Lecture 11
Geomorphic Processes (II): Weathering Processes

KEY QUESTIONS:

✓ *What influences the weathering of rocks?*

With the completion of this lecture, attached readings and tutorial, you should be able to understand the:
- Various chemical and physical weathering processes acting on rocks in the tropics
- Factors influencing the weathering of rocks in the tropics

Lecture Outline

11.1 Introduction

11.1.1 Types of Weathering Processes

- **Weathering** is *the process of breakdown of rock by disintegration and decomposition in situ* (in its original position), at or near, the earth's surface. Weathering does not involve the removal of the weathered material. Weathering is a slow process, especially in resistant rocks, but its effects are evident on any exposed rock mass.
- There are two main types of weathering processes namely chemical and physical weathering which can be further divided into sub-processes (see **Fig. 1**):

Chemical	Physical
• Carbonation • Hydrolysis • Oxidation & Reduction • Solution	• Freeze-thaw • Pressure release • Salt weathering • Thermal weathering

Fig. 1: Weathering Processes in the Tropics

  - **Chemical weathering** occurs when the original mineral in the rock **decomposes** or decays *in situ* due to chemical alteration of those minerals (see **Section 11.2**).
  - **Physical weathering** occurs when rocks are broken and **disintegrated** into smaller pieces *in situ without* any chemical alteration (see **Section 11.3**).
- Although both types of weathering may occur together, usually one predominates. The type and degree of weathering depends on the local climate, vegetation, structure and mineral composition of the rocks and the length of time during which the weathering process operate.
- The pattern and products of weathering are therefore different in various parts of the tropics.
  - In the **humid tropics (A climates)**, chemical weathering is more effective as it is accelerated in the presence of high temperature and high rainfall.
  - In the **arid tropics (B climates)**, where rainfall is very low and there is a high diurnal temperature range, physical weathering is more effective and rocks tend to break up into smaller components by physical breakdown. Physical weathering is also dominant in high altitudes such as high mountains where temperature fluctuates above and below 0°C.
  - Whatever the processes involved, a number of characteristics that are common:

1. Weathering produces irreversible changes in rocks from a massive state to a clastic (made of fragments, like scree) or plastic (pliable, like clay) state.
2. Rocks experience a number of changes during weathering in characteristics such as volume, density, grain size, surface area, permeability, consolidation and strength.
3. New minerals, aggregates and solutions are formed.
4. Some original minerals may be resistant to weathering and persist in their original state.
5. Minerals and salts may be transferred, dispersed, consolidated or concentrated.
6. Weathering prepares the rock for subsequent erosion and movement downslope.
7. New land surfaces and deposits are produced after weathered materials are removed.

11.2 Chemical Weathering Processes

- Chemical weathering involves the breakdown of rock minerals through interactions with agents like water, oxygen, carbon dioxide, and various organic acids. These reactions result in changes to the mineral composition, volume, strength, and coherence of the rock.
- Chemical weathering processes are typically selective, affecting some minerals while leaving others unaffected, particularly in complex crystalline rocks.
- Nearly all minerals can undergo chemical alteration when exposed to atmospheric and biological agents. While some minerals, such as quartz, are highly resistant to chemical changes, many others are more vulnerable. Few rocks remain entirely unaffected by chemical weathering, as the alteration of even a single key mineral can lead to the disintegration of the entire rock.
- Moisture is essential for nearly all forms of chemical weathering, which has significant implications:
  - Chemical weathering operates more effectively in humid tropical regions (e.g., Af and Am climates) due to the abundance of water, compared to arid tropical regions.
  - Unlike physical weathering, chemical weathering typically occurs at greater depths, as water can penetrate deeper into the ground, whereas temperature fluctuations, crucial for many physical weathering processes, are limited to the surface.
- The products of chemical weathering include "residual" decomposition products and "soluble" products, which are carried away by percolating water and eventually reach rivers.
  - Generally, the products of chemical weathering are finer than those produced by physical weathering. Chemical weathering is often accelerated by physical weathering, which breaks rocks apart and increases the surface area exposed to chemical agents.
- Temperature is another key factor influencing the rate of chemical weathering:
  - In general, higher temperatures speed up chemical weathering. Studies indicate that the rate increases 2.5 times for every 10°C rise in temperature (up to 60°C). However, this does not imply that chemical weathering does not occur in colder regions.

11.2.1 Carbonation

- Carbonation involves **the reaction of minerals with dissolved carbon dioxide in water**.
- Carbon dioxide from the atmosphere or soil is absorbed by water to form a weak acid, referred to as **carbonic acid**. This acid is strong enough to dissolve many minerals, especially calcium carbonate present in limestone, in the process of carbonation.
  - When rainwater reacts with limestone, calcium carbonate changes into a solution known as calcium bicarbonate and is removed easily in solution (see **Section 11.2.4**) thus breaking down the rock (see **Fig. 2**).

Calcium carbonate + Carbonic acid → Calcium bicarbonate

- The effects of carbonation will be examined in **Lect. 13** when we study karst landscapes.

Fig. 2
Limestone cave (karst landscapes) is an outcome of carbonation and solution acting along the joints commonly found within bodies of limestone, giving a distinctive underground cave formation.

Such landscapes are associated more with hot and humid tropics where chemical weathering is most effective.

11.2.2 Hydrolysis

- Hydrolysis is the complex chemical reaction which happens when hydrogen (H^+) ions in the water react with the silicate minerals present in the rock to create new compounds which tend to be softer and weaker than the original rock material and thus the rock crumbles.
  - For example, granite is made up of three minerals namely feldspar, mica and quartz. Out of these three minerals only feldspar (silicate) reacts with H^+ ions in water which turns feldspar into clay or kaolinite. As clay or kaolinite is softer and weaker than feldspar, it causes granite to breakdown or weather chemically by hydrolysis. Quartz particles, which are resistant to chemical weathering, remains as sand particles (silica).
- Hydrolysis usually results in granular disintegration of the rock minerals, as in the case of granite where feldspar is turned into grains of clay.

