Higher 2 (9173)	Tropical Environments	TMJC
Lecture 6	***Weathering Processes***	2025

(A) WHAT ARE ROCKS?

1. A rock is made up of various types of minerals or multiple individual grains of the same type of mineral. Minerals may be elements or compounds.

2. The combination of elements and the crystal structure give each mineral its character such as hardness, colour, density and other properties. For example, the mineral quartz (SiO_2) (Fig. 1) consists of Earth's two most abundant elements, silicon (Si) and oxygen (O).

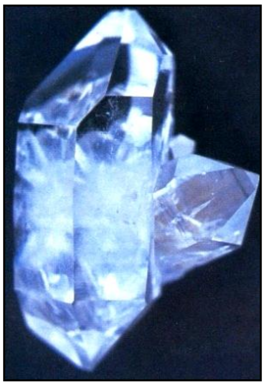

Fig. 1: Quartz crystal (SiO_2)

3. The appearance and physical properties of the rock then depend on:

   a. the kinds of minerals they contain,

   b. the amounts of different minerals they contain, and

   c. how the grains of these minerals are held together. For example, the rock granite is mainly made up of the minerals mica, feldspar and quartz (Fig. 2) held together in a crystalline structure.

Fig. 2: Granite

4. Minerals combine in various ways to produce different types of rocks. Thousands of different rock types have been identified.

(B) WHAT IS WEATHERING?

1. **Weathering** refers to the process of disintegration (physical break down) or decomposition (chemical decay) of rocks in situ[1] at or near the Earth's surface. It is the result of rocks interacting with their environment.

2. Weathering creates loosened rock fragments which are then ready for movement under the influence of gravity (mass movement), or for removal by the agents of erosion such as running water, moving ice and wind.

3. There are two main types of weathering:

    a. physical weathering &

    b. chemical weathering.

   It should be noted that in any given area and time, both physical and chemical weathering are occurring and complement each other (Fig. 13) (except under very specific conditions e.g. very cold or very dry conditions), although there may be a dominant form of weathering. For example, granite may undergo both pressure release (a form of physical weathering) as well as hydrolysis (a form of chemical weathering).

