# Geomorphology

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

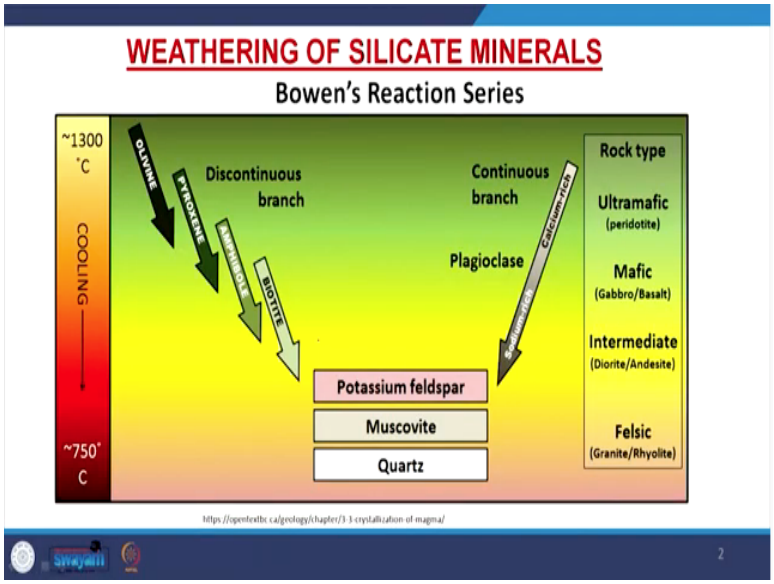
## Lecture – 13
## Weathering of Silicate rocks & Weathering Products

So friends good morning welcome to this lecture series of geomorphology and today we are going to discuss about this weathering of silicate rocks and weathering products. So if you remember your last class we are talking something about this weathering its type. Mostly we divided the weathering into 3 different units one is the mechanical or physical weathering, then chemical weathering, then 3rd is the biological weathering.

And in chemical weathering we are talking something about this carbonate. Calcium carbonate compensation depth or CCD that means there is an imaginary level of ocean basin below which there is no precipitation of calcium carbonate that is called CCD. Similarly, in carbonate terrain different type of weathering processes that we have discussed. Mostly it is the carbonation by which the carbonate rocks get dissolved in carbonic acid and finally these weather products or these impurities they remain at this place that is called terra rossa.

And today we will confine ourself in the weathering of silicate rocks. So before moving to weathering of silicate rock we must understand what is silicate rock. And what is their structural properties? And why they weather? And what are the different factors that are responsible for the weathering of the silicate rocks? So to introduce yourself in silicate properties we should remember our these bowen's reaction series. So you know Bowen's reaction series it is the order of crystallization of silicate minerals from a magma.

**(Refer Slide Time: 02:40)**

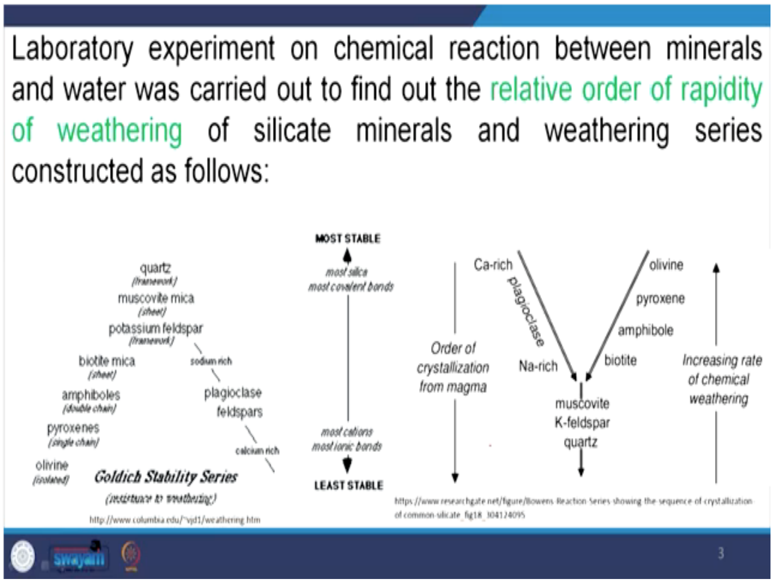



So if you see this Bowen's reaction series it is starting from about 1300 degrees celsius and it is coming to about 750 or less than that about 550 or 500 degree celsius. And the first silicate mineral to crystallize in Bowen's reaction series it is the olivine in the discontinuous part or discontinuous series and anorthite in the continuous series. So if we analyze these structural properties the structural behavior of those minerals we can say at this top of this Bowen's reaction series the minerals which are crystallized they occur isolated manner.

So that means the tetrahedra they are the unit crystal structure. They remain isolated and once temperature decreases and mineral crystallization takes place so those tetrahedra get interconnected with each other sometimes it is connected with 1, sometimes it is connected with 2, sometimes 3, sometimes 4 like that. So that means I want to say once the mineralization starts the crystallization starts the degree of connectedness among this tetrahedra increases.

