Chapter 14

Weathering, Karst Landscapes, and Mass Movement

Denudation

- In geology, **denudation** involves the processes that cause the wearing away of the Earth's surface by moving water, by ice, by wind, waves, and by mass movement, leading to a reduction in relief of landforms and of landscapes.
- Exogenic processes that wear landforms down.

Denudation incorporates the mechanical, biological and chemical processes of erosion, weathering and mass wasting. Denudation can involve the removal of both solid particles and dissolved material.

Differential weathering

- Weathering that occurs at different rates, as a result of variations in composition and resistance of a rock or differences in intensity of weathering, and usually resulting in an uneven surface where more resistant material protrudes above softer or less resistant parts.

- **Fig. 14.1** and **14.2**

Dynamic Equilibrium Model

- **Dynamic equilibrium** - the idea of landscape formation as a balancing act between uplift and reduction by weathering and erosion.
- Landscapes in a dynamic equilibrium show ongoing adaptations to the ever-changing conditions of local relief, rock structure, and climate.

Example: In a new bottle of soda the concentration of carbon dioxide in the liquid phase has a particular value. If half of the liquid is poured out and the bottle is sealed, carbon dioxide will leave the liquid phase at an ever decreasing rate and the partial pressure of carbon dioxide in the gas phase will increase until equilibrium is reached. At that point, due to thermal motion, a molecule of CO_2 may leave the liquid phase, but within a very short time another molecule of CO_2 will pass from the gas to the liquid, and vice versa. At equilibrium the rate of transfer of CO_2 from the gas to the liquid phase is equal to the rate from liquid to gas.

Geomorphic Threshold

During or following a destabilizing event, a landform system sometimes arrives at a **geomorphic threshold**, or tipping point, where the system lurches to a new operational level.

- *Example*:
  - when a flood establishes a new river channel
  - a hillslope adjusts after a landslide

After crossing the threshold, the sytem establishes a new set of equilibrium relationships.

Slope

Material loosened by weathering is susceptible to erosion and transportation.

- For material to move downslope it must overcome friction, inertia, and the cohesion of particles. *
- If the angle of the slope is steep enough, and if the conditions are right, gravity will work.

Slope - curved or inclined surfaces that form the boundaries of landforms.

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***inertia** is the resistance to movement

Weathering

Weathering is the process that breaks down rock at the surface and slightly below by either:

- disintegrating rocks into mineral particles
- dissolving rocks into water

Two important classifications of weathering processes exist:

- Physical
- Chemical Weathering

each sometimes involves a biological component.

Weathering occurs *in situ* (on site), that is, in the same place, with little or 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.

Factors Influencing Weathering

- Rock composition and structure (**jointing**) *
- Climate - precipitation and temperature **
- Slope orientation (directional) ***
- Subsurface water - the positions and movement of groundwater in rock and soil
- Vegetation ****

*Some rocks are softer than others
Joints - fractures or separations in rock that occur without displacement of the rock - increases the surface area of rock exposed to weathering
** warm & humid climates speed up chemical weathering for some rocks / colder environments have the freeze-thaw situation
*** slopes facing away from the sun's rays tend to be cooler, moister, and have more vegetation
****Vegetative cover can shield, and roots can stabilize soil, BUT it also produces organic acids as it decays which contribute to chemcial weathering.   Roots can enter crevices and mechanically break up rock
Fig. 14.5

Physical Weathering

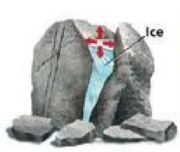
- **Mechanical** or **physical weathering** - the breakdown, or disintegration, of rocks and soils through direct contact with atmospheric conditions, such as heat, water, ice and pressure.
- Breaking up rock exposes more surface area on which all forms of weathering may operate.