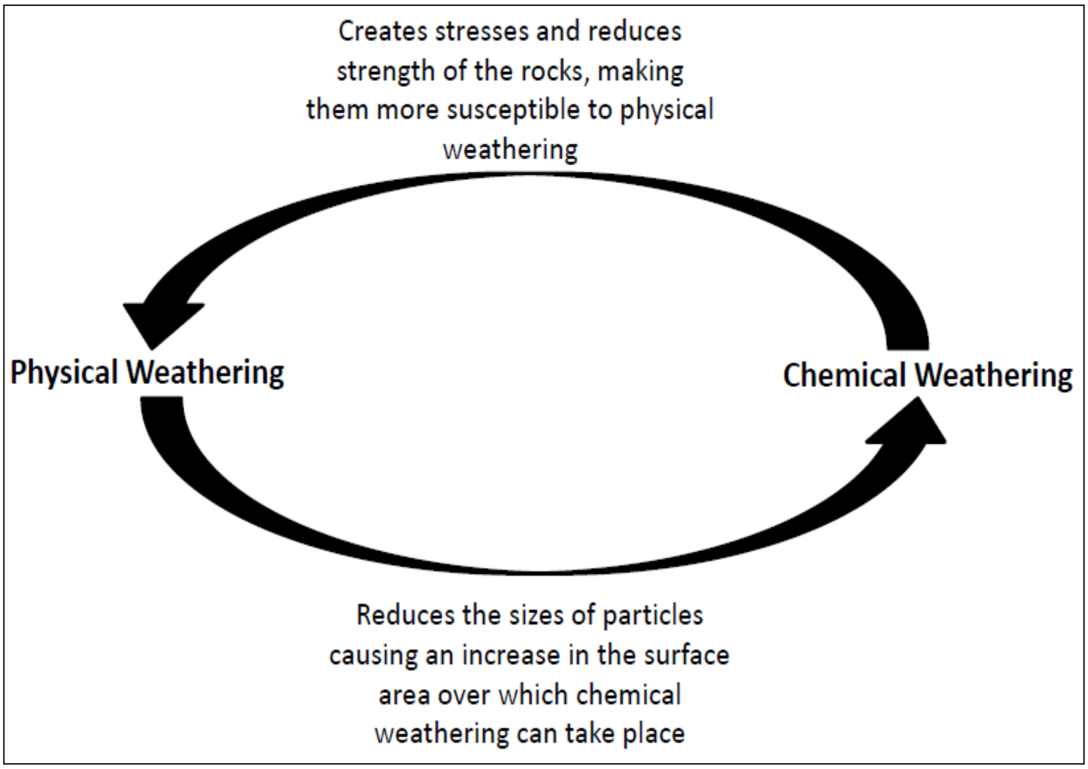

Fig. 13: Relationship between Physical and Chemical Weathering

[1] In situ means in its original position with little or no movement of material.

(C) WHAT ARE THE VARIOUS TYPES OF PHYSICAL WEATHERING PROCESSES?

1. Physical weathering (also known as mechanical weathering) is the mechanical disintegration of rocks into smaller fragments *without involving any change in the chemical composition of the rocks.* Only the size and shape of the rock changes.

2. The broken rock fragments are usually angular debris or blocks.

3. Physical weathering is most dominant in areas with **great diurnal range of temperature**, notably the desert regions and high mountains.

4. Physical weathering encourages chemical weathering by increasing the rock's surface area and exposing more of the rock to possible chemical weathering.

5. There are four main types of physical weathering processes. They are frost shattering, thermal fracture, pressure release and salt crystallization.

(i) Freeze-Thaw Weathering (also known as Frost Shattering)

1. Freeze-Thaw Weathering is the mechanical breakdown of rock due to stress brought about by repeated freezing and thawing of water.

2. Freeze-Thaw Weathering is predominant in areas with plentiful of moisture and there are daily temperatures fluctuating above and below 0^oC, notably in high mountains in temperate latitudes.

3. During the daytime, ice thaws when the temperature rises above freezing point. The water seeps into the cracks or joints of the rocks.

4. At night, the temperature drops to below freezing point. When water freezes it expands by about 9% and exerts great pressure on the rock walls.

5. The repeated growth and melting of ice crystal in the joints or fractures of rocks, or repeated and alternate freeze-and-thaw, cause the rocks to loosen and break down into smaller, angular fragments (Fig. 14).

6. Thus, the most potent circumstances for frost shattering are those where there is temperature fluctuation above and below the freezing point, as compared to exceptionally cold areas where water is permanently frozen.

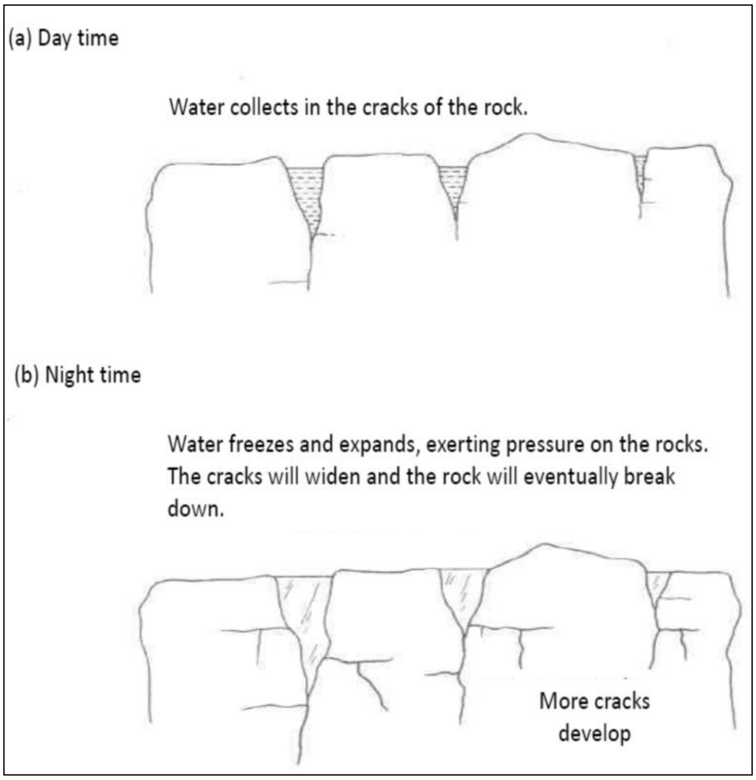

Fig. 14: Frost Shattering

(ii) Thermal Fracture (also known as Insolation Weathering)

1. Thermal fracture is the mechanical breakdown of rocks due to differential rates of expansion and contraction within the rock.

