Topography, Landforms, and Geomorphology

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

Department of Natural Resources
South Carolina Geological Survey

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Basic Definitions

- **Topography** refers to the elevation and relief of the Earth's surface.
- **Landforms** are the topographic features on the Earth's surface.
- **Geomorphology** is the study of earth surface processes and landforms.

The maps above represent the same area on Earth's surface and they show three different ways we can view landforms. The image on the far left is a clip from a topographic elevation map, the image in the middle is an infrared aerial photo, and the image on the right is the geologic interpretation of surface sediments and geomorphology. This location is interesting because it contains elements of a natural and human altered physical environment. The lake in the image, (coded blue in the topographic and geology map, and black in the infrared aerial photo) was formed by artificial damming a stream the flows through this landscape.

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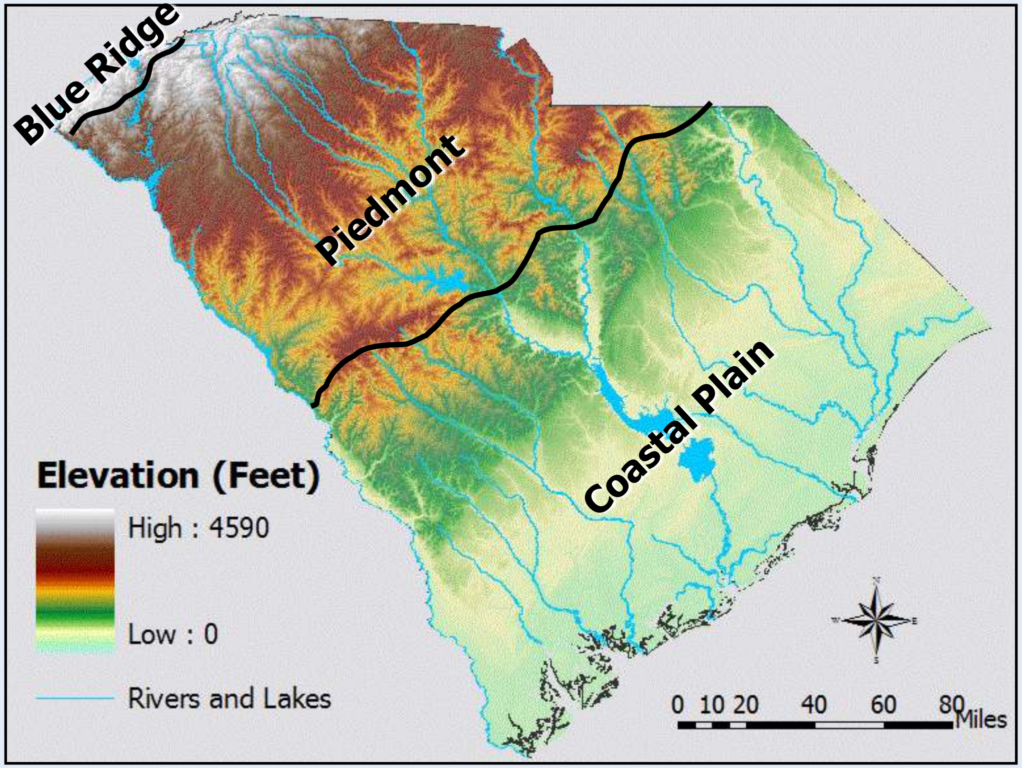
Topography

- **Topography is a term used to describe the Earth's surface. Topography includes a variety of different features, collectively referred to as landforms.**
- **Topography is measured by the differences in elevation across the earth's surface.**
- **Differences between high and low elevation are referred to as changes in relief.**
- **Scientist examine topography using a variety of different sources ranging from paper topographic maps to digital elevation models developed using specialized geographic information systems commonly referred to as a GIS.**



South Carolina's elevation relief ranges from 4,590 feet in the Blue Ridge Region to 0 feet along the Coastal Plain. The rivers dissect the topography and drain down-slope from headwaters in the mountainous Blue Ridge and Piedmont, into the alluvial valleys of the Coastal Plain before draining into the Atlantic Ocean.

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Landforms

- Landforms are the individual topographic features exposed on the Earth's surface.
- Landforms vary in size and shape and include features such as small creeks or sand dunes, or large features such as the Mississippi River or Blue Ridge Mountains.
- Landforms develop over a range of different time-scales. Some landforms develop rather quickly (over a few seconds, minutes, or hours), such as a landslide, while others may involve many millions of years to form, such as a mountain range.
- Landform development can be relatively simple and involve only a few processes, or very complex and involve a combination of multiple processes and agents.
- Landforms are dynamic features that are continually affected by a variety of earth-surface processes including weathering, erosion, and deposition.
- Earth scientists who study landforms provide decision makers with information to make natural resource, cultural management, and infrastructure decisions, that affect humans and the environment.

Table Rock Mountain is a metamorphosed igneous intrusion exposed by millions of years of weathering and erosion in South Carolina's Piedmont Region.

Photo Source: SCGS

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Landforms and Scale: Crustal Orders of Relief

- **First Order of Relief:**
  - The broadest landform scale is divided into continental landmasses, which include all of the crust above sea-level (30% Earth's surface), and ocean basins, which include the crustal areas below sea-level (70% of Earth's surface)
- **Second Order of Relief:**
  - The second order of relief includes regional-scale continental features such as mountain ranges, plateaus, plains, and lowlands. Examples include the Rocky Mountains, Atlantic Coastal Plain, and Tibetan Plateau.
  - Major ocean basin features including continental shelves, slopes, abyssal plains, mid-ocean ridges, and trenches are all second-order relief landforms.
- **Third Order of Relief:**
  - The third order of relief includes individual landform features that collectively make up the larger second-order relief landforms. Examples include individual volcanoes, glaciers, valleys, rivers, flood plains, lakes, marine terraces, beaches, and dunes.
  - Each major landform categorized within the third order of relief may also contain many smaller features or different types of a single feature. For example, although a flood plain is an individual landform it may also contain a mosaic of smaller landforms including pointbars, oxbow lakes, and natural levees. Rivers, although a single landform, may be classified by a variety of channel types including straight, meandering, or braided.

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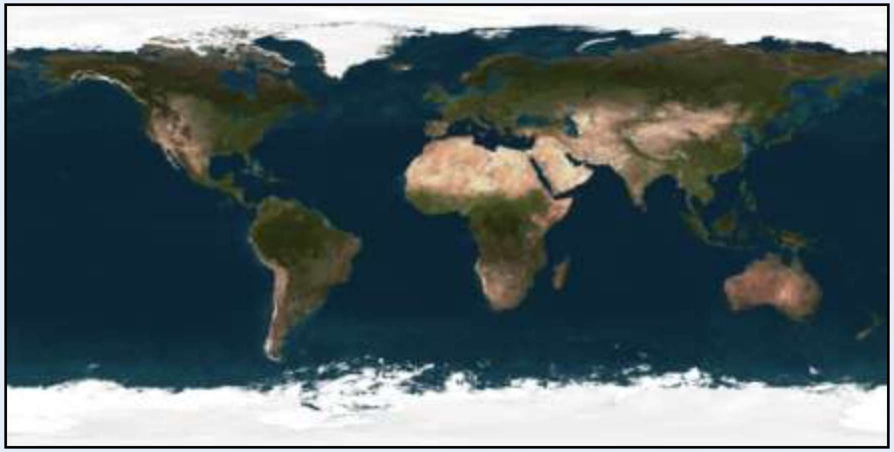
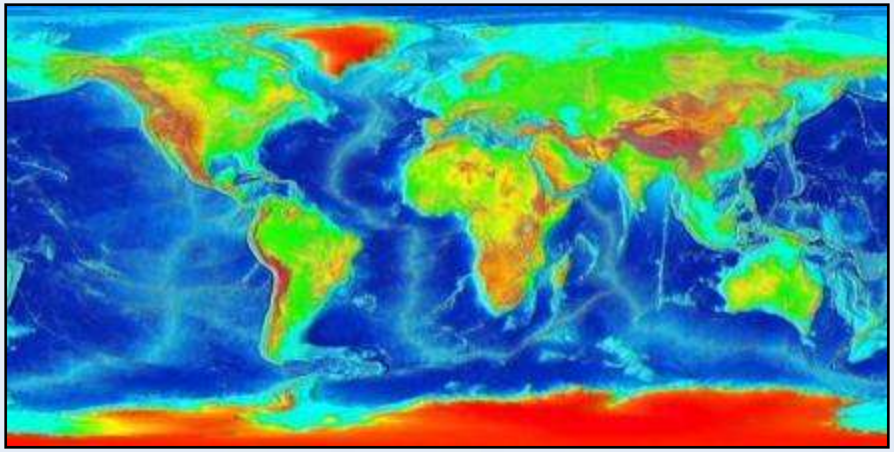
Crustal Orders of Relief

I. First Order or Relief: Continental Landmasses and Ocean Basins



II. Second Order of Relief: Major Continental and Ocean Landforms



III. Third Order of Relief: Genetic Landform Features

Images and Photos: SCGS

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Geomorphology

- **Geomorphology is the process-based study of landforms.**
  - **Geo-morph-ology originates from Greek: *Geo* meaning the "Earth", *morph* meaning its "shape", and *ology* refers to "the study of".**
  - **Scientists who study landforms are Geomorphologists.**
- **Geomorphology defines the processes and conditions that influence landform development, and the physical, morphological, and structural characteristics of landforms.**
- **Geomorphologists who study landforms often seek to answer fundamental questions that help them study landforms, such as:**
  - **What is the physical form or shape of the landform?**
  - **What is the elevation and topographic relief of the landform?**
  - **How did the landform originate?**
  - **What is the distribution of the landform and where else does it occur?**
  - **Are their any patterns associated with the landform or topography?**
  - **What is the significance of the landform in relation to other elements of the landscape or environment?**
  - **Has the landform or geomorphology been altered by humans?**
  - **Does the landform or geomorphology affect humans?**

Standard: 3-3.8
Standard: 8-3.7

Uniformitarianism

- Uniformitarianism is a common theory held by earth scientists that states "the present is the key to the past". Uniformitarianism implies that the processes currently shaping the Earth's topography and landforms are the same processes as those which occurred in the past.
- By studying geomorphology, we are better able to interpret the origin of landforms and infer their future evolution within the landscape.
- Such applications are especially important for predicting, preventing, and mitigating natural hazards impact to humans, and managing our natural resources for future generations.

The two images below illustrate the concept of uniformitarianism. On the left is an imprint of ripple marks in sandstone, similar current ripple forms in the right image. If the present is the key to the past, we can infer that the sandstone rock formed in a low energy, fluvial environment similar to the conditions in the right image.

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Constructive and Destructive Processes

- **Constructive processes build landforms through tectonic and depositional processes.**
  - **Tectonic processes** include movements at plate boundaries, earthquakes, orogeny, deformation, and volcanic activity.
  - **Deposition** is the accumulation or accretion of weathered and eroded materials.

- **Destructive processes break down landforms through weathering, erosion, and mass wasting.**
  - **Weathering** is the disintegration of rocks by mechanical, chemical, and biological agents.
  - **Erosion** is the removal and transportation of weathered material by water, wind, ice, or gravity.
  - **Mass wasting** is the rapid down-slope movement of materials by gravity.

- **Other Agents and Processes that Affect Landform Development**
  - **Climate**: temperature, precipitation, water cycle, atmospheric conditions
  - **Time**: fast and slow rates of change
  - **People:** influences on natural resources and earth surface processes

Constructive Processes

- **Constructive processes are responsible for physically building or constructing certain landforms. Constructive processes include tectonic and depositional processes and their landforms.**
  - **Tectonic Landforms** are created by massive earth movements due to tectonic and volcanic activity, and include landforms such as: **mountains, rift valleys, volcanoes, and intrusive igneous landforms**
  - **Depositional Landforms** are produced from the deposition of weathered and eroded surface materials. Depositional landforms include features such as: **beaches, barrier islands, spits, deltas, flood plains, dunes, alluvial fans, and glacial moraines.**

The Stromboli Volcano erupting off the coast of Sicily in the Mediterranean Sea.

Source: wikimedia commons

Floodplain deposits at the confluence of Mississippi and Arkansas Rivers.

Destructive Processes

- **Destructive processes create landforms through weathering and erosion of surface materials facilitated by water, wind, ice, and gravity. Mass-wasting events occur in areas where weathering and erosion is accelerated.**
  - **Weathering** is the disintegration and decomposition of rock at or near the Earth's surface by **mechanical, chemical, or biological** weathering processes.
  - **Erosion** is the removal and transportation of weathered or unweathered materials by **water, wind, ice, and gravity**.
  - **Mass-Wasting** is a rapid period of weathering and erosion that removes and transports materials very quickly and is often triggered by an environmental stimuli. Mass wasting includes **rock falls, landslides, debris and mud flows, slumps, and creep**.
- **Landforms formed by destructive processes include river and stream valleys, waterfalls, glacial valleys, karst landscapes, coastal cliffs, and wave-cut scarps.**

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Genetic Landform Classification

- The genetic landform classification system groups landforms by the dominant set of geomorphic processes responsible for their formation. This includes the following processes and associated landforms:
  - Tectonic Landforms
  - Extrusive Igneous Landforms
  - Intrusive Igneous Landforms
  - Fluvial Landforms
  - Karst Landforms
  - Aeolian Landforms
  - Coastal Landforms
  - Ocean Floor Topography
  - Glacial Landforms
- Within each of these genetic classifications, the resulting landforms are a product of either constructive and destructive processes or a combination of both.
- Landforms are also influenced by other agents or processes including time, climate, and human activity.

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Tectonic Landforms

- Mountains: Orogenesis and Deformation
    - Folding
    - Faulting
    - Fractures
  - Domes and Basins
  - Horst and Graben Rift Valleys
- Major Mountain Ranges:
  - Rocky Mountains
  - Appalachian Mountains
  - Himalayan Mountains
  - Andes Mountains

Standards: 3-3.6
Standards: 5-3.1
Standards: 8-3.7

Orogenesis

- Orogenesis is the thickening of the continental crust and the building of mountains over millions of years and it translates from Greek as "birth of mountains", (*oros* is the Greek word for mountain).
- Orogeny encompasses all aspects of mountain formation including plate tectonics, terrane accretion, regional metamorphism, thrusting, folding, faulting, and igneous intrusions.
- Orogenesis is primarily covered in the plate tectonics section of the earth science education materials, but it is important to review for the landform section because it includes deformation processes responsible for mountain building.

Photo courtesy of SCGS, SCDNR

South Carolina's Blue Ridge Mountains and Inner Piedmont Region were formed by multiple orogenic events when rocks forming South Carolina were uplifted, metamorphosed, folded, faulted, and thrusted. More information on the Blue ridge mountains is included on the section for the Appalachian Mountain Range.

Deformation

- **Deformation processes deform or alter the earth's crust by extreme stress or pressure in the crust and mantle.**

- **Most deformation occurs along plate margins from plate tectonic movements. Folding and faulting are the most common deformation processes.**

  - **Folding occurs when rocks are compressed such that the layers buckle and fold.**

  - **Faulting occurs when rocks fracture under the accumulation of extreme stress created by compression and extensional forces.**

Both of these folds are in biotite-rich gneiss from the South Carolina Piedmont, the areas where the folds are most pronounced contain greater amounts of quartz from the granitic composition of the rock. The scale card shows us that the rock on the left contains smaller folds than the rock on the right.

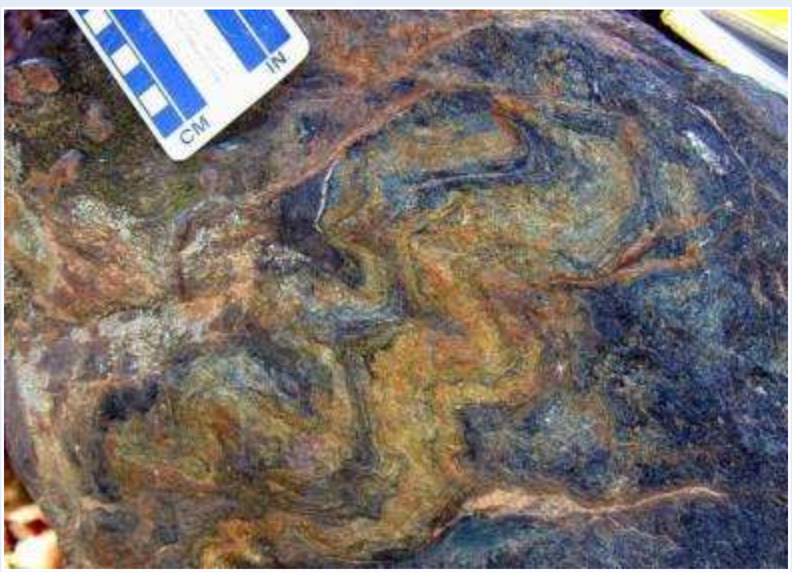


Photo: South Carolina Geological Survey

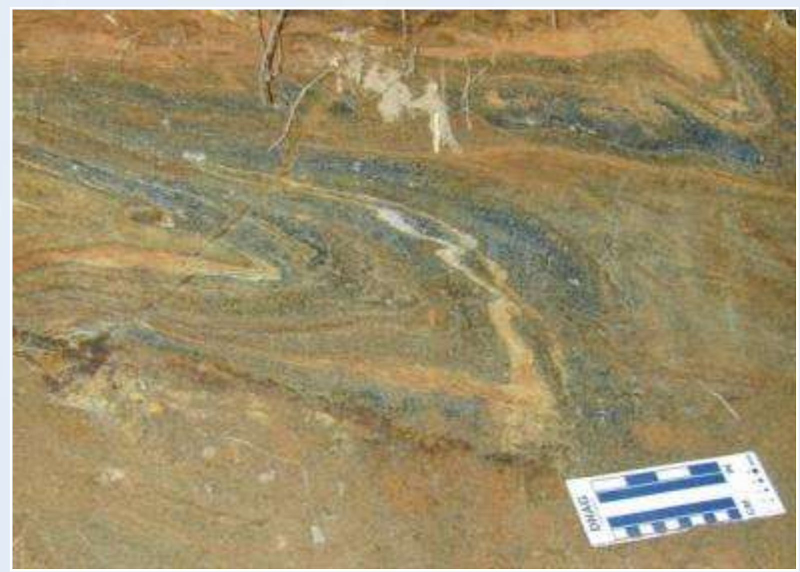
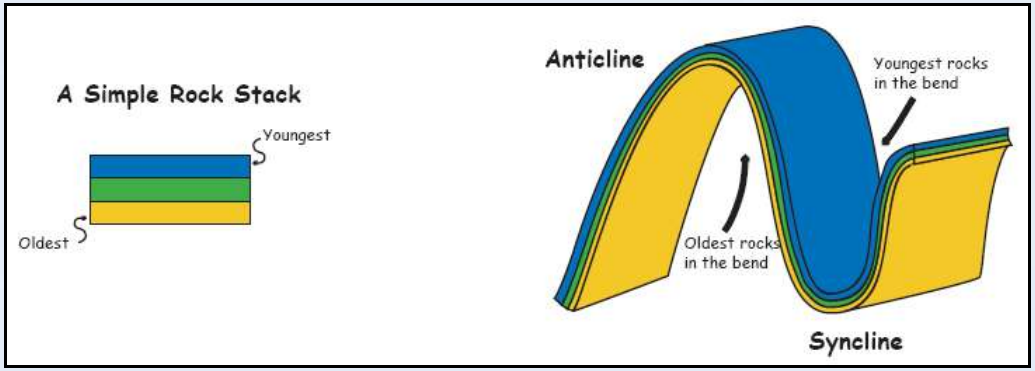