So once the degree of connectedness increases the minerals becomes more and more stronger. So those rocks which are composed of the minerals which are interconnected tetrahedra. They are more strong as compared to these rocks which formed due to this combination of the minerals which found at the top of this Bowen's reaction series. So that is why if we compare this stability of the minerals the minerals which are formed at the top like this olivine, pyroxene and they are less prone to they are less stable as compared to this mineral which formed at the bottom like quartz.

**(Refer Slide Time: 04:59)**

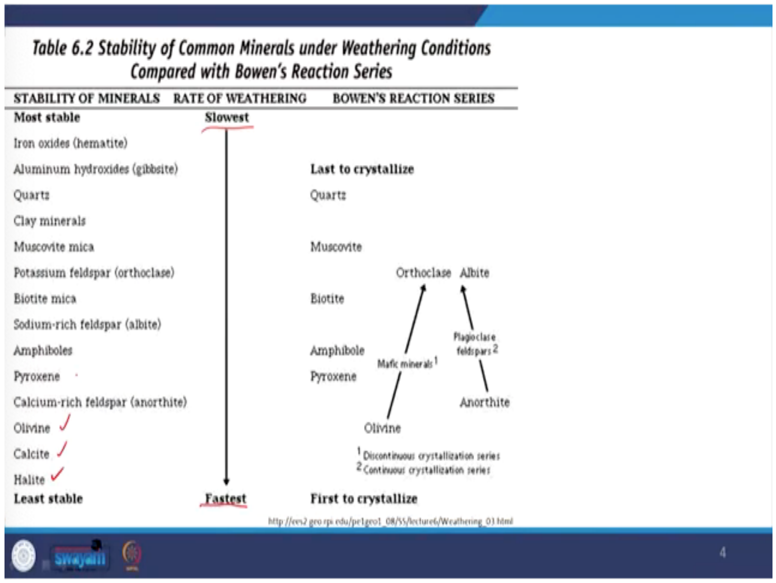



Laboratory experiment was carried out on chemical reaction of water with silicate minerals and find out the relative order of rapidity of weathering and found it is found that this weathering is totally different or weathering is totally opposite to the Bowen's reaction series and this order of weathering the minerals are arranged that is called Goldich stability series. And this side is your Bowen's reaction series.

If you compare this 2 then you can say here quartz forms at the last and quartz is more stable. Because here this side is the most stable this side is the least stable part. So the minerals which are at the top they are most stable as compared to the bottom part. And in Bowen's reaction series quartz occurs last and in Goldich stability series quartz is in top. That means those minerals which form first in Bowen's reaction series they also weather first in Goldich stability series.

So Goldich stability series and Bowen's reaction series they are totally opposite to each other. Here the minerals are arranged according to the rate of weathering. Weathering is not sufficient to rate of weathering that means at what rate they will get weathered? So if you see here it is the slowest and this side is the fastest.

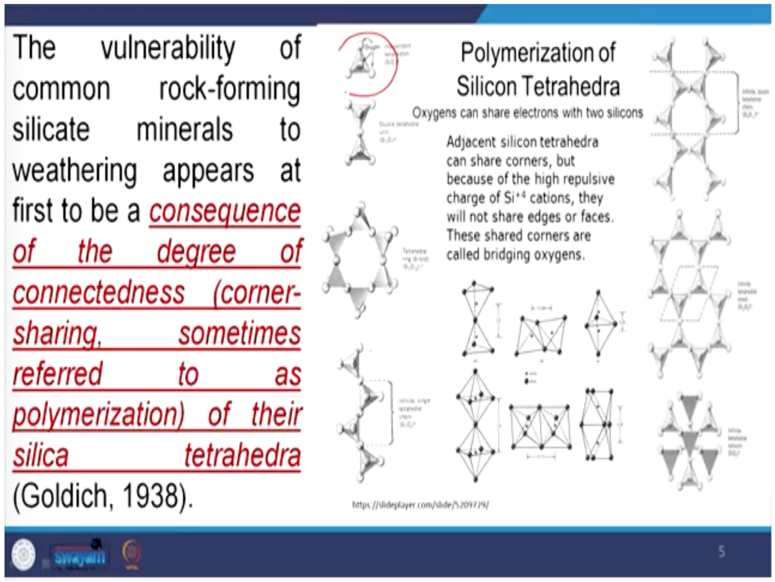
**(Refer Slide Time: 06:46)**




So that means those minerals like halite, calcite, olivine they weather very fast rate as compared to this iron oxide, hematite, aluminum hydroxide, gibbsite, quartz, clay minerals like that. So that means the rate of weathering also the rate of weathering in these minerals are more as compared to the rate of weathering of those minerals. So that means it can be summarized here this is the Goldich stability series and the Bowen's reaction series they are totally diametrically opposite.

And the rate of weathering of the minerals which are occurring at the first stage of this crystallization in the Bowen's reaction series the rate of weathering is more as compared to this minerals which form at the last stage. Then why the minerals weather? So that is we are discussing we have to understand their connectedness or the interconnectedness of this tetrahedra. So for example if you see here the olivine $Mg_2SiO_4$ it creates 1 tetrahedra.

