What is weathering?

It is the breaking down of rocks, soil and minerals as well as wood and artificial materials through contact with the Earth's atmosphere, biota and waters. Weathering occurs in situ, roughly translated to: "with no movement", and thus should not be confused with erosion, which involves the movement of rocks and minerals by agents such as water, ice, snow, wind, waves and gravity and then being transported and deposited in other locations."

Weathering processes are of three main types: mechanical/or Physical, Chemical and Biological weathering.

Mechanical/or Physical Weathering

Physical weathering is caused by the effects of changing temperature on rocks, causing the rock to break apart. The process is sometimes assisted by water.

There are two main types of physical weathering:

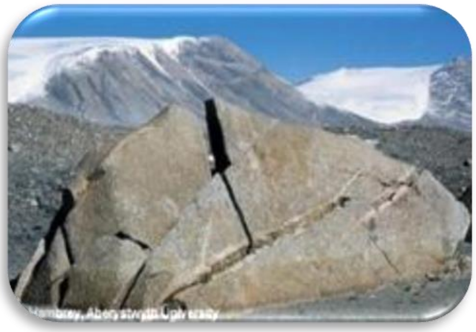
- Freeze-thaw occurs when water continually seeps into cracks, freezes and expands, eventually breaking the rock apart.
- Exfoliation occurs as cracks develop parallel to the land surface a consequence of the reduction in pressure during uplift and erosion.

Where does it occur?

Physical weathering happens especially in places where there is little soil and few plants grow, such as in mountain regions and hot deserts.

How does it occur?

Either through repeated melting and freezing of water (mountains and tundra) or through expansion and contraction of the surface layer of rocks that are baked by the sun (hot deserts).



Find out more about freeze-thaw.

Find out more about exfoliation

CHEMICAL WEATHERING

It is the weakening and subsequent disintegration of **rock** by **chemical** reactions. These reactions include oxidation, hydrolysis, and carbonation. These processes either form or destroy minerals, thus altering the nature of the **rock's** mineral composition.

Chemical Processes of Weathering

1. Hydration: Chemical combination of water molecules with a particular substance or mineral leading to a change in structure. Soil forming minerals in rocks do not contain any water and they undergo hydration when exposed to humid conditions. Upon hydration there is swelling and increase in volume of minerals. The minerals lose their luster and become soft. It is one of the most common processes in nature and works with secondary minerals, such as aluminum oxide and iron oxide minerals and gypsum (e.g).

a) 2Fe2O3 + 3HOH -> 2Fe2O3 .3H2O

(Hematite) (Red) (Limonite) (Yellow)

b) Al2O3 + 3HOH -> Al2O3 .3H2O

(Bauxite) (Hyd. aluminium Oxide)

c) CaSO4 + 2H2O -> CaSO4 .2H2O

(Anhydrite) (Gypsum)

d) 3(MgO.FeO.SiO2) + 2H2O -> 3MgO.2SiO2.2H2O + SiO2 + 3H2O

(Olivine) (Serpentine)

2. Hydrolysis: Most important process in chemical weathering. It is due to the dissociation of H_2O into H+ and OH- ions which chemically combine with minerals and bring about changes, such as exchange, decomposition of crystalline structure and formation of new compounds. Water acts as a weak acid on silicate minerals.

KAlSi3O8 + H2O -> HAlSi3O8 + KOH

(Orthoclase) (Acid silt clay)

HAlSi3O8 + 8 HOH -> Al2O3 .3H2O + 6 H2SiO3

(Recombination) (Hyd. Alum. oxide) (Silicic acid)

This reaction is important because of two reasons.

1. Clay, bases and silicic acid - the substances formed in these reactions - are available to plants
2. Water often containing CO_2 (absorbed from atmosphere), reacts with the minerals directly to produce insoluble clay minerals, positively charged metal ions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and negatively

charged ions (OH^-, HCO_3^-) and some soluble silica – all these ions are made available for plant growth.

3. Solution: Some substances present in the rocks are directly soluble in water. The soluble substances are removed by the continuous action of water and the rock no longer remains solid and form holes, rills or rough surface and ultimately falls into pieces or decomposes. The action is considerably increased when the water is acidified by the dissolution of organic and inorganic acids (e.g) NaCl etc.,

NaCl + H2O -> Na+, Cl- , H2O (dissolved ions with water)

4. Carbonation: Carbon dioxide when dissolved in water it forms carbonic acid.

2H2O + CO2 -> H2CO3

This carbonic acid attacks many rocks and minerals and brings them into solution. The carbonated water has an etching effect up on some rocks, especially lime stone. The removal of cement that holds sand particles together leads to their disintegration.