Photo: South Carolina Geological Survey

Folding

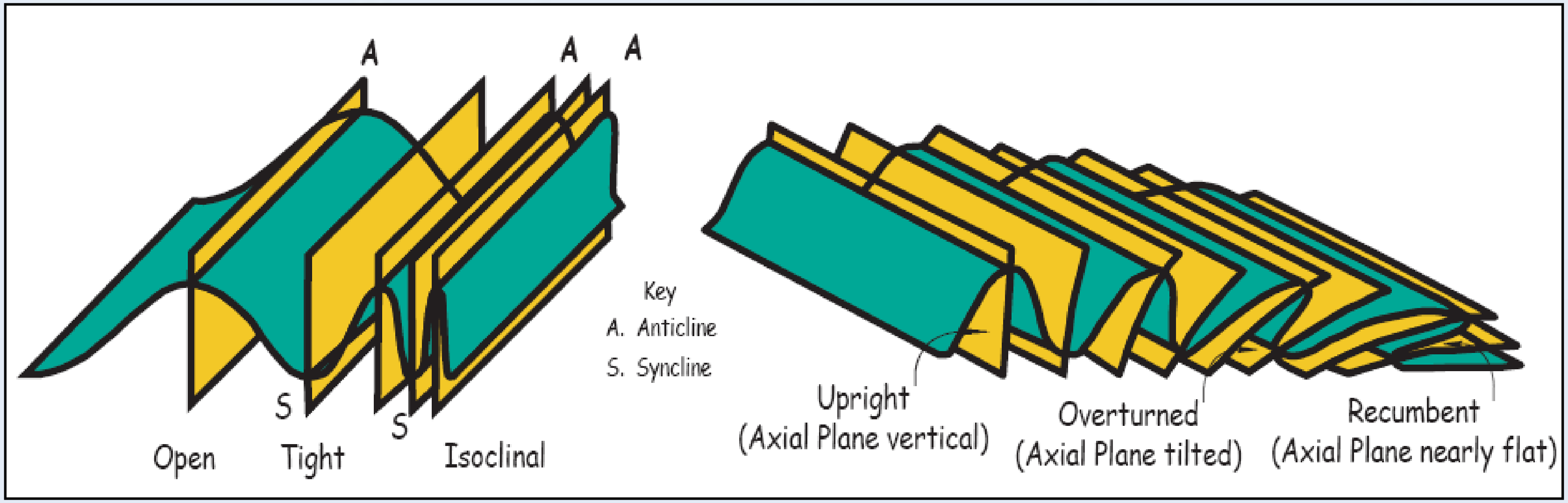
- Folding occurs when rocks are compressed or deformed and they buckle under the stress.
- The diagram below is a cartoon illustrating how rocks fold.

- The crest of the fold, where the rock layers slope downward form the anticline.
- The valley of the fold where the layers slope toward the lower axis form the syncline.



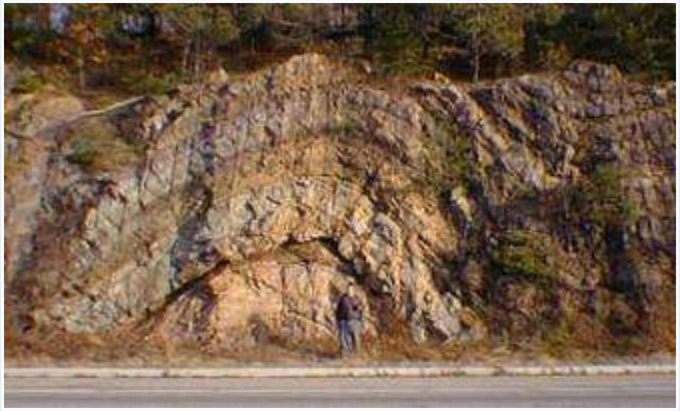
Folding

- Anticlines and synclines can take on slightly different geometries depending on the compressional forces that form them.
- Very intense compressional forces form tight isoclinal folds, less intense compressional forces produce open folds.
- Folds can be asymmetric, upright, overturned, or curved. A fold pushed all the way over onto its side is called recumbent.
- Twisting or tilting during rock deformation and compression can cause folds to form at different angles.
- Some folds are very small and can be viewed in hand held specimens, while other folds are as large as a mountain and can be viewed from aerial photos.



Folding

Anticline exposed along NJ Route 23 near Butler NJ. The man in the bottom of the photo helps show the scale of the folds.

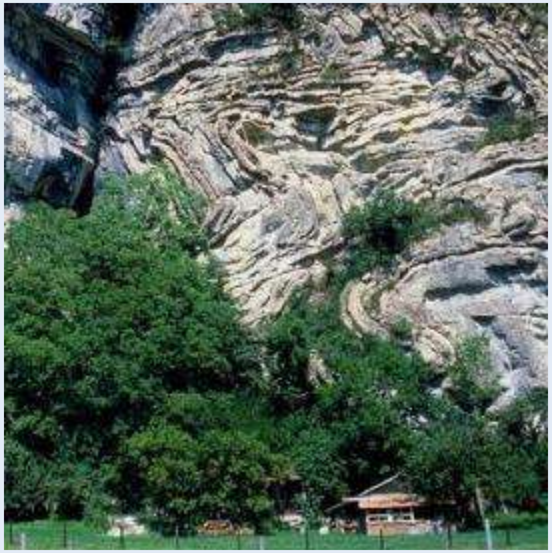


Syncline valley between mountain peaks.

Overturned folds in the Table Rock gneiss in South Carolina’s piedmont. The rock hammer in the photo is used for scale.

SCGS photo

Recumbent folds in limestone.

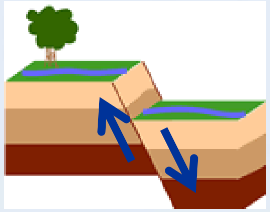


Standard: 8-3.7

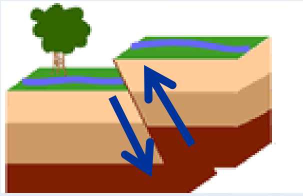
Faulting

- Faulting occurs when the rocks fail under deformation processes. A fault is a planar discontinuity along which displacement of the rocks occurs.
- There are four basic types of faulting: normal, reverse, strike-slip, and oblique.

Normal

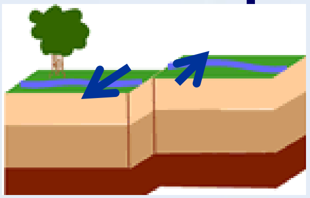


Reverse



1. **Normal**: rocks above the fault plane, or hanging wall, move down relative to the rocks below the fault plane, or footwall.
2. **Reverse**: rocks above the hanging wall moves up relative to the footwall
3. **Strike-slip**: rocks on either side of a nearly vertical fault plane move horizontally
4. **Oblique-slip**: normal or reverse faults have some strike-slip movement, or when strike-slip faults have normal or reverse movement

Strike-Slip



- Geologists recognize faults by looking for off-set rock layers in outcrops.
- Faults may also be recognized by debris, breccia, clay, or rock fragments that break apart or are pulverized during the movement of the rocks along the fault plane. Fault 'gouge' is a term used to describe the material produced by faulting.
- If a fault plane is exposed, there may be grooves, striations (scratches), and slickenslides (symmetrical fractures) that show evidence of the rocks movement.
- Large fault systems, such as the San Andreas fault can be seen from aerial imagery.

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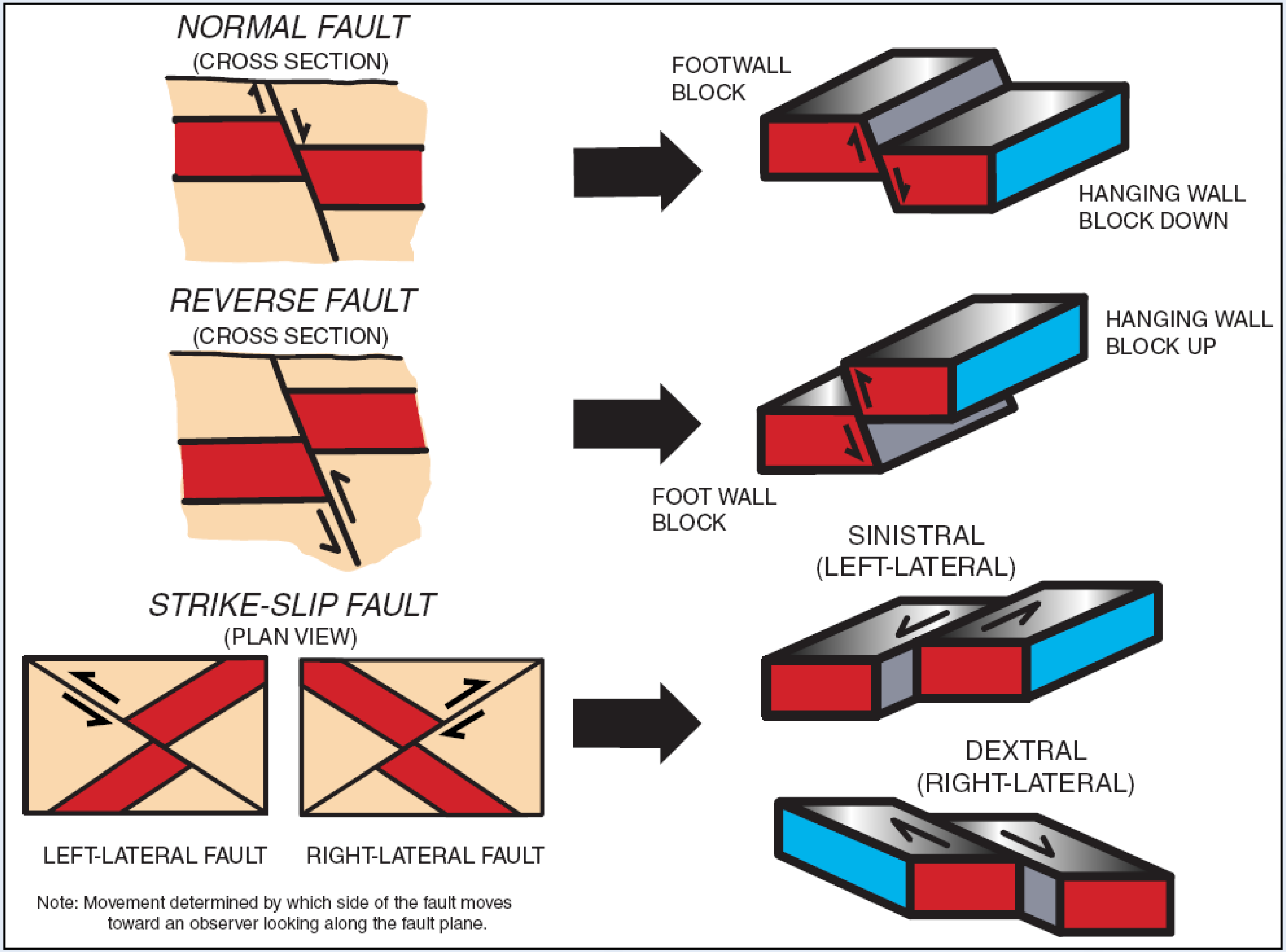
Faulting


NORMAL FAULT
(CROSS SECTION)
FOOTWALL BLOCK
HANGING WALL BLOCK DOWN
REVERSE FAULT
(CROSS SECTION)
HANGING WALL BLOCK UP
FOOT WALL BLOCK
STRIKE-SLIP FAULT
(PLAN VIEW)
SINISTRAL
(LEFT-LATERAL)
DEXTRAL
(RIGHT-LATERAL)
LEFT-LATERAL FAULT
RIGHT-LATERAL FAULT
Note: Movement determined by which side of the fault moves toward an observer looking along the fault plane.

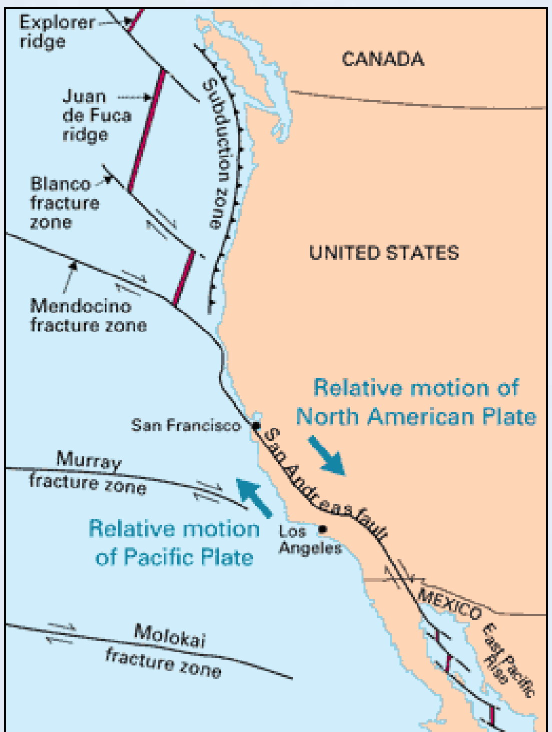
Standard: 3-3.6, 3-3.8
Standard: 8-3.7, 8-3.9

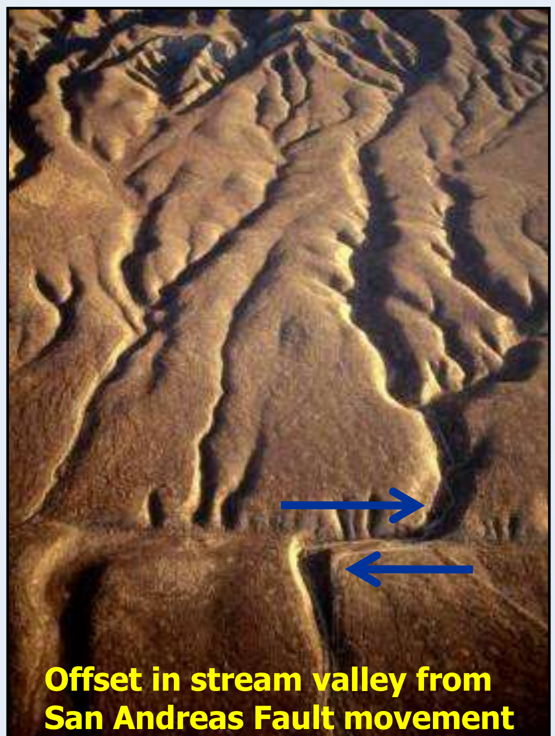
Faulting

The San Andreas fault is the largest fault system in North America and it runs for nearly 780 miles through western California and in some places the width of the fault zone is 60 miles. The San Andreas fault is a transform boundary between the Pacific Plate on the west and the North American Plate to the east. The Pacific Plate is moving northwestward against the North American Plate. This motion generates earthquakes along the fault that pose significant hazards to people and alters the physical landscape.

Photo: South Carolina Geological Survey

These two faults are from South Carolina's Piedmont. These faults are evident by the off-set igneous intrusions in the rock.





Offset in stream valley from San Andreas Fault movement

Copyright © Michael Collier

Photo: South Carolina Geological Survey

Fractures and Joints

- Joints occur where a rock breaks but there is no displacement or faulting associated with the break. Joints are not singular features, but they occur in sets within a given type or area of a rock.
- Fractures are breaks in rocks that are often singular more random features and are not associated with a set of joints. Fractures often occur in association with faults or folds.
- Crustal movements, deformation, or other tectonic related movements can cause rocks to joint or fracture.
- Joints and fractures form from compression, tension, or shear stress and can range in size from millimeters to kilometers.

- Common forms of jointing are columnar, sheet jointing, and tensional joints.
  - Columnar jointing occurs when igneous rocks cool and develop shrinkage joints along pillar-like columns.
  - Sheeting joints occur when the layers of rock release pressure and exfoliate along parallel planes.
  - Brittle fractures and tensional joints are caused by regionally extensive compressional or elongated pressures along folds in the crustal rocks.

- Sometimes, jointing is obvious, but the processes that caused it may be unknown, or difficult to identify.
- Fractures and joints create a variety of pathways for water to flow through, which weaken the rock and facilitate chemical, biological, and mechanical weathering processes.

Jointing

Copyright Larry Fellows, Arizona Geological Survey

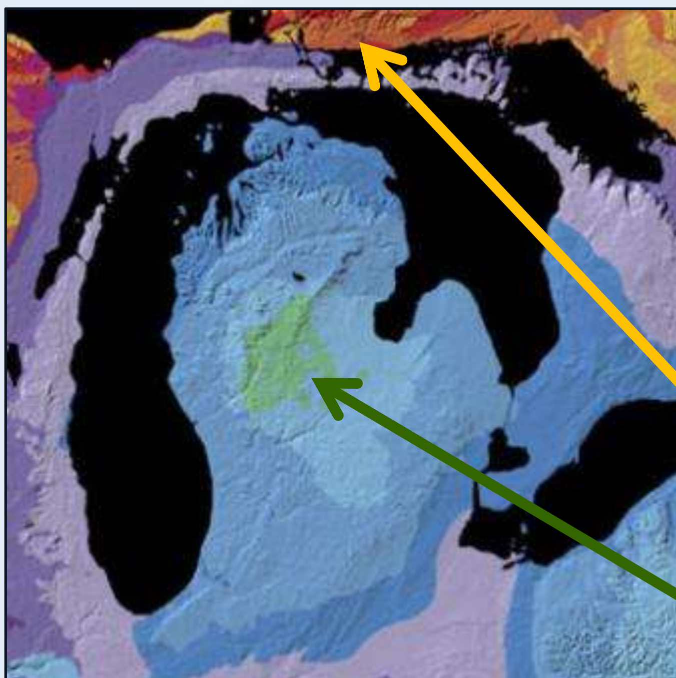
These two images are an example of columnar jointing. The image on the top is a side view and the image below is from the top. These hexagonal columns of rock formed from cooled basalt are part of Devil's Postpile National Monument in California.

The image below is of vertical jointed, bedded meta-sandstone in the Snake Range in Nevada.

Copyright © Bruce Molnia, USGS

Domes and Basins

- Domes and basins are large, elongated folds formed by broad warping processes including mantle convection, isostatic adjustment, or swelling from a hot spot.
- Upwarping produces domes, while downwarping produces basins.
- Geologists identify dome and basin structures by the stratified ages of the rock folds:
  - **Domes** contain strata which increase in age toward the center as the younger layers are eroded from the top and sides.
  - **Basins** contain strata which is youngest toward the center and the oldest rocks form the flanks or sides.



http://en.wikipedia.org/wiki/Michigan_Basin

This geologic map of the Michigan Basin illustrates the circular pattern of the sedimentary strata. The green color in the center of the map represents the youngest rocks which are Upper Pennsylvanian; and the rocks progressively increase in age toward the periphery where the reddish-orange colors represent the oldest rocks flanking this structure which are Ordovician and Cambrian age.