2. It occurs in areas with a great diurnal range of temperature such as in deserts, where the lack of cloud and vegetation cover results in a great diurnal range of temperature that can exceed 50^{o}c. Research by Blackwelder and Griggs has also shown that the rate of weathering increases with the addition of a layer of moisture on the rock's surface.

3. Due to the poor thermal conductivity of rocks, the outer layers of the rocks warm up faster and cool more rapidly than the inner ones. This causes stress within the rock and result in the outer layers to peel off like the layers of an onion. This process is called **exfoliation** (Fig. 15).

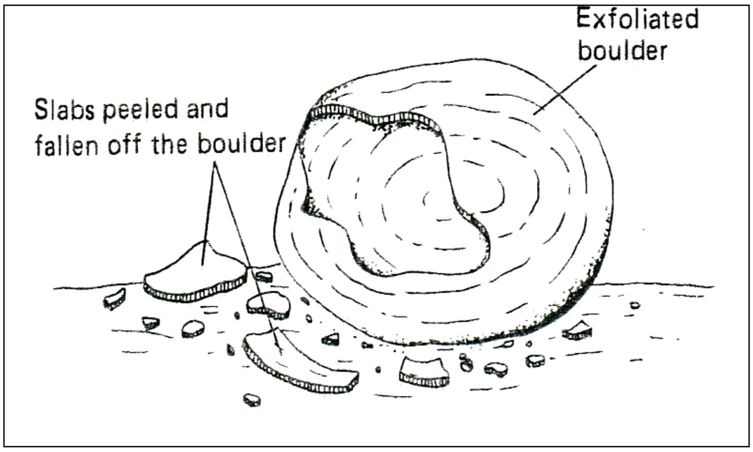

Fig. 15: Exfoliation

4. A particular rock may also be made up of different types of minerals. Since different minerals have different rates of expansion and contraction, this creates stress in the rock and may result in **granular disintegration** where individual grains break away from the rock (Fig. 16).

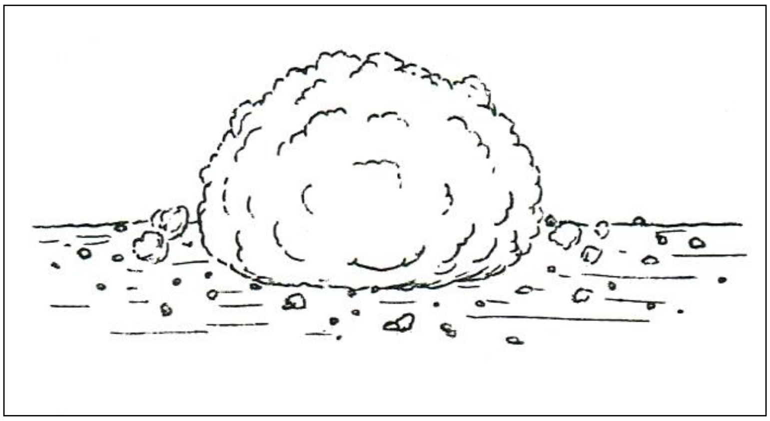

Fig. 16: Granular Disintegration

(iii) Pressure Release (also known as Dilatation)

1. Pressure Release/Dilatation is the mechanical breakdown of rocks due to the removal of overlying pressure on rocks, causing tensional stress to develop cracks within the rock.

2. Rocks formed deep within the Earth's crust such as intrusive igneous rocks are under great confining pressure from the weight of thousands of meters of overlying rocks. Pressure release is most common with granitic rock.

3. As this overlying cover is removed by erosion, the underlying rocks are exposed. The confining pressure is released and buried rock body tends to expand outwards where the pressure has decreased (Fig. 17).

4. The expansion of the rock causes internal tensional stresses in the rock and results in cracks or joints parallel (curvilinear joints) to the surface of the Earth, forming layers. This is known as **sheeting**. These cracks and joints can later be attacked to cause rocks to peel off on the surface of the exposed rocks through **exfoliation**.

