Weathering &
Mass-Wasting Processes

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Definitions

- **Weathering** is the physical disintegration or chemical alteration of rocks at or near the Earth's surface.

- **Erosion** is the physical removal and transportation of weathered material by water, wind, ice, or gravity.

- **Mass wasting** is the transfer or movement of rock or soil down slope primarily by gravity.

- **Deposition** is the process by which weathered and eroded materials are laid down or placed in a location that is different from their source.

Note

- Weathering, erosion, mass-wasting, and depositional processes occur at or near the Earth's surface and produce changes to the landscape that influence surface and subsurface topography and landform development.

- These processes are all very important to the rock cycle because over geologic time weathering, erosion, and mass wasting transform solid rock into sediments and soil that result in the redeposition of material forming new sedimentary rocks.

Types of Weathering

I. Mechanical (physical) weathering is the physical disintegration and reduction in the size of the rocks without changing their chemical composition.

- Examples: exfoliation, frost wedging, salt wedging, temperature changes, and abrasion

II. Chemical weathering decomposes, dissolves, alters, or weakens the rock through chemical processes to form residual materials.

- Examples: carbonation, hydration, hydrolosis, oxidation, and solution

III. Biological weathering is the disintegration or decay of rocks and minerals caused by chemical or physical agents of organisms.

- Examples: organic activity from lichen and algae, rock disintegration by plant or root growth, burrowing and tunneling organisms, and acid secretion

I. Mechanical Weathering

Mechanical weathering is the physical disintegration and reduction in the size of the rocks without changing their chemical composition.

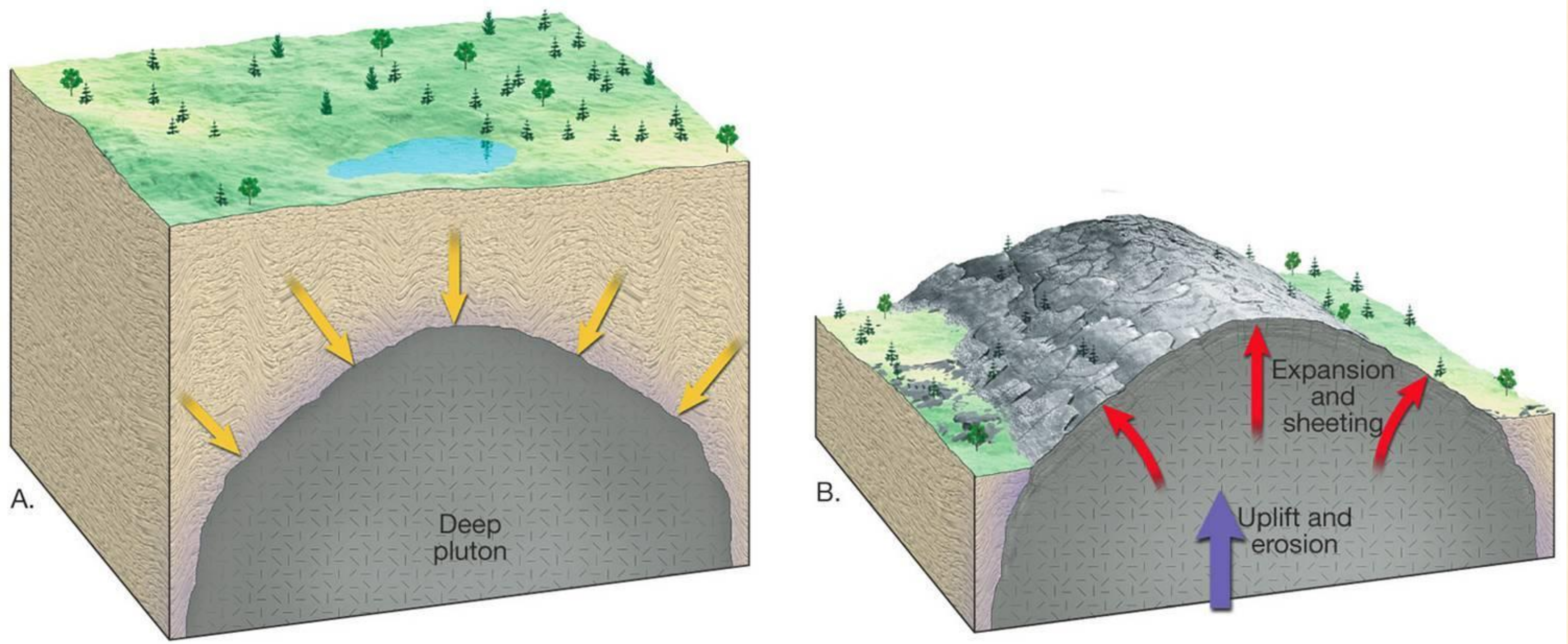
- Exfoliation
- Frost Wedging
- Salt Wedging
- Temperature Changes
- Abrasion

Mechanical weathering processes disintegrate metamorphic rocks in South Carolina's Piedmont Region.

