that creates cracks among these mineral walls among the mineral junctions. So it has been noticed some of the minerals they expand 20 times greater than others along their axis. So those type of minerals which expands and contracts more they are prone to weathering much faster as compared to the other part.

So in a rock block if it is composed of this type of mineral having anisotropic characteristics those rocks will be more prone to weathering as compared to the rocks which is composed of like this monomineralic rock as compared to monomineralic rock. So this type of thermal expansion and contraction it is a prominent reason of weathering on lunar surface. And because we know this moon, we do not have water there at present and in moon we do not have air, we do not have rivers, we do not have oceans, we do not have glaciers is it not ?

So and the second thing that we do not have tectonic process evidences we do not have evidences of tectonic process working on the lunar surface. And the second thing that as it is no atmosphere at present so sun rays can directly hit the rocks surface on the moon. That is why the weathering of lunar surface or the moon it is totally different than the weathering on the earths surface. So that is why this thermal expansion and contraction it is thought to be playing prominent role in weathering or the physical weathering in the lunar surface.

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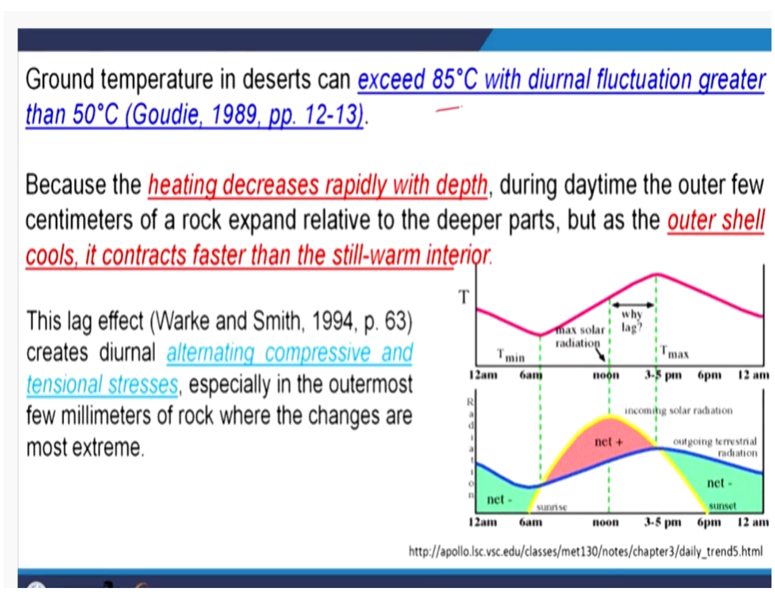

And ground temperature in hot deserts exceeds 85 degree in diurnal fluctuation greater than 50 degree. So now you see in this figure if you concentrate here this is outgoing terrestrial radiation and this is the temperature where solar radiation is there. So finally by reducing those we are getting the net gain of temperature this much. So if this happens so a rock body which is accumulating this much heat that means it is under expansion that means under tension.

So these type of tension is mostly responsible for development of cracks on the rock surface and therefore this hot desert rocks they are more prone to weathering by these thermal expansion and contraction. Why? If you see here because heating decreases rapidly with depth. During daytime outer few centimeters of the rock expand relative to this deeper part. However as the outer surface outer cell cools it contracts faster then also in the inner part.

These type of differential expansion and contraction is responsible for development of cracks because alternating we are compressing it and extending it in the nighttime, we are compressing the system we are cooling the system. We are allowed to compress but, in the daytime, we are expanding the system because we are putting heat and finally rock surface is expanding.

So during daytime expansion and night time compaction. This is mostly responsible for the development of cracks on the rock body. Then whenever we talk about this thermal expansion, we are always talking about this the hot area or hot desserts or these moons like it. But there are cold deserts also because we know there are two types of deserts existing on the earth surface. One is called low latitude deserts low latitude desert means it remains from 0 degree or from the equator to 30 degree. In this area there are called low latitude deserts. Mostly these are the hot deserts.

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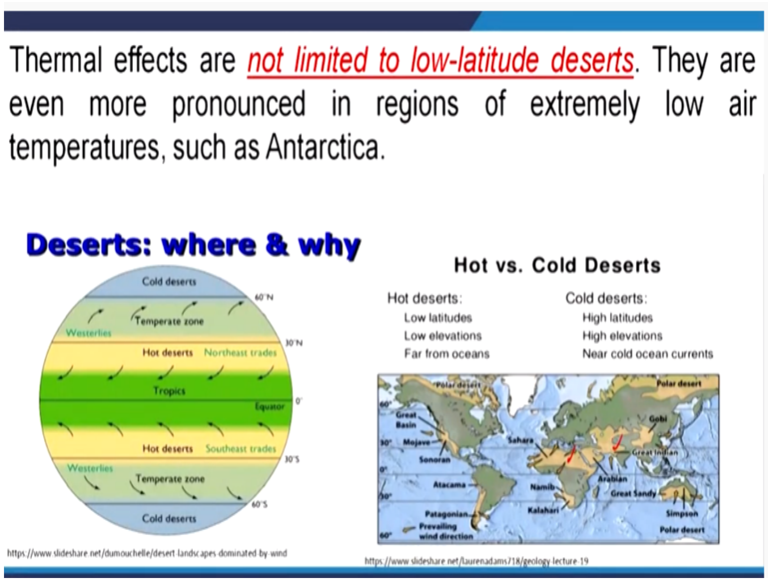