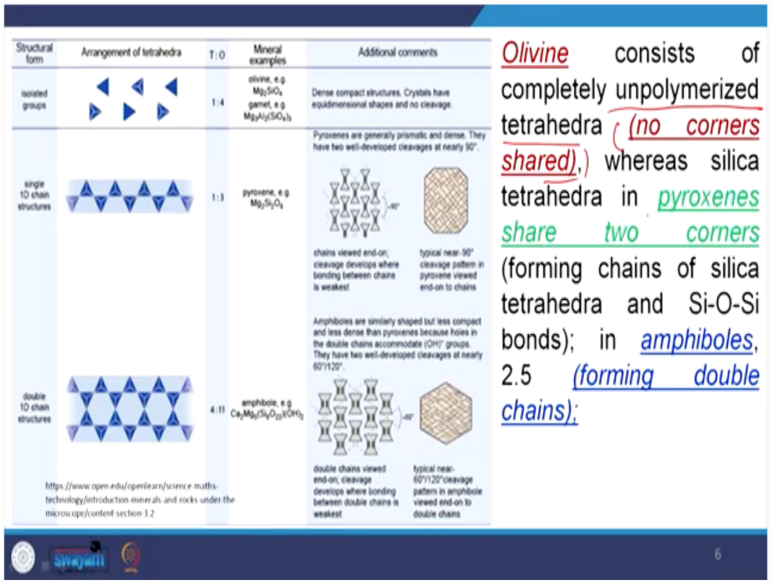
**(Refer Slide Time: 07:54)**




1 tetrahedra that becomes isolated. So once this system becomes isolated they are very prone to be attacked by the external agents. But those minerals which are interconnected they are very stable. It is very difficult the external agent to attack this colony. So that is why colonization of the tetrahedra it is important case for weathering. So those minerals which are occurring isolate tetrahedras in forms of isolated tetrahedra. They are more prone to weathering as compared to the colonized tetrahedras.

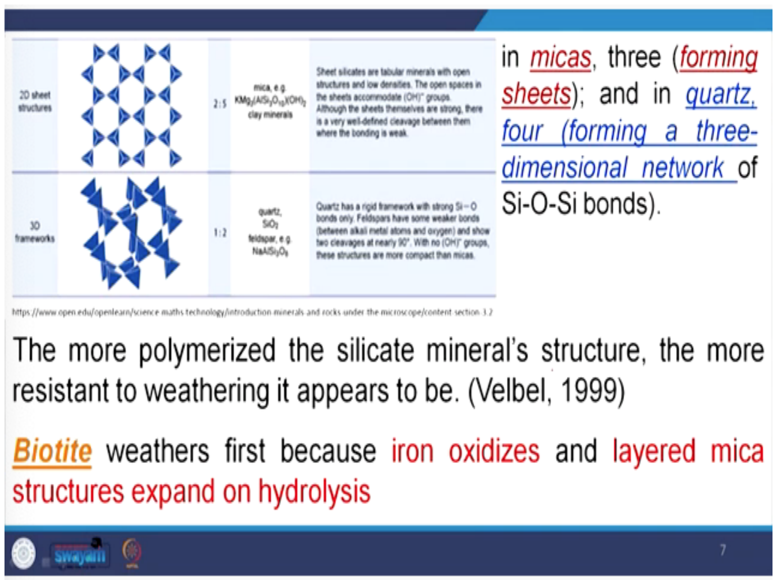
So if you see the vulnerability of common rock forming silicate minerals to weathering appears at the first to be consequence of the degree of connectedness that is very important the degree of connectedness. The more connected the tetrahedras are the most stable the mineral is. So if you compare with in this Bowen’s reaction series we have this olivine, the pyroxene, the amphiboles, the K feldspar, these albite to anorthite it is in continuous series. So here the olivine consist of completely unpolymerized tetrahedra no corners are share that means it occurs isolate.

**(Refer Slide Time: 09:20)**




Pyroxenes here shares 2 corners. So that means relative to olivine pyroxene is stable and amphiboles their corners their shares 2.5 corners. So again amphiboles are more stable relatively compared to olivine and pyroxene.