11.2.3 Oxidation and Reduction

- The processes of **combining or dissociating from oxygen** are called oxidation or reduction respectively.

- **Oxidation** is the chemical weathering process which occurs when certain metallic minerals react with oxygen in air and water to form oxides. It is more likely in well-drained areas and is more rapid at higher temperatures.
  - Perhaps the most familiar oxidation form is the "rusting" of iron mineral in rocks.
  - Iron in ferrous state (FeO) changes to ferric (Fe_2O_3) state by the addition of oxygen. This ferric oxide is reddish-brown rust and is weak and helps rock to crumble easily. It also accounts for the bright red colour of rocks (see **Fig. 3**) and soils in tropical environments.

Fig. 3: Effect of Oxidation

- When oxidised minerals are placed in an environment where oxygen is absent, **reduction** takes place. Such conditions exist usually below the water table, in areas of stagnant water and waterlogged ground. The red colour of iron upon reduction turns to greenish or bluish grey (see **Fig. 4**).

Fig. 4: Gley Soil as a Result of Reduction

11.2.4 Solution

- Solution is a process where minerals dissolve directly into water without any chemical reaction with acids or other substances. It typically occurs when water interacts with soluble minerals, leading to their disintegration into ions that are carried away in solution.
- For example, rock salt dissolve readily in water through solution. Calcium carbonate ($CaCO_3$), found in limestone, can also dissolve in pure water, but this process is significantly enhanced in the presence of carbonic acid formed when water combines with atmospheric CO_2.
- Solution plays an active role in removing certain residual products of other weathering processes, exposing the joints to further weathering processes.

11.3 Physical Weathering Processes

- The physical breakdown of rocks is mainly attributed to the effects of **changes of temperature**. However, rock disintegration may occur without the intervention of climate (for example, see **Section 11.3.4**).
- In essence, big rocks are mechanically weathered into little ones by various stresses that cause rock to fracture into smaller fragments. Most physical weathering occurs **at or very near surface**, but under certain conditions it may occur at considerable depth.
- Physical weathering encourages chemical weathering by increasing the rock surface area and exposing them to more weathering agents and vice versa.

11.3.1 Thermal Weathering

- Thermal weathering is associated with the arid climatic regions (i.e. BWh and BSh) *where there are **large fluctuations of daily temperature*** (high diurnal range of temperature) i.e. extremely hot during day and very cold at night.
  - For example, in hot deserts the daytime temperature of a rock can be raised to 50°C or more by solar heating; during the night, the temperature may drop to 10°C or less by radiation heat loss.
  - As rocks are bad conductor of heat, usually high temperature during the day causes only the outer layer of the rock to expand as heating penetrates only a few millimetres into the rock. At night due to low temperature the outer layer of the rock contracts. This alternate expansion and contraction of the outer layer of rock causes the rock to develop cracks parallel to the surface known as sheet joints. Overtime the outer layer peel off as platy fragments of rock (see **Fig. 5**). This process by which the rock peels off is known as exfoliation. In thermal weathering exfoliation happens on a smaller scale compared to pressure release (see **Section 11.3.4**).
- On the other hand, the process of thermal weathering may be particularly effective in crystalline rocks composed of dark and light-coloured minerals which expand and contract at different rates.
  - This results in granular disintegration. Dark coloured grains expand faster than light coloured and thus exert pressure on those surrounding them, forcing them to break off as grains.