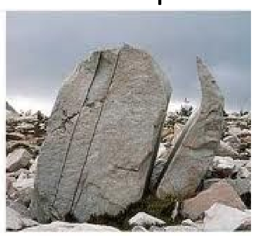
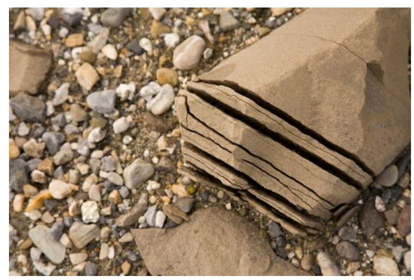
The primary process in physical weathering is abrasion (the process by which clasts and other particles are reduced in size). However, chemical and physical weathering often go hand in hand.
Physical weathering can occur due to temperature, pressure, frost etc. For example, cracks exploited by physical weathering will increase the surface area exposed to chemical action, thus amplifying the rate of disintegration.
Abrasion by water, ice, and wind processes loaded with sediment can have tremendous cutting power, as is amply demonstrated by the gorges, ravines, and valleys around the world.
In glacial areas, huge moving ice masses embedded with soil and rock fragments grind down rocks in their path and carry away large volumes of material.

Frost action (frost wedging)

Frost weathering, **frost wedging**, or *ice wedging* is the collective name for several processes where ice is present. **Fig. 14.6**

1. Water works itself into cracks
2. Freezes and expands - widening the cracks

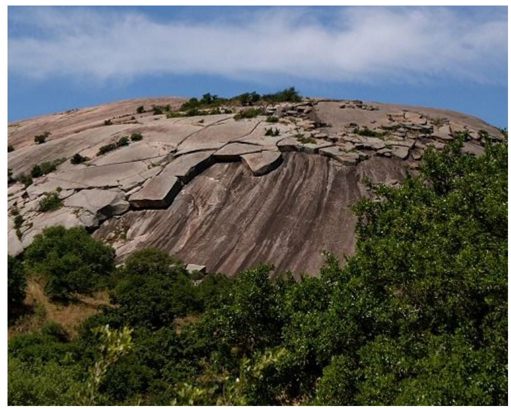


Severe frost shattering produces huge piles of rock fragments called scree which may be located at the foot of mountain areas or along slopes. Frost weathering is common in mountain areas where the temperature is around the freezing point of water. Certain frost-susceptible soils expand or heave upon freezing as a result of water migrating via capillary action to grow ice lenses near the freezing front.[

Exfoliation

Exfoliation - the process where rock peels or slips off in sheets instead of breaking up into grains. *



*Can be due to pressure release - bedrock finally uncovered by erosional processes - pressure of overlying material is no longer holding the rock together

Fig. 14.10

Exfoliation Joint

- **Exfoliation joints** or **sheet joints**
  - Half Dome

Formation of exfoliation joints

Despite their common occurrence in many different landscapes, geologists have yet to reach an agreement on a general theory of exfoliation joint formation. Many different theories have been suggested, below is a short overview of the most common.

General characteristics of exfoliation joints

•Commonly follow topography.[1][2][3]

•Divide the rock into sub-planar slabs.[3]

•Joint spacing increases with depth from a few centimeters near the surface to a few meters[3][4][5]

•Maximum depth of observed occurrence is around 100 meters.[3][4][5][6]

•Deeper joints have a larger radius of curvature, which tends to round the corners of the landscape as material is eroded[1][2][3][4][5]

•Fracture mode is tensile[7][8]

•Occur in many different lithologies and climate zones, not unique to glaciated landscapes.[3][9][10]

•Host rock is generally sparsely jointed, fairly isotropic, and has high compressive strength.[1][5][10]

•Can have concave and convex upwards curvatures.[1][2][11]

•Often associated with secondary compressive forms such as arching, buckling, and A-tents (buckled slabs)[11]

Chemical Weathering

- **Chemical weathering** involves the direct effect of atmospheric chemicals or biologically produced chemicals also known as biological weathering in the breakdown of rocks, soils and minerals.
  - Water is a primary component in the chemical breakdown.

Chemical weathering changes the composition of rocks, often transforming them when water interacts with minerals to create various chemical reactions. Chemical weathering is a gradual and ongoing process as the mineralogy of the rock adjusts to the near surface environment.
New or *secondary minerals* develop from the original minerals of the rock. In this the processes of oxidation and hydrolysis are most important.
Chemical weathering is enhanced by such geological agents as the presence of water and oxygen, as well as by such biological agents as the acids produced by microbial and plant-root metabolism.