If you see here this Sahara's, Kalahari's, the Thar Desert Indian context if you see the Thar desert all are the low latitude deserts. They are a very hot so other types of deserts that they are called cold deserts. Cold deserts they are mostly in the higher latitudes like the Antarctica ice sheet, the Arctic these are called the cold deserts.

So irrespective of this hot and cold desert the thermal expansion is there. And even in cold deserts the thermal expansion is more pronounced because in most of this time they remains in the cool condition. And once there is some sun rays that are heating the surface the rate of cooling is much fast as compared to this rate of expansion. So that is why this rocks surface on this cold desert expand more as compared to the rocks of this hot deserts.

So thermal effects are not limited to low altitude deserts. They are even more pronounced in the regions of extremely low air temperature such as Antarctica. So that means I want to say the thermal expansion and contraction this phenomenon is not only restricted to this lower part of the lower deserts or the low latitude area that can also be felt in a high latitude areas.

Then another factor of thermal expansion and contraction is due to forest fire because you know many square kilometers of the forest, we are losing every year due to the forest fire.

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And thermal shock generated by bush fire and forest fire has been observed to spall 5 to 50 % even 70 to 90% rock surface or the boulder surface in the forest. It expands and contracts during this forest fire the rock expand and finally cracking takes place. And we have felt that rifle like this rifle shot sounds during our field work when we were in Geological Survey of India.

There are forest fires and finally these boulders they were cracking like getting some sound similar as to this rifle shot. So spalls ranging from few millimeters to few centimeters remove areas of several hundreds of centimeter square of boulders and mostly in their sides. So that means this forest fire gradually reduces the boulder size because it removes layers of this rocks due to this thermal expansion and cracking.

Then here there is a culprit what is called water. This is mostly responsible for rock surface weathering because if you see water in pore space and fracture has an important but a variable importance on fire spalling. Water plays major role in spalling of boulders during forest fire.

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It has two roles what one is on one hand by boiling away it can delay, and it reduced the heating of this rock. Water once there is water which is confined within rocks and forest fire takes place. So water starts boiling. Once water starts to boiling it will reduce the temperatures it would delay the rock to expand. In the other hand the steam can be a potent mechanical and chemical reactant. This steams which is created it is mechanical and chemical reactant to fracture the rocks because it is expanding it has to move up. So the pore spaces of the rock if it is water is there. So it is heated up the water will try to make try to convert to steam and it tries to move up.

So it is to expand. Once it expands that means it increases pore pressures. So due to this increment of pore pressure the rocks are cracked. And finally and second thing that water behaves as a reagent to chemically transport salt from one place to another place. This also one reason for chemical weathering we will discuss in later classes. Then whatever we are talking so far it is due to pressure unloading due to development or due to growth of foreign crystal due to thermal expansion and contraction.

This all are related to mechanical weathering or physical weathering. So now onward we are going to discuss about chemical weathering. So in initial classes when we are talking something about the difference between physical and chemical weathering you can remember that physical weathering is simply breaking down of rocks.

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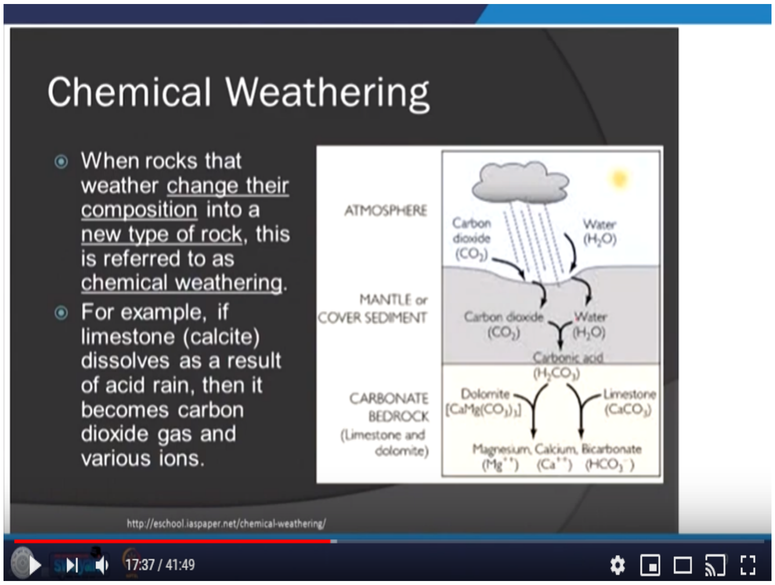

Without change of its chemical composition. However the chemical weathering is concerned it chemical composition of the rock changes its product is different. In physical weathering quartzite will produce quartzite. But in chemical weathering quartzite will not produce quartzite it will quartz and some liquid or fluid. So that means I want to say in chemical weathering we get a product which is compositionally different from its parent rock. So this is called chemical weathering.