CaCO3 + H2CO3 -> Ca(HCO3)2

(Calcite) slightly soluble (Ca bi carbonate) readily soluble

5. Oxidation: The process of addition and combination of oxygen to minerals. The absorption is usually from O2 dissolved in soil water and that present in atmosphere. The oxidation is more active in the presence of moisture and results in hydrated oxides.(e.g) minerals containing Fe and Mg.

- 4FeO (Ferrous oxide) + O2 -> 2Fe2O3 (Ferric oxide)
- 4Fe3O4 (Magnetite) + O2 -> 6Fe2O3 (Hematite)
- 2Fe2O3 (Hematite) + 3H2O -> 2Fe2O3 .3H2O(Limonite)

6. Reduction: The process of removal of oxygen and is the reverse of oxidation and is equally important in changing soil color 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

In conclusion, during chemical weathering igneous and metamorphic rocks can be regarded as involving destruction of primary minerals and the production of secondary minerals. In sedimentary rocks, which is made up of primary and secondary minerals, weathering acts initially to destroy any relatively weak bonding agents (FeO) and the particles are freed and can be individually subjected to weathering.

Biological Weathering

Organic or biological weathering refers to the same thing. It is the disintegration of rocks as a result of the action by living organisms. Trees and other plants can wear away rocks since as they penetrate into the soil and as their roots get bigger, they exert pressure on rocks and makes the cracks wider and deeper. Eventually, the plants break the rocks apart. Some plants also grow within the fissures in the rocks which lead to widening of the fissures and then eventual disintegration.

Microscopic organisms like algae, moss, lichens and bacteria can grow on the surface of the rocks and produce chemicals that have the potential of breaking down the outer layer of the rock. They eat away the surface of the rocks. These microscopic organisms also bring about moist chemical micro-environments which encourage the chemical and physical breakdown of the rock surfaces. The amount of biological activity depends upon how much life is in that area. Burrowing animals such as moles, squirrels and rabbits can speed up the development of fissures.

SOIL FORMATION AND GEOGRAPHY

How do soils form in different places?

1. Soil Formation Factors

Soils around the world have different properties that affect their ability to supply nutrients and water to support food production, and these differences result from different factors that vary from place to place. For example the age of a soil: the time over which rainfall, plants, and microbes have been able to alter rocks in the earth's crust via weathering-- varies greatly, from just a few years where soil has been recently deposited by glaciers or rivers, to millions of years. A soil's age plus the type of rock it is made from gives it different properties as a key resource for food systems. Knowing some basics of soil formation helps us to understand the soil resources that farmers use when they engage in food production. Below are some of the most important factors that contribute to creating a soil:

1.1 Climate: It has a big influence on soils over the long term because water from rain and warm temperatures will promote weathering, which is the dissolution of rock particles and liberating of nutrients that proceed in soils with the help of plant roots and microbes. Weathering requires rainfall and is initially a positive process that replenishes these solubilized nutrients in soils year after year and helps plants to access nutrients. However over the long run (thousands to millions of years) and in rainy climates, rain water passing through a soil (leaching) leaves acid-producing elements in the soil like aluminum and hydrogen ions, and carries away more of the nutrients that foster a neutral pH (e.g. Ca, Mg, K). Old soils in rainy areas, therefore, tend to be more acidic, while dry-region soils tend to be neutral or alkaline in pH. Acid soils can make it difficult for many crops to grow. Meanwhile, dry climate soils retain nutrients gained in weathering of rock - a good thing - but may lack plant cover because of dry conditions. A lack of plant cover leaves the soil unprotected from damage by soil erosion and means that dry climate soils often lack dead plant material (residues) to enrich the soil with organic matter. Both dry and wet climate soils have advantages as well as challenges that must be addressed by human knowledge in managing them well so that they are protected as valuable resources.

1.2. Parent Material: Soils form through gradual modification of an original raw material like rock, ash, or river sediments. The nature of this raw material is very important. Granite rock (magma that hardened under the earth) versus shale (old, compressed seabed sediments) produce very different soils. An important example of parent material influencing soils with consequences for human food production are soils made from limestone or calcium and magnesium carbonates. These rocks strongly resist the process of acidification by rainfall and leaching described above. Limestone soils maintain their neutral level of acidity (or pH) even after thousands of years of weathering, and thus can better maintain their productivity. In summary, as part of learning about a food production systems of a region, it can be helpful to consider the types of rock that occur in that region, which you may want to consider for your capstone regions.