**(Refer Slide Time: 09:39)**

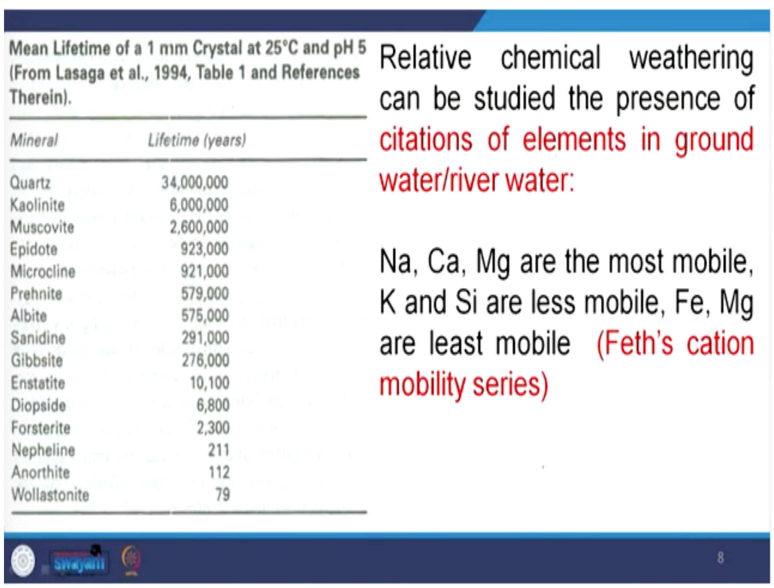



Micas forming sheet and quartz 4 corners are shared and it becomes more stable one. It is called framework structure. So that means more polymerized the silicate mineral structure the more resistant to weathering. So that means these minerals like quartz like a feldspar they are more stable as compared to olivine, pyroxene. But within that series there is a mineral which is called biotite. Biotite it is exception why it is exception? First and foremost thing is that it contains iron oxide.

If you remember our weathering class in the last class, we are talking something about the oxidation. So oxidation is a major reason for weathering or chemical weathering of iron bearing minerals. So this biotite it contains iron in its crystal structure and its layered mica form. So layered mica hydration and dehydration again it is the last class we are discussing. So hydration and dehydration that means alternate absorbing of water it is hydrated and dehydration again it is squeezing.

So alternating that is in swelling up and squeezing that is why like this it expands and contract finally it recreates it promotes weathering. Second thing is that this ends once the biotite as it contains iron oxide it is more prone to chemical weathering by oxidation. So that is why this biotite is an exception in Bowen's reaction series. So that means as compared to olivine and pyroxene biotite also weathers similarly. So that means olivine, pyroxene and biotite they weathers at the same time as compared to quartz, feldspars like this. So biotite is a exception.

**(Refer Slide Time: 11:51)**




| Mineral | Lifetime (years) |
|---|---|
| Quartz | 34,000,000 |
| Kaolinite | 6,000,000 |
| Muscovite | 2,600,000 |
| Epidote | 923,000 |
| Microcline | 921,000 |
| Prehnite | 579,000 |
| Albite | 575,000 |
| Sanidine | 291,000 |
| Gibbsite | 276,000 |
| Enstatite | 10,100 |
| Diopside | 6,800 |
| Forsterite | 2,300 |
| Nepheline | 211 |
| Anorthite | 112 |
| Wollastonite | 79 |

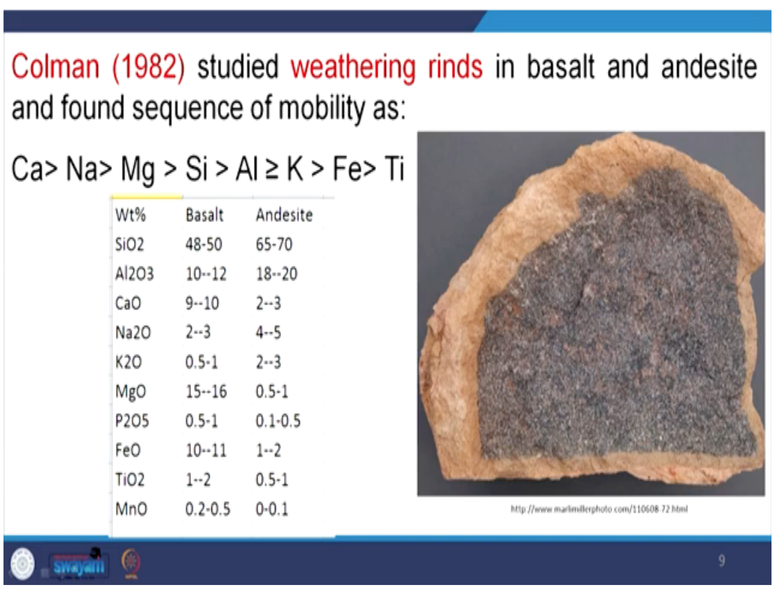
Here an interesting example is given lifetime of one millimeter crystal at 25 degree celsius that means room temperature and pH5. So if you see here quartz 1 millimeter quartz crystal to weather it completely it takes this much years. However, if we have wollastonite, wollastonite is a pyroxene. Wollastonite it is 79 years. So that means here pyroxene is there, here quartz is there. Then Kaolinite, muscovite, epidote, microcline, prehnite, albite so like this.

So those minerals are arranged in terms of their increasing lifetime. So even if 1 millimeter crystal of quartz remains on the surface of the earth. It will survive up to this much year and 1 millimeter wollastonite it will totally vanish from this Earths surface from 79 years. So that is also the reason if you compare this mineral abundance on the surface of this Earth mostly you will get sand.

And sand it is composed of quartz and feldspar mostly. That is why the other minerals they do not found in terms of sand or if it is there their relative proportion is very low. Because they are least stable in this surficial conditions. Because once these minerals we are talking, we are talking about this 25 degree celsius and pH5 which is normally occurs in the Earths surface. So relative chemical weathering can be studied in the presence of ground or it is water or river water Na, Ca, Mg are most mobile K, Si are least mobile Fe, Mg are least mobile.