Photo courtesy of SCGS

Mechanical Weathering: Exfoliation

- **Exfoliation** is a mechanical weathering process in which pressure in a rock is released (**unloading**) along parallel alignments (**sheet joints**) near the surface of the bedrock and layers or slabs of the rock along these alignments break off from the bedrock and move downhill by gravity.
- Exfoliation primarily occurs on **intrusive igneous** or **metamorphosed** rocks that are exposed at the Earth's surface.



Mechanical Weathering: Exfoliation

- Exfoliation can occur both very slowly or very rapidly as a form of mass wasting.
- Large rocks characterized by exfoliation are commonly referred to as **exfoliation domes**.
- Table Rock mountain in South Carolina, and Enchanted Rock in Texas are both examples of exfoliation domes with large slabs of rock exfoliating from the bedrock.

Mechanical Weathering: Exfoliation

Mechanical Weathering: Frost Wedging

- **Frost wedging** is a mechanical weathering process caused by the freeze-thaw action of water that is trapped between cracks in the rock.

- When water freezes, it expands and applies pressure to the surrounding rock forcing the rock to accommodate the expansion of the ice.

This example of frost wedging is from Pikes Peak in Colorado. The weathered fragments of rock break apart from the exposed rock from freeze-thaw action and collect as angular blocks of talus material.

Mechanical Weathering: Frost Wedging

- This process gradually weakens, fractures, and breaks the rock through **repetitive freeze-thaw weathering cycles**.
- Frost wedging generally produces angular blocks and **talus** material. Talus is a term used to describe weathered rock fragments deposited at the base of a hill slope or mountain.

This example of frost wedging is from Pikes Peak in Colorado. The weathered fragments of rock break apart from the exposed rock from freeze-thaw action and collect as angular blocks of talus material.

Temperature Changes

- Daily (diurnal) and seasonal temperature changes affect certain minerals and facilitates the mechanical weathering of bedrock.
- Warmer temperatures may cause some minerals to expand, and cooler temperatures cause them to contract.
- This gradual expansion and contraction of mineral grains weakens the rock causing it to break apart into smaller fragments or to fracture.

The rock fragments in the lower right side of this image have weathered as a result of extreme fluctuations in day and night temperature changes.

Temperature Changes

- This process is more common in desert climates because they experience extreme fluctuations in daily temperature changes.

- Temperature changes are often not the dominant form of weathering, but instead temperature changes tend to accelerate other forms of weathering already occurring.

- **Insolation weathering, thermal expansion/contraction**

Thermal expansion of rocks	
rock type	linear-expansion coefficient (in 10^{-6} per degree Celsius)
granite and rhyolite	8 ± 3
andesite and diorite	7 ± 2
basalt, gabbro, and diabase	5.4 ± 1
sandstone	10 ± 2
limestone	8 ± 4
marble	7 ± 2
slate	9 ± 1

Mechanical Weathering: Salt Wedging

- **Salt wedging** occurs when salts crystallize out of solution as water evaporates. As the salt crystals grow, they apply pressure to the surrounding rock weakening it, until it eventually cracks and breaks down, enabling the salt crystal to continue growing.

- Salt wedging is most common in **drier climates, high evaporative climates**, such as deserts.

These salt crystals were found growing between rock fractures in California's Death Valley.

Mechanical Weathering: Abrasion

- **Abrasion** occurs when rocks collide against each other while they are transported by water, glacial ice, wind, or gravitational force.
- The constant collision or gravitational falling of the rocks causes them to slowly break apart into progressively smaller particles.
- **Flowing water** is the primary medium of abrasion and it produces the 'rounded' shape of fluvial/coastal sediments.

Abrasion processes in creek beds produce rounded boulders and cobbles. Over time, abrasion processes will eventually break these rocks into progressively smaller particle sizes, such as gravel, sand, silt, and clay.