1.3. Soil age: the time that a soil has been exposed to weathering processes from climate, and the time over which vegetation has been able to contribute dead organic material, are important influences on a soil. Very young soils are often shallow and have little organic matter. In a rainy climate, young (e.g. 1000 years) to medium aged (e.g. 100,000 years) soils may be inherently very fertile because rainfall and weathering have not yet removed their nutrients. Old soils are usually deep and may be fertile or infertile depending on the parent material and long-term climatic conditions. Soils in previously glaciated regions (e.g. Europe) are usually thought of as young because glaciers recently (~10,000 years ago) left fresh sediments made from ground up rock materials.

1.4. Soil slopes, relief, and soil depth: Steep slopes in mountain and hilly areas cause's soils to be eroded quickly by rainfall unless soils are covered by throughout the year by crops or forest. These hilly and mountain regions may also have young soils, and the combination of young soils and erosion can make for soils that are quite thin. Meanwhile, flat valley areas are where the eroded soil is likely to accumulate, so soils will be deep. Along with the water holding capacity and the nutrient content of a soil, soil depth determines how much soil "space" or soil volume crop's roots can explore for nutrients and water. Soil depth is an important and often overlooked determinant of crop productivity of soils. Moreover, these large-scale "mountain versus valley" differences can be mirrored within a single field, with small differences in topography creating differences in drainage, depth, and other soil properties that dramatically affect soil productivity within ten to twenty meters distance.

Soil Properties and human responses to boost food production

1. Nutrients, pH, soil water, erosion, and salinization

In growing crops for food, farmers around the world deal with local soil properties that we started to describe on the previous page. These properties can either be a positive resource for crop production or limitations that are confronted using management methods carried out by farmers. Because nutrients are only important to emphasize here that most nutrients taken up by plants (other than CO_2 gas) come to plant roots from the soil, and that the supply of these nutrients often has to do with the amount of dead plant remains, manure, or other organic matter that is returned to the soil by farmers, as well as fertilizers that are put into soils to directly boost crop growth. Here are the other major soil properties that farmers pay attention to in order to sustain the production of food and forage crops:

2. Soil pH or acidity: near neutral is best

Most crops prefer soils that have a pH between 5 and 8, mildly acidic to mildly alkaline. As discussed above under the *climate* and *parent material* sections describing soil formation, soils in rainy regions tend to become more acidic over time. Soils with too low a pH will have trouble growing abundant food or feed for animals. Farmers manage soils with low pH by adding ground up limestone (lime) and other basic (that is, acid-neutralizing) materials like wood ash to their soils. As an alternative, farmers sometimes adapt to soil pH by choosing or even creating crops or crop varieties that have adapted to low pH, acidic soils. For example, potatoes do well in high elevation, acidic soils of the Andes and other areas around the world. Alfalfa for livestock does better in neutral and alkaline soils while clovers for animal food grow better in more acidic soils.

3. Soil water holding capacity and drainage: deep, loamy, and loose is best

The importance of water for food production and the way that humans go to great lengths to provide irrigation water to crops in some regions. Soil properties also play a role in the amount of water that can be stored in soils (for days to weeks) that is then available to crops. A soil that holds more water for crops is more valuable to a farmer compared to a soil that runs out of water quickly. Among the properties that create water storage in soils is soil depth or thickness, where a deep soil is basically a larger water tank for plant roots to access than a thin soil. The proportions of fine particles (clay) versus coarse particles (sand) in a soil, called soil texture, also influences the water available to plants: Neither pure clay nor pure sand hold much plant-available water because clay holds the water too tightly in very small pores (less than 1 micron or 0.001 mm, or smaller than most bacteria) while sand drains too rapidly because of its large pores and leaves very little water. Therefore an even mix of sand, clay, and medium-sized silt particles holds the maximum amount of plant available water. This soil type is known as loamy, which for many farmers is synonymous with "productive". In addition to these soil properties, farmers try to maintain good soil structure (also called "tilth"), which is the aggregation of soil particles into crumb-like structures, that help to further increase the ability of soils to retain water. Soil aggregation or structure, and its multiple benefits for food production are further described in Module 7 on soil quality.

Clayey soils, and soils that have been compacted by livestock or farm machinery ("tight" vs. "loose" soils), can also have problems allowing enough water to drain through them (poor drainage), which can lead to an oversupply of water and a shortage of air in soil pores. Too much water and too little air in a soil lead to low oxygen in the soil and an inability for roots and soil microbes to function in providing nutrients and water to plants. Part of good *tilth*, described above, is maintaining a loose structure of the soil.