So here this element also within that mineral what are the elements are there? The elements the degree of mobility it has been given sodium, then calcium, magnesium they are most mobile that is why those minerals which are olivine, pyroxene they weather fast and Fe, Mg are least mobile.

**(Refer Slide Time: 14:30)**

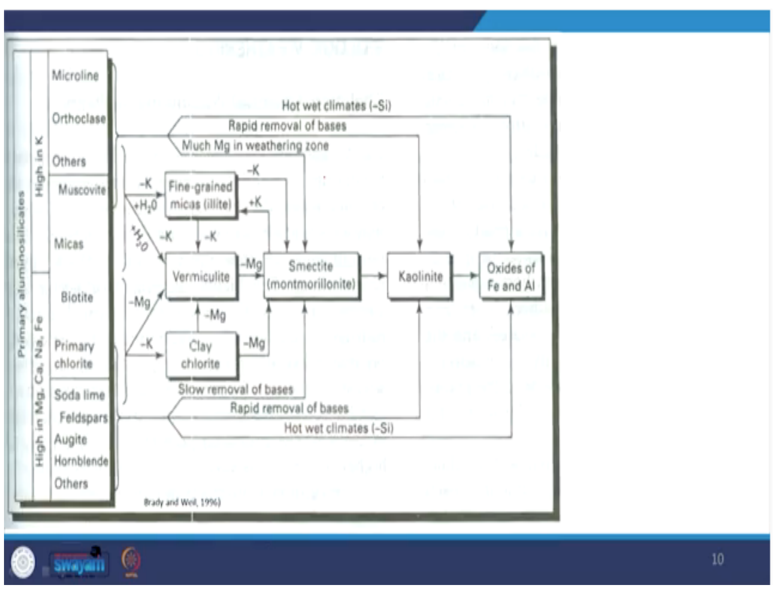



Colman studied weathering rinds in basalt and andesite and found the degree of mobility. Here is it the basalt and andesite if you compare the abundance of oxides weather oxides if you see here silicon in basalt is this much and andesite is this much. So silicon means Si it is the most stable part. So if you compare this basalt and andesite in terms of weathering andesite will be more stable as compared to basalt.

So this is the mobility series it is Colmans mobility series. Here calcium is more mobile than sodium, magnesium, silicon, aluminum, potassium, iron and titanium. So these are these least mobile parts and these are most mobile parts okay. So in the weathering series if you analyze from here to here that means here we will get this type of minerals at the periphery because they are least mobile.

And in the fresh rock all those elements can be distributed found to be uniformly. However, in the weathering rind if you compare the degree of presence of this mineral or absence of this mineral the least part you will find here because weathering starts from the periphery. So that is why iron and titanium that we mostly found at the periphery of this weathering rind as compared to this inner circle or inner part which is abundant by this middle part of this elements.

**(Refer Slide Time: 16:18)**




Now different climates how it is affecting the different type of weathering? So if you see here there are 2 subdivisions brought with subdivision of the mineral. This side up to here it is high K and **here** high Mg, Ca, Na, and Fe. So within that high K here muscovite, mica, biotite, fluoride, chlorite. They are the mica groups and here microcline, orthoclase and others. This is feldspar groups. Now you see here in high K content microcline, orthoclase others and muscovite.

Now you see if it is rapid removal of bases they will form kaolinite. In hot wet climate if silicon is removed they will convert to oxides of Fe and Al. Similarly, these groups if K is removed fine-grained micas, K removed it is coming it is getting smectite, K is added montmorillonite. Similarly, here micas, biotite, primary chlorite if you see here H2O or water is added. Magnesium loss is there it is forming vermiculite.

Similarly, from vermiculite if again magnesium removed that is converting to smectite. Then through smectite it will go to kaolinite and other minerals. Similarly, here the feldspar, augite, hornblende and others if you remove this bases rapidly that will again converted to kaolinite and hot wet climate removal of silica that will convert to oxides of iron and aluminum. So that means in different climatic condition different elements are removed from this minerals primary minerals and the rate of removal that also defines what type of product we are going to get.

Rapid removal if you see here once we rapidly removing were forming kaolinite. If slowly 1 thing is 1 base is removed another is added so then that mineral is converting to different types. So that means I want to say whatever this kaolinite and other clay mineral deposits is there in the Earth's surface they are the indicators of the degree of weathering and the rate of weathering too. Since geological past the Earth had suffer many times climatic change and those climatic conditions they are responsible for chemical weathering and finally the product is there.

By looking this product by analysing the product we can say what type of weathering was prevalent at that geological timescale. Then comes to factors of weathering. We have already discussed weathering in brief and different factors what are these factors? The past and the foremost thing is your tectonic setting. Tectonic setting you know tectonics is the interaction of lithospheric plate. So the question arises if tectonic plates are there which part of the plate will be more prone to weathering and why?

