EENS 1110	Physical Geology
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Weathering and Soils

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Earth is covered by a thin “veneer” of sediment. The veneer caps igneous and metamorphic “basement.” This sediment cover varies in thickness from 0 to 20 km. It is thinner (or missing) where igneous and metamorphic rocks outcrop, and is thicker in sedimentary basins.

In order to make this sediment and sedimentary rock, several steps are required:

- Weathering – Breaks pre-existing rock into small fragments or new minerals
- Transportation of the sediments to a sedimentary basin.
- Deposition of the sediment
- Burial and Lithification to make sedimentary rock.

Each Step in the process of forming sediment and sedimentary rocks leaves clues in the sediment. These clues can be interpreted to determine the history of the sediment and thus the history of the Earth.

Weathering

Geologists recognize two categories of weathering processes

1. ***Physical Weathering*** - disintegration of rocks and minerals by a physical or mechanical process.
2. ***Chemical Weathering*** - chemical alteration or decomposition of rocks and minerals.

Although we separate these processes, as we will see, both work together to break down rocks and minerals to smaller fragments or to minerals more stable near the Earth's surface.Both types are a response to the low pressure, low temperature, and water and oxygen rich nature of the earth’s surface.

Physical Weathering

The mechanical breakup or disintegration of rock doesn't change mineral makeup. It creates broken fragments or “detritus.” which are classified by size:

- Coarse-grained – Boulders, Cobbles, and Pebbles.
- Medium-grained – Sand
- Fine-grained – Silt and clay (mud).

Physical weathering takes place by a variety of processes. Among them are:

- Development of ***Joints*** - Joints are regularly spaced fractures or cracks in rocks that show no offset across the fracture (fractures that show an offset are called faults).
    - Joints form as a result of expansion due to cooling or relief of pressure as overlying rocks are removed by erosion.

- Igneous plutons crack in onion like "exfoliation" layers. These layers break off as sheets that slide off of a pluton. Over time, this process creates domed remnants. (See figure B.4 in your text) Examples: Half-Dome (CA.) (see figure 22.12a in your text) and Stone Mountain (GA.).
- Joints form free space in rock by which other agents of chemical or physical weathering can enter.

- Crystal Growth - As water percolates through fractures and pore spaces it may contain ions that precipitate to form crystals. As these crystals grow they may exert an outward force that can expand or weaken rocks.
- Thermal Expansion - Although daily heating and cooling of rocks do not seem to have an effect, sudden exposure to high temperature, such as in a forest or grass fire may cause expansion and eventual breakage of rock. Campfire example.
- Root Wedging - Plant roots can extend into fractures and grow, causing expansion of the fracture. Growth of plants can break rock - look at the sidewalks of New Orleans for example.
- Animal Activity - Animals burrowing or moving through cracks can break rock.
- ***Frost Wedging*** - Upon freezing, there is an increase in the volume of the water (that's why we use antifreeze in auto engines or why the pipes break in New Orleans during the rare freeze). As the water freezes it expands and exerts a force on its surroundings. Frost wedging is more prevalent at high altitudes where there may be many freeze-thaw cycles.

Chemical Weathering

Since many rocks and minerals are formed under conditions present deep within the Earth, when they arrive near the surface as a result of uplift and erosion, they encounter conditions very different from those under which they originally formed. Among the conditions present near the Earth's surface that are different from those deep within the Earth are:

- Lower Temperature (Near the surface T = 0-50^{o}C)
- Lower Pressure (Near the surface P = 1 to several hundred atmospheres)
- Higher free water (there is a lot of liquid water near the surface, compared with deep in the Earth)
- Higher free oxygen (although O_2 is the most abundant element in the crust, most of it is tied up bonded into silicate and oxide minerals - at the surface there is much more free oxygen, particularly in the atmosphere).