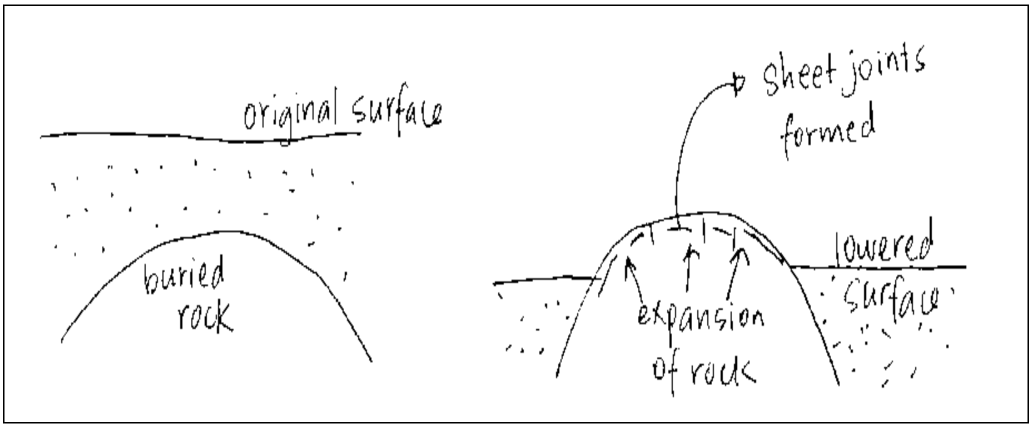

Fig. 17: Pressure Release

(iv) Salt Weathering / Salt Crystallization

1. Salt weathering / salt crystallization occurs when soluble minerals solidify in the pores/cracks of rocks and exert mechanical stress.

2. In arid climates, dry weather draws moisture draws water up to the ground surface and enters the rocks through capillary action. This water usually contains dissolved salts.

3. When the water evaporates, crystallization occurs as salt crystals are precipitated.

4. Over time, as the salt crystals grow and enlarge, they exert a force great enough to begin weakening the internal structure of the rock.

5. The cracks and joints in the rock become widened and the rock would start breaking up through **granular disintegration**.
6. Physical weathering by crystal growth is notable in desert regions where the rate of evaporation is high. Salt crystallization also occurs on coasts where there is a constant supply of water and salt.

Due to the climatic conditions (e.g. low rainfall, seasonality in temperature, higher diurnal, temperature range) in the arid tropics, physical weathering is more dominant in arid tropics than humid tropics.

(D) WHAT ARE THE VARIOUS TYPES OF CHEMICAL WEATHERING PROCESSES?

1. Chemical weathering is the decomposition of solid rocks as a result of chemical reactions between the rock minerals and agents in the environment such as air, water and organic acids.

2. The original chemical composition and structure of the rocks are changed, and new substances result.

3. Chemical weathering is often accelerated by:

   a) Abundant rainfall or high humidity, as water and moisture is available to react with the minerals and also act as a solvent.

   b) High temperature as it accelerates the rate of chemical reactions.

   c) Physical weathering, as physical weathering helps to break rocks up and increase the surface exposed to possible chemical weathering.

4. There are four main types of chemical weathering processes: oxidation and reduction, hydrolysis, solution and carbonation.

(i) Oxidation and Reduction

1. **Oxidation** is the process of the combination of oxygen ions in air, water or moisture with metallic ions, such as iron, calcium and magnesium in rock minerals to form oxides.

2. For example, iron reacts with oxygen to form iron oxide. It often has a red, orange or yellow colour. Oxidized aluminium frequently appears yellow.

3. The new products are usually softer and more easily eroded than the original compounds. In addition, the disruption of the crystal structures in the structures in the rock's minerals makes the rock more susceptible to further chemical weathering and disintegration.

ferric iron oxide ($4FeO$)	+	water (H_2O)	+	oxygen (O_2)	$\longrightarrow$	ferrous iron oxide [crumbles] ($2Fe_2O_3$)	+	water (H_2O)

4. **Reduction** is the process of removal of oxygen and is the reverse of oxidation and is equally important in changing soil colour to grey, blue or green as ferric iron is converted to ferrous iron compounds. Under the conditions of excess water or water logged condition (less or no oxygen), reduction takes place.

2Fe2O3 (Hematite) - O2 -> 4FeO(Ferrous oxide) - reduced form

(ii) Hydrolysis

1. Hydrolysis occurs when water molecules chemically react with the minerals to form new insoluble compounds. This is different from hydration ewhere there is no change in the chemical formula of the mineral.