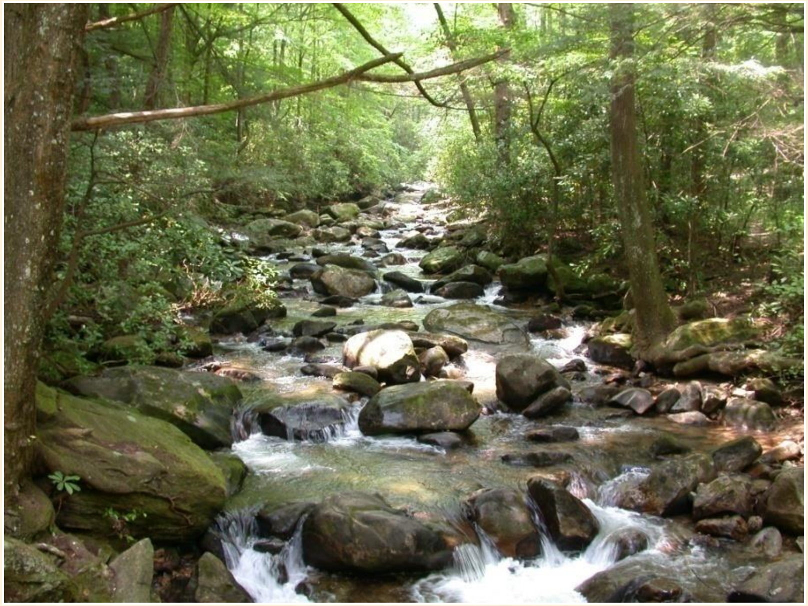


Photo Source: SCGS

Mechanical Weathering: Abrasion

- During abrasion, rocks may also weather the bedrock surface they are coming into contact with as well as breaking into smaller particles and eventually individual grains.

- Bedrock weathering through abrasion may produces a smooth surface.


Types of Chemical Weathering

Chemical weathering decomposes, dissolves, alters, or weakens the rock through chemical processes to form residual materials.

- Carbonation
- Hydrolysis
- Hydration
- Oxidation
- Solution

Stalactite and stalagmite joining together in Onondaga Cave State Park, Missouri.

Chemical Weathering: Carbonation

- Carbonation is a process by which carbon dioxide and water chemically react to produce carbonic acid, a weak acid, that reacts with carbonate minerals in the rock.

- This process simultaneously weakens the rock and removes the chemically weathered materials.

Influenced by:
Temperature
Pressure
Partial pressure of CO_2
pH
Ion concentration

$$\underset{\text{air}}{CO_2} + \underset{\text{water}}{H_2O} \longrightarrow \underset{\text{carbonic acid}}{H_2CO_3}$$

$$\underset{\text{calcium carbonate}}{CaCO_3} + \underset{\text{carbonic acid}}{H_2CO_3} \rightleftharpoons \underset{\text{calcium ion}}{Ca^{++}} + \underset{\text{bicarbonate ion}}{HCO^-_3}$$

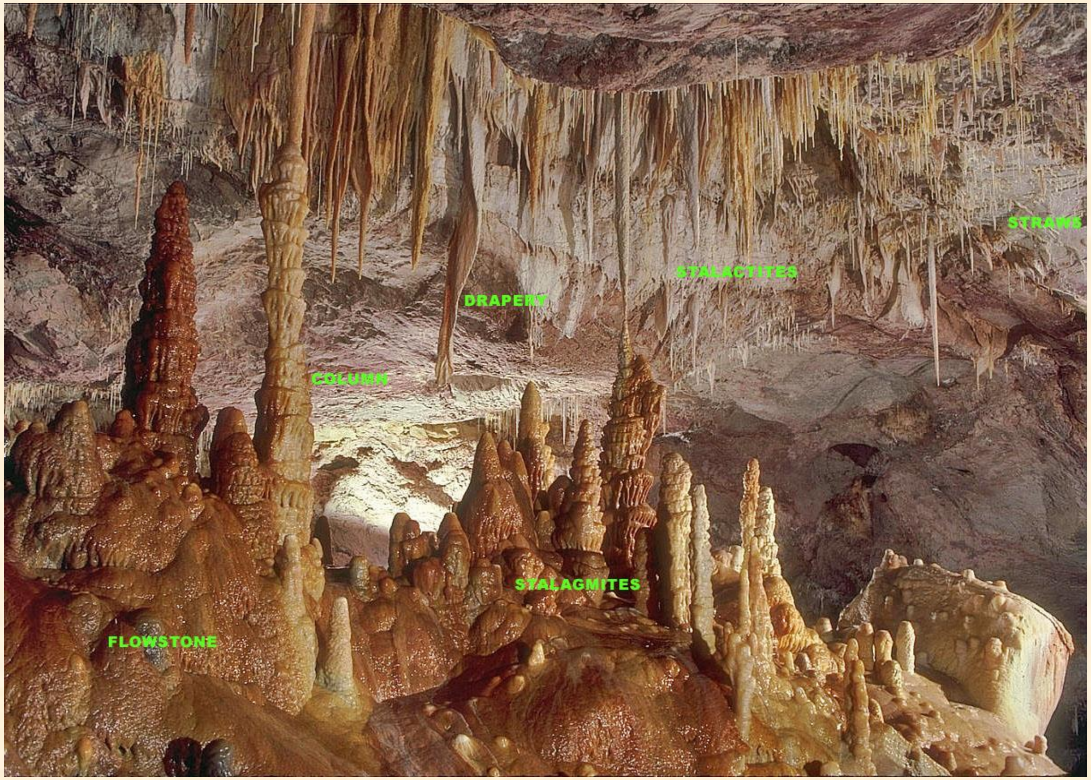
Chemical Weathering: Carbonation

- Carbonation primarily occurs in wet, moist climates and effects rocks both on and beneath the surface.

- Carbonation occurs with limestone or dolomite rocks and usually produces very fine, clayey particles.

