Weathering, Erosion, and Mass-Wasting Processes

Designed to meet South Carolina Department of Education 2005 Science Academic Standards

Department of Natural Resources
South Carolina Geological Survey

Table of Contents (1 of 2)

Table of Contents, cont. (2 of 2)

Definitions

- 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.
  - **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.
- 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

Standard: 3-3.8
Standard: 5-3.1

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 whereby pressure in a rock is released along parallel alignments 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.
- 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.

Photo: SCGS

Enchanted Rock in the Texas Hill Country is an example of an exfoliation dome. As pressure is released from the surface layer, slabs of rock exfoliate from the dome and move down slope. As they are transported down slope, weathering and erosion processes break the rocks into progressively smaller fragments. Overtime, each new layer that is exposed will eventually exfoliate, from the bedrock.

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 process gradually weakens, cracks, 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.
- 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.

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.

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, 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 sediments.
- 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.
- In addition to the transported rocks being weathered by abrasion, the bedrock surface is also experiencing the effects of collision and mechanical weathering. This smoothes the surface of the bedrock and can also cause it to break apart.

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

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 rainwater or moisture in the surrounding environment 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.
- 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.
- 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.

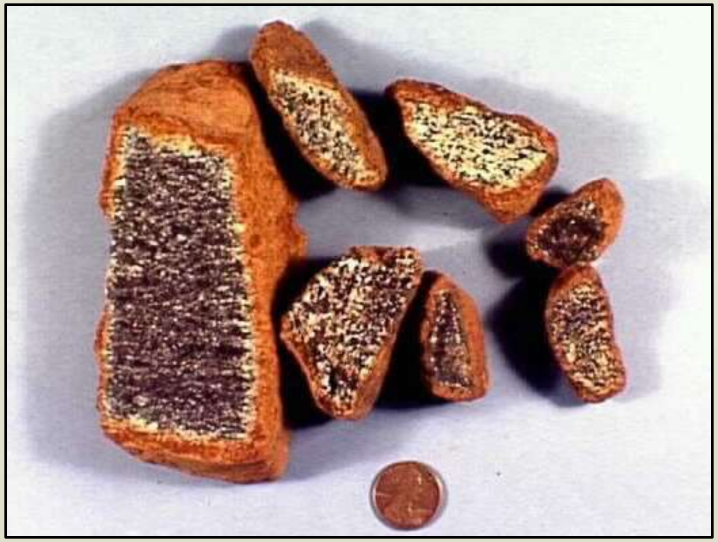


Photo Source: Dr. Hugh Mills, Tennessee Technical University

The weathering rinds shown on this sample of amphibolite illustrate the effects of hydrolysis weathering on deposited rock fragments. Geologists measure the 'thickness' of the weathering rinds on in-situ rock fragments to estimate the relative age of depositional landforms such as river terraces or alluvial fans. The thicker the weathering rinds, the older the landform.

Standard: 3-3.8
Standard: 5-3.1

Chemical Weathering: Hydration

- Hydration is a process where mineral structure in the rock forms a weak bond with H_20 which causes the mineral grains to expand, creating stress which causes the disintegration of the rock.
- Hydration often produces a new mineral compound that is larger than the original compound. The increased size expanse the rock and can lead to decay.
- Hydration can also lead to color changes in the weathered rock surface.
- 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 oxygen and water react with iron-rich minerals and weaken the structure of the mineral.
- During oxidation the minerals in the rock will change colors, taking on a ‘rusty’, reddish-orange appearance.
- Similar to other chemical weathering processes, oxidation accelerates rock decay, rendering it more vulnerable to other forms of weathering.

Photo: SCGS

The reddish-orange color of this sandstone is a result of oxidation processes weathering the rock.

Standard: 3-3.8
Standard: 5-3.1

Chemical Weathering: Solution

- Solution occurs when minerals in rock dissolve directly into water.
- Solution most commonly occurs on rocks containing carbonates such as limestone, but may also affect 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 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.
- The decaying of plant materials can also produce acidic compounds which dissolve the exposed rock.
- The presence of organisms growing, expanding, or moving across the surface of the rock also exerts a small amount of abrasion and pressure that gradually cause the mechanical weathering of the rock as the organisms extract various minerals.

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

- The most common form of biological weathering is when plant roots penetrate into cracks and crevices of rocks and cause the rock to split or break into smaller particles through mechanical weathering.
- Although, this process is gradual, it can be fairly effective at breaking apart 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.