2. The new compound is commonly softer and weaker than the original.

3. Igneous rocks are particularly susceptible to hydrolysis because their silicate minerals (such as feldspar and mica) combine readily with water. An example of hydrolysis is the breakdown of feldspar (a mineral in granite) into kaolinite, a form of clay.

(iii) Solution

1. Solution occurs when water molecules chemically react with the minerals to form new compounds which are soluble. Some minerals such as rock salt (sodium chloride) are soluble in water and simply dissolve *in situ*, causing the rocks to crumble.

(iv) Carbonation

1. Rain water or moisture contains dissolved carbon dioxide from the atmosphere, which is known as acidulated water.

2. Carbon dioxide in solution forms a weak carbonic acid which is capable of reaction with certain minerals such as calcium carbonate to form calcium bicarbonate which is very soluble in water.

carbon dioxide (CO_2)	+	water (H_2O)	$\longrightarrow$	carbonic acid (H_2CO_3)
carbonic acid (H_2CO_3)	+	calcium carbonate ($CaCO_3$)	$\longrightarrow$	calcium bicarbonate [soluble] ($Ca(HCO_3)_2$)

3. Besides being effective in warm tropical climates (due to Van Hoff's rule), carbonation is also effective in temperate regions with a cooler climate as carbon dioxide dissolves in water at a faster rate in such climates, creating a stronger carbonic acid for weathering to take place.

Due to the climatic conditions (e.g. high rainfall, high temperature) in the humid tropics, chemical weathering is more dominant in humid tropics than arid tropics.

(E) WHAT IS THE INFLUENCE OF CLIMATE ON WEATHERING PROCESSES?

1. Climate is one of the most important controlling factors of the type of weathering that will occur in any given location.

2. Mechanical weathering will not take place without significant changes in temperature. Insolation weathering and frost shattering both require temperature fluctuations. On the other hand, places with high temperature and heavy rainfall will give a thick protective vegetation cover against insolation.

3. Frost shattering will occur if temperatures fluctuate around 0°C, but will not operate if the climate is too cold (permanently frozen), too warm (no freezing), too dry (no water to freeze) or too wet (covered by vegetation).

4. Chemical weathering increases as temperature and rainfall increase. **Van Hoff's rule** states that the speed of chemical reactions increases by 2.5 times with each 10°C rise in temperature.

5. In addition, chemical weathering is strong in places with high rainfall and temperature due to increased presence of vegetation which promotes infiltration of water into the deeper layers of the soil structure. Where there is low rainfall, chemical weathering is weak as there is insufficient moisture for the chemical decomposition of rocks.

6. **Peltier's model** is an attempt by the American physicist and climatologist Louis Peltier to predict the type and rate of weathering at any given place in the world from its mean annual temperature and mean annual rainfall (Fig. 18).