When the rock that weather change their composition into a new type of rock this referred to as chemical weathering. For example if limestone is there limestone mostly composed of calcite. So it dissolves as a result of acid rain then it becomes carbon dioxide and various iron. So that means here you see the product we are getting it is totally different from this surrounding or from the parent rock, so this is chemical weathering.

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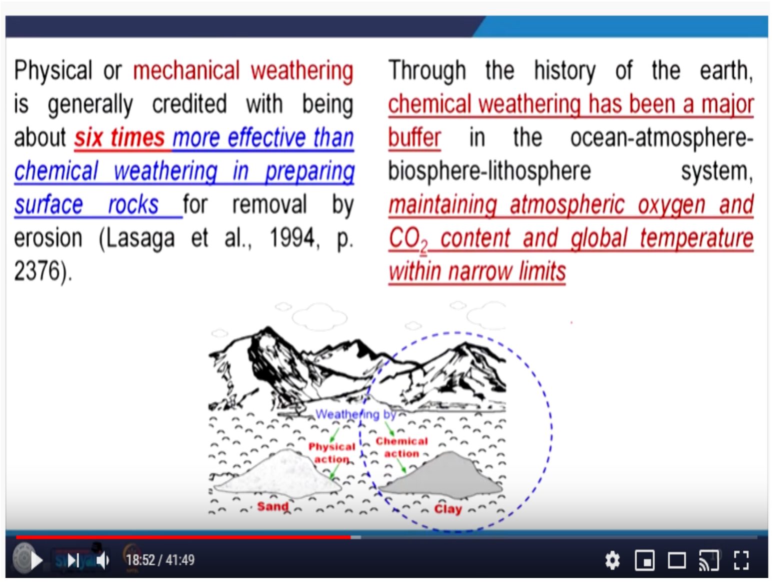

If we distinguish physical or mechanical weathering is generally credited with being 6 times more effective than the chemical weathering. Though we have weathering's of 3 types but this physical weathering it plays a prominent role in reshaping the earth crust. Most part of this earth surface area is affected by physical weathering and that is why it says its 6 times more effective than the chemical weathering.

But through the earth's geological history if you remember the chemical weathering has played a major role in ocean atmospheric, Biospheric, lithospheric system maintaining atmospheric oxygen and CO2 content at the global temperature within narrow limit. So that means this oxygen supplying oxygen to the atmosphere this water formation of water those have played chemical weathering has played major role.

However physical weathering these are simply broke down the surface but chemical weathering this global atmospheric pressure, global atmospheric composition, global ocean water EH-pH condition. Those were maintained due to this chemical weathering. In this figure if you see suppose we have a hill and half part we allow it for physical weathering and half part we allow for chemical weathering. What we are getting here? By weathering physical weathering we are getting sand, silt, clay that means fragments, clastic and non-clastic.

Clastic means we have clasts, we have fragments some sand, silt, clay those are the clastic. And non-clastic that means we cannot distinguish grains. like limestone, dolomite they are non-clastic rocks shale, sandstone they are clastic rocks. So if we allow physical weathering from this hill, we will get boulders, pebbles, cobbles, sand, silt, clay that means fragments we are generating. But if we concentrate our in the chemical part were getting clays. So that means here no fragments only chemically precipitates. So that means physical weathering one part is giving us grains or clasts chemical weathering it is chemically precipitates okay.

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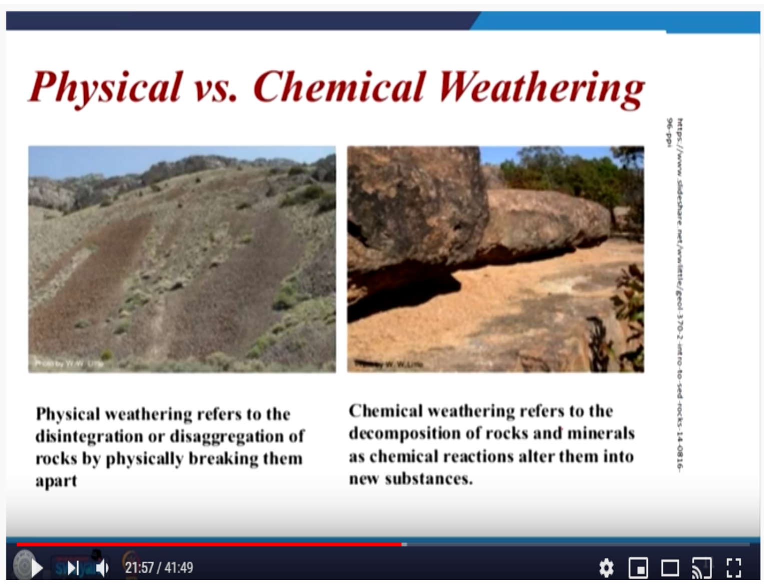

Physical versus chemical weathering if you concentrate here physical weathering refers to the disintegration and disaggregation of rocks by physical breaking them apart. Chemical weathering refers to decomposition of rocks and minerals as chemical reactions alter them into new substances. So this is the basic difference between physical and chemical weathering.