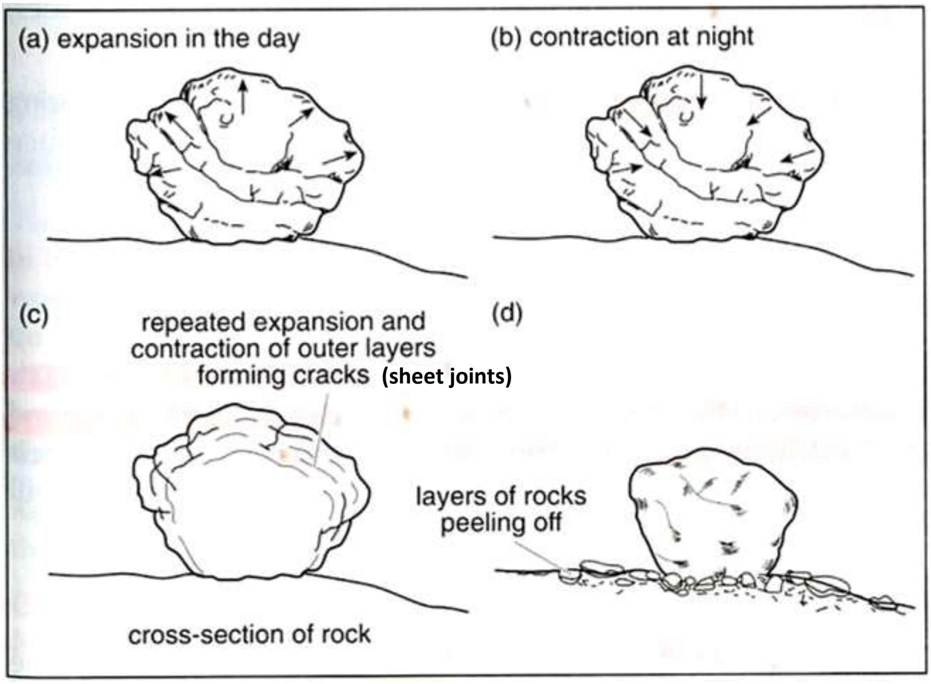

Fig. 5 Thermal weathering resulting in small-scale exfoliation

11.3.2 Freeze-Thaw Weathering

- Freeze-thaw weathering occurs in high altitudes in the tropics where ***temperature fluctuates above and below 0°C***. It occurs most effectively when water penetrates cracks or joints in the rock, freezes and in the process expands by approximately 8-10%, exerting pressure up to 2,100 kg/cm^2. (Rocks can only withstand a maximum pressure of about 500 kg/cm^2)
- The pressure exerted by the frozen water widens and deepens the cracks. Overtime, the rock breaks down into angular pieces of rocks with sharp corners and edges (see **Fig. 6**).
- Repeated cycles of freezing and thawing is necessary for freeze-thaw weathering to be most effective.

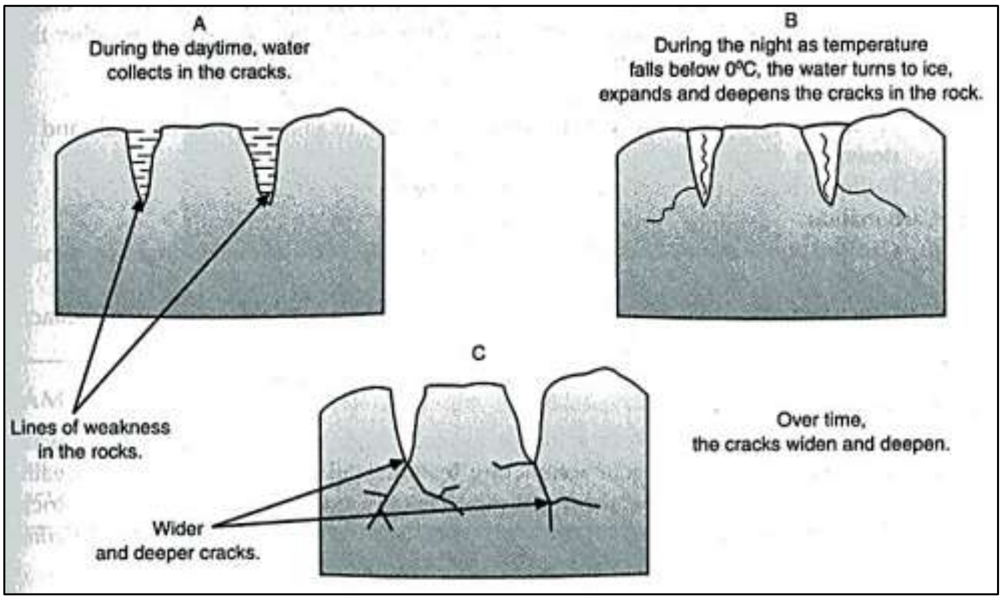

Fig. 6 Repeated cycles of freezing and thawing is necessary for freeze-thaw weathering to be effective

- While large blocks of rock may be detached along **joints** (i.e. block disintegration; see **Fig. 7**), freeze-thaw weathering can also operate on a smaller scale, when water penetrates the rock through **pores**; on freezing, it will form ice crystals that by expansion, are able to break the rock into flakes or granular particles (i.e. granular disintegration).

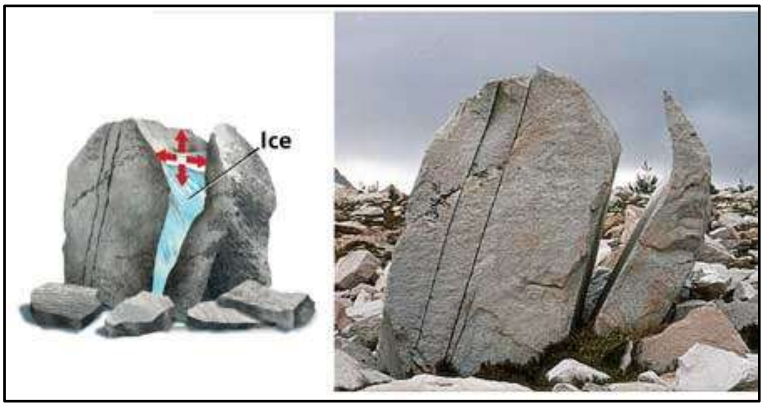

Fig. 7 Block disintegration resulting from freeze-thaw weathering

- On very steep slopes, these angular and coarse rock debris will slide and accumulate as masses of scree at the foot of the slope. If it accumulates at the base of cliffs, it is known as talus. If the accumulation occurs on flatter areas, it will form blockfields (see **Fig. 8** and **9**).

Fig. 8: Scree (left) and blockfields (right)

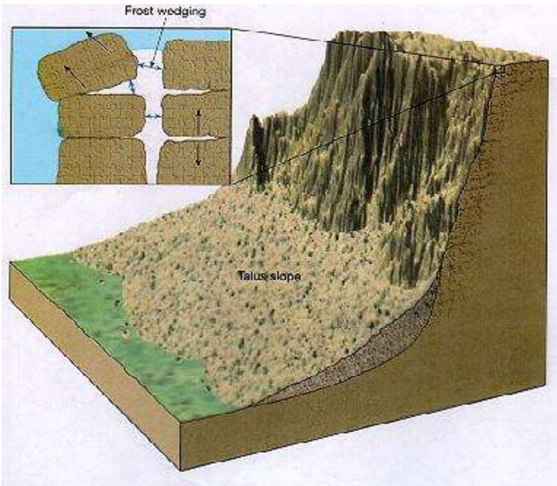

Fig. 9: Talus

11.3.3 Salt Weathering

- Salt weathering occurs in areas with high temperature and availability of salt. It involves the *evaporation and crystallisation of saline solution in a confined space within the rocks*.
- **Salt crystals** are formed in pore and cracks of the rock and over time the salt accumulates, crystal grows larger in size and **applies pressure to the walls of the pores and cracks thus breaking down the rock.**
- Where salt weathering is particularly concentrated, *weathering pits* and *tafoni* (cavernous weathering) are formed:

- Salt weathering occurs in **coastal areas** with high temperature and low rainfall where water evaporates leaving behind salt which accumulates in rock pores and cracks as a result of the rocks being in close proximity to salty sea water or moisture (see **Fig. 10**).
- Salt weathering is particularly effective in **hot deserts** (e.g. BWh climate) where low rainfall and high temperatures (hence high evaporation rates) cause salts to accumulate just below the surface. As saline water rises towards the surface by capillary action in the arid regions like deserts, due to high temperature and high rate of evaporation, water gets evaporated leaving behind salt crystals near the surface (see **Fig. 11**).

Fig. 10 Tafoni
Effects of salt weathering by the coast. Such a result is sometimes described as *honeycomb weathering*.

Fig. 11
Weathering pits in a hot desert.

Compared to Fig. 10, the cavities are larger, but tafonis and weathering pits are both evidence of salt weathering.

11.3.4 Pressure Release

- Rocks, such as granite and gneiss, are formed deep below the earth's surface, buried and subjected to great pressure by the overlying rocks. *Over time the rocks may be subjected to uplift, or the materials lying on top of these intrusive rocks are removed*. When this happens, pressure on the underlying rocks are decreased and the process is known as **pressure release** (see **Fig. 12**).
- As unloading occurs, the once deeply buried rocks expand upward and outward, creating tensional stresses perpendicular to the surface. This stress results in the development of cracks parallel to the surface, known as sheet joints (see **Fig. 13**). The rock breaks or peels away along

these sheet joints, layer by layer, forming curved slabs that can range from thin sheets to large blocks (i.e. block disintegration). This exfoliation occurs on a much larger scale compared to the smaller-scale exfoliation seen in thermal weathering. The resulting arch- or dome-shaped landforms, formed by large-scale exfoliation, are known as exfoliation domes.

- *The sheet joints are lines of weaknesses that can be subsequently exploited by other weathering processes* (see **Section 11.4.2b**).

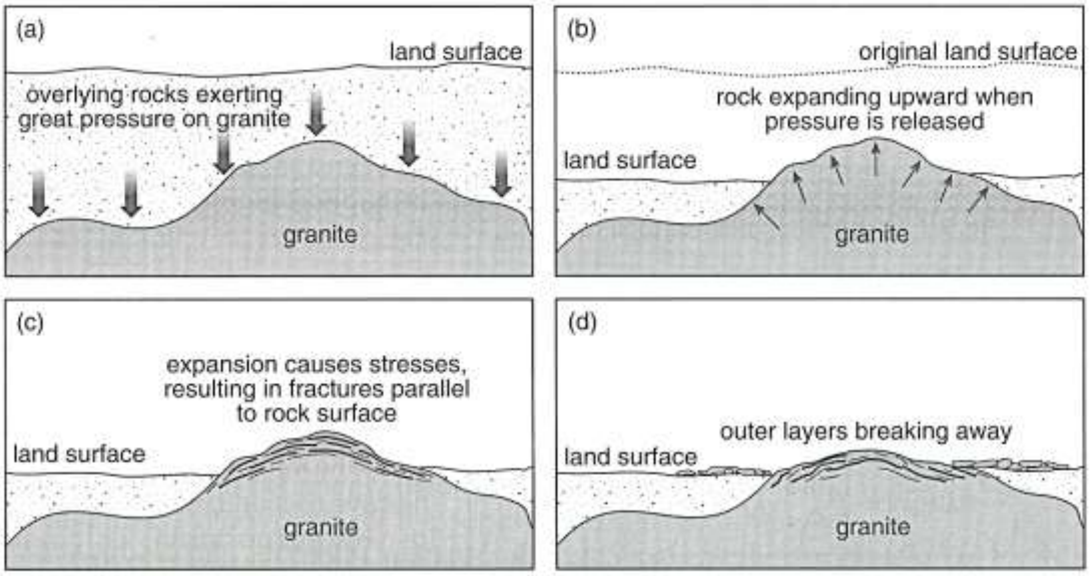

Fig. 12 **Pressure release**

Fig. 13
An exfoliation dome

Notice the sheet joints that are parallel to the rock surface. In some cases, the rock slabs separated by these sheet joints may be very large and thick, but it is also just as likely to find thinner layers. This means that exfoliation can take place over different scales.

11.4 Factors Influencing Weathering of Rocks

- Physical weathering dominates in drier (e.g. BWh) and cooler climates (high altitudes within the tropics), whereas chemical weathering dominates in wetter and warmer climates (e.g. Af and Am).
- However, geographers also notice that the **effectiveness** (i.e. type and rate) of weathering *within* a climatic region is *not the same throughout* the region. Thus, weathering is not only due to climatic conditions but also more localised factors, especially the geology of rocks.

11.4.1 Climate

- Climate is without doubt one of the most important controlling factors of the type and rate of weathering that will occur in any given location (see **Table 1** on pg 13). This is not especially surprising, given that we learnt that almost every weathering process requires either the **addition of water** and/or **a change in temperature** to work effectively.