[Standard: 3-3.8](#)
[Standard: 5-3.1](#)

Organism Activity

- Burrowing, tunneling, and acid-secreting organisms are another form of biological weathering that chemically or mechanically contribute to weathering.
- Some animals may burrow or tunnel into rocks or cracks in rocks and cause the rock to break down and disintegrate. Small animals, worms, termites, and other insects, often contribute to this form of biological weathering.
- Some organisms, such as 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

- Weathering rates will not only vary depending on the type of weathering process, whether it is mechanical, chemical, or biological, but they will also vary depending on the rock material that is being weathered.
- Some rocks are harder than other rocks, and will weather slower than softer rocks.
- The differences in rates of weathering due to different types of rocks, textures, or other characteristics is referred to as differential weathering.
- Differential weathering processes contribute to the unique formation of many landforms, including pedestals, waterfalls, and monadnocks.
- 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

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.

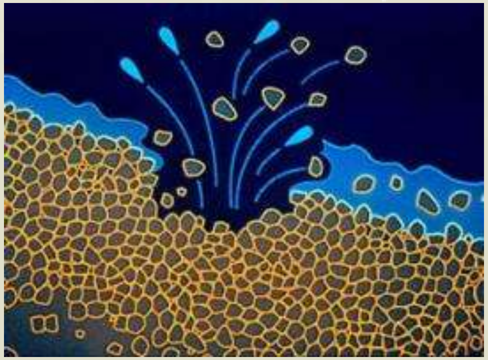
Erosion

- **Water** erodes rocks and the landscapes by transporting weathered materials from their source to another location where they are deposited.
- **Wind** erodes materials by picking them up and temporarily transporting them from their source to another location where they are deposited, and either stored or re-mobilized and transported to another location.
- **Ice** erosion occurs when particles are plucked up or incorporated by moving ice, such as a glaciers, and are transported downhill, or when friction between the ice and bedrock erodes materials and then transports them downhill.
- **Gravity** facilitates the down slope transportation of loosened, weathered materials and enables them to move without the aid of water, wind, or ice. Gravity related erosion is a major component of mass-wasting events.

This basin and range landscape is influenced by several erosional processes. The mountains in the background are dissected by fluvial erosion (water) and the sandstorm in the valley is a form of aeolian (wind) erosion. The mountains may contain numerous rocks falls or landslides a form of gravity related mass-wasting erosion.

Erosion: Water (Fluvial)

- Water erodes rocks and shapes the landscapes by removing and transporting weathered materials from their source to another location where they are deposited and either stored or transported to another location.
- Fluvial erosion is often broken into 3 distinct categories: **rain-splash erosion, sheet erosion**, and **rill/gully erosion.**
  - **Rain splash erosion** occurs when the impact of a rain drop loosens and mobilizes particles.
  - **Sheet erosion** is a process where particles loosened buy rain-splash erosion are transported by runoff water down the slope of a surface.
  - **Rill erosion** occurs when water concentrates during sheet erosion and erodes small rills or gullys into the surface that channel flow down slope.
- Fluvial erosion can occur during rainfall events, from melt-water runoff, or ground water percolation. Materials being eroded and transported are either suspended in the water, bounced by saltation, or rolled along the ground by traction depending on a variety of conditions.
- The accumulation of fluvial erosion and associated processes over a large area forms pathways for surface and groundwater flow and carves v-shaped river valleys that continue to erode, transport, and deposit weathered sediments across the landscape.



www.montcalm.org

This drawing on the left illustrates rain-splash impact on the soil and the erosion of individual grains of sediment. The image on the right shows the landscape scale effects of fluvial erosion.

Erosion: Wind (Aeolian)

- Wind erodes weathered rocks by picking them up and temporarily transporting them from their source to another location where they are deposited, and either stored or re-mobilized and transported to another location
- Erosion by wind is divided into two different categories: **Deflation** and **Abrasion**
  - **Deflation** is the movement or transport of particles through the air or along the ground
  - **Abrasion** is the process that occurs when wind-transported particles sculpt features in the landscape through a "sand-blasting" like process
- Aeolian erosion and deposition processes create a diversity of landforms including sand dunes, loess deposits, and yardangs.

Courtesy Modis, Nasa

This satellite image captured a regional dust storm transporting aeolian sediments from Sudan and Africa over the Red Sea. In arid, desert climates wind erosion is very common and can transport sediments 100's of miles before they are deposited.

Erosion: Ice (Periglacial and Glacial)

- Ice erosion occurs in combination with periglacial and glacial processes
- Glacial erosion occurs when particles are incorporated into the glacial ice through a process referred to as plucking, and they are transported downslope within the glacier.
- The friction and abrasion of the ice and rock moving across the bedrock, erodes the surface of the bedrock and often leaves scrapes, grooves, striae, or polished rock surfaces.
- The cumulative effects of glacial erosion on a mountainous landscape can produce distinct u-shaped valleys which are a common glacial landform.