Limestone weathered by carbonation processes

Photo source: Wikipedia GNU Free Documentation License



Chemical Weathering: Hydrolysis

- Hydrolysis is a chemical reaction between **H^+** and **OH^-** ions in water and the **minerals** in the rock. The H^+ ions in the water react with the minerals to produce weak acids.

- The reaction creates new compounds which tend to be softer and weaker than the original parent rock material.

- Hydrolysis can also cause certain minerals to expand, which also facilitates mechanical weathering processes.

$$\underset{\text{air}}{CO_2} + \underset{\text{water}}{H_2O} \longrightarrow \underset{\text{carbonic acid}}{H_2CO_3} \rightleftharpoons H^+ + \underset{\text{bicarbonic ion}}{HCO^-_3}$$

$$\underset{\text{calcium carbonate}}{CaCO_3} + \underset{\text{carbonic acid}}{H_2CO_3} \rightleftharpoons \underset{\text{calcium ion}}{Ca^{++}} + \underset{\text{bicarbonate ion}}{HCO^-_3}$$

Chemical Weathering: Hydrolysis

- Hydrolysis commonly affects igneous rocks because they are composed of silicate minerals, such as quartz and feldspar, which readily combine with water.

- Hydrolysis may also be accompanied by **hydration** and **oxidation** weathering processes.

- The hydrolysis of feldspars produces kaolinite, which is a **clay**.

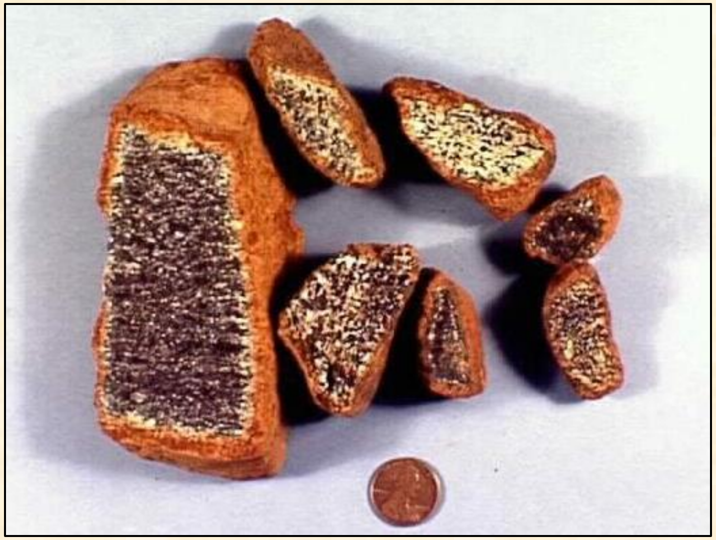
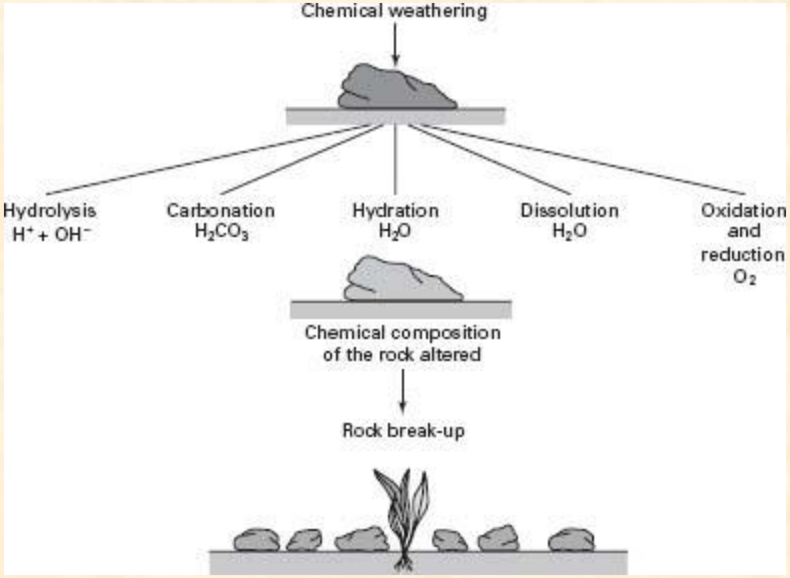


Photo Source: Dr. Hugh Mills, Tennessee Technical University

Chemical Weathering: Hydration

- Hydration is a process where mineral structure in the rock forms a weak bond with $\mathbf{H_20}$
- Mineral grains **expand**, increased **stress** promotes the **disintegration** of the rock.
- Often **color changes** in the weathered rock surface.



Chemical Weathering: Hydration

- Once hydration begins, it accelerates other weathering processes and may also be accompanied by **hydrolysis** and **oxidation**.
- An example of hydrolosis: Anhydrite ($CaSO_4$) can absorb two water molecules to become gypsum ($CaSO_4 \cdot 2H_2O$).
- Hydration in granite transforms feldspar minerals to clay and accelerates the physical weathering of buried or exposed rocks.