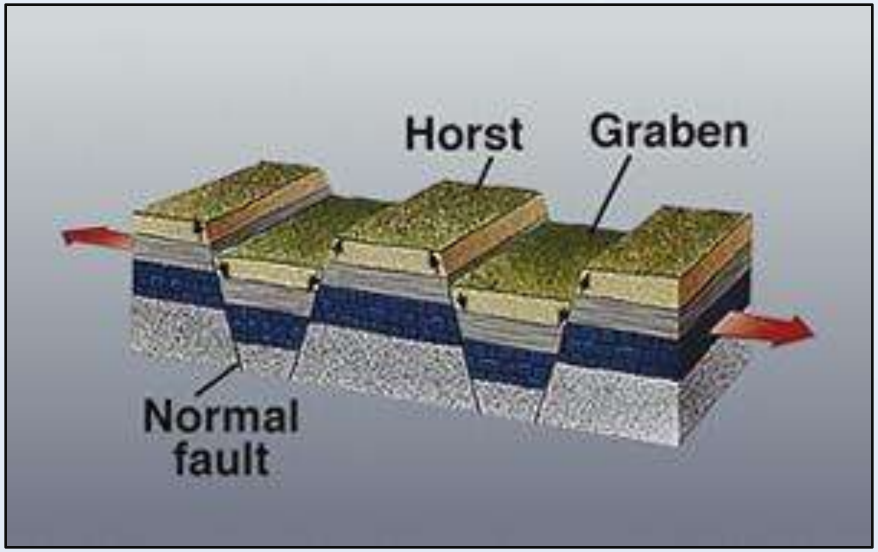
Oldest Rocks (Ordivician and Cambrian)

Youngest rocks (Upper Pennsylvanian)

Standards: 5-3.1
Standards: 8-3.7, 8-3.9

Horst and Graben: Basin and Range

- Horst and graben topography is generated by normal faulting associated with crustal extension.
- The central block termed graben is bounded by normal faults and the graben drops as the crust separates.
- The graben forms an elongated valley that is bound by uplifted ridge-like mountainous structures referred to as horsts.
- Some horsts may tilt slightly producing asymmetric, tilted terrane or mountain ranges.
- In the Western United States, horst and graben fault sequences are described as "Basin and Range" topography.



Basin and Range topography, Nevada.

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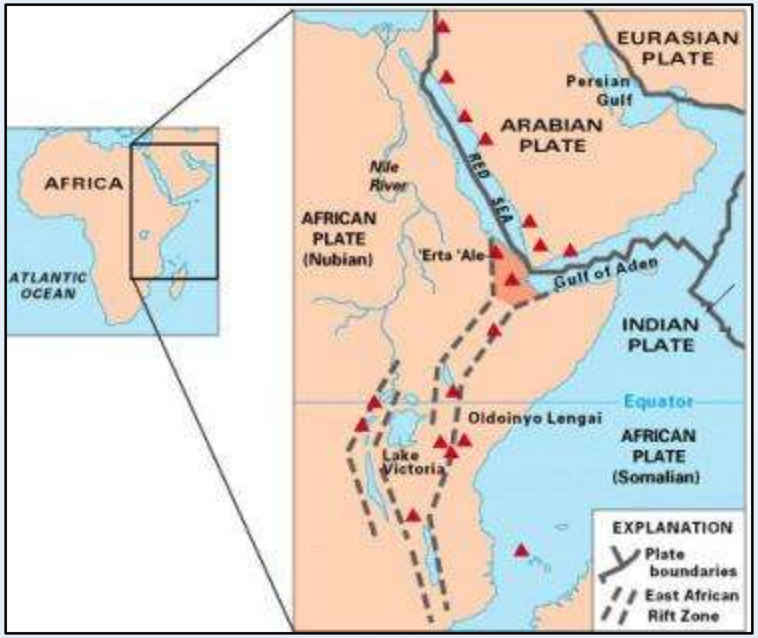
Rift Valleys

- Rift valleys are fault structures formed by normal faults.
- Rising magma below the crust upwells, forcing the lithosphere to fracture, as it fractures and cracks, one or more faults cause the crustal rocks to separate forming a rift valley.
- Rift valleys can eventually form lakes or seas such as the Red Sea, which separates Africa from the Arabian Peninsula. Rift valleys can become inactive and fill in with volcanic material, such as the rift structure in the United States which extends from Lake Superior to Oklahoma.

Rift Valleys in Africa

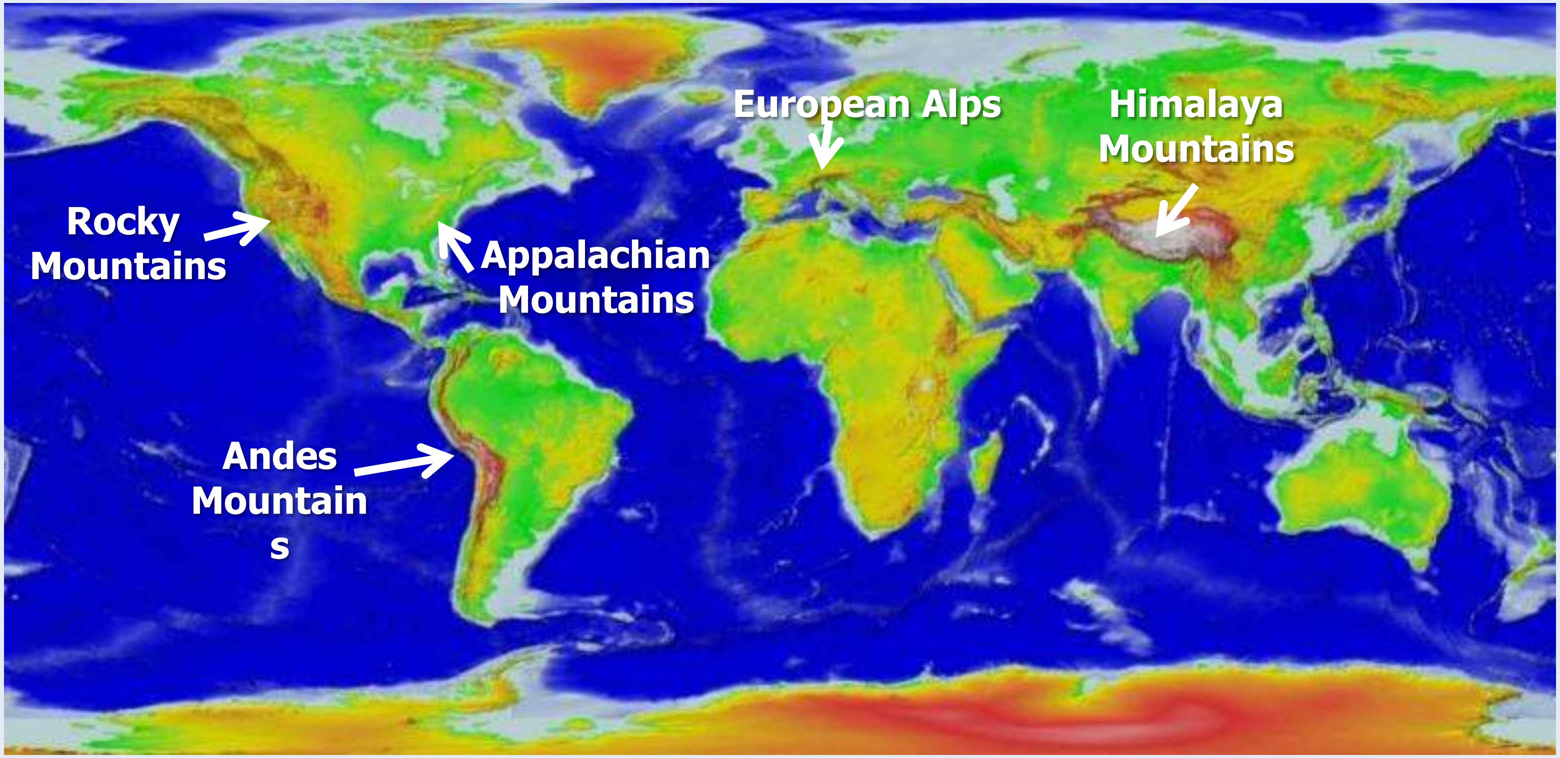


East African Rift Valley Lake

www.visibleearth.nasa.gov

Major Mountain Ranges of the World

- Antarctica: Antarctic Peninsula, Transantarctic Mountains
- Africa: Atlas, Eastern African Highlands, Ethiopian Highlands
- Asian: Himalayas, Taurus, Elburz, Japanese Mountains
- Australia: MacDonnell Mountains
- Europe: Pyrenees, Alps, Carpathians, Apennines, Urals, Balkan Mountains
- North American: Appalachians, Sierra Nevada, Rocky Mountains, Laurentides
- South American: Andes, Brazilian Highlands



Standards: 3-3.6
Standards: 5-3.1
Standards: 8-3.7, 8-3.9

Rocky Mountains

- The Rocky Mountains, which extend from British Columbia to Texas were formed by the Laramide Orogeny 40-80 million years ago; however, there is still active uplift today.
- Colorado's Front Range, the Sangre de Cristo Mountains of Colorado and New Mexico, the Franklin Mountains in Texas, and Wyoming's Bighorn Mountains are all part of the "Rocky Mountain Range".

Source: USGS

The Laramide Orogeny was characterized by intense tectonic activity resulting from a series of compressional and extensional events. The subduction of the Pacific Ocean Plate caused compressional forces in the continental plate, and pushed the oceanic plate downward. Following subduction of the oceanic plate, upwelling and extensional forces caused the literal uplift of the continental bedrock and formed of the Rocky Mountains. The lower crust in this region of upwelling and uplifting is relatively thin and stretches under pressure. The upper crust is very brittle and deforms easily. As a result the upper crust is characterized by large angular tilted faults blocks which form the Rocky Mountains we see today.

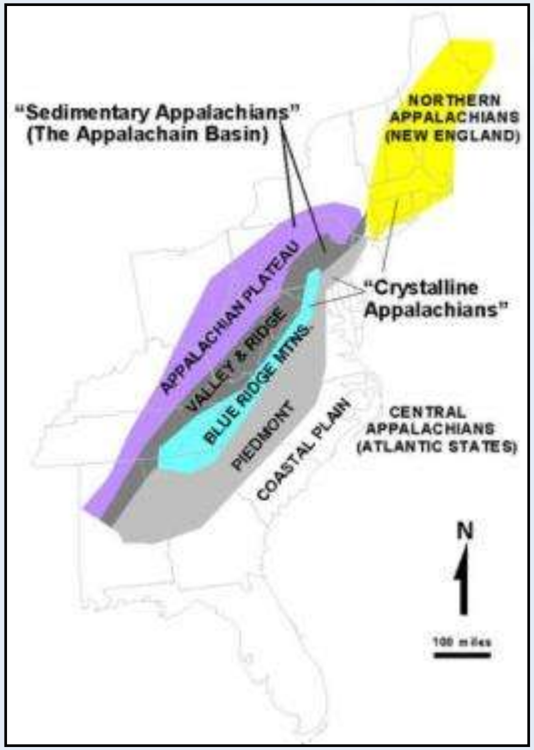
The Rocky Mountains contain some of the most beautiful scenery in North America and are home to hundreds of parks and recreational areas including Rocky Mountain National Park, Yosemite National Park, Glacier National Park, and Grand Tetons National Park.

Copyright© Dr. Roger Slatt, University of Oklahoma

Standards: 3-3.6
Standards: 5-3.1
Standards: 8-3.7, 8-3.9

Appalachian Mountains

- The Appalachian Mountains extend along the eastern margin of North America from Alabama to Maine in the United States, and through the southeastern provinces of Canada to Newfoundland.
- The Appalachian Mountains were formed during the Paleozoic Era from several orogenic episodes, the Taconic Orogeny (Ordovician ~480 mya), followed by the Acadian Orogeny (Devonian ~400 mya), and lastly the Alleghany Orogeny (Permian ~ 300 mya).
- Each of these major orogenic episodes involved multiple events of folding, faulting, metamorphism, emplacements of igneous intrusions, and uplift.
- The Appalachian Mountains are divided into four major provinces: Piedmont, Blue Ridge, Valley and Ridge, and Appalachian Plateau.



Source: USGS

Waterfall carved into valley of Blue Ridge Province of the Appalachians near the South Carolina and North Carolina border.

Source: SCGS

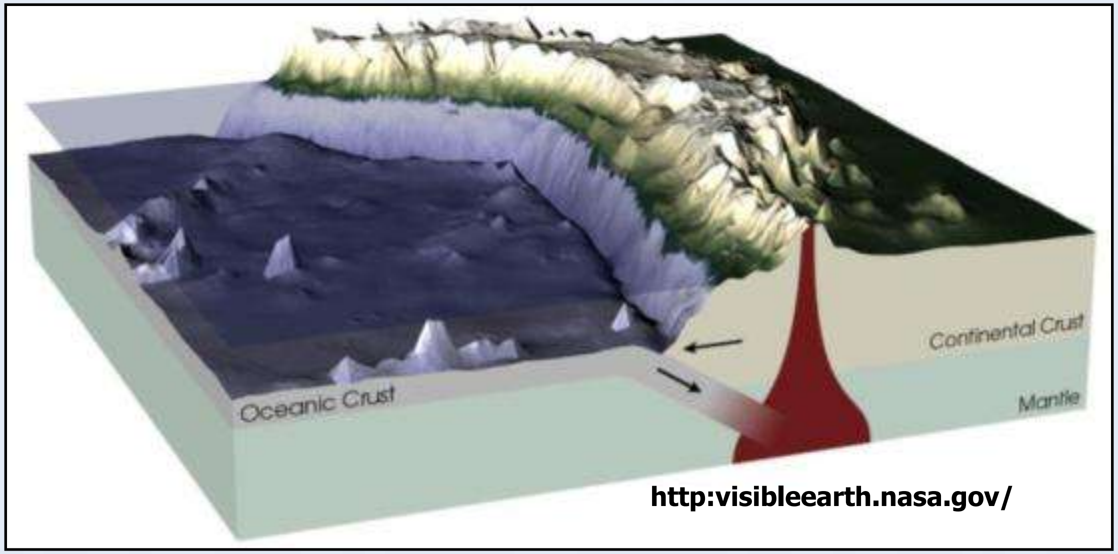
www. maps.google.com

This is an aerial view of the Susquehanna River in Pennsylvania flowing through the folded and faulted Valley and Ridge Province of the Appalachian Mountains.

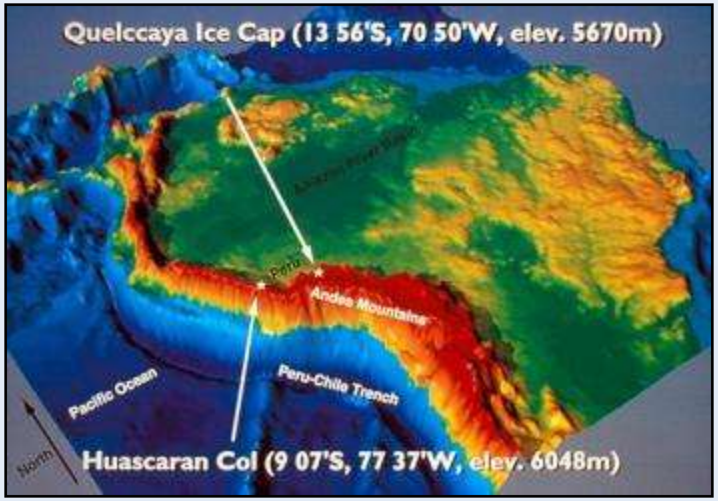
Standards: 3-3.6
Standards: 5-3.1
Standards: 8-3.7, 8-3.9

Andes Mountains

- The Andes Mountains began forming during the Jurrasic period (~200 mya) when plate tectonics forced the oceanic Nazca plate to subduct beneath the continental South American plate.
- The subduction zone between the plate margins marks the Peru-Chile ocean trench which is 26,500 ft (8,065 meters) below sea level.
- Tectonic forces along this active continental margin are forcing the ongoing uplift, folding, faulting, and thrusting of bedrock forming the Andes Mountains.
- The Andes are the longest mountain range on land and they extend along the entire western coast of South America. They are divide into three sections: (1) Southern Andes in Argentina and Chile, (2) Central Andes including the Chilean and Peruvian cordilleras an parts of Bolivia, and (3) Northern sections in Venezuela, Columbia, and Ecuador, including to parallel ranges the Cordillera Occidental and the Cordillera Oriental.
- The Andes Mountains contain many active volcanoes, including Cotopaxi in Ecuador, one of the largest active volcanoes in the world.



http:visibleearth.nasa.gov/



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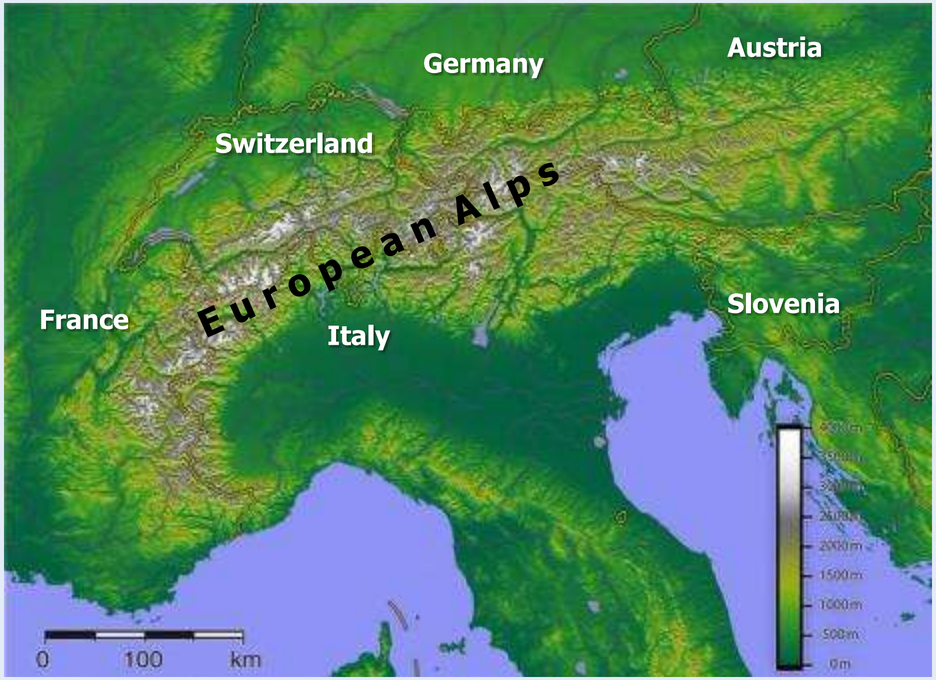
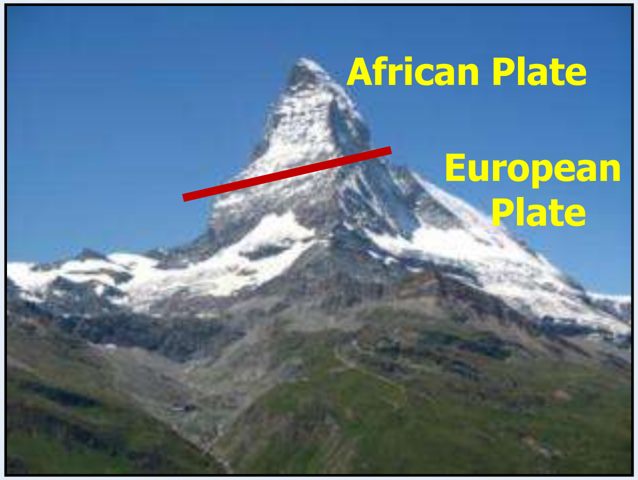
Standards: 5-3.1
Standards: 8-3.7, 8-3.9

European Alps

- The European Alps began forming during the Alpine Orogeny (~ 20-120 mya) with the collision of the African Plate moving northward into the European Plate. This motion is still active today as the Alps continue to uplift, fold, fault, and accrete.
- The Alps are the largest mountain range in Europe and they extend from Austria and Slovenia in the east, through Italy, Switzerland, Germany, and France in the west.
- Major orogenic events involved recumbent folding and thrust faulting of crystalline basement rocks that today form some of the highest peaks in the Alps.
- The Alps were one of the first mountain ranges to be studied by geologists and as a result many geomorphic terms, especially those relating to glaciation and 'alpine' environments, were first defined in the European Alps.