Because of these differing conditions, minerals in rocks react with their new environment to produce new minerals that are stable under conditions near the surface. Minerals that are stable under P, T, H_2O, and O_2 conditions near the surface are, in order of most stable to least stable:

- Iron oxides, Aluminum oxides - such as hematite Fe_2O_3, & gibbsite $Al(OH)_3$.
- Quartz*
- Clay Minerals
- Muscovite*
- Alkali Feldspar*
- Biotite*
- Amphiboles*
- Pyroxenes*
- Ca-rich plagioclase*
- Olivine*

Note the minerals with a *. These are igneous minerals that crystallize from a liquid. Note the minerals that occur low on this list are the minerals that crystallize at high temperature from magma. The higher the temperature of crystallization, the less stable are these minerals at the low temperature found near the Earth's surface (see Bowen's reaction series in the igneous rocks chapter).

The main agent responsible for chemical weathering reactions is water and weak acids formed in water.

- An acid is solution that has abundant free H^+ ions.
- The most common weak acid that occurs in surface waters is carbonic acid.
- Carbonic acid is produced in rainwater by reaction of the water with carbon dioxide (CO_2) gas in the atmosphere.

$$\underset{\text{water}}{H_2O} + \underset{\text{carbon dioxide}}{CO_2} \longrightarrow \underset{\text{carbonic acid}}{H_2CO_3} \longrightarrow \underset{\text{hydrogen ion}}{H^+} + \underset{\text{bicarbonate ion}}{HCO_3^-}$$

H^+ is a small ion and can easily enter crystal structures, releasing other ions into the water.

Types of Chemical Weathering Reactions

- ***Hydrolysis*** - H^+ or OH^- replaces an ion in the mineral. Example:

$$\underset{\text{Orthoclase}}{4KAlSi_3O_8} + \underset{\text{Hydrogen ion}}{4H^+} + \underset{\text{water}}{2H_2O} \longrightarrow \underset{\text{Potassium ion}}{4K^+} + \underset{\text{Kaolinite (clay mineral)}}{Al_4Si_4O_{10}(OH)_8} + \underset{\text{quartz}}{8\ SiO_2}$$

- ***Leaching*** - ions are removed by dissolution into water. In the example above we say that the K^+ ion was leached.

- ***Oxidation*** - Since free oxygen (O_2) is more common near the Earth's surface, it may react with minerals to change the oxidation state of an ion. This is more common in Fe (iron) bearing minerals, since Fe can have several oxidation states, Fe, Fe^{+2}, Fe^{+3}. Deep in the Earth the most common oxidation state of Fe is Fe^{+2}.

$$\underset{\text{Pyroxene}}{3Fe^{+2}SiO_3} + \underset{\text{Oxygen}}{1/2O_2} \longrightarrow \underset{\text{Magnetite}}{Fe_3O_4} + \underset{\text{Quartz}}{3SiO_2}$$

- ***Dehydration*** **-** removal of H_2O or OH^- ion from a mineral.

$$\underset{\text{Goethite}}{2FeO \cdot OH} \longrightarrow \underset{\text{Hematite}}{Fe_2O_3} + \underset{\text{water}}{H_2O}$$

- ***Complete Dissolution*** - all of the mineral is completely dissolved by the water.

$$\underset{\text{Calcite}}{CaCO_3} + \underset{\text{Carbonic Acid}}{H_2CO_3} \longrightarrow \underset{\text{Calcium ion}}{Ca^{2+}} + \underset{\text{Bicarbonate ion}}{2(HCO_3)^-}$$

- Living Organisms - Organisms like plants, fungi, lichen, and bacteria can secrete organic acids that can cause dissolution of minerals to extract nutrients. The role of microorganisms like bacteria has only recent been discovered.

Weathering of Common Rocks

Rock	Primary Minerals	Residual Minerals*	Leached Ions
Granite	Feldspars	Clay Minerals	Na^+, K^+
	Micas	Clay Minerals	K^+
	Quartz	Quartz	---
	Fe-Mg Minerals	Clay Minerals + Hematite + Goethite	Mg^{+2}
Basalt	Feldspars	Clay Minerals	Na^+, Ca^{+2}
	Fe-Mg Minerals	Clay Minerals	Mg^{+2}
	Magnetite	Hematite, Goethite	---
Limestone	Calcite	None	Ca^{+2}, CO_3^{-2}
*Residual Minerals = Minerals stable at the Earth's surface and left in the rock after weathering.			