This boulder is surrounded by saprolitic soils formed by the weathered rock. Hydration processes cause the formation of clays and contribute to the reddish-tan color of the saprolite.

Chemical Weathering: Oxidation

- Oxidation occurs when an ion in a mineral structure loses an electron to an oxygen ion.
- Common in iron bearing, rock forming minerals. Ferrous iron (Fe^{++}) oxidizes to ferric iron (Fe^{+++})
- Oxidation accelerates rock decay, rendering it more vulnerable to other forms of weathering.

Chemical Weathering: Solution

- Solution occurs when minerals in rock dissolve directly into water.
- Solution most commonly occurs on rocks containing **carbonates** , also affects rocks with large amount of halite, or rock salt.
- Solution of large areas of bedrock may cause sinkholes to form, where large areas of the ground subside or collapse forming a depression.

Subsurface dissolution of halite has caused overlying rocks to collapse and form crater-like features.

This is an example of a limestone solution karst feature found in Florida's Everglades National Park.

Biological Weathering

Biological weathering is the disintegration or decay of rocks and minerals caused by chemical or physical agents of organisms.

- Organic activity from lichen and algae
- Rock disintegration by plant growth
- Burrowing and tunneling organisms
- Secretion of acids

Lichen, Algae, and Decaying Plants

- Organisms such as lichen (https://en.wikipedia.org/wiki/Lichen) and algae often live on bare rock and extract minerals from the rock by ion-exchange mechanisms.

- This bio-chemical weathering process leaches minerals from the rock causing it to weaken and breakdown.

Photo: SCGS

This is an example of biological weathering that is caused by mosses and lichen growing on the face of a rock.

Lichen, Algae, and Decaying Plants

- The decaying of plant materials can also produce acidic compounds which dissolve the exposed rock.
- Organism growth across the surface may also exerts a small amount of abrasion and pressure that gradually cause the mechanical weathering of the rock.

Photo: SCGS

This is an example of biological weathering that is caused by mosses and lichen growing on the face of a rock.

Plant Roots

- Plant roots penetrate into cracks and crevices of rocks and cause the rock to split or break into smaller particles through mechanical weathering.
- Process enhanced in rocks that may already have a pre-existing weaknesses such as fractures, faults, or joints.

This is an example of a tree that is growing between a crevasse in a rock. The tree is splitting the rock along parallel planes of alignment that are already weakened by foliation processes, a form of mechanical weathering.

Organism Activity

- Burrowing, tunneling, and acid-secreting organisms chemically or mechanically weather rocks.
- Burrowing organisms disintegrate rock. Small animals, worms, termites, and other insects.
- Snails, barnacles, or limpets, attach themselves to rocks and secrete acid acids that chemically dissolve the rock surface.

Photo: D. Kroessig

The periwinkle snails on this rock are secreting acids that dissolve the rock. This picture is taken from a volcanic shoreline in Hawaii.

Differential Weathering

- Rates are controlled by the type of weathering processes and rock material.
- Harder rocks typically weather slower than softer rocks in the same env.
- The differences in rates of weathering due to types of rocks, textures, or other characteristics is referred to as **differential weathering**.