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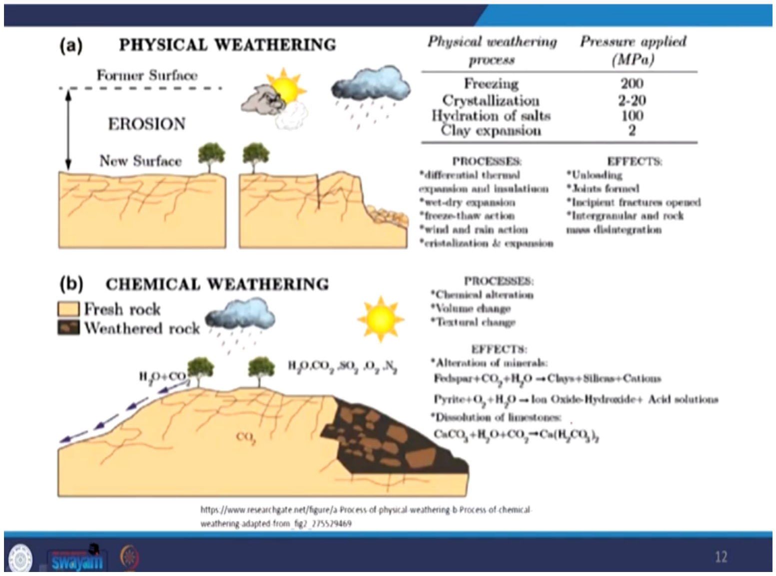

Now physical weathering erosion new surface finally you see earlier this was the rock block and due to physical weathering, this Cracks are developed finally these are these boulders we are getting down. In chemical weathering you see these were the hills and finally we are getting chemically altered rock chemically altered product it will have different composition as compared to this hill is concerned. And here physical weathering processes and pressure applied, freezing and here the pressure is 200 megapascal, crystallization, hydration of salt, clay expansion.

So these are this pressure related for each of this corresponding processes. Process and effect differential thermal expansion and insulation, pressure on unloading, joints is formed wet and dry expansion. Similarly incipient fractures opened, freezing and thawing, disintegration of rocks. So that means only though we have discuss those things. That means physical processes are there and this product are there. Chemical process will be there, and its products will be there so total different system okay.

Now the question arises if the chemical weathering is there. Then where it starts and where it ends. In the earlier classes I have told you this weathering and erosion process it starts from micro particles, micro nano levels and it may goes up to the regional scale. Similarly the chemical process also it just starts from micro nano levels it is from crystal levels from these cleavage level and there is crystal discontinuity level and it is moves to the regional level too.

So if you see here this is a photo micrograph of some rocks. These are the altered products that means this mineral constituents of this rocks they are chemically altered and chemically alteration product is the clay product is the clay. So that means these chemical weathering it starts from mineral crystal lattice. These are these sites mineral dislocation if you see here.

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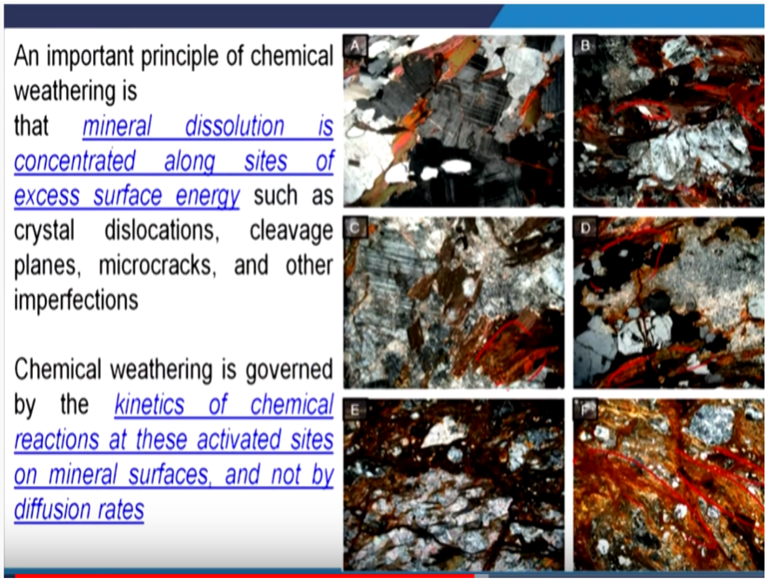

An important principle of chemical weathering is that the mineral dissolution is concentrated along sides of excess surface energy. This is very important to understand these sites it starts from the sites of accumulation of excess surface energy. What are those? Those are generally the crystal dislocation, cleavage planes, micro cracks and other imperfections. So during crystallization we have crystal imperfections like this crystal dislocation will be there. Like the cleavage will be there some micro cracks are later developed also.