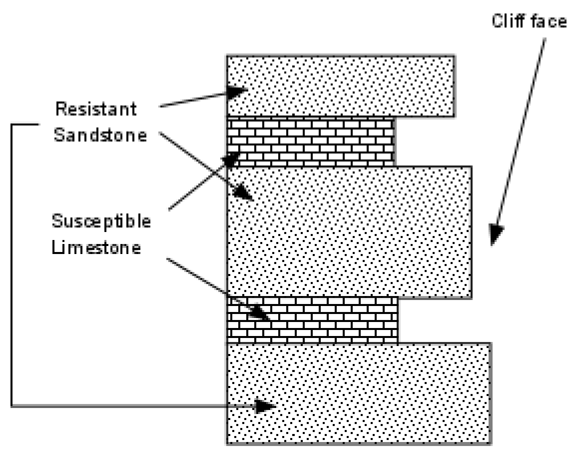
Interaction of Physical and Chemical Weathering

Since chemical weathering occurs on the surface of minerals, the water and acids that control chemical weathering require access to the surface. Physical weathering breaks the rock to provide that surface. Fracturing the rocks, as occurs during jointing, increases the surface area that can be exposed to weathering and also provides pathways for water to enter the rock. (See figure B.7 in your text). As chemical weathering proceeds, new softer minerals, like oxides or clay minerals, will create zones of weakness in rock that will allow for further physical weathering. Dissolution of minerals will remove material that holds the rock together, thus making it weaker.

When rock weathers, it usually does so by working inward from a surface that is exposed to the weathering process. If joints and fractures in rock beneath the surface form a 3-dimensional network, the rock will be broken into cube like pieces separated by the fractures. Water can penetrate more easily along these fractures, and each of the cube-like pieces will begin to weather inward. The rate of weathering will be greatest along the corners of each cube, followed by the edges, and finally the faces of the cubes. As a result the cube will weather into a spherical shape, with unweathered rock in the center and weathered rock toward the outside. Such progression of weathering is referred to as spheroid al weathering (See figures B.8 in your text).

Factors that Influence Weathering

- Rock Type & Structure
    - Different rocks are composed of different minerals, and each mineral has a different susceptibility to weathering. For example a granite consisting mostly of quartz is already composed of a mineral that is very stable on the Earth's surface, and will not weather much in comparison to limestone, composed entirely of calcite, which will eventually dissolve completely in a wet climate.
    - Bedding planes, joints, and fractures, all provide pathways for the entry of water. A rock with lots of these features will weather more rapidly than a massive rock containing no bedding planes, joints, or fractures.
    - If there are large contrasts in the susceptibility to weathering within a large body of rock, the more susceptible parts of the rock will weather faster than the more resistant portions of the rock. This will result in ***differential weathering.***



- Slope - On steep slopes weathering products may be quickly washed away by rains. On gentle slopes the weathering products accumulate. On gentle slopes water may stay in contact with rock for longer periods of time, and thus result in higher weathering rates.