Glacial erosion of this landscape has carved several distinct landforms, such as the glacial u-shaped valleys and the arêtes, which form the ridges between the u-shape valleys.

Erosion: Gravity

- Gravity facilitates the down slope transportation of loosened, weathered materials and enables them to move without the aid of water, wind, or ice. However, these agents can act as catalysts for gravity related erosion.
- Movements by gravity may be very slow or very abrupt.
- Gravity related erosion can be coherent or incoherent. Coherent refers to the erosion of a consolidated mass of materials that erode or move as a single unit, incoherent refers to the erosion or movement of a mass of unconsolidated individual fragments of materials.
- Unconsolidated materials tend to stabilize near an angle of 35° (referred to as the angle of repose) however this balance is easily disrupted by changes in environmental conditions, addition of weathered materials, and or other adjustments that may cause mass wasting.

Photo: wikimedia commons

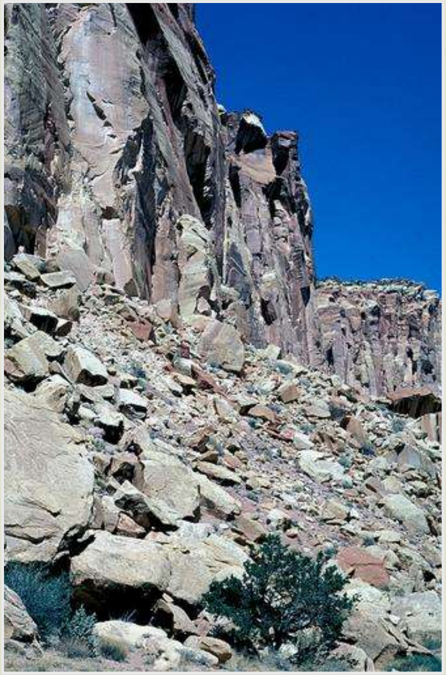
The rock fragments and sediments accumulated below this cliff were eroded by the force of gravity and were deposited as talus scree at the base of the cliff. When the slope at the base of the cliff becomes too steep, and exceeds the angle of repose, the unconsoldated particles will again be eroded and transported down slope by gravity.

Mass Wasting

Mass wasting is a rapid form of erosion that works primarily under the influence of gravity in combination with other erosional agents. Mass wasting occurs very quickly and can result in either small or large scale changes to the landscape depending on the type of event.

- Rock Falls
- Landslides
- Debris / Mud Flows
- Slumps
- Creep

Rock Fall



Landslide

Photo source: SCGS

Standard: 3-3.8
Standard: 5-3.1

Rock Falls

- Rock falls occur when rocks become dislodged, because their change in potential energy becomes to great to maintain, and the potential energy becomes kinetic energy which causes the rock fragment to fall, restoring equilibrium. As a result the rocks fall, roll, or bounce downhill.
- The rocks may be loosened by a recent rainfall or snow melt-water event that facilitates the movement of the rock before they fall from the force of gravity.
- Rock falls often form piles of loose rock below their source and are sometimes referred to as talus or scree.
- Large volumes of talus may form a talus slope, talus apron, or talus cone depending on its shape. Talus tends to stabilize near an angle of 35° (referred to as the angle of repose), or the steepest angle maintained before changes in energy lead to gravitational erosion. This balance is easily disrupted by changes in environmental conditions, addition of weathered materials, or other factors that lead to mass wasting.

Photo courtesy of SCGS

Fragments are breaking off from this rock exposure and collecting down-slope from their source. The fragments of fallen rock are angular and include a variety of different sizes. The tree growing above this boulder may also be contributing through biological weathering where the roots are penetrating into the cracks in the rock.

Landslides

- Landslides are mass-wasting events where large amounts of weathered rock material slide down a hillslope or mountain side primarily by gravity related erosion.
- Landslides occur very quickly and move with incredible speed and destruction, often removing or covering everything in their path.
- Nearly all landslides are triggered by an earthquake, or lubricant agent such as rainfall, or a snow or ice melt-water event.
- During intensive rainfall, soil and weathered rock material become unstable and loosened from the saturated conditions that separate the individual grains and other material fragments. The increased fluid pressures coupled with the loosened materials succumbs to gravity related erosion and the weathered materials plunge downhill as a powerful landslide.
- Landslides are a natural hazard that can cause serious damage to people and other obstacles in their path. Many earth scientists study landslides in order to predict their occurrence and prevent negative impacts to humans and infrastructure.

This landslide event occurred in Jones Gap State Park in the Mountain Bridge Wilderness Area of South Carolina. Boulders, trees, soil, and other weathered material tumbled down this hill-slope after 8" of heavy rain fell over 2-days.