So those are the sites for energy storage maximum surface energy stored in those sites. So those are the sites or alteration first. So that is why if a mineral is placed in a chemically active environment those sites will react first to these chemical compounds chemical reactions these sites will take play take part first and finally it will produce some chemically that means weathered product. Chemical weathering is governed by kinetics of these chemical reactions and these activated sites are mineral surface and not by diffusion rates.

So those sites first take place in chemical reaction and let us see what is their product? Mostly in chemical weathering the product is the clay.

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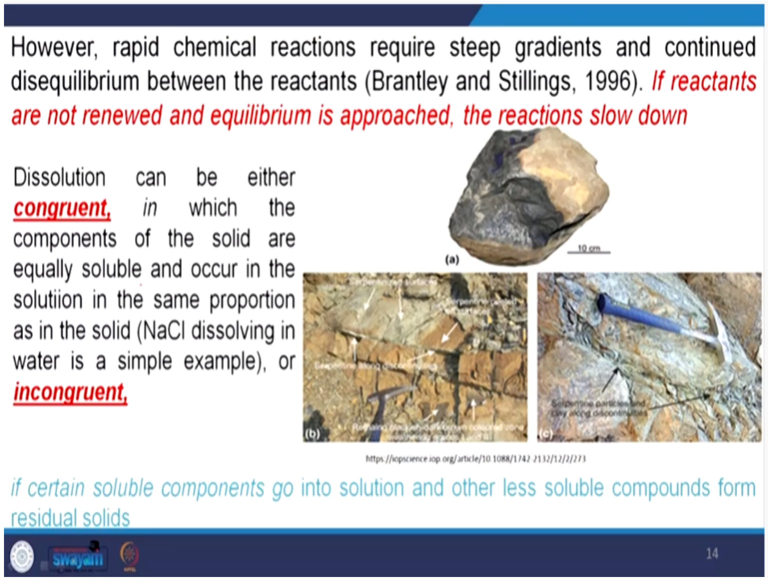

To what extent this chemical reaction will continue and to what rate it will continue. So that means a rock whether it is prone to weather at what rate whether the rock will weather very fast or the rate of chemical weathering or the rock will weather very slowly. At what rate the chemical reaction will go on that depends upon the equilibrium and disequilibrium. If rapid disequilibrium exist between the reactant and the products, then this chemical reaction will continue very fast.

So but if it equilibrium occurs then it is very slow, or it will not work at all. So that means if the reactant are not renewed and equilibrium is approached the reaction will slow down. So a rock will chemically weather fast or slow that depends upon the process. Okay so 2 types of chemical weathering we can expect one is congruent weathering another is incongruent weathering.

Congruent weathering means a rock which is getting weather uniformly that means dissolution can either be congruent in which the components of this solid are equally soluble and occurs in the solution in the same proportion as in the solid. This is called congruent chemical reactions and in congruent if certain soluble is a different component go in solution and others remains in the solution that is incongruent.

So in that case in the second case incongruent solution we are getting some residual product residual weathering that is called residual product or residual weathering. So generally due to this residual weathering incongruent melting incongruent chemical reaction some of this valuable minerals we can able to extract nowadays. The best example is your bauxite this is due to residual chemical reaction residual weathering, residual product is there it is bauxite.

All other remains in the solution and finally removed. But this aluminum remains inside aluminum enriched at the site. So that is why in Deccan basalt in eastern ghat mobile belt we will get bauxite deposit which are the example of residual weathering and residual accumulation. This is due to incongruent reactions in chemical weathering. So for the incongruent or the congruent whatever may be due to this for this chemical weathering water also plays major role.

You remember in physical weathering when we talk about this hot water response role of water in thermal expansion and contraction in forest fire related to forest fire and the rock in pore spaces due to heating and thawing process there also water played major role. Similarly in chemical weathering water plays very important role to distribute these products to react with this constituents. And now the question arises how the water works.