In the face of these important soil properties for water storage, farmers seek out appropriate soils with sufficient moisture (e.g. deep and loamy, Figure 1 & 2) but also adequate drainage. Food producers also modify and maintain the moisture conditions of soils, through irrigation but also through maintaining good soil aggregation or tilth, and by avoiding compaction of soils that also leads to poor drainage and soils that are effectively shallower because roots cannot reach down through compacted soils to reach deeper water.

4. Salinization and dry climates: hold the salt

Dry climate soils have less rainfall to leach them of minerals. They can, therefore, be high in nutrients, but also carry risks of harmful salts building up as rainfall does not carry these away either. Salt-affected soils may either be too salty to farm at all or may carry a risk that if irrigation water is too high in salts or applied in insufficient amounts to continually "re-rinse" the soil of salts, then salts can build up in soils until crops will not grow. The way that arid soils are managed is a key part of the human knowledge of food production in dry regions.

5. Relief and Erosion: Don't let soil wash down the hill

Soil slope and relief are described on the previous page as creating higher risks of erosion (Figure 3). To address this limitation food producers have either (a) not farmed exposed sloped land with annual crops, leaving them in forest, tree crops, and year-round grass cover and other vegetation that holds soils on slopes; (b) built terraces and patterned their crops and field divisions along the contours of fields (Figure 4). Nevertheless, while sloped soils have been seen in mountain areas, the extreme elevation differences present in mountain areas can also be seen as a benefit to these food systems. The benefits arise because soils with very different elevation-determined climates and soil properties in close proximity, which allows for the production of a greater variety of crops. The simultaneous production in the same communities of cold- and acid soil tolerant bitter potatoes and heat-loving maize and sugarcane in lower, more neutral soils is an example of this benefit in high-relief mountain regions.

Soil Health: Understanding soils as an integrated whole for food production

We hope that you are beginning to appreciate that appropriate management of soils is emphatically about integrating management principles like the ones presented here as *human responses*, along with an understanding of the basic properties of soils, and also the nutrient flows. Soils are very much a complex system, and managing them for food production and environmental sustainability means that we must understand the multiple components and interactions of this system. Soil health is an aspiration of effective management and means that management has maintained or promoted properties like nutrient availability,

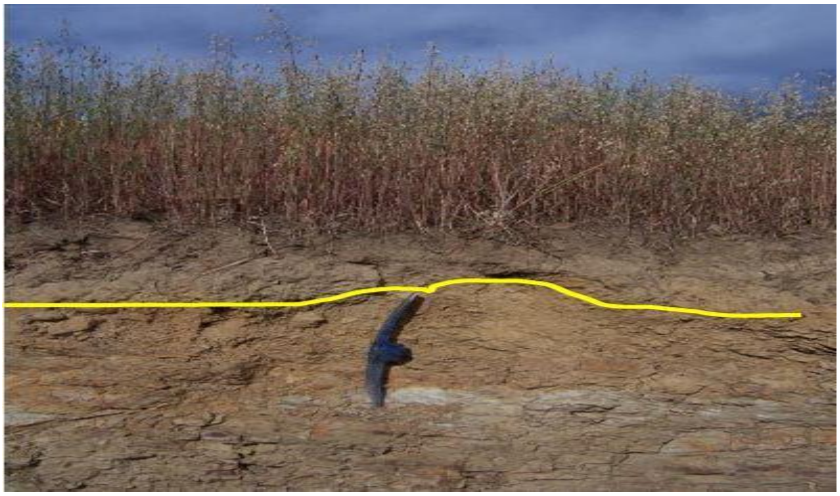


Figure 1: The shallow soil with an oat crop is in a mountainous region that has likely suffered erosion, and features of the bedrock can be seen within 50 cm of the surface (yellow line), where the soil becomes much poorer. The total volume available to store nutrients and water in this soil is low. A pick axe head is shown for scale.

Figure 2. This loamy, deep soil is likely in a flatter region and has an organic-matter rich layer that extends to about 40 cm below the surface and water storage capability to beyond one-meter depth (numbers on tape are cm), an excellent nutrient and water resource for food production**.**

Figure 3. Soil erosion in a mountain landscape

beneficial physical structure, and a diversity of functionally important and 'health-promoting' microbes and fauna in soils along with sufficient organic matter to feed the soil ecosystem. These integrated properties then allow production to avoid soil degradation, produce sufficient amount of food and livelihoods, and preserve biodiversity in soils as well as other significant ecosystem services like buffering of river flows and storage of carbon from the atmosphere.

Figure 4. Terracing in a mountain landscape.