Modified from: http://en.wikipedia.org/wiki/Alps



http://en.wikipedia.org/wiki/Matterhorn

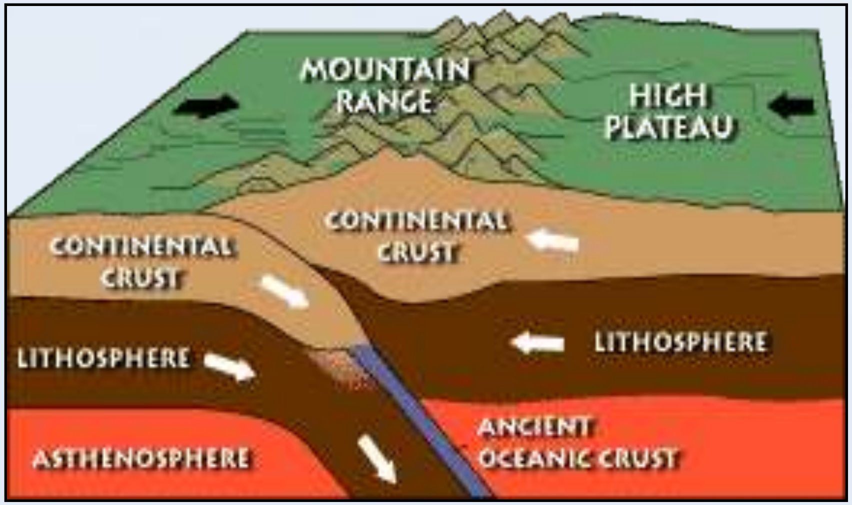
The Matterhorn, on the border between Switzerland an Italy, is one of the most familiar mountains in the world and is a popular climbing site. The continent-continent collision resulted in the peak of the Matterhorn containing bedrock from the African Plate while the lower portions contain bedrock from the European Plate.

Standards: 3-3.6
Standards: 5-3.1
Standards: 8-3.7, 8-3.9

Himalaya Mountains

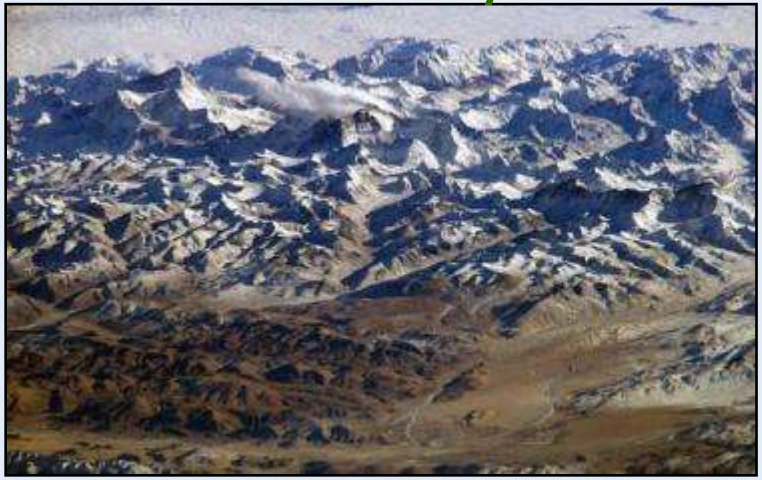
- Himalaya orogeny began 45-54 million years ago from the collision between the India and Eurasian Plates and is still active today.
- When two continental plates collide, the Earth's crust at the plate boundaries is folded, faulted, overthrusted, uplifted forming an extensive continental mountain range.
- Today, the Himalayas separate the Indian sub-continent from the Tibetan Plateau and they are recognized as the tallest above sea level mountains on Earth. The Himalayas contain 10 of the tallest mountain peaks on Earth >8,000 meters , including Mount Everest with a peak of 8850 meters (29,035 ft). In addition, the Himalayas include three major individual mountain ranges, the Karakoram, Hindu Kush, and Toba Kakar.
- Shallow, intermediate, and deep earthquakes are associated with this zone, and scientists predict that several major earthquakes will occur in the region posing a significant hazard to millions of people.

Continental – Continental Plate Collision



www.usgs.gov

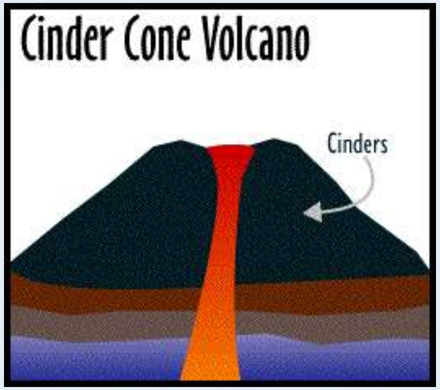
The name Himalaya is from Sanskirt, and it means "the abode of snow". 'Hima' for snow and 'alaya' for abode.

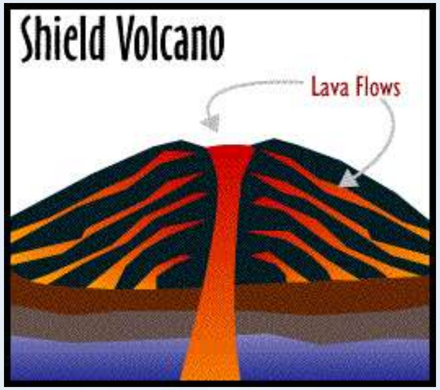


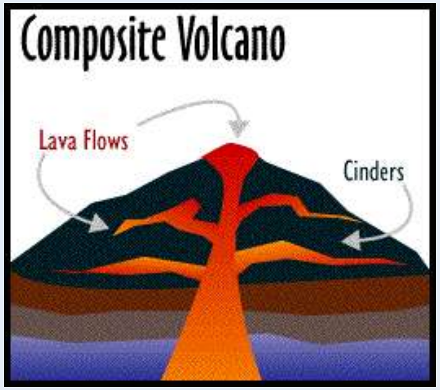
http://en.wikipedia.org/wiki/Image:Himalayas.jpg

Volcanic Landforms: Extrusive Igneous

- Cinder Cones
- Shield Volcanoes
- Strato (Composite)Volcanoes
- Lava Domes
- Caldera
- Volcanic Necks
- Volcanic Hot-Spots







Standards: 3-3.6, 3-3.8
Standards: 5-3.1
Standards: 8-3.7, 8-3.9

Cinder Cones

- Cinder cones are relatively small cone shaped hills (≤ 2000 ft of relief) formed by the accumulation of cinders and ash during volcanic eruptions. The cinders form from bursting bubbles of gas in the magma that eject lava into the air. The summit my be truncated or bowl-shaped where the magma emerges from a single central vent or volcanic neck.
- Cinder cones are formed from an accumulation of ejected tephra and scoria rocks. Tephra and scoria occur in a range of different sizes from fine ashes to large volcanic rock fragments. Once the magma is ejected into the air, it cools, hardens, and is deposited on the summit or slopes of the cinder cone. The pyroclastic tephra and scoria rocks are produced from gas-rich basaltic magma, and is usually reddish-brown to black in color.
- Cinder cones generally form from a single volcanic episode and are rarely associated with eruptions lasting more than a decade.
- Cinder cones can be found in combination with shield and strato volcanos and can occur at convergent or divergent plate boundaries.
- Cinder cones are the most common type of volcano and often occur in large numbers within a region forming 'volcano fields'. Flagstaff Arizona contains a volcanic field of nearly 600 cinder cones.

Cinder cones have an easily recognizable hill shape form with relatively steep 30-40 degree slopes. This angle represents the steepest angle maintained by unconsolidated, loose material and is commonly referred to as the angle of repose. This image is of an older cinder cone with small caldera depression on the summit.

Standards: 3-3.6, 3-3.8
Standards: 5-3.1
Standards: 8-3.7, 8-3.9

Shield Volcanoes

- Shield volcanoes are broad shaped mountain landforms built by the accumulation of fluid basaltic lava. Their slopes are often very gentle and may be < 5 degrees, and their summits, or peaks, are relatively flat. They received their name because their gently domed form resembles the exterior of a warrior's shield.
- Most shield volcanoes originate from the ocean floor and have 'grown' to form islands or seamounts. Hawaii and the Galapagos Islands are examples of shield volcanoes that formed in the ocean and emerged as mountainous, island landforms.
- Magma, or lava, discharges from both the summit and rifts along the slopes. Most lava that forms shield volcanoes erupts as a flow from fissures; however, occasional high intensity pyroclastic ejections may occur.
- Shield volcanoes usually have either smooth, ropy pahoehoe lava, or blocky, sharp aa lava.
- Shield volcanoes form the largest volcanoes on Earth.

Photo: D. Little, USGS

Mauna Loa Volcano on Hawaii is a shield volcano and the lava flow below illustrates a typical eruption for a shield volcano.

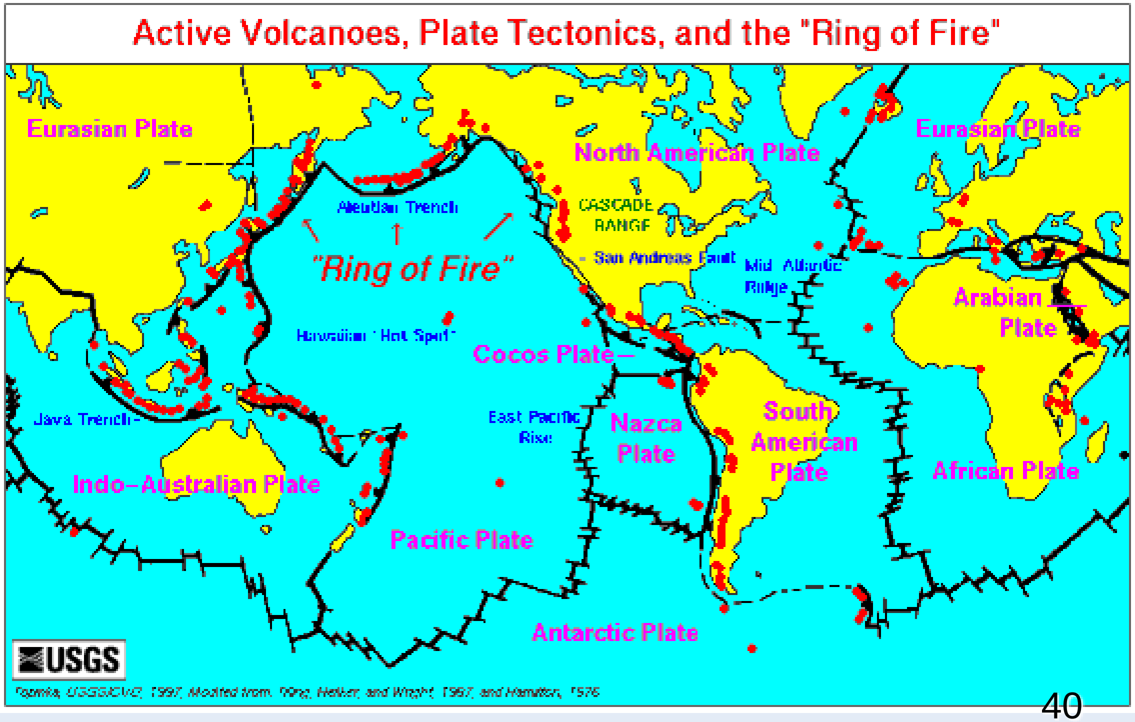
Courtesy USGS Hawaiian Volcano Observatory

Strato Volcanoes

- Strato-volcanoes, also referred to as composite cones, are large, nearly symmetrical mountainous landforms, formed by a combination of lava flows and intense pyroclastic eruptions.
- Eruptions are violent and the ejected material is primarily a gas-rich, high viscosity (resistance to flow) magma with an andesitic composition. Eruptions can also produce extensive ash deposits.
- Most strato volcanoes are located along the *ring of fire* which is a geographic zone that rims the Pacific Plate where it is in contact with the Eurasian, North American, and Indo-Australian Plate.
- Well-known strato volcanoes occur in the Andes, the Cascade Range of the United States and Canada (including Mount St. Helens, Mount Ranier, and Mount Garibaldi), and the volcanic islands of the western Pacific from the Aleutian Islands to Japan, the Philippines, and New Zealand.

Mount St. Helens 1980 eruption

USGS Cascades Volcano Observatory

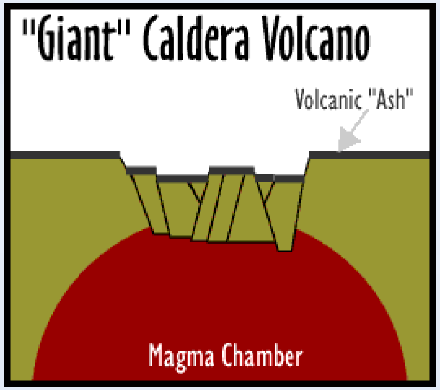


Caldera

- Calderas are bowl-shaped collapse depressions formed by volcanic processes.
- Calderas most likely result from one of three collapse type events:
  - 1. Collapse of the summit following an explosive eruption of silica-rich pumice and ash pyroclastics
  - 2. Collapse of the summit following the subterranean or fissure drainage of the magma chamber
  - 3. Collapse of a large area following the discharge of silica-rich pumice and ash along ring fractures that may or may not have been previously active volcanoes
- Crater Lake in Oregon is an example of a 700 year old caldera that formed from the eruption and collapse of Mount Mazama. Today it is filed in with rainwater and forms a lake. A small cinder cone, named Wizard Island, formed inside the caldera and today it emerges as an island in the lake.
- Many of the calderas on Hawaiian volcanoes formed after the magma drained through fissures in the central magma chamber and the summit eventually collapses.
- Yellowstone National Park contains a caldera that is >43 miles across and was formed by an intense pyroclastic eruption that ejected ash fragments as far as the gulf of Mexico.

Copyright Larry Fellows, USGS

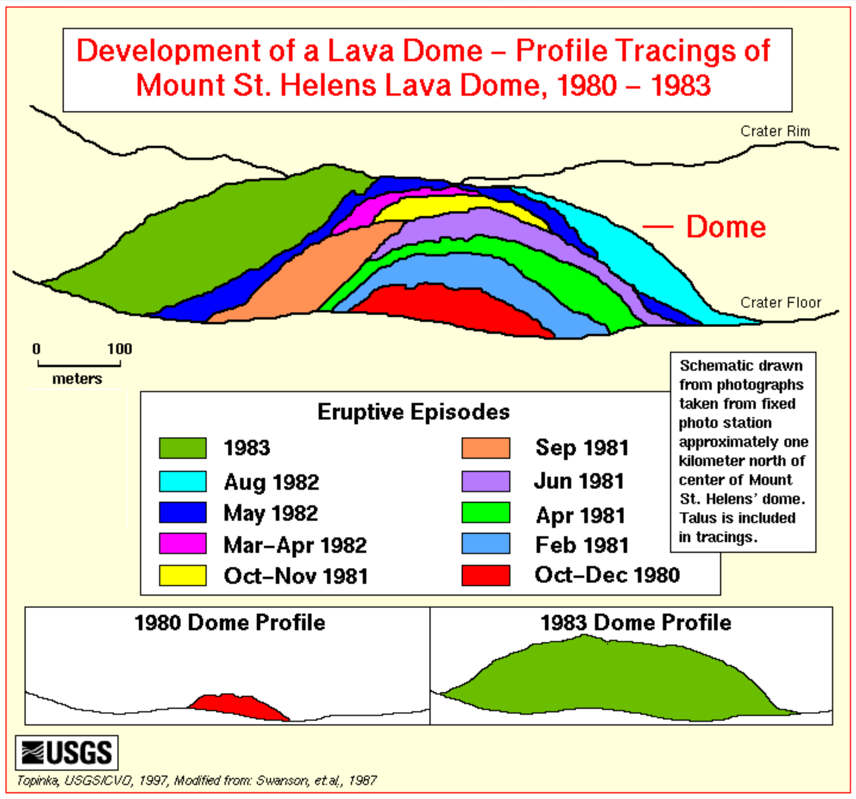
Crater Lake in Oregon is the collapsed caldera of Mount Mazama and is now filled in with water. Wizard Island is a volcanic cone in the middle of the lake. Crater Lake is the deepest lake in the United States at 1,932 feet deep!



Standards: 3-3.6, 3-3.8
Standards: 5-3.1
Standards: 8-3.7, 8-3.9

Lava Domes

- Lava domes are rounded, steep-sided mounds built by very viscous magma that is resistant to flow and builds up forming a dome.
- The magma does not move far from the vent before cooling and it crystallizes in very rough, angular basaltic rocks.
- A single lava dome may be formed by multiple lava flows that accumulate over time.

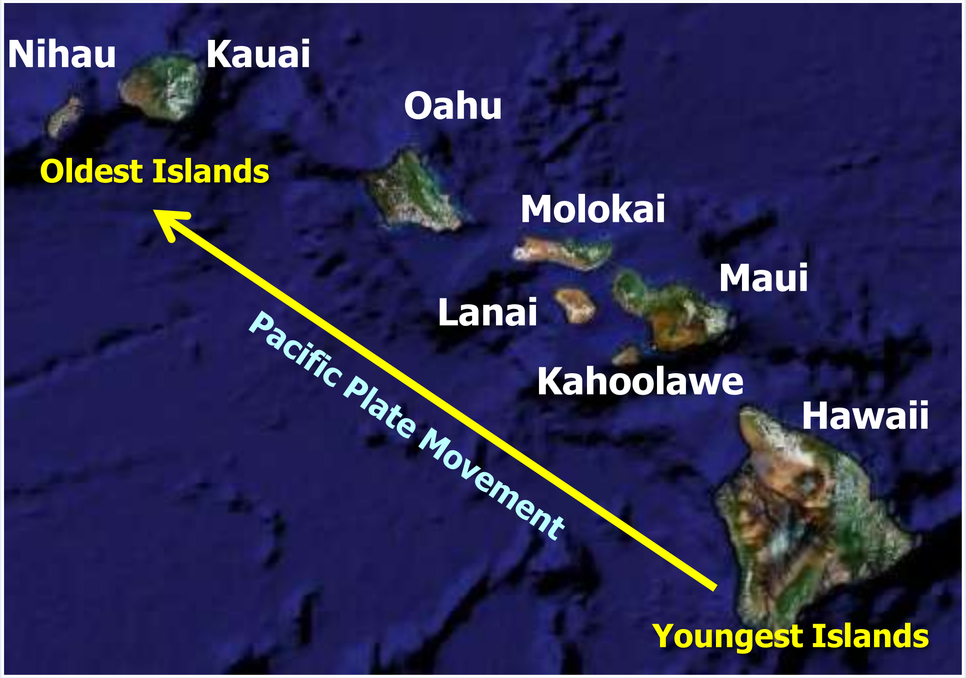


This lava dome began forming after the Mount St. Helen's eruption in 1980. Geologists set up a monitoring station to measure the growth of this lava dome and recorded that it is growing at a rate of about 40 feet per year.