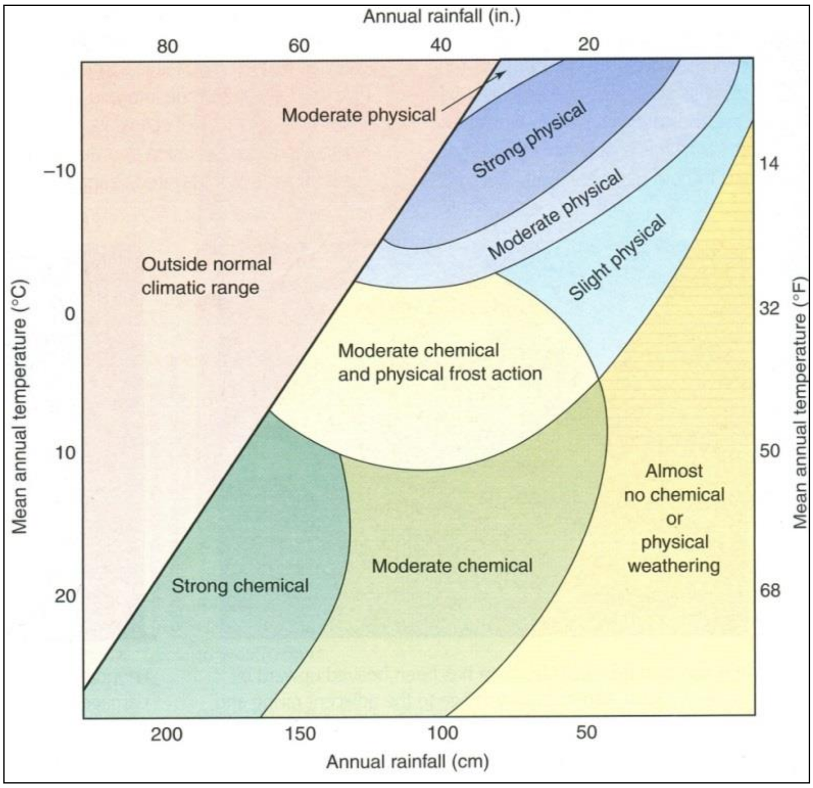

Fig. 18: Peltier's Model

which attempts to show the *relationship between climate and the type and rate of weathering*

7. However, although the model indicates the type of weathering that will occur at a particular place, it should be noted that mechanical and chemical weathering usually operate together at the same

time and at the same place, but it is likely that in each situation one type of weathering will be more significant.

8. The relationship between climate and weathering could also be examined by looking at the depth of weathered material (also known as regolith) that is present at each type of climatic zone, as illustrated by **Strakhov's model** (Figure 19).

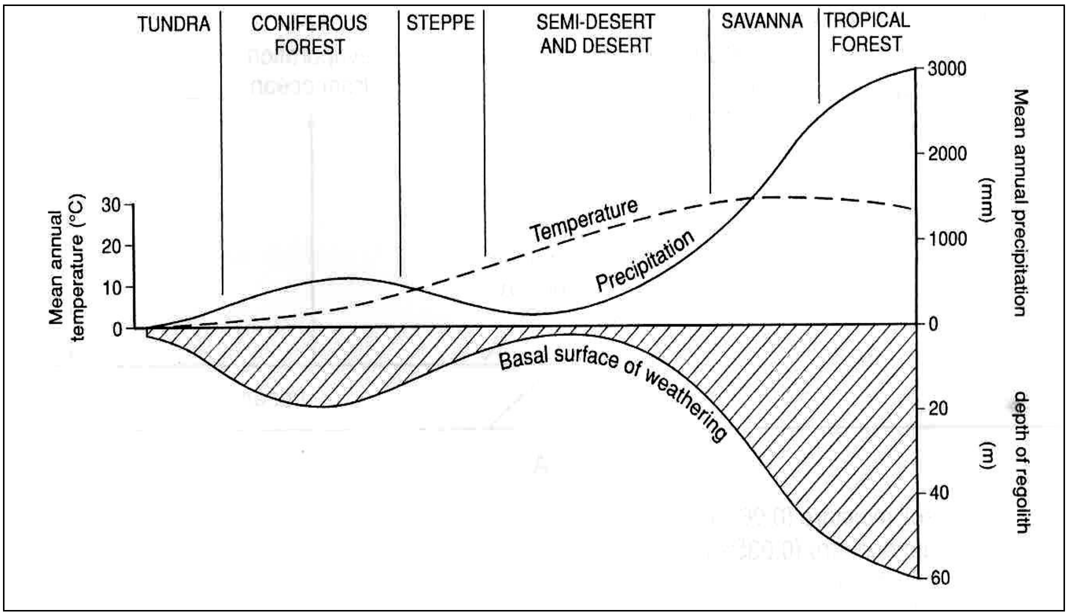

Fig. 19: Strakhov's Model (showing the relationship between climate and depth of weathering)

9. In the humid tropics such as places experiencing tropical forest (Af climate), the depth of regolith is high due to high temperatures and high precipitation throughout the year. High temperatures allow for faster rate of chemical weathering (Van Hoff's rule) and high precipitation allows for more infiltration and percolation to greater depths.

10. Deep regolith in the **tropical forest (Af)** is also due to the dense vegetation which allows for:
    a. Less erosion as roots hold the soil together.
    b. Less rain-drop impact and erosion due to leaf cover.
    c. More animals and plants which produce organic acids when they decompose and this helps to chemically weather the rocks.
    d. Plant and tree roots as well as burrowing animals also help break up the rocks.