Where is physical weathering most effective?

a) Cold regions (e.g. high altitudes in the Tropics)

- The curves for freeze-thaw weathering on the right (see **Fig. 14a**) shows that the optimum environment for freeze-thaw weathering is not the coldest environment, but **the one that is likely to produce the greatest number of freeze thaw cycles**.
- Along the same line of reasoning, the efficacy of freeze-thaw weathering decreases with rising temperature.
- Note also that with decreasing availability of water, freeze-thaw weathering also becomes relatively less effective. Although fluctuating temperature above and below 0°C is key for this weathering process, some water is still required for any ice to form.

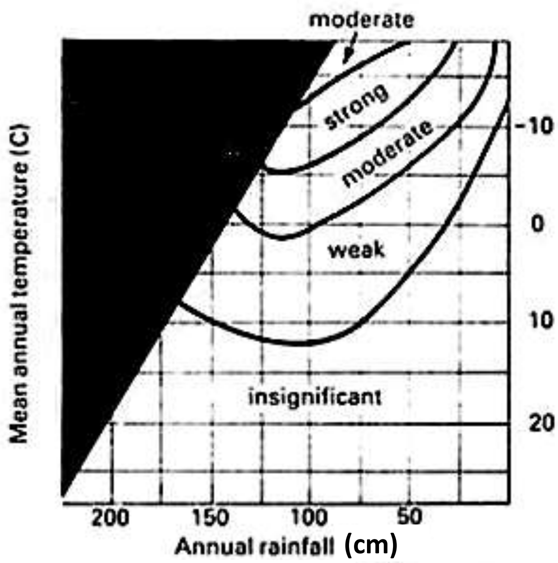

Fig. 14a Freeze-thaw

- The angular blocks often found near relatively larger rocks are evidence of freeze-thaw weathering having acted along joints. A field of such rocks is called *felsenmeer*. However, often granular disintegration is also seen as freeze-thaw weathering can work within pores.

b) Hot and arid regions

- While **Fig. 14a** is useful to show that freeze-thaw weathering is very effective in the high altitude regions within the Tropics, *it neglected other physical weathering processes*.
- Thermal weathering is more common in the arid regions (e.g. BWh). Here, **large temperature changes between day and night** may induce alternate expansion and contraction of rocks, resulting in their disintegration.
  - Small scale exfoliation in the form of flaky fragments found on rock surfaces or near the rocks themselves are evidence of thermal weathering at work.

- Also, salt weathering are very effective where **evaporation rates are high**. In hot deserts, subsurface saline water brought up to the surface by capillary action can undergo evaporation to leave behind salts near the surface.
  - Tafonis and weathering pits are evidence of this process.

Where is chemical weathering most effective?

c) Hot and wet regions

- Chemical weathering processes are solely dependent on availability of water. Unlike physical weathering, all chemical weathering processes need **water**.
- The curves for chemical weathering (**Fig. 14b**) show that the environments that will favour the most effective chemical weathering are those that provide the **wettest and hottest** conditions in which the processes can function.

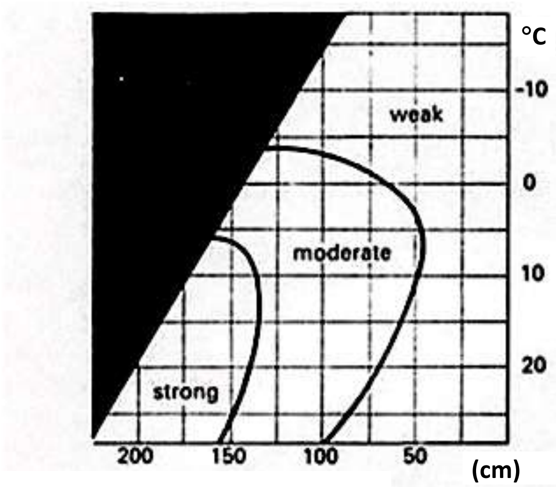

Fig. 14b Chemical weathering

- Recall that the speed of a chemical reaction **increases** about 2.5 times with each rise of temperature by 10°C, which explains the increased potency of chemical weathering in tropical humid climates (e.g. Af and Am) where not only temperatures of above 25°C are usually present but also vast supplies of fresh water.
- Such regions also promote **vegetation growth**, which itself is another important factor that encourages both physical and chemical weathering (see **Section 11.4.3**).
- Evidence of effective chemical weathering can be in the form of:
  - The **karst landforms** which we shall be learning in Lect. 13. Places such as parts of Vietnam, southern China and Malaysia have some very well-known tower and cockpit karst landforms, which are mainly due to carbonation and solution acting on limestone.
  - The **weathering at depth** below the surface. As we shall learn in Tutorial 11, chemical weathering below the surface (such as on granite) are most apparent in the humid tropics, rather than in the arid tropics and cold regions.
- The rate of hydrolysis depends on:
  - The amount of hydrogen ions, which in turn depends on the composition of air and water in the soil and the presence of organic acids.

However, chemical weathering is not limited to only hot and wet regions. It has been found that carbon dioxide can be twice as soluble in water at very low temperatures (near 0°C) as it can be at high temperatures (30°C), so carbonation is also likely in cold regions.