Fig. 14.12 / 14.13 / 14.14

Hydration

- Mineral **hydration** is a form of chemical weathering that involves the rigid attachment of H+ and OH- ions to the atoms and molecules of a mineral - results in a change in structure.
  - When rock minerals take up water, the increased volume creates physical stresses within the rock.

Hydrolosis

Hydrolysis - a chemical reaction of water with a mineral where the rock is broken down

The chemical composition of the rock is changed bit by bit.

Oxidation

- Within the weathering environment chemical **oxidation** of a variety of metals occurs.
  - Certain metallic elements inside the rock combine with oxygen to form oxides.
  - This gives the affected rocks a reddish-brown coloration on the surface which crumbles easily and weakens the rock.

This process is better known as 'rusting', though it is distinct from the rusting of metallic iron.

Carbonation

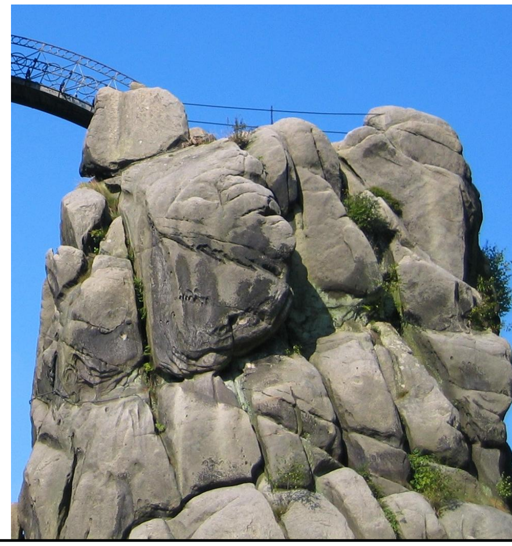
- **Carbonation** - process in which atmospheric carbon dioxide leads to solution weathering.
- Carbonation occurs on rocks which contain calcium carbonate, such as limestone and chalk.
- This takes place when rain combines with carbon dioxide to form a weak carbonic acid which reacts with calcium carbonate (the limestone) and forms calcium bicarbonate.
- Carbonation on the surface of well-jointed limestone produces a dissected limestone pavement. This process is most effective along the joints, widening and deepening them.

Rainfall is acidic because atmospheric carbon dioxide dissolves in the rainwater producing weak carbonic acid. In unpolluted environments, the rainfall pH is around 5.6. Acid rain occurs when gases such as sulfur dioxide and nitrogen oxides are present in the atmosphere. These oxides react in the rain water to produce stronger acids and can lower the pH to 4.5 or even 3.0. Sulfur dioxide, SO_2, comes from volcanic eruptions or from fossil fuels, can become sulfuric acid within rainwater, which can cause solution weathering to the rocks on which it falls.
Some minerals, due to their natural solubility (e.g. evaporites), oxidation potential (iron-rich minerals, such as pyrite), or instability relative to surficial conditions (see Goldich dissolution series) will weather through dissolution naturally, even without acidic water.

This process speeds up with a decrease in temperature, not because low temperatures generally drive reactions faster, but because colder water holds more dissolved carbon dioxide gas. Carbonation is therefore a large feature of glacial weathering.

Spheroidal weathering

Spheroidal weathering is a form of chemical weathering that affects jointed bedrock and results in the formation of concentric or spherical layers of highly decayed rock within weathered bedrock that is known as saprolite.



Biological weathering

- A number of plants and animals may create chemical weathering through release of acidic compounds, i.e. the effect of moss growing on roofs is classed as weathering.
- Mineral weathering can also be initiated and/or accelerated by soil microorganisms. Lichens on rocks are thought to increase chemical weathering rates.