11. In **arid tropics** such as places experiencing sub-tropical steppe (BSh), or hot-low latitude desert climate (BWh), (semi-desert / desert), the shallow regolith is due to the low precipitation amounts. Little water infiltrates into the ground to allow for deep weathering. Physical weathering processes dominant in desert areas such as salt crystal growth and thermal weathering affects the surface layers only.

(F) WHAT IS THE INFLUENCE OF OTHER FACTORS ON WEATHERING PROCESSES?

1. Besides climate, other factors that influence weathering processes include the rock characteristics, topography of the landscape, amount of soil and vegetation cover, as well as human activities.

2. **Geology** refers to the rock composition and structure of the rock.

    (a) The *mineral composition* of the rock is important as different minerals react differently to weathering processes. Therefore, rocks made up of more resistant minerals like granite (which is made up of feldspar, mica and quartz) is also resistant to weathering. Minerals made of different colours would also have different rates of absorbing insolation. For example, basalt consists of dark-coloured minerals such as pyroxene and olivine which would result in more insolation being absorbed, causing greater expansion and contraction.

    (b) The rate at which a rock weathers is also influenced by its *texture* and *structure*. Even a rock that consists entirely of the resistant quartz mineral may break down rapidly if it contains numerous joints and cracks that make it susceptible to frost shattering.

Rock Composition

Mineral/Chemical Composition

We can study this on 2 levels, the **ability of rock minerals** to resist chemical change and breakdown, as well as the overall rock composition and the **ability of the rock to resist rock weathering**. Both can contribute to the extent to which a rock is resistant to weathering.

Mineral weathering:

- **light** coloured minerals like **quartz** (usually white in colour) are more stable, thus more resistant to weathering.
- **dark** coloured minerals like **olivine** (dark green, close to black colour)are less stable, thus less resistant to weathering.

Rock weathering:

- **dark** coloured rocks such as **basalt** and **gabbro** heats up more rapidly, thus there is overall greater stress and strain within the rock as compared to
- **light** coloured rocks such as **chalk** and **limestone** which will reflect light rather than absorb it. With less heat absorbed, the extent of stress and strain on the rock structure is lower, thus generally more resistant to weathering
- however, if you actually recap the process of **insolation weathering,** a rock composed of different **coloured minerals** is also subjected to strain because they absorb heat differently → **differential expansion and contraction**, and this can result in weathering and eventual granular disintegration and breakdown of the rock.

Nature of Cement: Rock strength and hardness

The ability of a rock to resist weathering is also highly dependent on the **cementation of rock minerals** (how closely bonded the rocks are) and **constituent minerals** in the rock.

- e.g. igneous rocks are harder and generally stronger compared to sedimentary rock because the minerals in it (feldspar and quartz) are tightly bonded together.
- e.g. sedimentary rocks are softer (compared to igneous and metamorphic rock) because the minerals within a sedimentary rock tends to be bonded/held together by a **soft cement** such as iron oxide or calcium carbonate.
    - In addition, if we draw links to the weathering processes in Section B, we can recall that some of these cements are actually more susceptible to chemical weathering than others. For instance, calcium carbonate is susceptible to carbonation. As such,

carboniferous limestone, a type of limestone with more than 80% calcium carbonate is actually very susceptible to the chemical weathering process of carbonation.

Lastly, the **age** of the rock actually have a role to play in determining the strength of the rock.

- older rocks, having often been buried beneath younger rocks are generally more resistant to weathering as the resultant compression by overlying younger rocks and sediments help to bind and compact the mineral crystals together

However, do note that while some rocks are believed to be more resistant, we cannot ignore the presence of lines of weaknesses i.e. the rock structure, as these would allow them to be more vulnerable to weathering processes, which takes us to our next point: Rock Structure.

a) Rock Structure

When we discuss about rock structure, we are generally concerned about its **porosity** – the amount of air spaces between minerals, as well as its **permeability** – rock jointing, bedding planes, lines of weaknesses etc, as these actually create more surface area for weathering processes to take place on. In addition, rock porosity and rock permeability can actually determine how much water can enter the body of the rock for weathering processes to take place. We also do not want to overlook the overall structure of a rock – massive structures are generally more resistant to weathering as compared to a rock fragment or boulder due to the amount of surface area exposed to the elements.