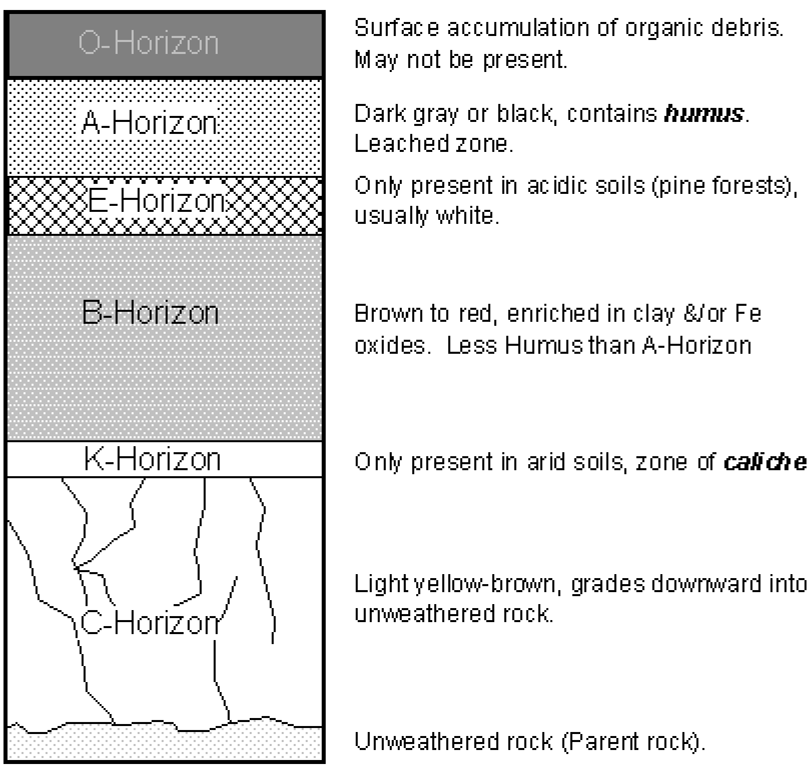
- Climate- High amounts of water and higher temperatures generally cause chemical reactions to run faster. Thus warm humid climates generally have more highly weathered rock, and rates of weathering are higher than in cold dry climates. Example: limestones in a dry desert climate are very resistant to weathering, but limestones in a tropical climate weather very rapidly.

- Animals- burrowing organisms like rodents, earthworms, & ants, bring material to the surface were it can be exposed to the agents of weathering.

Soils

"Soil consists of rock and sediment that has been modified by physical and chemical interaction with organic material and rainwater, over time, to produce a substrate that can support the growth of plants." Soils are an important natural resource. They represent the interface between the lithosphere and the biosphere - as soils provide nutrients for plants. Soils consist of weathered rock plus organic material that comes from decaying plants and animals. The same factors that control weathering control soil formation with the exception, that soils also requires the input of organic material as some form of Carbon.

When a soil develops on rock, a soil profile develops as shown below. These different layers are not the same as beds formed by sedimentation, instead each of the horizons forms and grows in place by weathering and the addition of organic material from decaying plants and plant roots.



Although you will not be expected to know all of the soil terminology discussed on page 196, the following terms are important.

- ***Caliche*** - Calcium Carbonate (Calcite) that forms in arid soils in the K-horizon by chemical precipitation of calcite. The Ca and Carbonate ions are dissolved from the upper soil horizons and precipitated at the K-horizon. In arid climates the amount of water passing through the soil horizons is not enough to completely dissolve this caliche, and as result the thickness of the layer may increase with time.
- ***Laterites*** - In humid tropical climates intense weathering involving leaching occurs, leaving behind a soil rich in Fe and Al oxides, and giving the soil a deep red color. This extremely leached soil is called a laterite.

Soil Erosion

In most climates it takes between 80 and 400 years to form about one centimeter of topsoil (an organic and nutrient rich soil suitable for agriculture). Thus soil that is eroded by poor farming practices is essentially lost and cannot be replaced in a reasonable amount of time. This could become a critical factor in controlling world population.

Questions on this material that might be asked on an exam

1. What is the difference between physical weathering and chemical weathering?
2. What types of things cause physical weathering?
3. Define the following: (a) acid, (b) leaching, (c) hydrolysis, (d) dissolution, (e) oxidation, (f) differential weathering, (g) joints, (h) caliche, (i) laterite
4. How do physical weathering and chemical weathering interact with each other?
5. Contrast the weathering process that would take place in hot humid tropical climates with those that would take place in hot, dry, desert climates.
6. What is a soil and how is a soil formed?
7. Why is it important for humans to prevent the erosion of soils?

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