Image source: SCDNR, Heritage Preserves

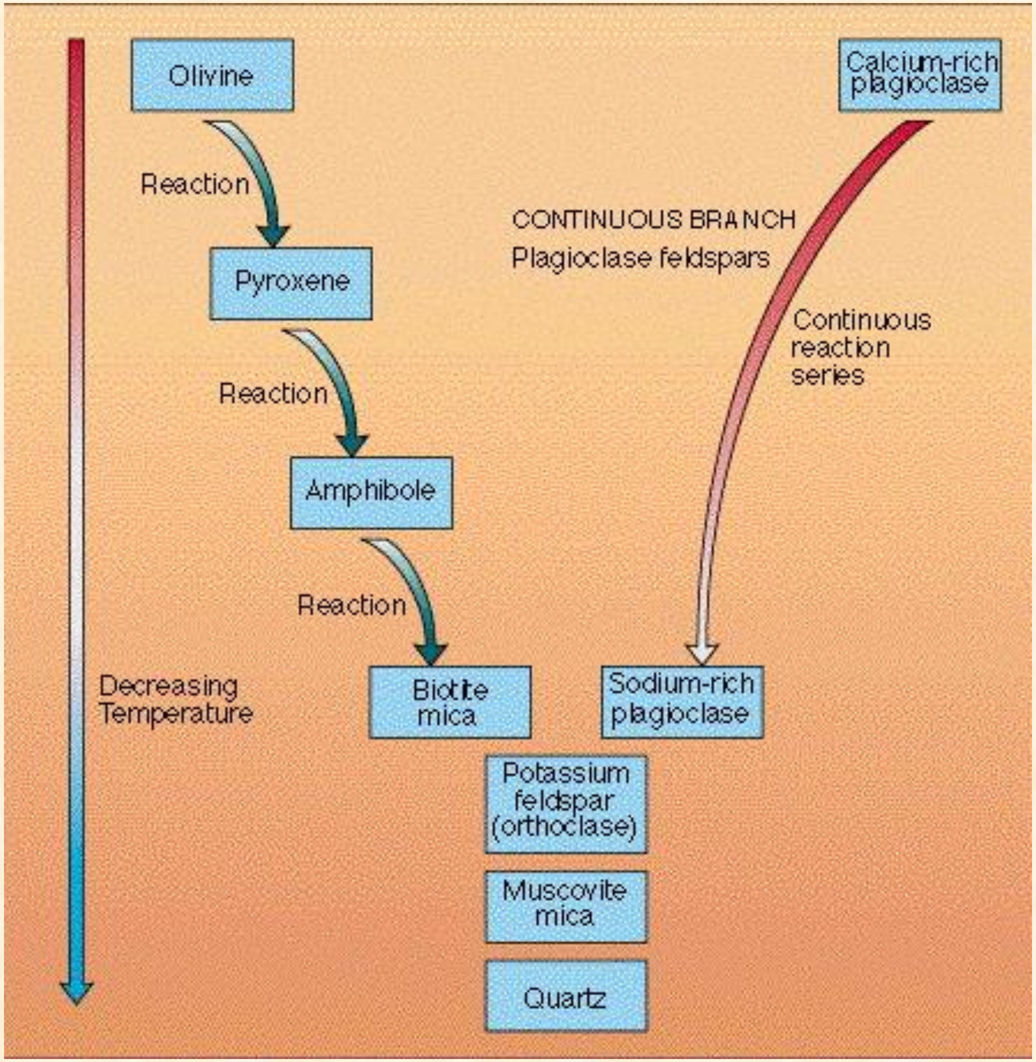
Peachtree Rock's unique pyramidal shape is a result of differential weathering associated with the different sedimentary sandstone rock components. The top portion of the outcrop consists of hard, coarse-grained sandstone, while the lower part of the rock consist of a less cohesive, sandstone layer. The lower portion of the rock has weathered more quickly than the upper portion ultimately producing its unique pyramidal shape.