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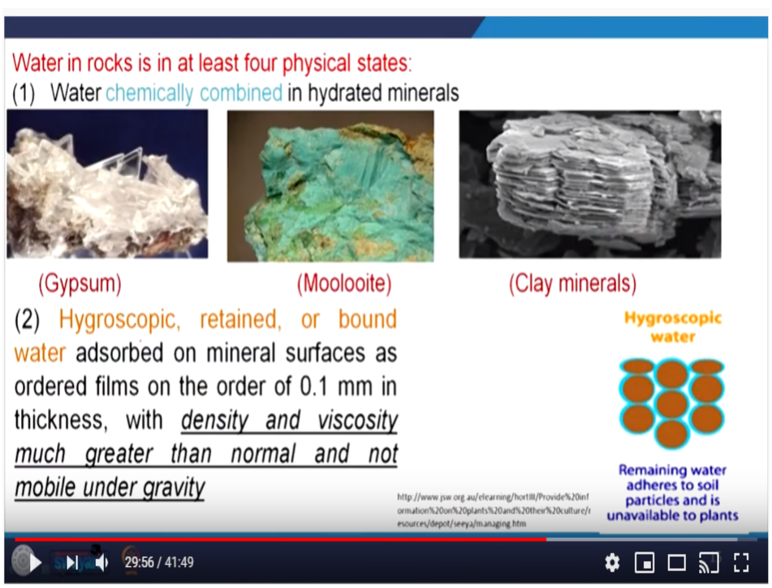

Here water in rocks they present in 4 forms, first is chemically combined water that means water remains in this mineral lattice itself, mineral structure itself. What is gypsum? It is Mg magnesium and water, calcium magnesium and water. Similarly moolooite it is a copper oxide or copper hydroxide. That means water is there then clay minerals we have water in their interlayered spaces. We have two types of clay TOT sorry two types of tetrahedral and octahedral

So here what are remains within this crystal lattice crystal structures. So in all those minerals either it is gypsum or Moolooite or clay minerals water remains in the crystal structures? It is inherent property of the mineral. Then need water to form this crystal. Second type of water it is hygroscopic water. That means due to water adhesive force thin film of water thin film you cannot see in your naked eye thin film that means 0.01 millimeter or so less than that.

The remains on the boulder surface the remains on the rock surface here if you see in this figure this is the water which is surrounding the boulder. This is called hygroscopic water with the density and viscosity most greater than the normal and not mobile under gravity. This water will not move under the gravity. but if water remains free? So if we tilt it water will moves towards lower slope. But these are the hygroscopic water their remains intact or this rock surface. It will not move in terms of gravity.

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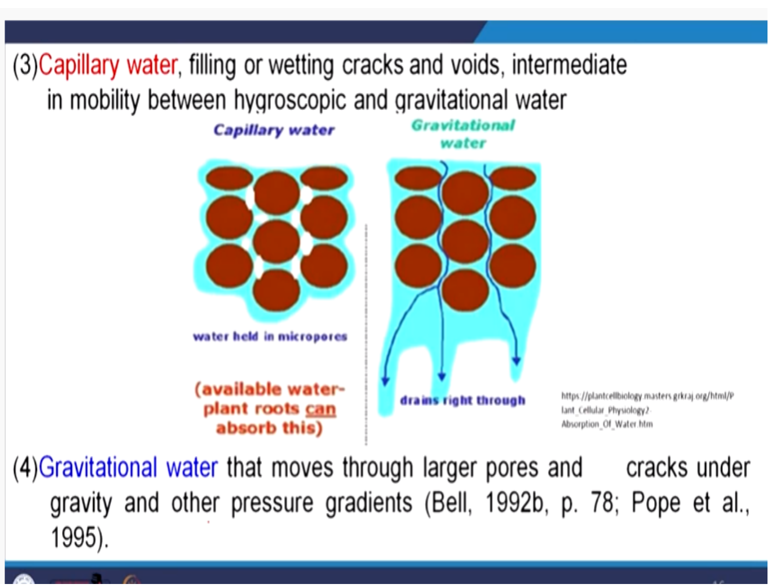

Third type of water present is called capillary water. We know within the pore space due to capillary force the water remains inside and fourth is gravity water that is free water and moves through larger pores and cracks under the gravity and other pressure gradients. So these 4 type of waters they all plays role in terms of chemical weathering. Each of this water facilitates weathering in a variety of way.

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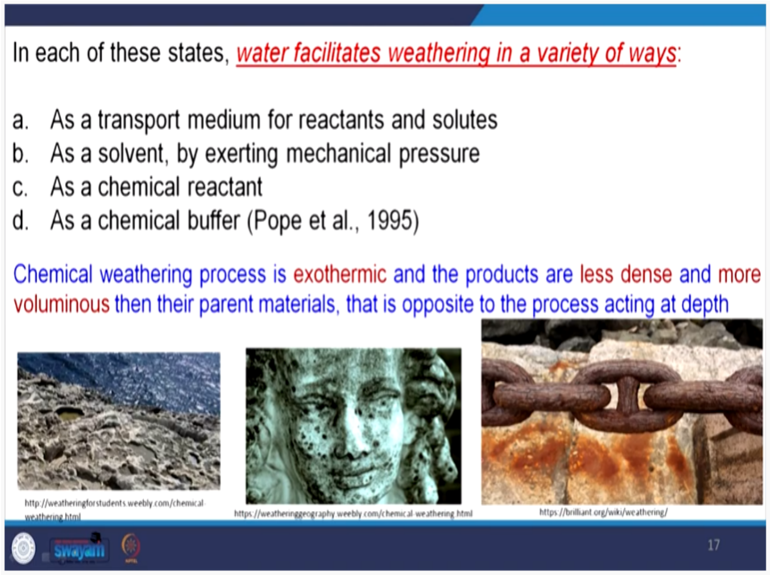