Karst topography

- **Karst** topography is a landscape formed from the dissolution of soluble rocks such as limestone, dolomite, and gypsum. It is characterized by underground drainage systems with sinkholes and caves

Fig. 14.18 and **Fig. 14.21**

Fig. 14.20 - Tower Karst

The study of karst is considered of prime importance in petroleum geology since as much as 50% of the world's hydrocarbon reserves are hosted in porous karst systems

Caves - Carlsbad Caverns - speleothems

Sinkhole

- A **sinkhole**, also known as a **cenote**, **sink**, **sink-hole**, **shakehole**, **swallet**, **swallow hole**, or **doline** (the different terms for sinkholes are often used interchangeably), is a depression or hole in the ground caused by some form of collapse of the surface layer.
- May reach 600 m (2000 ft)

Fig. 14.16 and **14.17**

Most are caused by karst processes—for example, the chemical dissolution of carbonate rocks[4] or suffosion processes.[5] Sinkholes vary in size from 1 to 600 m (3.3 to 2,000 ft) both in diameter and depth, and vary in form from soil-lined bowls to bedrock-edged chasms. Sinkholes may form gradually or suddenly, and are found worldwide.[

Mass Wasting /Mass Movement

- **Mass Wasting** or **Mass Movement**, is the geomorphic process by which soil, sand, regolith, and rock move downslope typically as a mass, largely under the force of gravity, but frequently affected by water and water content as in submarine environments and mudflows

Fig. 14.23

When the gravitational force acting on a slope exceeds its resisting force, slope failure (mass wasting) occurs. The slope material's strength and cohesion and the amount of internal friction between material help maintain the slope's stability and are known collectively as the slope's shear strength. The steepest angle that a cohesionless slope can maintain without losing its stability is known as its angle of repose. When a slope made of loose material possesses this angle, its shear strength perfectly counterbalances the force of gravity acting upon it.

Mass wasting may occur at a very slow rate, particularly in areas that are very dry or those areas that receive sufficient rainfall such that vegetation has stabilized the surface. It may also occur at very high speed, such as in rockslides or landslides, with disastrous consequences, both immediate and delayed, e.g., resulting from the formation of landslide dams.

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Rockfall

- A **rockfall** refers to quantities of rock falling freely from a cliff face.
- A rockfall is a fragment of rock (a block) detached by sliding, toppling, or falling, that falls along a vertical or sub-vertical cliff, proceeds down slope by bouncing and flying along ballistic trajectories or by rolling on talus or debris slopes

Scree/Talus slope

- **Scree** is a collection of broken rock fragments at the base of crags, mountain cliffs, volcanoes or valley shoulders that has accumulated through periodic rockfall from adjacent cliff faces.
- Landforms associated with these materials are often called **talus deposits**. Talus deposits typically have a concave upwards form.

Fig. 14.24

Debris avalanche

- Slope material that becomes saturated with water may develop into a debris flow or mud flow. The resulting slurry of rock and mud may pick up trees, houses and cars, thus blocking bridges and tributaries causing flooding along its path.
- Debris flow is often mistaken for a flash flood, but they are entirely different processes.

Fig. 14.25

Landslide

- A **landslide**, also known as a **landslip**, is a form of mass wasting that includes a wide range of ground movements, such as rockfalls, deep failure of slopes, and shallow debris flows.
- Landslides can occur underwater, called a submarine landslide, coastal and onshore environments. **Fig. 14.22**
- The action of gravity is the primary driving force for a landslide to occur. However, there are other contributing factors affecting the original slope stability.

Mudflow

- A **mudflow** or **mud flow** is a form of mass wasting involving “very rapid to extremely rapid surging flow“ of debris that has become partially or fully liquefied by the addition of significant amounts of water to the source material.

Lahar

Mudflows contain a significant proportion of clay, which makes them more fluid than debris flows; thus, they are able to travel farther and across lower slope angles.
Mudflows are often called *mudslides*, a term applied indiscriminately by the mass media to a variety of mass wasting events.[4] Mudflows often start as slides, becoming flows as water is entrained along the flow path; such events are often called *flow slides*

Soil creep

- **Soil creep** or commonly just **creep**, is the slow downward progression of rock and soil down a low grade slope.

Fig. 14.27

also refer to slow deformation of such materials as a result of prolonged pressure and stress. Creep may appear to an observer to be continuous, but it really is the sum of numerous minute, discrete movements of slope material caused by the force of gravity

Scarification

Scarification - human induced mass movement of earth materials - such as large scale open pit mining and strip mining.

Fig. 14.28