Resistance to Weathering

First to Crystallize

Bowen's Reaction Series

Last to Crystallize

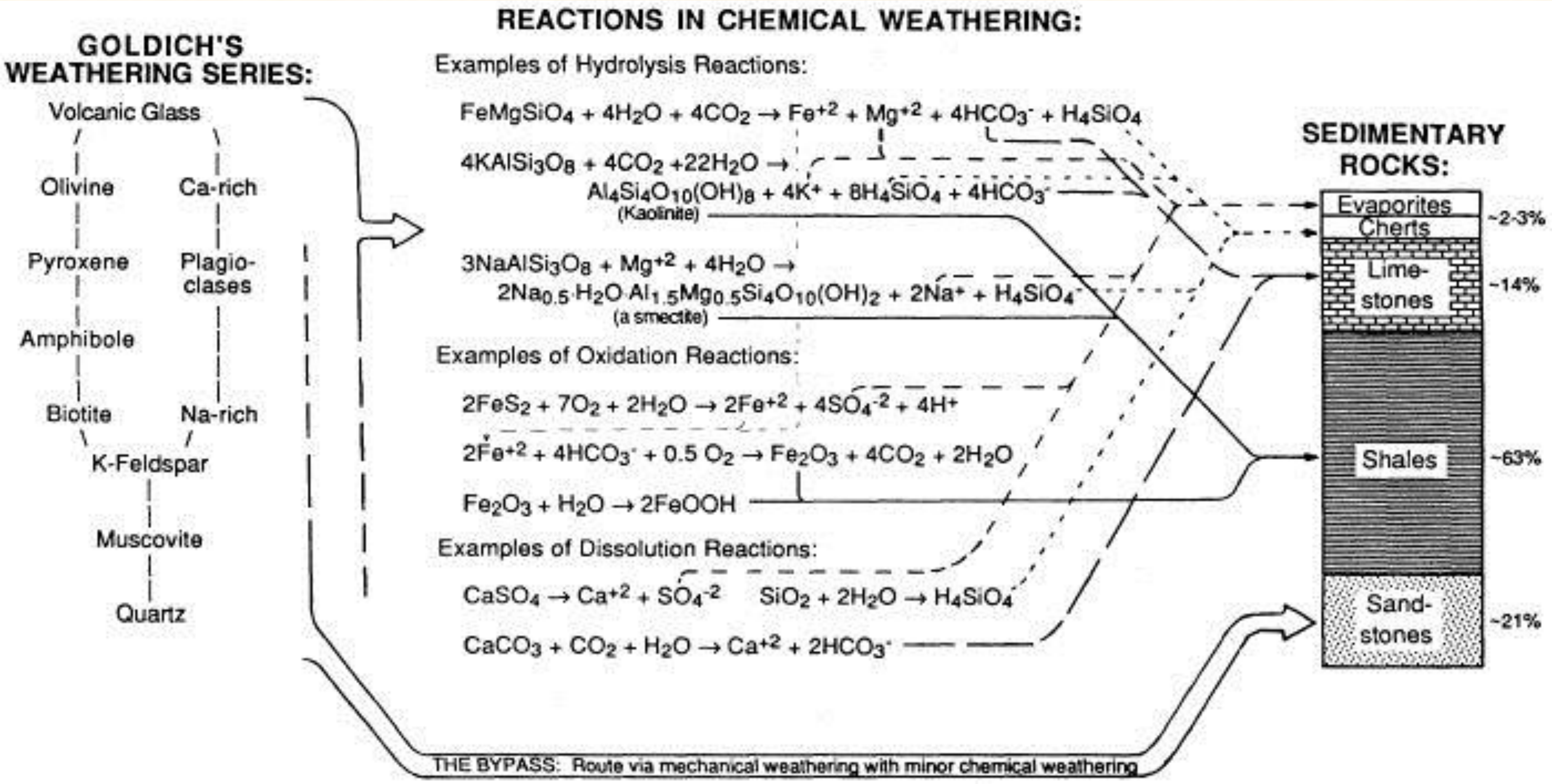


Fast Weathering

Goldrich Stability Series

Slow Weathering

Goldrich's Weathering Series



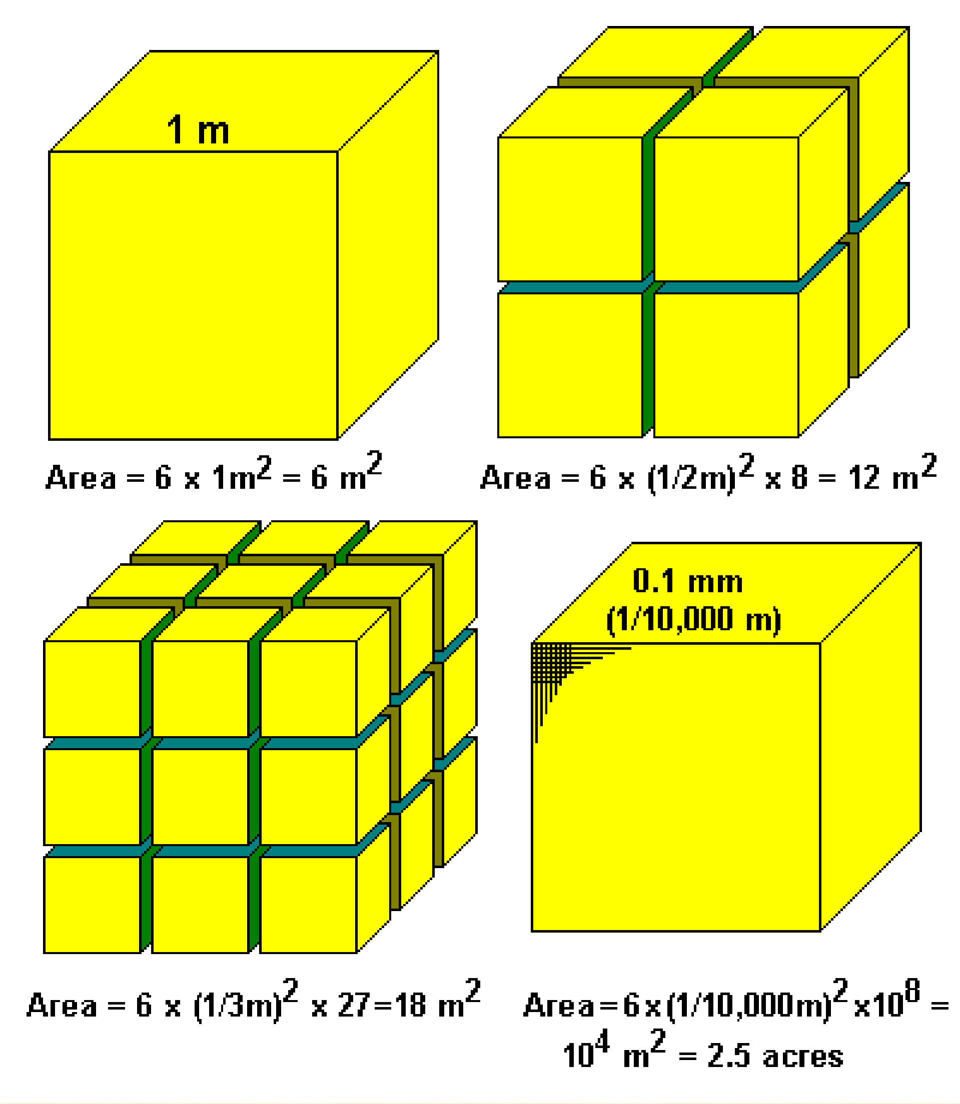
Differential Weathering

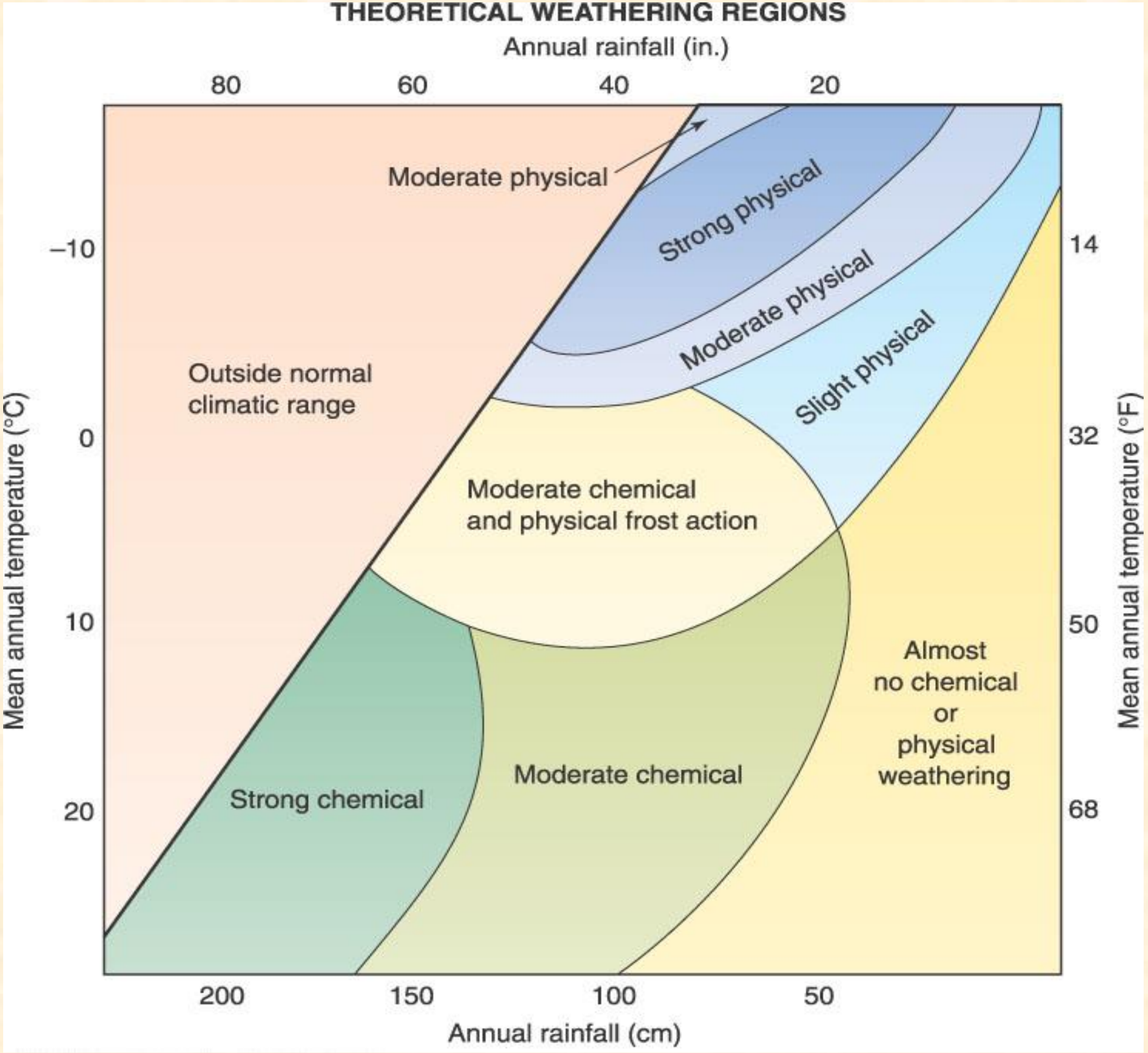
- Differential weathering processes contribute to the unique formation of many landforms, including **pedestals**, **waterfalls**, and **monadnocks** (inselberg; isolated mountain, lone mountain etc.).
- **Climate** can also produce differential weathering responses for the same rock type. For example, limestone weathers more quickly in wet climates than dry climates.

Image source: SCDNR, Heritage Preserves

Pietra di Bismantova, Apennines, Italy

Surface Area and Weathering




THEORETICAL WEATHERING REGIONS
Annual rainfall (in.)
80
60
40
20
Moderate physical
Strong physical
Moderate physical
Slight physical
Outside normal climatic range
Moderate chemical and physical frost action
Almost no chemical or physical weathering
Moderate chemical
Strong chemical
Mean annual temperature (°C)
−10
0
10
20
Mean annual temperature (°F)
14
32
50
68
200
150
100
50
Annual rainfall (cm)