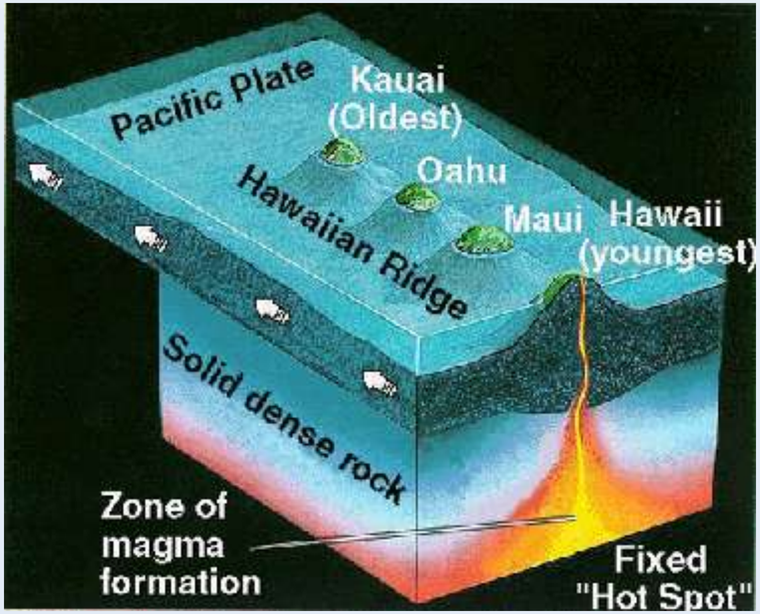
Standards: 3-3.6, 3-3.8
Standards: 5-3.1
Standards: 8-3.7, 8-3.9

Volcanic Hot Spots

- Volcanic hot-spots occur where a mass of magma ascends toward the earth's surface as a mantle plume, releasing basaltic magma that generates volcanic activity at a locally specific site.
- Hot-spots do not occur along plate boundaries but instead form as intraplate volcanic features characterized by magma upwelling. Once a hot spot is generated it may stay active for millions of years.
- Hot spots may produce thermal effects in the ground water and the crust producing geothermal power often in the form of steam. In Iceland and Italy geothermal power is used to generate electricity for industrial and municipal use.
- The Hawaiian Islands formed over the last 5 million years from a hot spot in the Pacific Ocean. As the Pacific plate moves over the hotspot, it generates a chain of islands that emerge as seamounts above the ocean's surface. Hot spot activity is currently most active on the big island, Hawaii.



www.maps.google.com



www.usgs.gov

Volcanic Necks

- Volcanic necks are remnant cooled lava pipes that are exposed after the exterior volcanic mountain is weathered and eroded.
- Volcanic necks are a good example of differential weathering. The magma cooled in the interior pipes is more resistant than the ejected deposits that accumulate on the exterior. As a result, when the volcanic mountain erodes, it leaves behind the remnant more resistant volcanic neck.

Shiprock is a volcanic neck of a solidified lava core from a dormant 40-million year old volcano. Its elevation is 7,178 feet above sea level with a local relief of 1,800 feet. It lies southwest of the town of Shiprock, New Mexico, and was named after 19th -century clipper ships.

Standards: 3-3.6, 3-3.8
Standards: 5-3.1
Standards: 8-3.7, 8-3.9

Flood Basalts

- Flood basalts, also referred to as plateau basalts, are massive accumulations of basaltic lava that are molten enough to flow for miles before cooling.
- Flood basalts form from lava released from fissures in the crust, and are not produced by classic volcanic mountain-related eruptions.
- The Columbia Plateau in northwest United States was formed when multiple fissures released successive lava flows producing regionally extensive flood basalts.

Photo courtesy: Stephen Riedel

The Columbia River Flood Basalt Province spans Idaho, Washington, and Oregon in the United States. The flood-basalt plateaus were formed by multiple extensive lava flows that accumulated over millions of years. Today the landscape is dissected by rivers and valleys and the individual layers of basalts are exposed. This image shows two major basalt layers, the Grande Basalt and the Imnahu Basalt.

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Standards: 5-3.1
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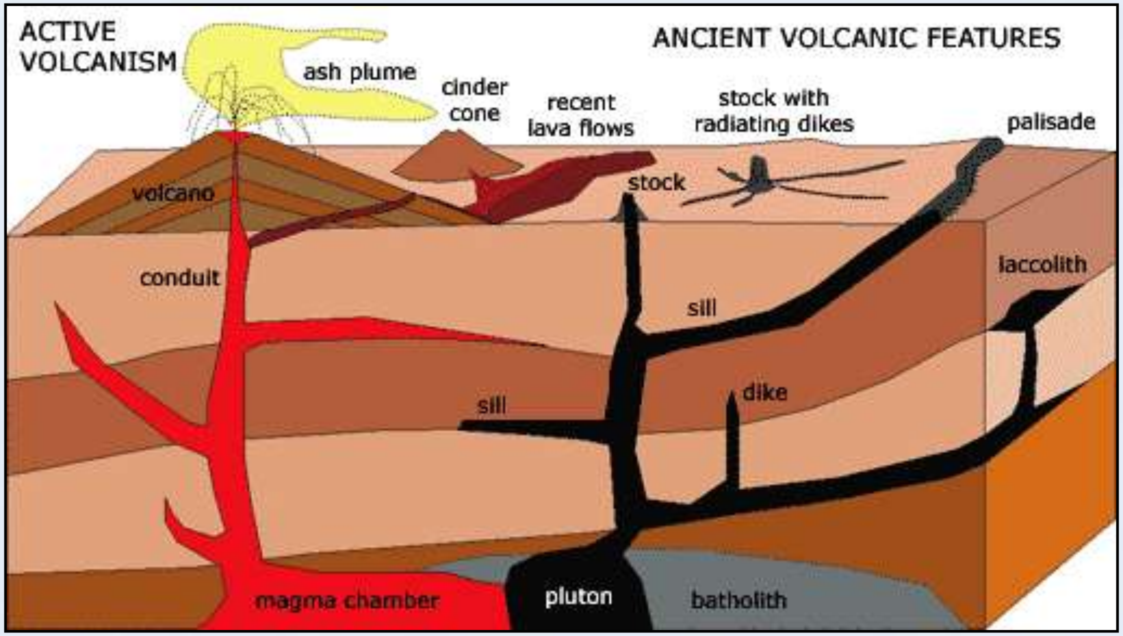
Volcanic Landforms: Intrusive Igneous

- Batholiths
- Plutons
- Stocks
- Monadnocks
- Laccoliths
- Dikes
- Sills
- Veins



Source: USGS

Standards: 3-3.6, 3-3.8
Standards: 5-3.1
Standards: 8-3.7, 8-3.9

Batholith

- Batholiths are massive igneous intrusions that form linear bodies that extend for hundreds of kilometers across the landscape and can be several kilometers thick.
- Some batholiths may incorporate groups of smaller plutons in addition to their massive structure.
- Batholiths form below the earth's surface as intrusions of magma emplaced during tectonic processes. Following emplacement they may be uplifted and exposed by weathering and erosion processes.
- Some batholiths are metamorphosed by heat and pressure. For example, many of the batholiths in the Appalachian Mountains are metamorphosed igneous intrusions.

Half Dome is a granitic igneous intrusion that forms an impressive mountain peak that is part of the greater Sierra Nevada Batholith in Yosemite National Park. The 'Half Dome' shape was carved by glacial erosion. The Sierra Nevada Batholith, which includes Half Dome, Mt. Whitney, and El Capitan, became exposed as the mountains uplifted and weathering and erosion removed the material surrounding the batholith.

Standards: 3-3.6, 3-3.8
Standards: 5-3.1
Standards: 8-3.7, 8-3.9

Plutons

- Plutons are intrusive igneous rocks which form below the Earth’s surface and are surrounded by sedimentary or metamorphic rocks.
- Plutons are formed as magma forces its way up through other rocks and solidifies before reaching the surface.
- Some plutons are remnant magma chambers that once fueled volcanic activity.
- Plutons become exposed on the landscape as the other rocks surrounding them are removed by weathering and erosion.
- Some plutons appear as small or large hills while others appear as tabular, flat rock exposures.

http://en.wikipedia.org/wiki/Image:Enchanted_rock_2006.jpg

Enchanted Rock is a large granitic pluton in the Llano Uplift of the Texas Hill Country Region that is part of a larger igneous batholith.

Standards: 3-3.6, 3-3.8
Standards: 5-3.1
Standards: 8-3.7, 8-3.9

Sills, Laccoliths, and Dikes

- Sills and laccoliths are igneous intrusions that form near the earth's surface. They are concordant features meaning that they form parallel to existing strata or structures.
- Sills form near the surface from very fluid magma that cools quickly they are usually mostly basaltic rocks with an aphanitic (fine-grained) texture.
- Laccoliths are similar to sills, accept they are formed by more viscous magma which collects in a lens shape prior to cooling as a concordant igneous intrusion near the surface. This process may force the overlaying strata to form a slightly domed structure over the bulging laccolith.
- Dikes are tabular intrusions of igneous rock that form when magma injects into fractures. Dikes are discordant features, meaning that they cut through layers of rock.
- Magma can force the rock apart separating the fracture.
- The cooled magma can range in thickness from centimeters to kilometers and may be more resistant to erosion than the surrounding rocks enabling them to protrude outward amidst their surroundings.

http://en.wikipedia.org/wiki/sill

Salisbury Craig is an exposed sill north of Edinburg, Scotland that forms a resistant cap on this hill top.

The dark linear feature in this image is an exposed dike that is more resistant to weathering and erosion than the surrounding landscape.

Standards: 3-3.6, 3-3.8
Standards: 5-3.1
Standards: 8-3.7, 8-3.9

Monadnocks

- Monadnocks are large hills or mountains of bedrock that stand out in the landscape.
- Monadnocks persist in the landscape because they consist of a more resistant rock material than the surrounding rock types which have been weathered and eroded away.
- In South Carolina, most monadnocks consist primarily of metamorphosed igneous intrusions, which are more resistant to weathering than the surrounding rocks. Little Mountain, Table Rock, Caesar's Head, and Glassy Mountain, are all examples of monadnocks in South Carolina.

Source: SCGS

Table Rock in South Carolina is an example of a monadnock landform. It's geologic history indicates that is was emplaced as an igneous intrusion during the Paleozoic, and it was later metamorphosed during the building of the Appalachian Mountains. Millions of years of weathering and erosion of the surrounding rock have enabled Table Rock to persist as a resistant outcrop at the edge of South Carolina's Piedmont.

Standards: 3-3.5, 3-3.6, 3-3.8
Standards: 5-3.1
Standards: 8-3.7, 8-3.9

River Systems and Fluvial Landforms

Photo: SCGS

The Congaree River in South Carolina is home to Congaree National Park which is a large flood plain ecosystem that protects some of the oldest and largest bottomland hardwood forests in the nation. Almost every year the Congaree River floods the National Park providing water, sediments, and nutrients that support the incredible growth of the forest and rich biodiversity of organisms.

Standards: 3-3.5, 3-3.6, 3-3.8
Standards: 5-3.1
Standards: 8-3.7, 8-3.9

River Systems and Fluvial Processes

- Rivers are one of the most dominant agents of landscape change because their flowing waters are continually eroding, transporting, and depositing sediments.
- Rivers are critically important to people because they provide fresh drinking water, transportation of people, goods, and wastes, hydro-electric power generation, irrigation, and recreation.
- Rivers, although very important to people, are also very dangerous because flooding is among one of the most frequent and widespread natural hazards that can damage or destroy land, property, and life.
- Because rivers systems are so important to humans, it is necessary for scientists to understand how rivers affect the landscape and also how humans affects rivers. Having this information enables people to better manage for future water resource needs and prevent hazardous situations.




Image Source: SCGS

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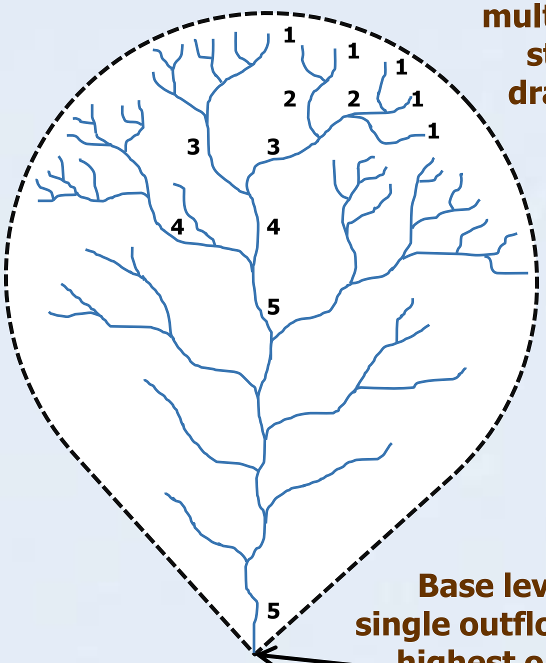
Longitudinal Profile and Watersheds

- The **longitudinal profile** of a river is an elevation cross-section of the entire watershed from the source of flowing water to the mouth of the stream.
  - The source area of flowing water is defined as the **headwaters**. Headwaters are the highest elevation where water collects to form a stream network and is generally formed by either snow-melt runoff, a natural spring, or rainwater.
  - The mouth of the stream is typically defined by the stream's ultimate **base level**, and this generally corresponds with the sea level where the river meets the ocean. Base level is the lowest elevation that a stream can erode its channel. Local or temporary base levels may be formed by reservoirs or waterfalls.
  - A river's gradient (slope) is steepest near the headwaters and gentlest near the mouth.
  - As rivers flow from their headwaters to their base level they carve valleys into the landscape by eroding, transporting, and depositing weathered rocks, soil, and sediment.
- A **watershed** or **basin** is the area of land bound by a local elevation ridge, referred to as a **drainage divide**, where all the water within that area drains downstream from its headwaters to a single outflow location. A watershed can include an entire river system from it headwaters to ultimate base level, or smaller watersheds can encompass tributary sub-basins that are part of the larger watershed.
- Drainage divides are high elevation ridges that separate one watershed from another.

Standards: 5-3
Standards: 8-3

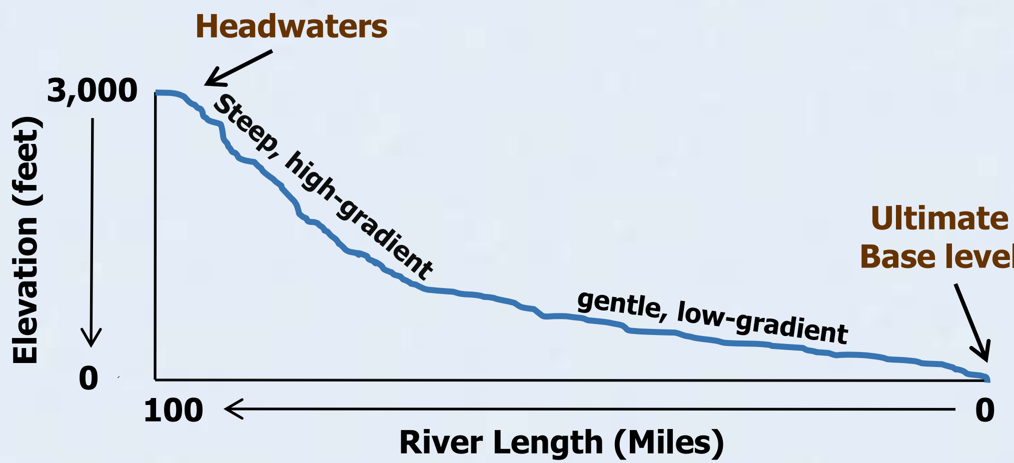
Longitudinal Profile and Watersheds



Stream Order:
1^{st} order and 1^{st} order = 2^{nd} order
2^{nd} order and 2^{nd} order = 3^{rd} order
3^{rd} order and 3^{rd} order = 4^{th} order
4^{th} order and 4^{th} order = 5^{th} order
And so on, 5 and 5 =6, 6 and 6 =7^{th} order…

This figure is a hypothetical river basin. The black dotted line represents the drainage divide and the numbers refer to stream order. Any rainfall that falls within the black dotted line will eventually flow into the main stem river and out at the mouth. Stream order increases from the headwaters to the base level. In this example, the river is a5^{th}-order river.

Longitudinal River Profile



This diagram outlines the longitudinal profile of a river basin from the headwaters to the ultimate base level, or sea level. A rivers gradient is steepest near the headwaters and gentlest near the base level. In South Carolina, the steepest sections are often found in the blue Ridge and Piedmont, while the gentler gradient occurs in the Coastal Plain. River length, or distance, is measured from the rivers mouth to its headwaters, seemingly reversed from what one might expect.