Table 1. Patterns of Weathering by Climatic Regions within the Tropics

	Humid Tropical Regions (e.g. Af)	**Seasonally Humid Tropical Regions (e.g. Am and Aw)**	**Hot Desert Regions (e.g. BWh)**	**Cold Regions (e.g. high altitudes in the Tropics)**
Climatic Features	High rf, high temp all year round	Alternate wet and dry season	Low rf, high evaporation rates, large and seasonal temp range	Abundant snowfall mainly in winter, generally low temp although frequently rising above 0°C especially in summer
Physical Weathering (PW) and Evidence	**Limited** ▪ Lack of exposure of rocks to the surface ▪ Low temp range	**More dominant in dry season** ▪ Exfoliation and pressure release are most active at the beginning and near the end of the rains when the temp range is high and the cooling is effected by frequent rain showers	**Dominant** ▪ Intense heating and rapid cooling by occasional rain showers, and the large temp range lead to constant expansion and contraction of the rock ▪ High evaporation rates also promote salt growth ▪ Exfoliation, flaking, tafonis and weathering pits are evidence	**Dominant** ▪ Meltwater is released from snow and ice during the day, enters joints and pores in rock, freezes at night, promoting freeze-thaw (both block and granular disintegration can result) ▪ Freeze-thaw is evident: Felsenmeer, angular debris
Chemical Weathering (CW) and Evidence	**Dominant** ▪ Abundance of moisture within the soil encourages the rapid growth and swift decay of vegetation → organic acids ▪ Chemical decay by solution, carbonation and hydrolysis is rapid when organic acids combine with water in soil under warm conditions ▪ Deep regolith (the result of chemically weathered rocks), up to 30-60m deep	**More dominant in wet season** ▪ Amt. of rf often equals that of the humid tropics ▪ But CW is not as not as intense as in the humid tropics because: ○ Temp is not continuously high ○ Rapid run-off ▪ CW is active only on flat and gently sloping rock surfaces and esp. in the afternoon when sun's heat is greatest ▪ Generally, CW is favoured but regolith is less thick then in humid tropical regions	**Limited** ▪ Infrequent rains allow water to enter pores and joints of rocks, encouraging internal weakening by CW ▪ Heavy dew and mists provide conditions for decay of rock surfaces	**Limited** ▪ Water from thawing of ice contains high proportion of dissolved CO_2 which increases at low temp thus promoting carbonation

11.4.2 Rock Characteristics (or Geology)

- Whilst the pattern of weathering on the broad scale reflects climatic variations from place to place, on a **local scale** it is influenced more by the diversity of rock type.
  - For example, within the Af climatic region, there will be important contrasts in the ways in which particular rocks, such as granite, basalt, sandstone and limestone are broken down by weathering.
- These variations in the response of individual rock types to weathering are related to a number of rock characteristics, some of which aid weathering processes and others which impede them.

a) Rock Composition

A rock's composition has a great effect on its rate of weathering. Minerals present in the rock determine the rocks vulnerability to different weathering processes.

i) Physical Weathering

- Dark-coloured rocks such as basalt absorbs solar heat more readily, heat up and expand quite rapidly, and thus experience stresses which may break them by thermal weathering.
- Rocks containing a mixture of light and dark coloured minerals may experience differential expansion and contraction and break down by thermal weathering. Granite is a good example, with light-coloured feldspar and quartz, and dark-coloured mica.

ii) Chemical Weathering

- Minerals like feldspar and mica make rocks like granite susceptible to chemical weathering, although quartz present in granite cannot be easily weathered. Feldspar, on the other hand, is one of the first minerals to be decayed by hydrolysis when granite is weathered under humid tropical conditions.
- Rocks with minerals like calcium carbonate, such as limestone, can be easily weathered by chemical weathering processes like carbonation as these minerals are highly soluble and easily reacts with acidic water; whereas rocks containing iron minerals can be weathered by oxidation.

b) Rock Structure

- **Bedding planes**, the lines of weakness separating individual layers of sedimentary rocks, are particularly apparent in most limestones and some types of sandstone.
  - They constitute lines along which the rock readily splits, and also provide routes for the underground movement of water; in limestone areas, underground passages frequently result from the opening up by solution of major bedding planes (see **Fig. 15**).

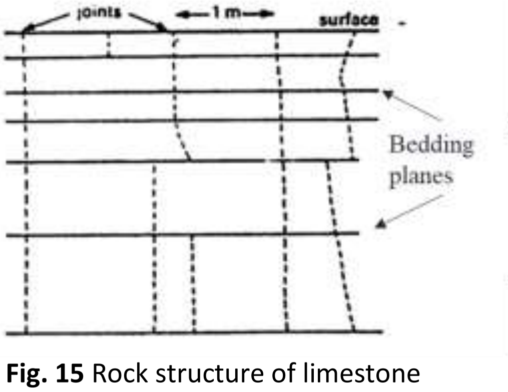

Fig. 15 Rock structure of limestone

- Rocks, like granite and limestone, may have natural **joints** (see again, **Fig. 15**).
  - Joints are very narrow, but often extensive, cracks. They result from the cooling and contraction of igneous rocks and the drying out of sedimentary rocks; they are also produced by the tensional forces which affect any type of rock subjected to Earth movements.
- Presence of joints, cracks, bedding planes make rocks **more permeable** and therefore also **more vulnerable** to weathering processes by *increasing the surface area* (see **Fig. 16**). For example, more water can enter through the openings, and thus increases the rate and effectiveness of chemical (e.g. carbonation) and even physical weathering (e.g. freeze-thaw).

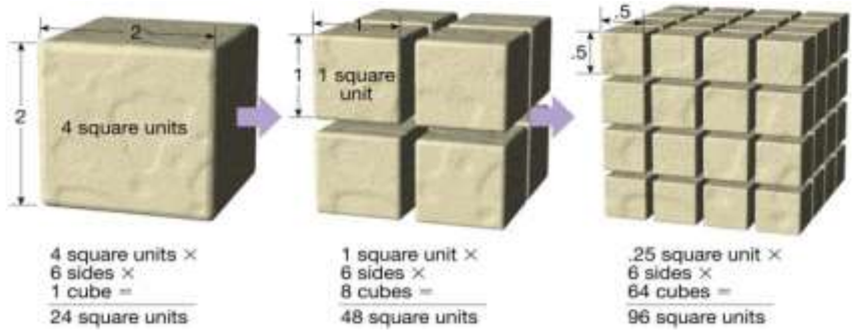

Fig. 16
Joints and bedding planes increase the surface area exposed to air and water

- By contrast, massive rocks without bedding planes and with few or no joints, are inherently resistant. Only the surface of the rock can be attacked by weathering agents, and little or no chemical or physical weathering can occur internally.

c) Rock Texture

- Rock texture refers to the crystalline nature of a rock or grain size, and in particular whether it is coarse-grained or fine-grained (see **Fig. 17**).
- The effect of grain size on weathering is not always straightforward. The relationship is highly complex and weathering effects differ from one rock type to another.