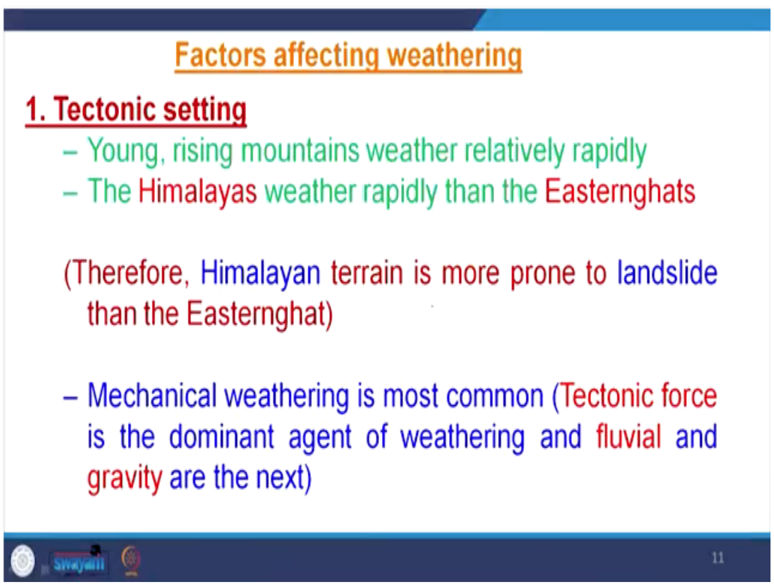
If you believe me that the regions which are close to this plate boundary they are more prone to weathering as compared to the outside or inner part of this plate why? Suppose for example we take this Himalayan example like this Indian and Eurasian plates. It is boundary which the

Himalayas defines the Indian plate boundary. Here due to tectonic stresses due to stress build up the rocks are under tremendous tension.

So cracks are developed. So thousands of cracks there within this rocks and once the cracks are there they promote both physical as well as chemical and also biological weathering. Through the cracks the blocks are removed physical weathering simply and the through cracks water percolate down and promotes alteration or chemical weathering. Through the cracks these trees or these vegetation they grow and promotes biological weathering.

So that is why the and due to tectonic shaking for every frequently they are sagged by this tectonic forces. So that get somewhat weak the rocks get weak. So that is why this tectonic setting plays a prominent role to define the degree of weathering of rocks.

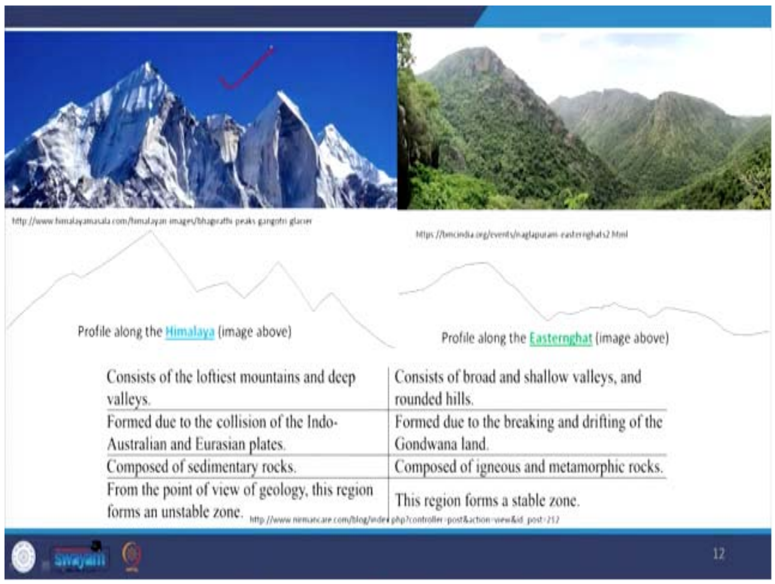
**(Refer Slide Time: 21:28)**




Therefore, Himalayan terrain is more prone to landslide than Easternghat. In Easternghat it is also a mountain belt and Himalaya it is also a mountain belt. But as compared to Easternghat Himalaya is relatively new and active tectonics is going on along the Himalayan terrain. So that is why Himalayan is more prone to weather as compared to Easternghat. Easternghat is called relict mountain. It is Himalaya is young mountain.

Relict mountain means after weathering after millions of years of weathering that remained as it is here. So mechanical weathering is most common that tectonic force is dominant agent of weathering and fluvial and gravity is the next. In the Himalayan terrain or in the mountain terrain or this tectonic active region the mechanical weathering is more common as compared to this other like fluvial and gravity they are next.

**(Refer Slide Time: 21:42)**




Here 2 photographs one is from the Himalayas this side it is the Himalayan system. This is the Easternghat system. Now if you see this profile I have done here the Himalayan profile it is very steep how? It is in the Easternghat this profile is relatively smooth not sharp as compared to the Himalayan. This is due to the reason the degree of activity. So the Himalayan edge is tectonically more active frequent activity is there, rapid rate of erosion is there that is why we are getting a profile of this much sharp.