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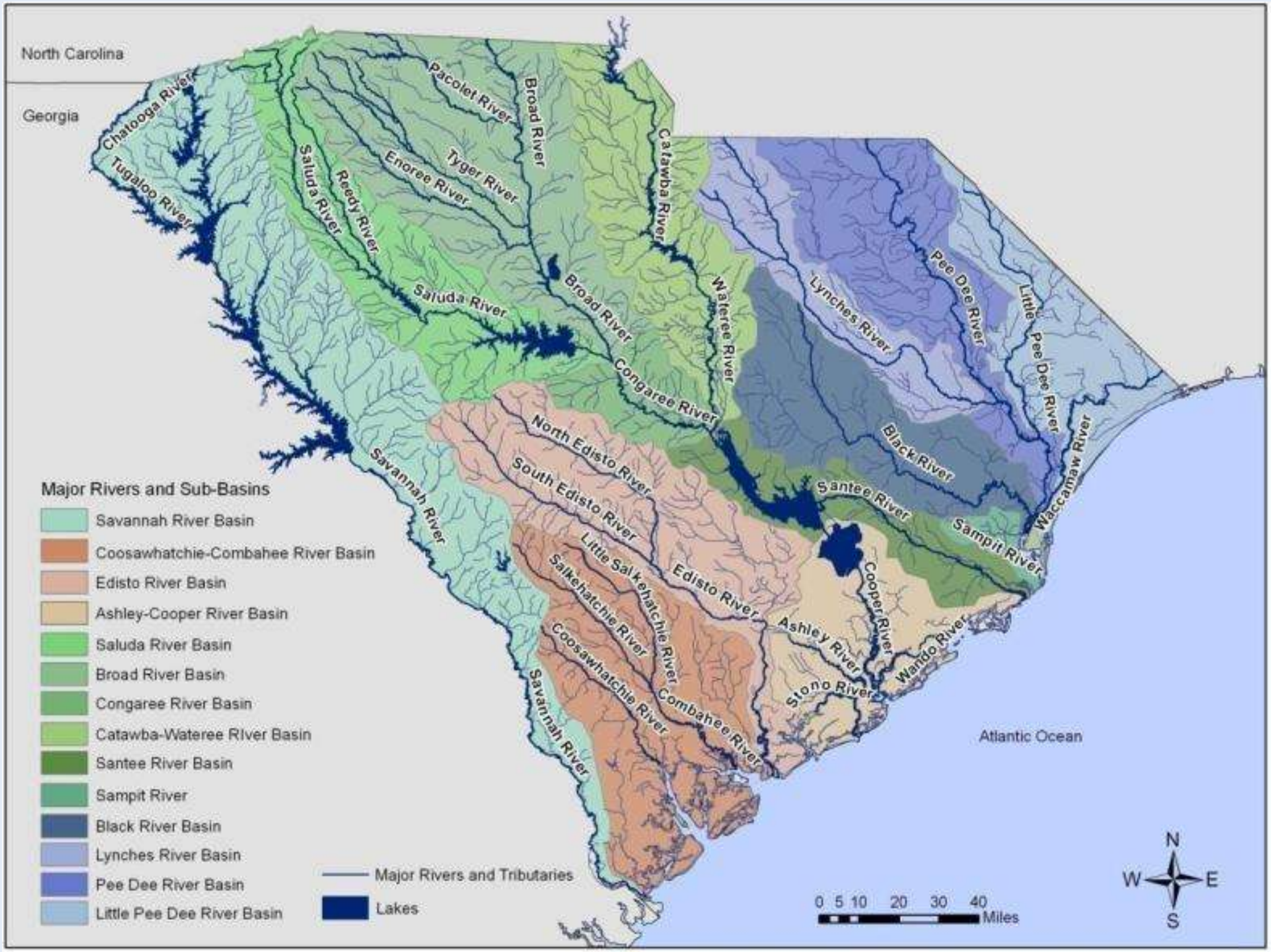
South Carolina Rivers and Basins



Standards: 3-3.5, 3-3.6, 3-3.8
Standards: 5-3.1
Standards: 8-3.7, 8-3.9

Dams and Lakes

- Dams are control structures on rivers which store and release river water from a lake (reservoir) according to specific operating regimes.
- Some dams are run-of-river structures which continually release the same amount of water entering the reservoir, while others are operated as storage facilities for regulated control on water releases.
- Although 70 percent of the earth is covered with water, only about 2.5 percent is freshwater, by building dams with reservoirs people are able to store the freshwater and use it as needed.
- Dams provide water for drinking, irrigation, hydro-electric power, river navigation, flood control, recreation, and many other needs.
- Dams disconnect river channels and can function as local base level controls on stream gradient and store sediment from transporting downstream. They also act as barriers to migrating species, such as fish traveling upstream to spawn, and the controlled water releases alter the downstream ecology of river systems and their floodplains.

Lake Murray and Saluda Dam: Saluda River, South Carolina

www.sceg.com

Lake Powell and Glen Canyon Dam: Colorado River, Arizona

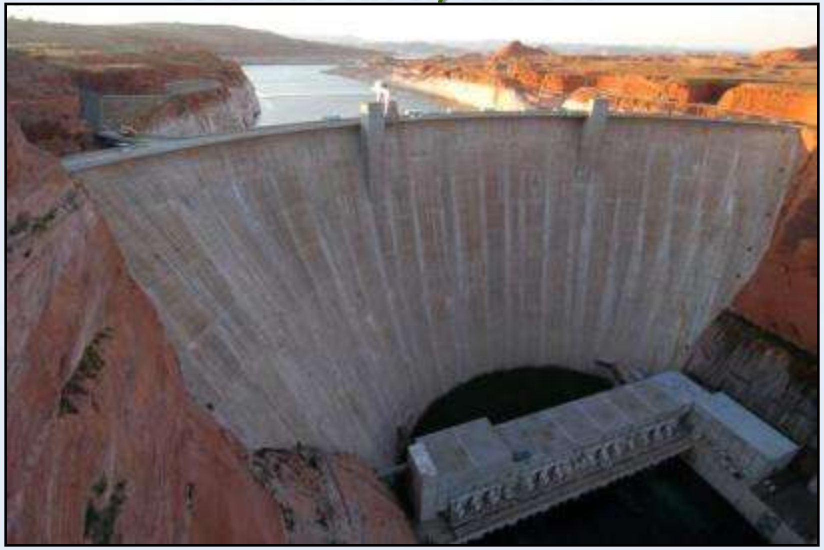


Photo: Paul R. Kucher

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Mountain Streams

- Mountain streams are high-gradient, low-order streams sourced from springs, rainfall, or snowmelt. They often contain a v-shaped valley, bedrock stream bottom, rapids, waterfalls, and a very narrow flood plain.
- Mountain streams form the headwaters of larger river basins and they generally contain the largest sediment sizes including boulders, cobbles, gravel, and coarse sand.
- Mountain streams often contain localized pools upstream and or downstream of small elevation drops, this pattern is referred to as a step-pool sequence. These pools are often important to aquatic ecology and increased biodiversity in mountain streams.

Step–pool sequence in the Middle Saluda River, South Carolina

This stream is in the Mountain Bridge Wilderness Area in South Carolina. It flows over bedrock and contains numerous waterfalls and step-pool sequences.

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Braided

- Braided river patterns occur in high-energy environments that contain an excessive sediment load that is deposited on the bed of the channel. The stream loses the capacity to transport the sediments and it forces its way through the accumulation of sediments forming an interwoven network of channels.
- The islands between the braided channels are ephemeral and dynamic. The sediment is continually remobilized, transported and deposited, leaving minimal time for vegetation to establish, as a result they are rarely vegetated.
- Braided channels tend to be wide and shallow with defined banks that are higher than the mid-channel islands.
- Braided channels occur downstream of areas with high sediment loads. Their sediment textures vary from silts, sands, and gravels depending on the sediment source.

This is the braided Resurrection River in Alaska. The sediment load consists primarily of silt that has been eroded and weathered from glacial debris. Braided river patterns may also be referred to as anastomosing.

Standards: 3-3.5, 3-3.6, 3-3.8
Standards: 5-3.1
Standards: 8-3.7, 8-3.9

Meandering

- Meandering river patterns are low-gradient, sinuous channels that contain multiple, individual meander bends that are laterally migrating across the flood plain.
- As they migrate or move across the flood plain they are continuously eroding, transporting, and depositing alluvial sediments.
- Meandering rivers and their hydrologic conditions create a variety of depositional and erosional landform features that collectively form the flood plain valley.
- The primary features of meandering channels are the aggrading pointbar deposit on the inside of a meander bend and eroding cut bank along the outside of the bend. As the channel migrates laterally across the flood plain, sediments are eroded from the outer cutbank and deposited on the inner pointbar.
- Occasionally, meandering channels cut-off entire meander bends; these cut-offs are incorporated into the flood plain as oxbow lakes or in-filled channels.

2006 Aerial imagery: http://www.dnr.sc.gov/GIS/gisdata.html

This is an aerial view of the meandering Congaree River and flood plain in Congaree National Park, South Carolina. This image uses infrared colors instead of true colors; the infrared reflectance causes healthy vegetation to show up as a reddish-pink color, instead of the green we expect to see. The bottom right of the image includes a recently cut off meander bend and oxbow lake.

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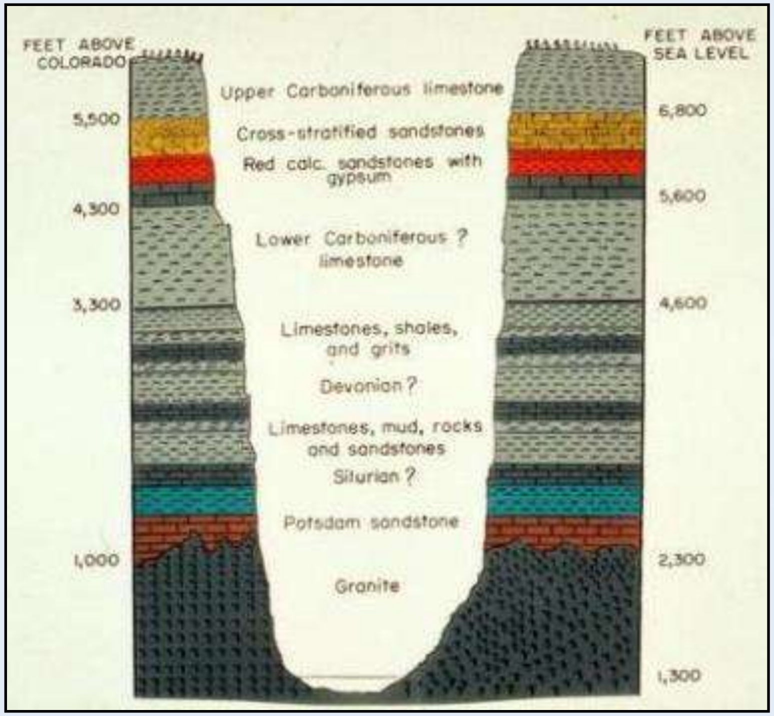
Standards: 5-3.1
Standards: 8-3.7, 8-3.9

Entrenched Meanders

- Entrenched meanders occur when a river channel cuts down into the flood plain or bedrock and the channel is trapped within a single course and it can not migrate laterally but erodes the landscape by down-cutting. This process will often leave behind numerous terraces of varying width and expose multiple layers of rock.
- The Colorado River flowing through the Grand Canyon in Arizona, provides a classic example of entrenched meanders. Down cutting began as the Colorado Plateau was uplifted about 5 million years ago and the river responded by eroding into the valley and has maintained roughly the same course ever since.

Below are the entrenched meanders of the Colorado River and to the right is the first geologic interpretation of the numerous geologic units exposed by the down cutting river.



Courtesy USGS Photographic Library

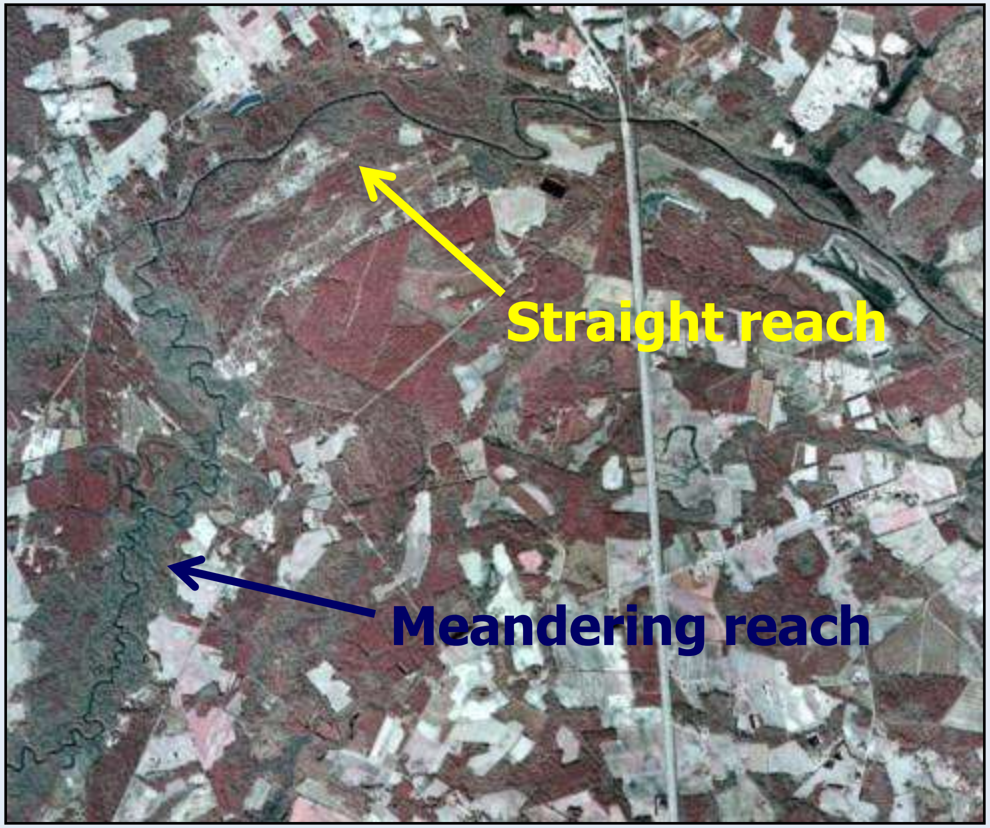
Anabranching

- Anabranching river patterns contain multiple channels that weave a mosaic through semi-permanent alluvial vegetated islands. The islands are often the same height as the flood plain and were likely isolated from the flood plain by meander bend cutoffs, channel avulsions (abandonment of an entire channel segment), or mid-channel deposition and subsequent vegetation.
- Anabranching rivers often occur in alternating combination with other river forms, such as meandering, braided, or straight rivers.
- Anabranching rivers provide added habitat complexity and support rich biodiversity.

This section of the Little Pee Dee River in South Carolina represents an anabranching river, most likely formed by channel avulsion (channel abandonment) and reoccupation of both the old and new channel. Upstream and downstream from this segment the river is mainly a single meandering channel with a wide alluvial flood plain and multiple meander bend cutoffs.

Straight

- Straight river patterns are often the result of reaches that are incised into bedrock, follow geological structures, or are engineered by people to not move laterally.
- They are not as common as meandering or braided streams and straight rivers generally only characterize a particular reach of a river channel.
- Straight reaches in a river system can provide important insight into bedrock controls or abrupt changes in stream gradient.



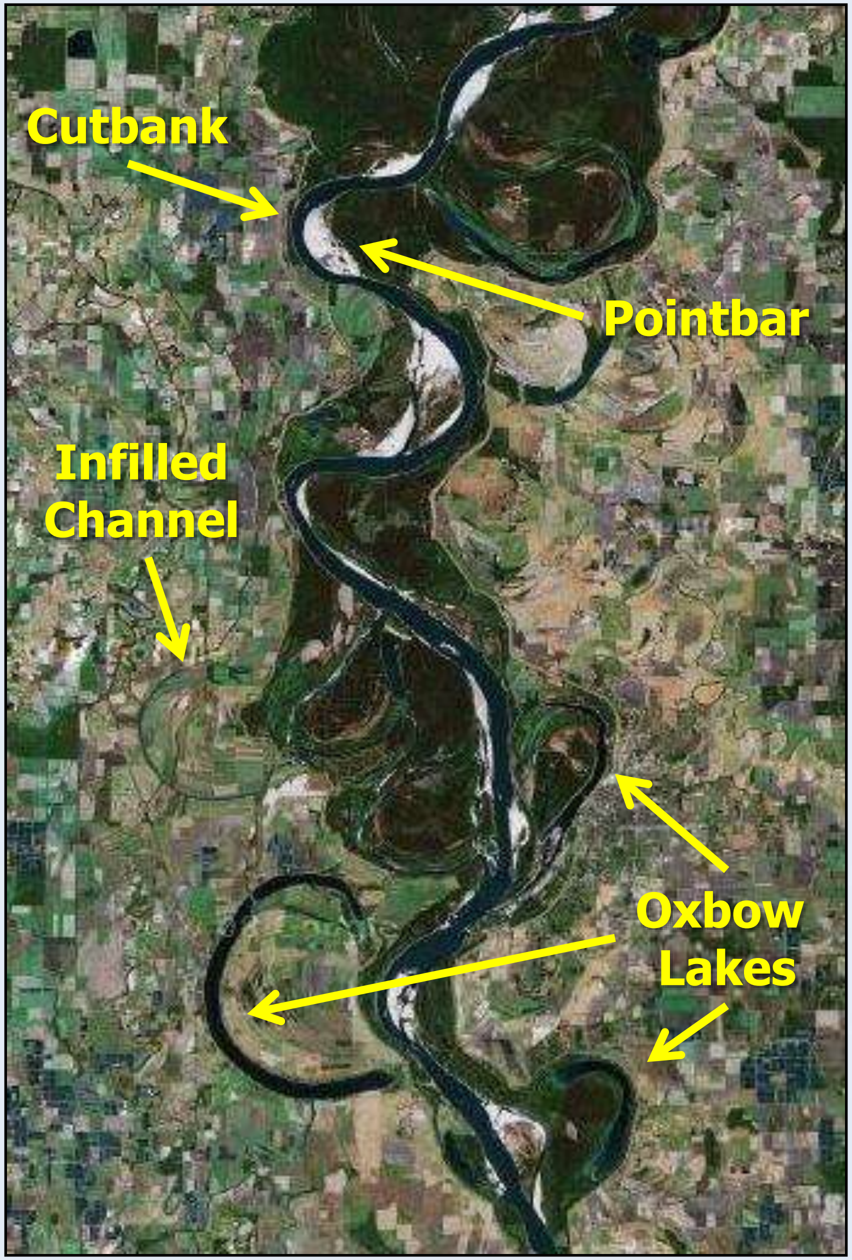
Data source: www.dnr.sc.gov/gis.html

This reach of the Lynches River in South Carolina is particularly interesting to geologists and geomorphologists because the river changes abruptly from a sinuous, meandering pattern to a very straight channel. The meandering sections occupy an alluvial flood plain and are able to migrate across the river's valley. The straight segments are incised into limestone bedrock, and the channel can not move laterally. Downstream from this large bend the river returns to a meandering pattern.

Flood plains

- Flood plains are the landform adjacent to the river channel that is influenced by modern river processes. Flood plains are constructive, depositional landforms created by stream flow and sediment deposition.
- Flood plain environments are composed of a mosaic of different landform features including **cutbanks**, **pointbars**, **natural levees**, **crevasse channels** and **crevasse splays**, **infilled channels** and **oxbow lakes**, **backswamps**, and occasionally yazoo tributaries and other flood plain channels.

This aerial view of the Mississippi River Valley contains many typical floodplain features. The darker, green areas are floodplain forest and they likely flood the most frequently and thus are not developed with agriculture or housing. The surrounding patchwork represents agricultural fields and other developed lands that are probably at a higher elevation formed by natural or artificial levees.