What are the different types of ways the water plays a role in weathering. First and foremost is As a transport medium for reactants and solutes. It is a transport medium through pore spaces is water is there it reacts this rocks and this product. Some of the soluble products it transports through the pores from one place to another. During transportation it will interact with the surrounding rock and if this if the liquid is reactive to this surrounding rocks then again it will promote chemical weathering in the surrounding.

So during transportation it transports the products and transport the solids from one place to another during transportation it reacts with the surrounding rock. As a solvent by exerting mechanical pressure, pore pressure mechanical pressure means pore pressure increases, pore pressure increases means it is cracks rocks. As a chemical reactant it works as a chemical reactant and 4th is as a chemical buffer.

So all these 4 ABCD all the 4 procedures are there. How water is working as an active role. A worker water is playing as an active role for chemical reactions. Chemical processes are exothermic, and it produces less denser material with high volume more volume. If you remember our physical weathering class when we are talking about the pyrite oxidation and formation of pyrite that is also that means this chemical reactions these are exothermic it increases heat it produces heat. That is why we are talking about the smoking hill.

Similarly here in the chemical products are voluminous material less dense material. So inside the rock pore spaces if the chemical reaction occurs so whatever product will be there of more volume. So to occupy that volume the rock has to expand so pore space increases. So that is why rocks getting cracked.

These are these few figures are here in the last figure if you see this is the iron chain and it is oxidized. Finally you see the thickness increased it swelled off. Similarly this is a chemical weathering here see differential weathering is there. Finally this is weather and this shape of the statue like that and this is very prominent type of chemical weathering of limestone. Chemical weathered materials are removed, and some were deposited in terms of clay and the surface is looking like this. So water plays major role in chemical weathering.

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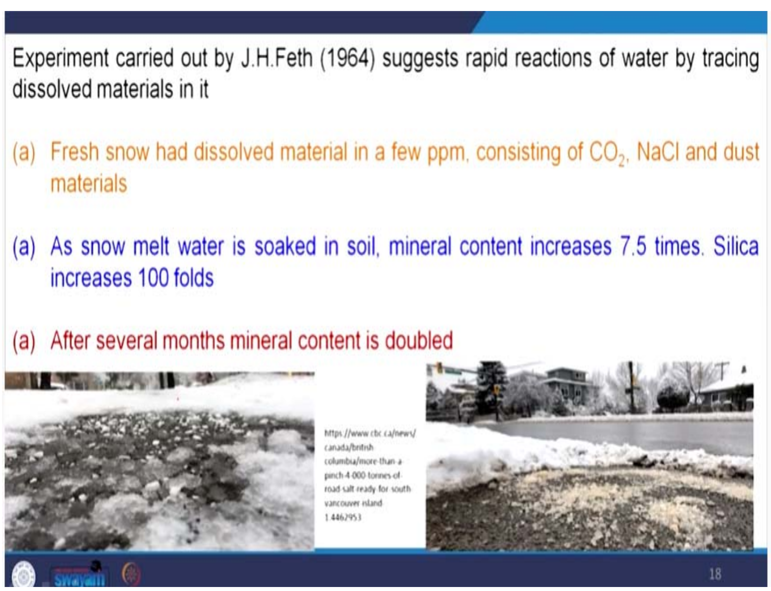

Experiment carried out by this gentleman J.H.Feth in 1964 suggesting rapid reaction of water by tracing dissolved material in it how? There are 3 points he noted the fresh snow had dissolved material in few PPM consisting of CO2, NaCl and dust material. As snow melt water is soaked in soil mineral content increases 7.5 times. After few months or few years this mineral content is doubled. So that means how is water is absorbed in rocks in the slow meltwater particularly how they try to change the rock composition the soil composition This is a classic example of a chemical weathering.