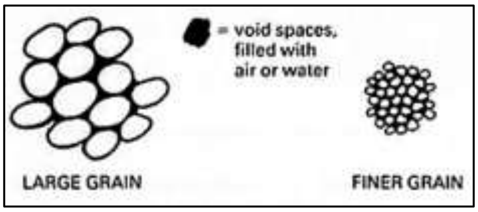

Fig. 17 The effects of different grain

  - In finer grained rocks, the many crystals are tightly bonded and interlocked, thus increasing strength. However, the crystal boundaries also provide an increased surface area of the rock open to attack by weathering agents. As a result, fine grained igneous rocks often weather more rapidly than coarse grained rocks.
  - Yet, this does not imply that all coarse grained rocks are resistant. In some which contain minerals that are unstable, selective chemical attack quickly reduces the rock's coherence. Moreover, large grains produce large void spaces between them and thus increase the possibility of the trapping of water for chemical weathering or freeze-thaw weathering.
- The water absorption capacity, or **porosity**, could thus be seen to be vital to a rock's resistance.
  - For example, if the degree of cementation in fine-grained sandstone is very high, its porosity will be low, and therefore more resistant to weathering. However, if the cementation is weak, the increased surface area within the rock may increase its vulnerability to weathering.

11.4.3 Vegetation

- Humid tropical regions with high temperature and high rainfall encourage the growth of dense tropical rainforest which facilitates both *bio-physical* and *bio-chemical* weathering processes.
- On the other hand, regions such as the arid tropics have sparser vegetation, hence the effects of weathering related to vegetation will be less dominant and effective.

Fig. 18a
Root action, a form of bio-physical weathering

Fig. 18b
Chelation, a form of bio-chemical weathering

a) Bio-physical weathering

- Vegetation can produce physical effects by growth in crevices.
  - One common example is the penetration of rock joints by tree roots, which as they grow and thicken prise the rock apart and cause block disintegration, in a manner not unlike free-thaw weathering in its effects (see **Fig. 18a**). We refer to this as **root action**.

b) Bio-chemical weathering

- Though physical effects can be considerable, of greater significance are the chemical changes brought about by plants and animals. For example, processes related to the decay of plants.
- The decomposition of plant materials, which is particularly active in humid tropical environments, forms **humic acids** which break down rock minerals by **chelation**. This complex process increases the solubility of iron compounds and allows them to be absorbed by other growing plants (see **Fig. 18b**).
  - The presence of organic acids also accelerates the rate of other chemical processes like hydrolysis.
- Vegetation also helps create **pathways for water** (such as through infiltration) which is essential for most forms of chemical weathering.
- Other notable processes include **respiration by plant roots**; this increases the carbon dioxide content of the soil and assists in the formation with rainwater, of weak **carbonic acids** which attack rock minerals, notably carbonates.

11.4.4 Topography

a) Steepness of slope

- When the relief of a place is steep, mass movement (see **Lect. 12**) like landslides may occur, exposing the unweathered bedrocks to weathering.
- As we have also learnt earlier that gentler slope increases the likelihood for water to be retained by soil moisture, so chemical weathering is facilitated.

11.4.5 Human Activities

- Human activities like mining and urbanisation have an influence on vegetation and soil cover, which are controls on weathering themselves.

a) Mining activity

- Mining activity often involves the excavation of large volumes of earth, which exposes previously buried layers of rock to environmental conditions that they were not subjected to when they were underground. When these lower layers of rock are brought to the surface, they become more vulnerable to weathering processes, which can break them down over time.
- For example, in a typical open-pit mine, layers of rock deep beneath the earth's surface are excavated and exposed to the atmosphere. These rocks, which were once shielded from elements such as rain, oxygen, and temperature fluctuations, are now subjected to chemical, physical, and biological weathering processes. A common example can be seen in copper mining operations. When the rock containing copper ore is extracted, the minerals within the rock may begin to oxidize when exposed to oxygen and water, leading to the formation of copper oxide, which can further break down into soluble compounds. This is a form of chemical weathering.
- Moreover, the disruption of these deeper rock layers can also lead to physical weathering. As mining equipment blasts and breaks apart the rock, fractures are created, increasing the surface area exposed to wind, water, and temperature changes, which can accelerate weathering. For instance, after mining operations in mountainous regions, the exposed rock surfaces may experience freeze-thaw cycles where water enters cracks, freezes, and expands, further breaking down the rock. Overall, mining activity accelerates the weathering of lower rock layers by exposing them to natural weathering agents that were previously inaccessible.

b) Construction of roads and residential areas

- The construction of roads and residential areas often involves significant earth-moving activities, such as excavation, blasting, and leveling, which can expose previously buried rock layers to weathering processes. This disruption of the natural landscape can accelerate both physical and chemical weathering of the rocks, leading to their breakdown and decomposition.
- For example, during the construction of a highway through a mountainous region, large-scale excavation may uncover solid rock formations that were previously protected from the elements. Once exposed, these rocks become vulnerable to physical weathering processes such as freeze-thaw cycles. Water from rain or snow can enter cracks in the rock, and when the temperature drops, the water freezes and expands. This expansion can cause the rock to fracture and break

apart over time. In cold climates, this freeze-thaw action can be particularly damaging and lead to the disintegration of the rock over several cycles.