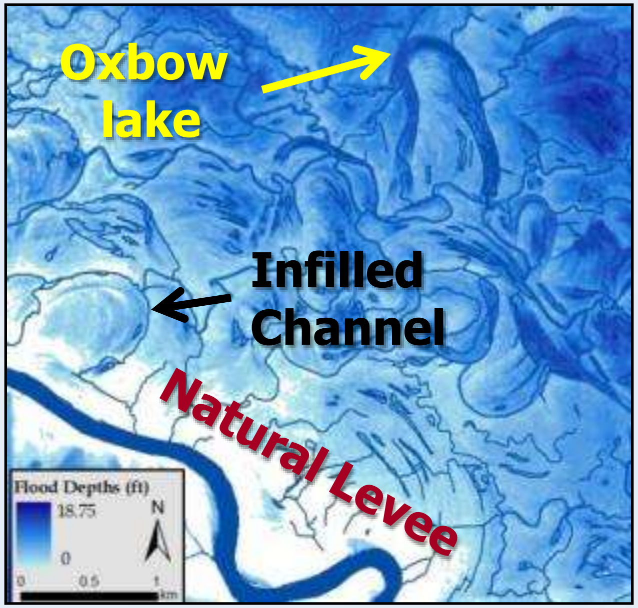


Flood Plains

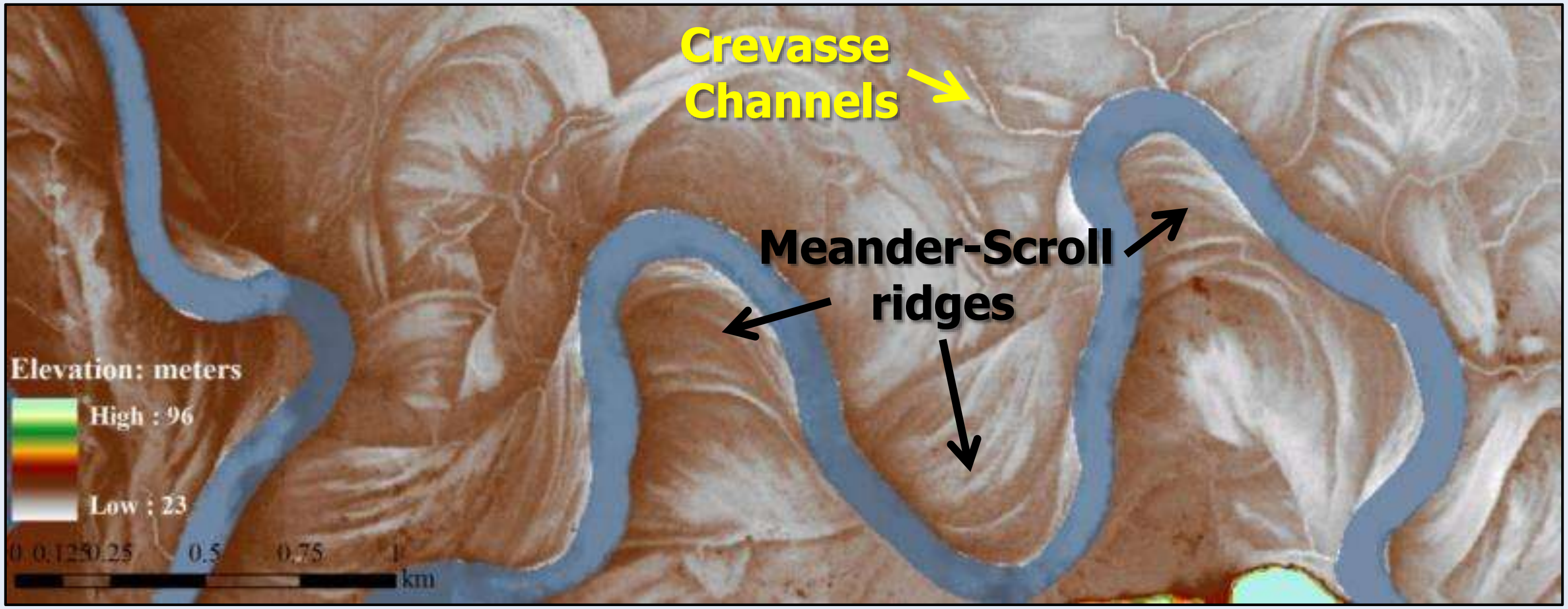
- **Cutbanks** form along the outer convex margin of meander bends. Cutbanks , unlike most floodplain landforms are actually erosional features formed by the lateral movement of the channel across the flood plain. Flood plain sediments are eroded from the cutbank and deposited on pointbar surfaces.
- **Pointbars** are concave, depositional landforms that form opposite of the eroding cutbanks, and they develop in concert with the laterally migrating river channel. Pointbars are typically composed of sands, gravel, silts, and clay deposits, that form arcuate, **meander-scroll ridges**.
- **Natural levees** are depositional landforms formed from the vertical accumulation of sediments deposited during flood events. Natural levees form topographically higher surfaces adjacent to the river channel, that generally consist of stratified, well-sorted sands, silts, and clays. Natural levees deposits are thickest and coarsest close to the channel and they become progressively thinner, and finer with increasing distance from the channel.
- **Crevasse channels and splays** are breaches in the natural levee that result in the fan-shaped deposition of flood deposits, beyond or over levee deposits. Crevasse channels can produce flooding in backswamp areas, even before the levees are submerged by floodwaters.
- **Oxbow lakes** or **infilled channels** form when a meander bend is cut off from the main river and abandoned in the floodplain. Abandoned meanders can occur in various stages from flooded oxbow lakes to being completely infilled with sediment deposits.
- **Backswamps** are typically low-lying areas of the floodplain beyond the natural levee deposits. Backswamps contain the finest-textured flood plain deposits and may even develop organic-rich soils from the forest litter. They often form along the margins or edge of the floodplain, and are usually influenced by connections to the groundwater.
- **Yazoo tributaries** are stream networks that enter the floodplain but the natural levee prevents the stream from flowing into the river. As a result the yazoo tributary flows parallel to the mainstem river before reaching a breach in the levee or occupying the course of an abandoned meander that allows the stream to cross the levee deposits and flow into the river.

Standards: 3-3.5, 3-3.6, 3-3.8
Standards: 5-3.1
Standards: 8-3.7, 8-3.9

Flood Plains



Both of these images are GIS-based models from the Congaree River floodplain in Congaree National Park. The image on the left is a clip from a flood model that shows the depth of flooding during a large flood event. The natural levee adjacent to the channel is one of the topographically highest features and it floods the least. The abandoned meanders and back swamps are topographically lower and flood more frequently and to greater depths. The channel networks fill up with water connecting the oxbow lakes to the main stem river. The image below is from a high resolution digital elevation model (DEM) of a floodplain. The DEM is useful for mapping the different landform features on a floodplain.



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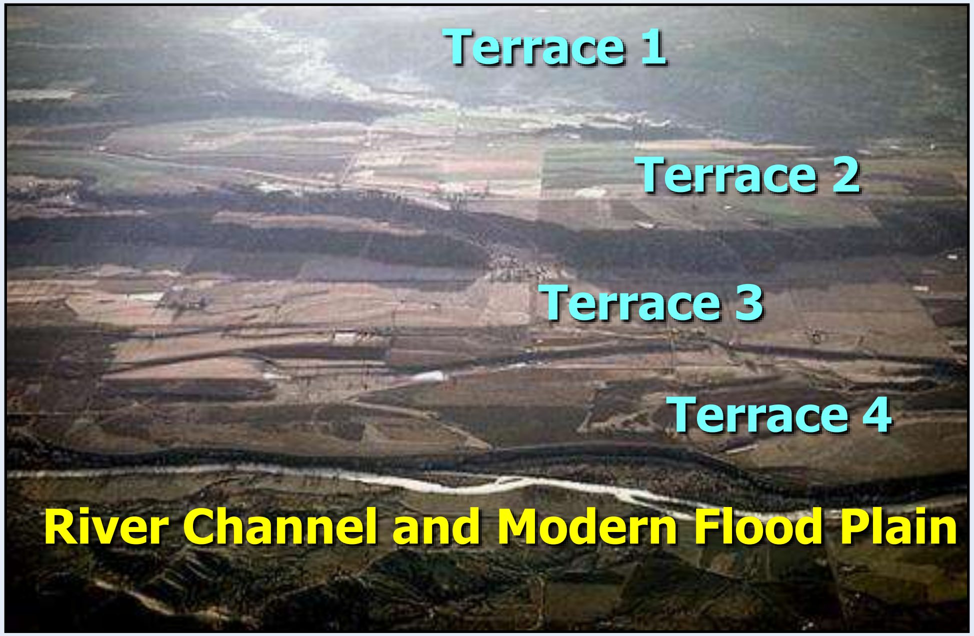
River Terraces

- River terraces are older remnant flood plain surfaces that are higher in elevation than the modern flood plain. They may occur on one or both sides of the valley.
- Terraces are formed when the river channel cuts down into the flood plain and laterally erodes the alluvial valley, carving a new river channel and flood plain entrenched within the older flood plain surfaces. Down cutting can occur because of hydrologic or sedimentary changes in the headwaters or valley gradient changes caused by a retreating sea-level and lowered or extended base-level. Terraces can also form from tectonics and valley uplifting.
- Terraces are generally isolated from the more recent river processes and may only flood during 100 or 500 year flood events. River terraces are often archeological hot spots because they contain artifacts from historic colonies that used the river and flood plain.



This river has gone through several different episodes of down cutting and rejuvenation. The modern flood plain is preceded by four different terraces that all reflect distinct periods of environmental conditions or valley gradients, each different from the other. Over time, it is possible that the river will down-cut again abandoning a fifth terrace.

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Waterfalls

- Waterfalls occur where there is resistant bedrock, abrupt changes in bedrock resistance, or along fractures or faults in the bedrock.
- Less resistant materials are weathered more quickly than resistant rocks, creating stair-stepped ledges or drop offs where waterfalls occur. Less resistant rocks may also form pools between resistant rocks that form waterfalls.
- Faults and fractures often provide natural pathways for the downslope movement of water.
- The location of the waterfalls origin may be referred to as a "knick-point", continued weathering by the stream flow causes the knick-point to slowly migrate upstream.
- Most waterfalls in South Carolina occur along streams in the Blue Ridge, Piedmont, and the along the Regional Fall Line where there are rock layers of varying resistance.

This waterfall was formed by differential weathering between the softer shale and harder more resistant limestone.

Photo: SCGS

Lower White Water Falls in the Jocassee Gorges area of South Carolina drops nearly 200 ft. Here, the Toxaway Gneiss forms a resistant bedrock that the Lower White Water River flows over before draining into Lake Jocasse.

Standards: 3-3.5, 3-3.6, 3-3.8
Standards: 5-3.1
Standards: 8-3.7, 8-3.9

Alluvial Fans

- Alluvial fans are fan-shaped fluvial deposits that accumulate at the base of stream where it flows out from a steep gradient and enters into a lower-gradient flood plain or valley setting.
- The stream enters the valley carrying a higher capacity sediment load than it can continue to carry, and as a result it deposits the sediments as an alluvial fan.
- Alluvial fans generally form in arid environments with a high sediment load and where there is minimal vegetation to disrupt the fan formation.
- Alluvial fans may form from a single high-flow event or from the accumulation of multiple events.

This alluvial fan is carrying a high sediment load from material weathered from the mountains. The dark line along the edge of the fan is a road. Because the road is not buried by recent deposits it suggest that this fan is not currently as active as it was in the past.

Gullys

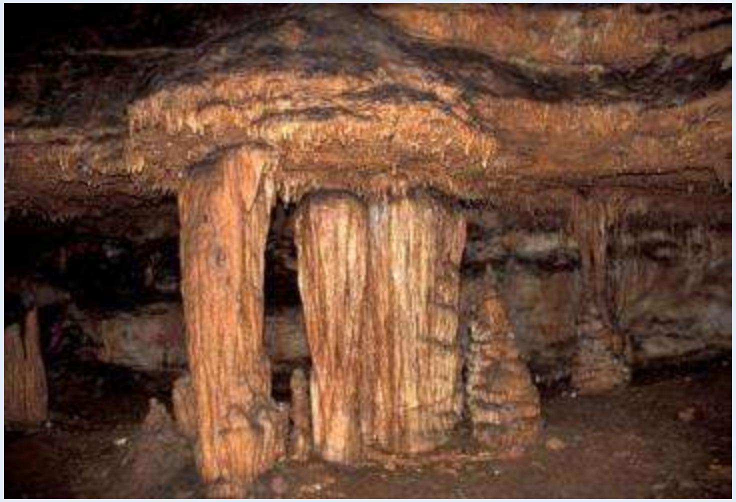
- Gullys are formed by hillslope erosion.
- Rainwater runoff draining over the surface of a hillslope generates erosive overland flows that remove weathered rocks and soil.
- When multiple gullys form they produce a disconnected network of headwater channels that dissect the hillslope and increase soil erosion.
- Gullys primarily form on disturbed hillslopes where forest and vegetation have been cleared.

The forest was cleared from this hill slope and corn was planted on the bare soil. Following the first few rain events, gullys began to form as a result of soil erosion. The gullys only carry water during rainfall events.

Karst Landforms

Karst is a term used to describe landscapes that are formed by chemical weathering process controlled by groundwater activity. Karst landscapes are predominantly composed of limestone rock that contains $\geq$ 70 percent calcium carbonate.

- Caverns
- Sinkholes
- Disappearing Streams
- Springs
- Towers

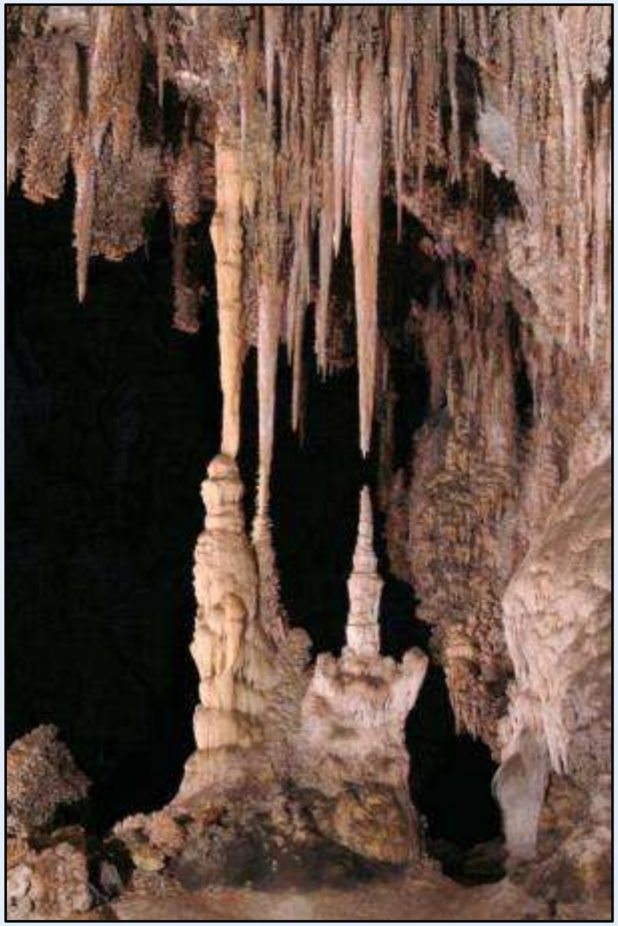


Onondaga Cave in Missouri is a karst landform formed by chemical solution in carbonate limestone rocks. Features within Onondaga Cave include stalagmites, stalactites, dripstones and active flowstone deposits. Missouri contains so many caves that it is nicknamed the "Cave State".

Standards: 3-3.6, 3-3.8
Standards: 5-3.1
Standards: 8-3.7, 8-3.9

Caverns

- Limestone caverns and caves are large sub-surface voids where the rocks has been dissolved by carbonation.
- Caverns and their various features form below the ground water table where dissolved minerals drip through the ceiling of the cave through fractures and joints in the limestone. Over time this mineral-rich ground water dissolves the rocks until eventually entire caverns are formed.
- Calcium carbonate precipitates out of the saturated carbonate solution and accumulates as deposits. **Stalactites** are deposits that grow from the ceiling downward and **stalagmites** are deposits that grow from the ground up. If the stalactite and stalagmites join they form a continuous column.
- Mammoth Cave in Kentucky and Carlsbad Caverns in New Mexico are two of the largest cave systems in North America and the world.
- Not all caves are formed by karst processes. Some caves are formed by lava tubes and others are formed by the erosion forces of large amounts of ground water flow.



This image of the "Chinese Theatre" in Carlsbad Caverns National Park illustrates how stalactites and stalagmites can join to form columns. Notice the person in the lower left for scale!

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Sinkholes

- Sinkholes are collapsed limestone features that develop in karst landscapes. Sinkholes form when the limestone bedrock is chemically weathered by naturally occurring chemicals in the ground water. The ground water slowly dissolves the limestone rock below the surface until it eventually becomes unstable and collapses creating local depressional features. Sinkholes occur in a range of sizes, and can be temporarily, seasonally, or permanently filled with water.
- Sinkholes pose a threat to developed areas, because if they occur beneath houses or other infrastructure they may collapse with the sinkhole.
- Increased pressure on water resources and depleted ground water tables can trigger sinkholes to collapse under the pressure of gravity or the void formed by the depleted ground water.

www.sfwmd.state.fl.us

Photo: USGS

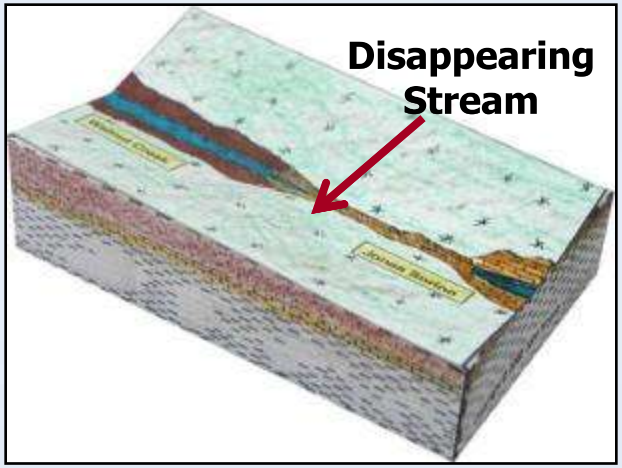
The left is an aerial view of the Tres Pueblos sinkhole in Puerto Rico. Solution of the underlying rock caused bedrock, soil, and vegetation to collapse into the sinkhole feature. The images above are from urban areas in Florida where sinkholes damaged several homes and businesses.

[Standards: 3-3.5, 3-3.6, 3-3.8]
[Standards: 5-3.1]
[Standards: 8-3.7, 8-3.9]

Disappearing Streams

- Disappearing streams are streams that flow on the surface and then seemingly "disappear" below ground. Disappearing streams disappear into a sinkhole or other karst solution features such as caves. They may also disappear into factures or faults in the bedrock near the stream. Disappearing streams are also referred to as losing streams, sinks, or sieves.
- Disappearing streams will often continue flowing underground and may resurface at another location downstream from where they disappeared.
- Disappearing streams often maintain a connection with the local or regional ground water, and thus it is important to protect their drainage basin from polluted run-off to prevent ground water contamination from harmful pollutants or chemicals.

www.northeastiowarcd.org



The stream in this image on the left disappears into the limestone and continues to flow underground before resurfacing downstream.

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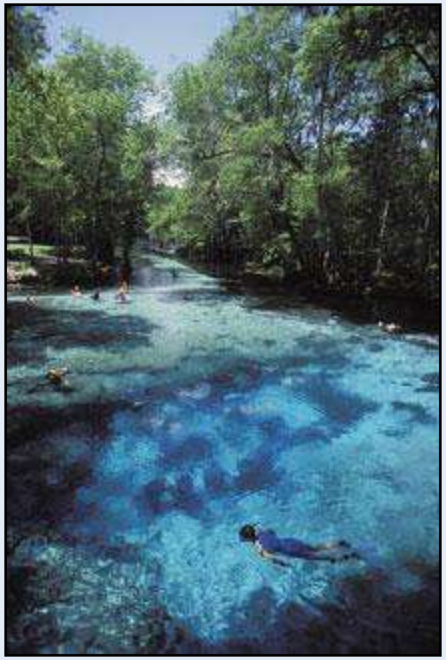
Springs

- Karst springs are locations where groundwater emerges from the limestone and flows across the surface forming a stream or contained pool.
- The flow of Karst springs is generally dependant on the weather and climate. Some are more permanent than others, while others only flow following rainfall or snowmelt events. Springs that are connected to aquifers flow year-round and support rich aquatic biodiversity.
- Karst springs generally do not support good water quality, and thus are not safe for drinking without filtering the water first; however, the springs often provide fun recreational opportunities and can be a popular place for swimming and snorkeling.