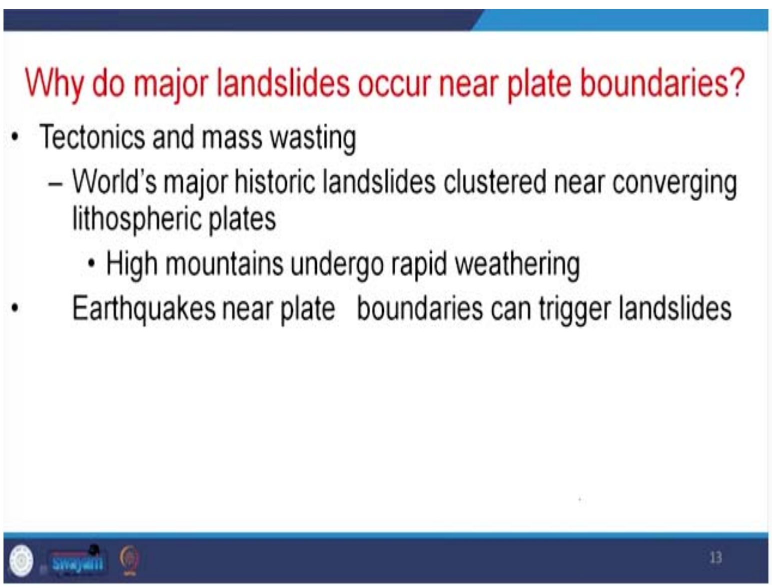
However, it is a relict mountain it remained after millions of scale of millions of years of weathering. So that is why this due to weathering this is this profile is like this. So if you compare the Himalaya and the Easternghat in terms of weathering the Himalayas is contest of loftiest mountain deep valleys. It is very important to note here.

The Himalayan rivers, the rivers within the Himalayan terrain like these Brahmaputra, the Ganga, the Sutlej whatever the rivers which are coming within the Himalayas. They occur deep valleys. Deep valleys it is called river incision. River incision means river is flowing and if the riverbed is uplifting. So river has to cut this riverbed and going deeper to adjust its valley. So this is called river incision.

We will talk detail in about this river incision in our fluvial morphology class. However, if you compare this Easternghat rivers it consists of broad and shallow valley and rounded hills. If you see here we are getting rounded hills but here we are getting sharp hills. Then Himalaya is formed due to collision of the Indo-Australian and Eurasian plate. Formed due to breaking and drifting of the Gondwana land. Composed of sedimentary rock. Composed of igneous and metamorphic rocks.

From the point of view of geology, the region forms a unstable zone. It is unstable zone. But it is a stable zone. That is why you will feel hundreds of earthquakes along the Himalayan region however there is no or hardly any earthquake in the Easternghat region due to this tectonic stability.

**(Refer Slide Time: 25:17)**

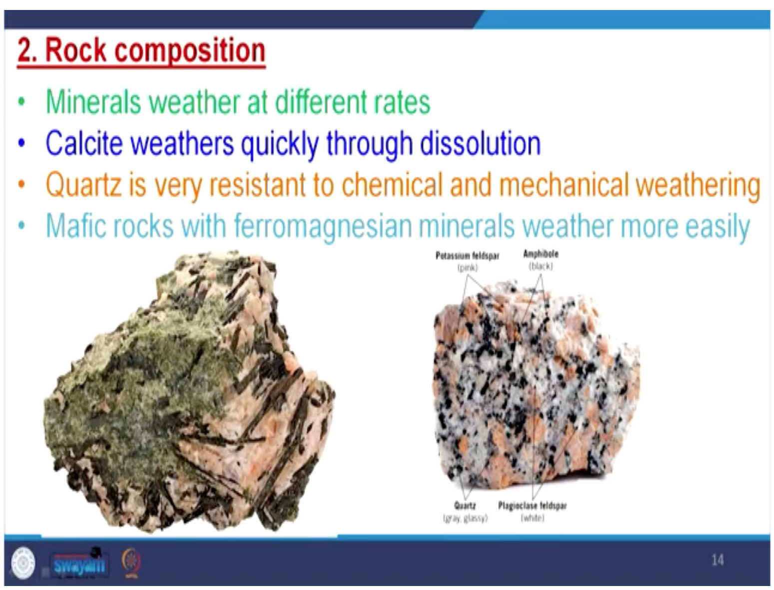



That is why major landslides they occur in the Himalayan terrain. So every year you might have heard about there are landslides in Chamoli, landslides in Kedarnath something like that. So due to their tectonic instability hundreds of landslides per year occurs along the Himalayan terrain. Due to this mechanical weathering. Because the rocks are very weak due to gravity, due to the glacial activity, due to fluvial activity, due to sliding those part of this hill they come down and this is called landslides.

And worlds major historic landslides clustered near converging lithospheric plate like the Himalayas. It is a converging lithospheric plate convergence of Indian plate and Eurasian plate. That is why world's major historic landslides they clustered here. High mountains undergo rapid weathering. Again another factor it is the high mountains. If you compare this mountains height of Easternghat, Western Ghat, and the Himalayas.