- Additionally, the construction process can also trigger chemical weathering. For instance, when roads or residential buildings are built in areas with high rainfall, water can seep into the exposed rock and interact with minerals. If the rock contains iron-bearing minerals, the presence of oxygen and moisture can lead to oxidation, forming rust-like deposits and weakening the rock structure. Similarly, in areas with high levels of carbon dioxide in the atmosphere, the combination of rainwater and CO_2 can lead to carbonation, a chemical weathering process where calcium carbonate in limestone reacts with acidic water and dissolves over time.
- Furthermore, the removal of vegetation during construction can also contribute to weathering. Plants help to stabilise the soil and rock by absorbing water and reducing the impact of rainfall. Without this natural cover, the exposed rock is more likely to be affected by direct rainfall and temperature fluctuations, increasing the rate of weathering. In urban settings, the increased human activity, such as the use of water for construction or landscaping, can further exacerbate the weathering process.
- So, the construction of roads, residential areas, and other infrastructure can significantly contribute to the weathering of rocks by exposing them to the elements and disrupting the natural protective barriers, leading to both physical and chemical breakdown over time.

c) Urbanised impermeable surfaces

- Concrete, when used extensively for construction purposes such as roads, buildings, and pavements, can significantly alter the natural processes of weathering by covering the land surface and preventing water from penetrating into the ground. This reduction in water infiltration can limit the physical and chemical weathering of rocks and soil beneath the concrete.
- For example, in urban areas, large stretches of land are often paved with concrete for roads, parking lots, and sidewalks. This impermeable surface prevents rainwater from seeping into the soil and reaching the underlying rock layers. Normally, when water penetrates the ground, it can interact with minerals in the rocks, causing chemical weathering processes such as hydration, oxidation, or carbonation. For instance, when rainwater containing dissolved carbon dioxide interacts with limestone, it can lead to the dissolution of calcium carbonate, a process known as carbonation. However, if the land is covered by concrete, this natural infiltration does not occur, and the rocks below remain largely unaffected by these weathering processes.
- Moreover, concrete surfaces can also reduce physical weathering that typically occurs due to the movement of water. In natural environments, water infiltrates the soil and may cause freeze-thaw cycles, where water entering cracks in the rock freezes during cold weather and expands, causing the rock to fracture. Without the ability for water to seep into the ground, this physical weathering process is minimized, as there is less moisture reaching the rock layers to undergo freezing and thawing.
- Additionally, in urbanised areas, the absence of vegetation due to concrete covering can further exacerbate this effect. Plants play an essential role in weathering by stabilising the soil and facilitating the infiltration of water. When vegetation is removed and replaced with impermeable concrete surfaces, not only is water penetration reduced, but the cooling and

buffering effects of plants are also lost, which could otherwise moderate the temperature extremes that contribute to physical weathering.

- However, it is important to note that while concrete reduces the natural processes of weathering on the land it covers, it can lead to other environmental issues such as increased surface runoff. Rainwater that would have otherwise infiltrated the soil now flows over the concrete surface, potentially carrying pollutants and debris into water bodies, which can lead to erosion and other forms of degradation elsewhere.

d) Emissions from industries and automobiles

- Industries and automobiles are major sources of air pollution, particularly the emission of gases such as carbon dioxide (CO_2), sulfur dioxide (SO_2) and nitrogen oxides (NO_x). These pollutants, when released into the atmosphere, can react with water vapor, oxygen, and other chemicals to form acidic compounds. These acids, in turn, can lead to the formation of acid rain, which significantly accelerates chemical weathering of rocks and minerals.
- For example, when sulfur dioxide, released from the burning of fossil fuels in power plants and industrial processes, combines with water vapor in the atmosphere, it forms sulfuric acid (H_2SO_4). Similarly, nitrogen oxides from vehicle exhausts can react with water to form nitric acid (HNO_3). These acids, carried by rain, snow, or fog, fall to the earth's surface, lowering the pH of rainwater and making it much more acidic than normal rain. When acid rain falls on rocks, it accelerates chemical weathering by dissolving minerals and causing them to break down more quickly.
- Another example is the weathering of granite, which contains feldspar, quartz, and mica. Acid rain can break down feldspar into clay minerals through a process called hydrolysis, which involves the reaction of minerals with acidic water. This reaction can cause the feldspar to weaken and the overall structure of the rock to break down over time.
- So, air pollution from industries and automobiles contributes to the formation of acid rain, which in turn accelerates chemical weathering. This process not only leads to the breakdown of natural rock formations but also poses a significant threat to man-made structures, cultural heritage, and the environment as a whole.

11.5 Conclusion

- The exploration of weathering processes in tropical environments highlights the intricate interplay between physical and chemical weathering, influenced significantly by climatic conditions, geological characteristics, and human activities. In humid tropical regions, chemical weathering dominates due to high temperatures and abundant rainfall, leading to profound alterations in rock structure and the formation of unique landforms such as karst landforms. Conversely, arid and high-altitude regions exhibit a prevalence of physical weathering, including thermal weathering and freeze-thaw cycles.
- The discussion emphasises the localised nature of weathering, shaped by factors such as rock composition, structure, texture, vegetation, and topography. Human interventions, including mining and urbanisation, are shown to accelerate weathering by exposing rocks to new environmental conditions, while also altering natural processes through the creation of impermeable surfaces and emissions contributing to acid rain.
- Overall, understanding these weathering processes and their interdependencies is crucial for understanding the formation of different landforms in the tropics like fluvial landforms and karst landform.