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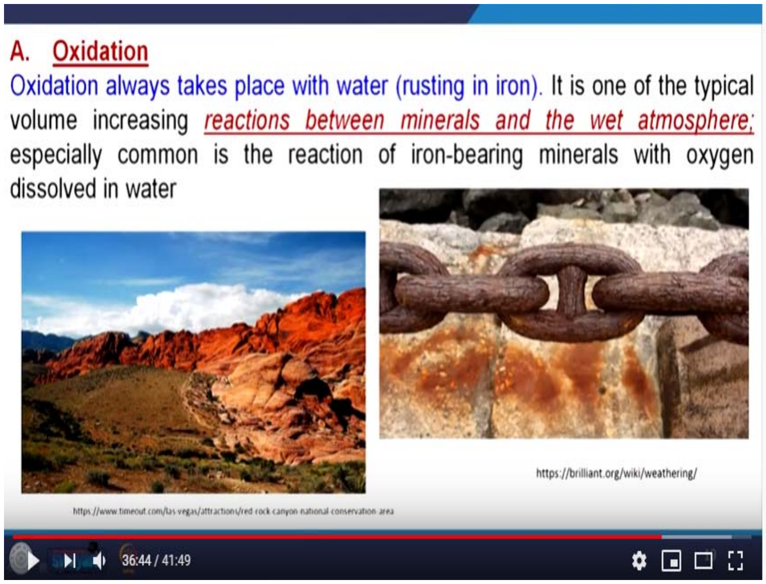

Then another type of chemical weathering is, and the most important type is the oxidation. Oxidation always takes place with the presence of water, that is rusting of iron oxidation oxygen oxygen is involved here. It is a typical type of weathering which increase volume reactions between mineral and the wet atmosphere and if you see it here 2 figures are there first figure, we have discussed this is the oxidation of iron.

Similarly here this red color of the rocks the red colored rocks it is due to mineral oxidation. Even if 1% iron is there in rock in a sediment rock or any rock 1% iron is there it will create whole rock red. We have red beds we have oxidized sediments we have sandstones. That is totally red color this is due to oxidation but mind it if we have igneous rock and sedimentary rock together both content same percentage of iron.

This sedimentary rock will react very fast as compared to this Igneous rocks that means reaction will be same but the rate of spreading of this red color. Because sedimentary rocks are porous and permeable it will allowed this water to pass. Again water comes here that means water plays major role in chemical weathering. So if rock is porous and permeable and due to this chemical reaction, this water will move fast within the pore spaces. And finally the whole rock will create a red color. So the red sandstone these are the products of oxidation

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Reduction of iron to ferrous state takes place by some organic process in stagnant water. It imparts grey and dark grey color to the sediments and results in deposition of foul sediment on organic rich mud. We have these type of colored sediments nowadays its very well exposed. So this is due to the oxidation and due to this oxidation, there are many mineral deposits we get nowadays in the Precambrian time there are oxidation. Huge oxidised environment was occurred. Some point of geological times these iron deposits these are the products of oxidations.

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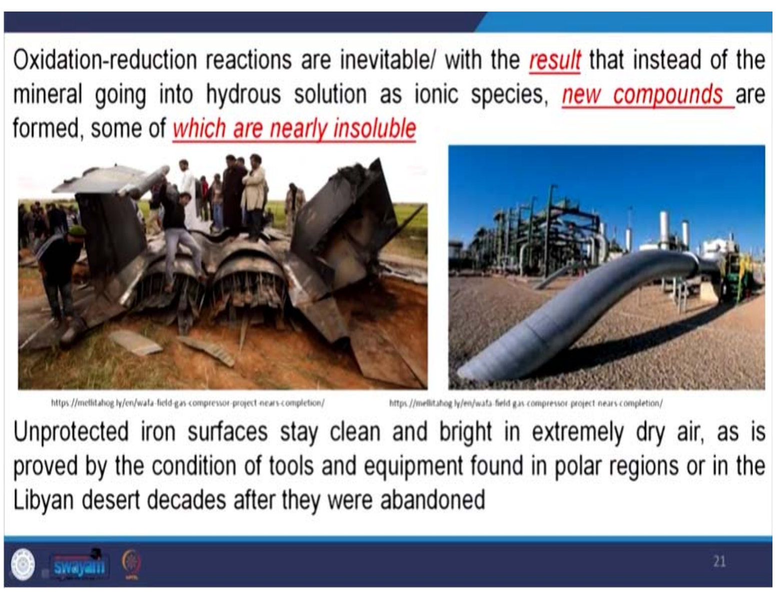

Oxidation reduction reactions are inevitable with the result that instead of mineral going into hydrous solution as ionic species new compounds are formed some are not soluble or insoluble And oxidation it mostly effective in a most environment humid environment as compared to dry environment. There are example in the dry most dry environment in Sahara’s, in Kalahari’s. There are equipment’s abandoned equipment’s still lying which is unaffected by oxidation due to deficiency of moisture, deficiency of water.

So that is when it is again it gives an another example that presence of water the reaction is more as compared to these deficiency of water. So if water is there in the atmosphere that will oxidize the iron very fast as compared to the dry air. So here this example is quoted unprotected iron surfaces stay clean and bright in extremely dry air as it is proved by the condition of tools and equipment found in polar region or in the Libyan desert decades after they were abandoned.

So that remained as it is However this most environment the humid environment these equipment’s reacts fast with the atmosphere and finally it creates this oxidized product and it is rust very fast. So this is the end of the story. so thank you very much. We will meet in the next class.