Photo source: SCGS

Debris and Mud Flows

- Debris and mudflows are mass-wasting events that form when heavy rainfalls produce large amounts of runoff that transport eroded soils, sediments, and plant debris down slope where the flows eventually spreads out across valley bottoms.
- Sometimes the debris and mudflows follow existing drainage paths and other times they carve out new paths as they flow downhill
- Debris and mudflows can carry particles of a range of sizes from clays (mud) to large debris and boulders; however, debris flows consists primarily of coarse-grained materials and mudflows consist primarily of fine-grained materials.
- The consistency of a debris or mudflow is representative of a thick, muddy sludge carrying rocks, twigs, branches, trees, and other available debris
- Debris flows are natural hazards that pose a threat to communities in their path

This debris flow flooded and destroyed several homes as it carried, mud, trees, and boulders through a valley in Colorado's Rocky Mountain Range.

Slump

- Slumps are a fairly common form of mass wasting where the rock or soil collapses, breaks off from the hill slope, rotates slightly, and slumps downhill.
- If the slump occurs as a large consolidated mass of materials it is considered coherent, if it occurs as a mass of unconsolidated materials or sediments it is referred to as incoherent.
- Slumping can cause damage to houses, roads, and other infrastructure.

This slump failure in California poses a threat to homes developed along the edge of the cliff.

The asphalt from the road surface makes it easy to see the soil displacement from this slump.

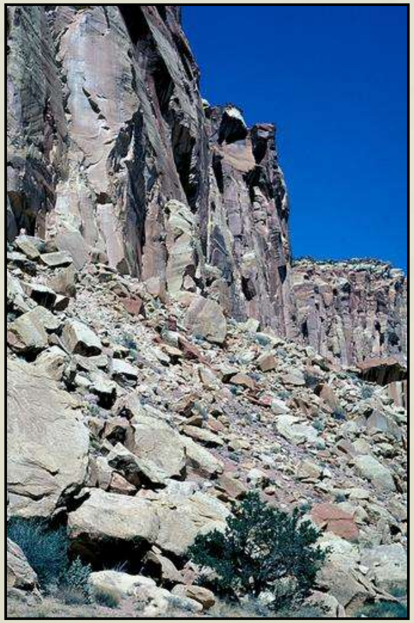
Creep

- Creep is the slowest mass-wasting process and involves a very gradual downhill movement of soil, bedrock, and weathered rock fragments.
- Usually, the entire slope is slowly creeping downhill as a complete unit.
- Creep processes occur to some degree on nearly every hillslope because of gravity.
- Creep is evident by bent or extended tree trunks that are adjusting to the slow movement of the soil, regolith, and weathered material they are rooted into.
- Freeze-thaw cycles and saturated conditions may accelerate creep processes but usually only for a short time-period
- Solifluction is a certain form of creep where frozen tundra soils thaw out and gently 'flow' or sag downslope

The bent, leaning trees in this image are an indication of soil creep. The soil beneath the tree roots is slowing creeping downhill, as a result the tree trunks curve upslope in order for the trees to remain upright.

Deposition

- Deposition is a constructive process that lays down or places weathered and eroded materials in a location that is different from their source.
- Deposition is not specific to a single weathering, erosion, or mass wasting event, but is applied to any consolidated or unconsolidated materials that have accumulated as a result of some natural process or agent. Deposits can result from mechanical, chemical, or biological weathering, and water, wind, ice, or gravity-related erosional processes.
- The accumulation of deposited materials alters the landscapes and builds various landform features. For example, floodplains are large depositional landforms built by the accumulation of fluvial deposits, and sand dunes are depositional landforms built by wind-related processes.



Colluvium is the term used to describe weathered and eroded rocks, soil, and sediments deposited at the base of a hill slope or cliff by the force of gravity and mass wasting. Alluvium is a term used to refer materials deposited by running water. The talus slope on the left is colluvium and the alluvial fan on the right is alluvium.

South Carolina Science Academic Standards: Grade 3

1) Earth's Materials and Changes:
Standard 3-3:
The student will demonstrate an understanding of Earth's composition and the changes that occur to the features of Earth's surface.

Indicators:
3-3.8: Illustrate changes in Earth's surface that are due to slow processes (including weathering, erosion, and deposition) and changes that are due to rapid processes (including landslides, volcanic eruptions, floods, and earthquakes).

South Carolina Science Academic Standards: Grade 5

1) Lanforms and Ocean:

Standard 5-3:

The student will demonstrate an understanding of features, processes, and changes in Earth's lands and oceans.

Indicators:

5-3.1: Explain how natural processes (including weathering, erosion, deposition, landslides, volcanic eruptions, earthquakes, and floods) affect Earth's oceans and land in constructive and destructive ways.

Resources and References

- AGI, 1972, Glossary of Geology: American Geological Institute, Washington, D.C.
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