The Himalayas consist of high mountain. So higher altitude more weathering is there okay. Earthquakes near plate boundary can trigger landslides frequent earthquakes they occur along this Himalayan boundary. So that also weakens the rocks. So all those factors they merge together and promote mechanically removal of this hill sides or hillsides from this main hill. So that is why major landslides they occur in the tectonically active mountain regions as compared to other parts.

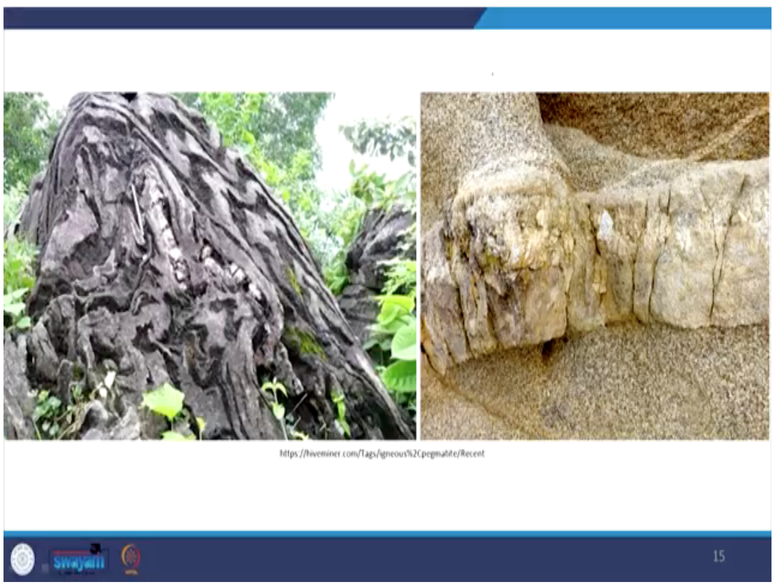
**(Refer Slide Time: 27:09)**




So after tectonic setting the second foremost for the second most point is the rock composition that is very important. Rock composition if you remember when we were talking about this mechanical weathering we are talking about the mineral composition of a rock. So the rocks which composed of different minerals and different minerals they are very differently sensitive to this same weathering conditions as we are discussing olivine and quartz.

If a rock which is composed of 2 different minerals like olivine, pyroxene and quartz. The quartz will be most stable as compared to olivine and pyroxene. Similarly, different minerals weather at a different rate. Olivine you will weather higher rate as compared to quartz. Calcite weathers quickly through dissolution. Then quartz is very resistant to chemical and mechanical weathering. Mafic rocks with ferromagnesian minerals weather more easily. So these are the factors that is why there will be differential weathering in a rock.

**(Refer Slide Time: 28:20)**



So if you here see this example there are 2 photographs one rock it is from the central part of this Indian Peninsula that is called calc-silicate. Calc-silicate means calc calcium carbonate and silicate is silicate. So a rock composed of calcium carbonate and silicate alternatively. If you see here weathering here these ridges they are forming ridge these are the ridge. However, these are this groups they are depressed part the black one is depressed part.

So that means I want to say those which is forming a positive relief it is represented by the silicates and the negative relief the black one that is representing the calc part or the carbonate parts. So that means I want to say if a rock is composed of both the carbonates and silicate. The silicate part remains unweathered and as compared to its carbonate part within a time limit this carbonate rocks getting removed and this enriched in silicate part.

This is due to differential weathering differential resistance of different minerals in a same weathering condition. Similarly, here you see we have a sandstone body and it is intruded by a pegmatite vein and you leave it for weathering. So these sandstones getting weathered however this pegmatite vein they remain as a higher relief due to differential weathering.

Third one is the rock structure what is rock structure? How structures were formed during this rock or the primary structure? Or how the structures are superimposed after formation of the rock? That is secondary structure. Primary structure for example here it is given one is the columnar basalt.

**(Refer Slide Time: 30:36)**


Columnar basalt it is a typical part of the Magma pool which is formed during this formation of this basalt. So now you see we have columns different columns and those columns are those fracture planes or the joint planes among these columns. They are the avenues for a passage of water to this inter surface into the surface and promotes weathering. Similarly, structures like fractures they are superimposed after the formation of the rocks they are the fractures.

So through this fractures water percolates down and due to percolation of water it reacts with these rocks and physically and chemically weathers this rock itself. Now if you see here the comparison of these 3 photographs combined together those parts which are close spaced joints or fractures are there those parts are getting weathered fast as compared to other part. So that means closeness of the structure, the closeness of the fractures they also playing a major role of physical or chemical weathering.

So here if you compare this part to this part here the fractures are more closely spaced as compared to this part. That is why the rocks become relatively more stable in this region and this part the rocks have been removed. This is due to the closeness of this rock fractures.

**(Refer Slide Time: 32:13)**


Now topography as we are talking something about the steep sides of a hill they are more prone to weathering as compared to the gentle part. So if you come see here this part it is gentle slope but here it is steep slope. So that is why the rocks will be more weather here as compared to this gentle slope. So that is why topography also plays a major role in defining this weathering. So steep slopes are more prone to weather as compared to gentle slope. So I think we should stop here and we will meet in the next class. Thank you.