Rock Porosity & Texture

Porosity can be defined as the amount of air spaces/areas between particles of a rock. We call them **pore spaces**, and the size and alignment of them determines how much water can be stored or pass through a rock. Porosity also depends on the **texture** of the rock – whether they are fine-grained or coarse-grained. Generally, porosity is greatest in rocks that are coarse-grained, and lowest in fine-grained rocks. With lower porosity, rock strength generally increases as the particles within the rock are more tightly bonded and interlocked. Also, as the boundaries between the mineral crystals/particles are potential lines of weaknesses (more surface area within the rock), the lower the porosity, the greater the strength of the rock.

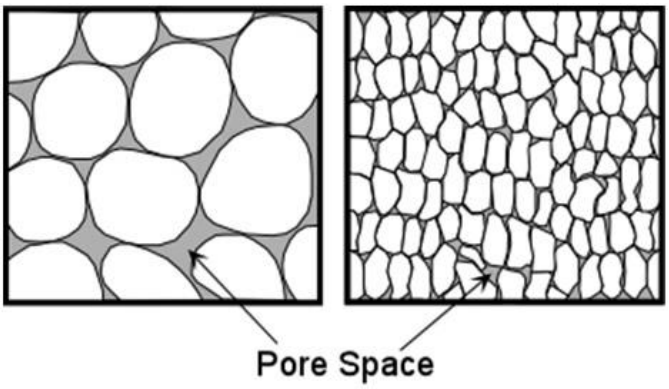

Figure 4: Porosity
(Source: http://rmccs.org/images/poreSpace.jpg)

Porosity is sometimes expressed as the percentage of the total rock which is taken up by pore spaces. Saturation of the rock occurs when all the pore spaces are filled with water.

Rock Permeability and Rock Jointing

Joints, fissures, bedding planes etc. are all **structural weaknesses** in rocks and these allow water to flow into and through them. These joints also increase the surface area for weathering processes to take place on. As such, generally, the more permeable a rock is, the more susceptible it is to weathering. Joint patterns can be discontinuous minor features or well-defined major joint patterns. In sedimentary rock, horizontal lines of weaknesses are called bedding planes. In igneous rocks, horizontal lines of weaknesses are sometimes termed as pseudo-bedding planes.

Drawing links to chemical and physical weathering processes, as well as landform development (this will serve as a prelude to Lecture 7), rock jointing can aid weathering in a number of ways:
- Rock jointing allowing passage of water and oxygen, which can facilitate higher rates of **chemical weathering**
- Rock joints can promote frost and ice wedging in periglacial and glacial climates (and also on high altitudes) i.e. **physical weathering** processes.

When pressure release fracturing occur, sheet joints can also develop, which can give rise to exfoliation and very distinct curvilinear joint patterns.

3. The **topography** of a landscape refers to its form such as slope angle, aspect and altitude. The *slope angle* would affect the rate at which the weathered material is removed. On steep slopes, especially if unvegetated, weathered material is usually removed through mass movement or soil erosion, exposing the underlying rocks to weathering. However, there is also less water available for chemical weathering on a steep slope than on a gentler slope.

4. The ***altitude*** of a location will have an impact on the effectiveness of processes that will occur in that location. At higher altitudes in the tropics, temperatures are lower (remember lapse rates?), resulting in reduced rates of chemical weathering. In high altitude mountainous areas, temperatures may well fall sufficiently to allow effective frost shattering to occur. However, at too high an altitude there will be less temperature fluctuations around the freezing point.

5. The **amount of soil and vegetation cover** affects the type of weathering that is able to take place. This is largely affected by the climate experienced.

   The presence of soil and dense vegetation cover (generally in humid tropics – Af, Am climate) prevents physical weathering processes such as thermal fracture from taking place as it protects the rocks from sunlight. However, on the other hand, soil and vegetation will cause an increase in the amount of carbonation. Dense vegetation cover retains more rainwater and for a longer period of time, keeping the rocks moist and facilitating chemical weathering.

   Conversely, in areas with sparse / lack of vegetation cover (generally arid tropics – BSh, BWh climate with low rainfall), the lack of vegetation to hold the soil together allows rocks to be exposed and hence more susceptible to physical weathering processes

6. **Human activities** such as mining, quarrying and the clearing of forests for farming expose bare rock for weathering. The use of explosives in mining may also result in more cracks within the rocks, increasing the reaction surfaces for chemical weathering and frost shattering to occur. Air pollution causes by human activities may also result in rainwater becoming more acidic resulting in higher rates of chemical weathering.