Karst springs provide cool, clear, water that is inviting for people to swim and snorkel in. The left is from a karst spring in Florida an the image above is from Barton Springs, a karst spring in the Texas Hill Country.

http://www.floridasprings.com/about.html

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Standards: 5-3.1
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Towers

- Karst towers create a unique topography where the landscape is mottled with a maze of steep, isolated limestone hills.
- The towers are weathered features formed where the limestone beds are thick and highly jointed, as a result the remnant towers contain caves and a variety of other passageways for water to percolate along fractures in the joints.
- Karst towers occur in tropical climates of Puerto Rico, western Cuba, southern China, and northern Vietnam. Lush vegetation from the tropical climates produce greater carbon dioxide that concentrates as a carbonic acid in the rain water which facilitates the weathering processes which form karst towers.

Photo: Pat Kambesis

These karst towers in southern China produce an interesting and unique landscape. Although they have a very thin soil, the towers are capable of supporting lush tropical vegetation.

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Standards: 5-3.1
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Aeolian Landforms

Aeolian landforms are formed by the deposition of windblown sediments. The sediments are generally sourced from deserts, glacial deposits, rivers, or coastal shorelines. Aeolian sediments are often composed of well-rounded, sand-to silt-sized particles, that are weathered by wind abrasion during transport. Sediments are deposited when the velocity of the wind falls and there is not enough energy available to entrain and transport the sediments. Sands will begin to accumulate wherever they are deposited and often continue to move along the ground.

- Dunes
- Loess Formations
- Carolina Bays

Coastal parabolic sand dunes in The ACE Basin region of South Carolina.

Photo courtesy of SCDNR

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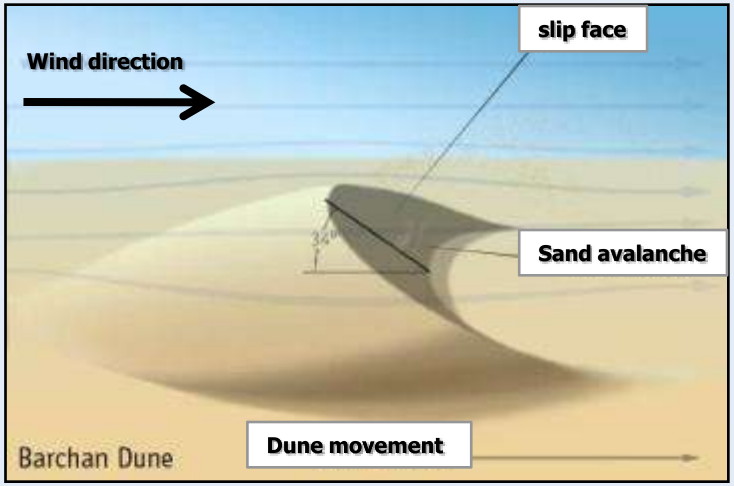
Dunes

- Dunes are formed as mounds or ridges of aeolian sand deposits and are then sculpted by near-surface wind processes, such as **saltation**. Saltation transports sediment up slope on the windward side and once the sediments reach the crest they fall over and accumulate as a steeper slope on the leeward side of the dune, referred to as the **slip face**. This section will cover **barchan**, **transverse**, **longitudinal**, **parabolic**, and **star dunes**. An area covered by many dunes is an **erg**.

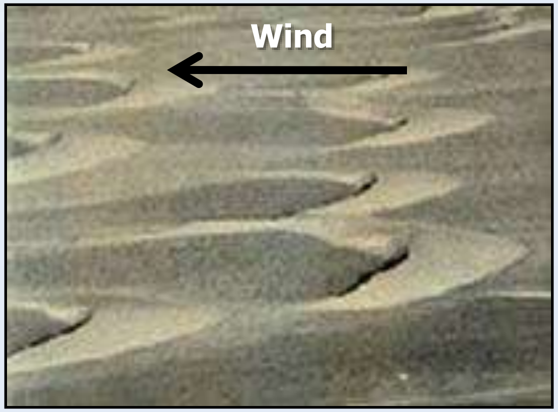
- **Barchan dunes** are solitary, crescent shaped dunes with their tips pointing downwind. They form where sand source is limited, wind direction is constant, and the ground is void of vegetation. They can reach heights of 30 meters and spread nearly 300 meters.

- **Transverse dunes** are a series of long ridges that are parallel to one another, and are perpendicular to the prevailing wind. They form in areas where the prevailing winds are steady, there is an abundant supply of sand, and vegetation is sparse. They can reach heights of 200 meters and may extend for 100's of kilometers.



http://www.nps.gov/archive/grsa/resources/images/lgformat/barchan.jpg

Barchan Dunes



John McCauley, USGS

Transverse Dunes

John McCauley, USGS

Standards: 3-3.6, 3-3.8
Standards: 5-3.1
Standards: 8-3.7, 8-3.9

Dunes

- **Longitudinal dunes,** also referred to as **Seifs** are long ridges of sand that form parallel to the prevailing wind. They form in areas where there is moderate supply of sand, and they range in size 5-10 meters tall to 100 meters in height and width.
- **Star dunes** are complex dunes with a central mound surrounded by radiating points. From above they resemble a star shape. They are formed by shifting wind patterns that create the unique star shape. Star dunes can reach heights of 90 meters and extend outward for over twice their height.
- **Parabolic dunes** are similar in form to barchan dunes except their tips point into the wind. They form as blow outs where the sand has carved out the sediments and deposited it onto the leeward side. Parabolic dunes form inland from coastal shorelines from sands on the beach.

Star Dune in Namib Desert, Namibia

http://en.wikipedia.org/wiki/Image:Dune_7_in_the_Namib_Desert.jpeg

Longitudinal Dune

Photo: www.googleearth.com Eve, Montana

Standards: 3-3.6, 3-3.8
Standards: 5-3.1
Standards: 8-3.7, 8-3.9

Loess

- Loess deposits are regionally extensive accumulations of windblown silt resulting from thousands of dust storms.
- During the dust storms, silt is entrained, transported, and deposited as loess. Loess deposits are generally sourced from either glacial or desert terranes, and silt may be transported for 100's of miles before being deposited.
- Loess deposits are generally coarsest and thickest close to their source, and they decrease in thickness and grain size with increasing distance from their source.
- Loess is not stratified, meaning it lacks distinctive layers. Instead they are massive accumulations of silt. Loess deposits range from 30 to >100 meters thick, and they provide very fertile soils for agriculture and farmland.
- The most extensive loess deposit occurs in western and northern China, and it contains sediments that were blown from the deserts of Central Asia.
- In the United States, extensive loess deposits occur in South Dakota, North Dakota, Nebraska, Iowa, Missouri, Mississippi, and Illinois. These deposits were sourced from glacial sediments.

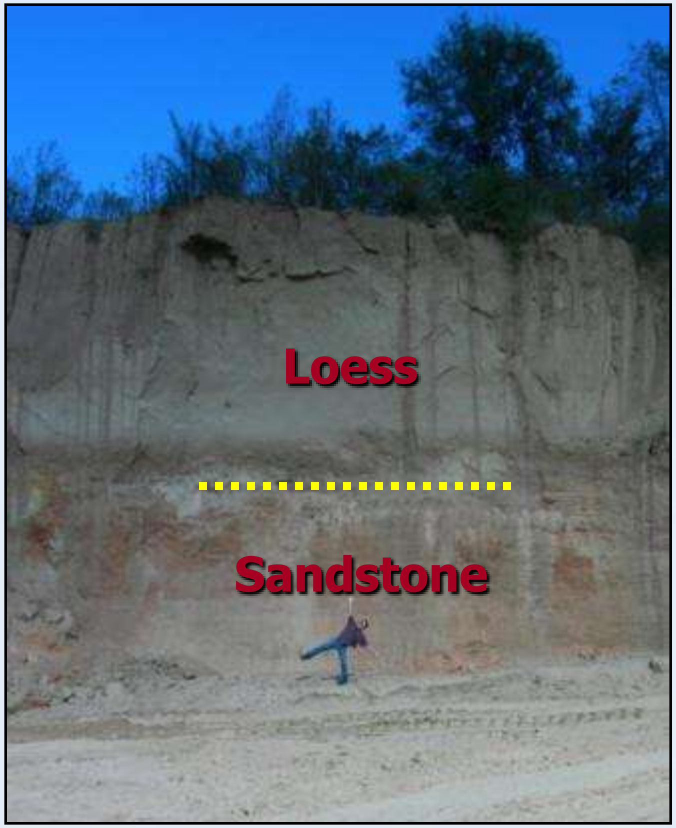


Photo: SCGS

This loess and sandstone contact is from a quarry near Vicksburg, Mississippi where both deposits are being mined. This loess was sourced from glacial till and blown down the Mississippi River Valley. The person in the picture provides a context for the thickness of the loess deposit.

Standards: 3-3.6, 3-3.8
Standards: 5-3.1
Standards: 8-3.7, 8-3.9

Yardang

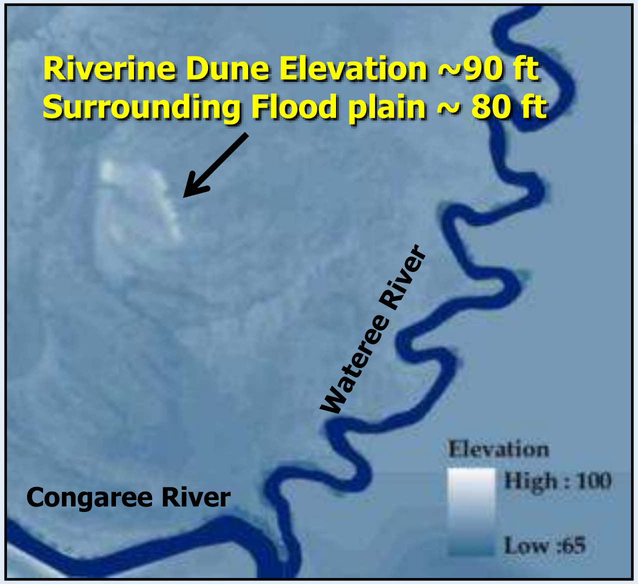
- A yardang is an elongate ridge or remnant rock feature sculpted by abrasive wind erosion.
- Yardangs occur in arid environments where prevailing winds come from a single direction. The winds must be strong, steady, and carry a coarse-sediment load that weathers the exposed face of the yardang.
- Yardangs are sculpted into a variety of forms, and some may resemble common objects or human-like forms.
- Mega-yardangs are those that are several kilometers wide and hundreds of meters high, meso-yardangs are only a few meters high and 10-15 meters long, and micro-yardangs may only be a few centimeters in size.

Yardangs are eroded over long time periods and occur in a variety of sizes and forms. The Egyptians would often sculpt yardangs into animal and human forms. Some ancient cultures also carved caves into yardangs and used them for dwellings or sacred religious places.

[Standards: 3-3.6, 3-3.8](#)
Standards: 5-3.1
Standards: 8-3.7, 8-3.9

Riverine Dunes and Sand Sheets

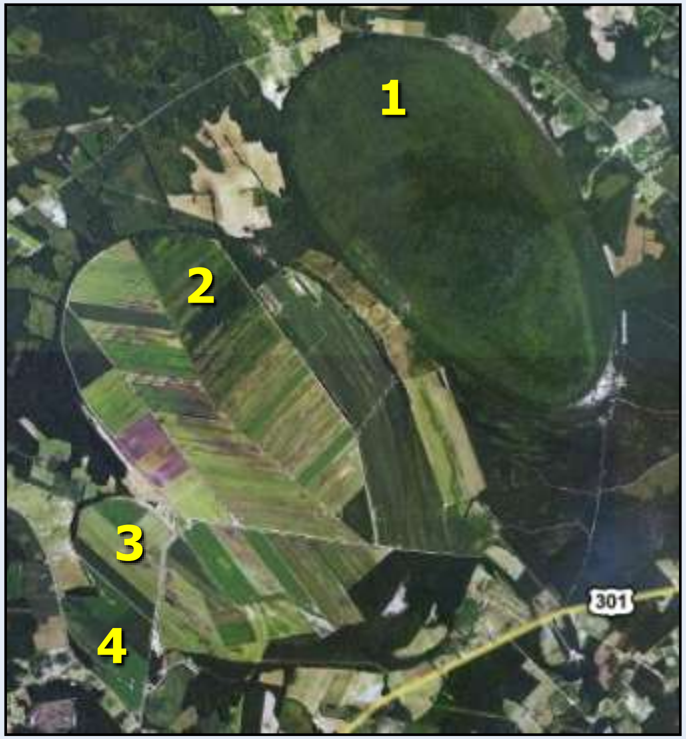
- Riverine sand dunes occur on flood plains throughout the South Eastern United States Coastal Plain. They sit 10-30 feet above the flood plain and are composed of thick uniform deposits of well-sorted fine to coarse sands.
- Most dunes are oriented from the northwest to southeast, and in many cases they parallel river channels. From their orientation and shape, it is suggested that most are transverse dunes.
- Recent-dating indicate that dunes formed during the late Quaternary, with most dune ages ranging from 15,000-100,000 years old.
- Riverine sand sheets are depositional eolian landforms that occur in association with riverine sand dunes. They extend leeward (downwind or away from the wind) from the dune and become progressively thinner with increasing distance away from the dune. The sand sheets are composed of the same homogenous sands that form the dunes.



This digital elevation model (DEM) of the confluence area between the Wateree and Congaree Rivers, in the Coastal Plain of South Carolina contains a riverine sand dune. The sand dune is about ten feet higher than the surrounding flood plain and rarely floods except during 100-500 year flood events. For this reason, it is hypothesized that early explorers and Native American Indians may have lived on this sand dune and farmed in the surrounding flood plain.

Carolina Bays

- Carolina Bays are oval or elliptical, depressional wetland features enclosed by a low sandy ridge. The depth of Carolina Bays varies depending on their size and land use history, most average about 5-15 feet deep; however, some have been measured with depths greater than 30 feet . Sand rims enclosing the Carolina Bays also vary in size, but generally range from 5-15 feet.
- The origin of Carolina Bays is currently debatable. Most Geologists agree that they are eolian landforms. Carolina Bays were formed 100,000-30,000 years ago, during the Quaternary and occur through the coastal plain of Georgia, South Carolina, North Carolina, Virginia, and Maryland.
- Carolina Bays occur in varying stages of flooding dependant on their land-use history, rainfall, and connection to ground water. Carolina Bays can be dry, temporarily flooded, or support a permanent lake.



www.maps.google.com

Most Carolina Bays have their longest axis oriented from northwest to southeast, although there are a few oriented in other directions. The sand rims are largest along the southeastern edge, but in some cases may be completely lacking. Many Carolina Bays have been drained to support agriculture. Undisturbed Carolina Bays contain unique assemblages of wetland plants and aquatic organisms. This aerial image contains four Carolina Bays, three of which support agriculture and one, Woods Bay, that is protected by the Department of Natural Resources Heritage Trust Program.

Standards: 3-3.5, 3-3.6, 3-3.8
Standards: 5-3.1, 5-3.4
Standards: 8-3.7, 8-3.9

Coastal Landforms

Coastal landforms include a diverse array of shoreline and near-shoreline features, as well as some coastal plain landforms far removed from the modern ocean by long term sea-level changes. This section will explore both constructive and destructive landforms formed by current coastal processes, as well as marine related landforms that were formed during periods of higher sea level.

- Littoral Zone
- Beaches
- Barrier Islands
- Beach Ridges
- Spits
- Deltas
- Coastal Cliffs
- Marine Terraces
- Wave-Cut Scarps

Hawaiian coastline

Photo source: SCGS

Standards: 3-3.5, 3-3.6, 3-3.8
Standards: 5-3.1, 5-3.4
Standards: 8-3.7, 8-3.9

Littoral Zone

- The littoral zone extends inland to the highest water line during storms and seaward to the furthest area where shoreline wave processes stop influencing sediment transport and deposition on the seafloor and includes several coastal landforms.
- The shoreline refers to the exact area where the land meets the sea, and coast refers to the land adjacent to the shoreline. The 'coastal area', includes the coast, shoreline, and near-shore area.
- The littoral zone is a continuously changing environment, and it can shift inland or seaward depending on changes in sea level. Rising sea-level will submerge the coastal areas, and a drop in sea level will produce coastline emergence.
- Sea level is commonly referred to and measured as mean sea level (MSL). Mean sea level is a value based on the average tidal levels recorded hourly for a given site over at least a 19-year record. Present MSL measurements indicate that sea level is currently rising.

Littoral Zone

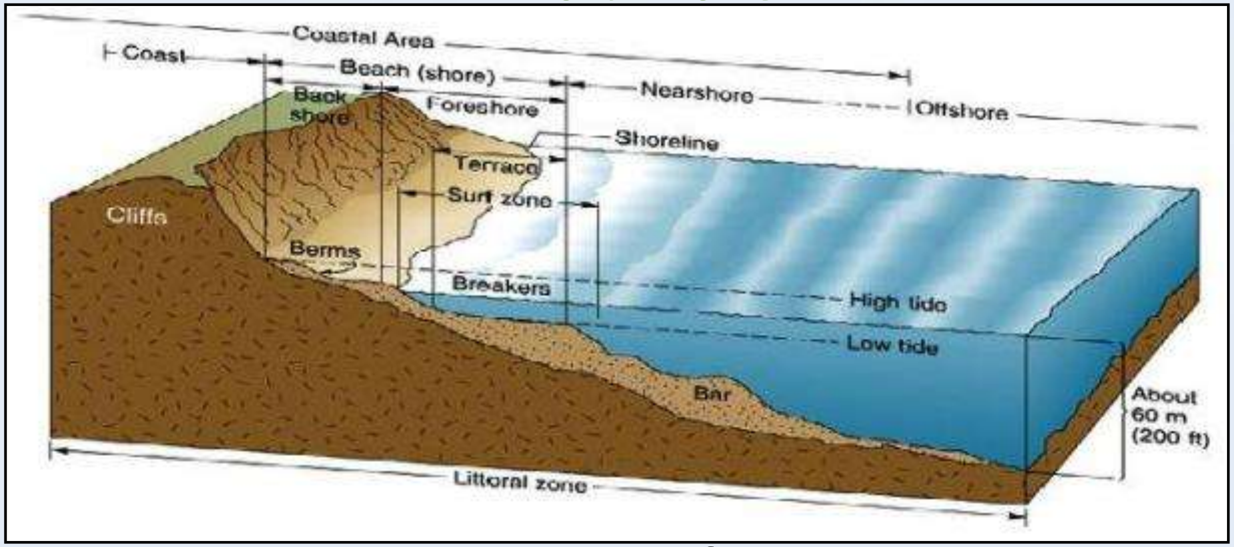


Image courtesy of US Navy

Beaches

- Beaches are depositional landforms along the coastal area where sediment is transported and deposited by waves and currents. Although the sediment along the beach is continually being mobilized there is an overall net accretion of deposition.
- The width of the beaches vary from one location to another and from one shoreline to another. In some locations a shoreline might even lack a beach altogether.
- Most beaches are dominated by sand-sized quartz grains, and shells or shell fragments. However, this can be highly variable depending on the landscape that drains into the ocean and near-shore sediment sources. For example, some beaches in the Hawaiian islands consist of coarse, red and black rock fragments formed by weathered lava; and in France and Italy many beaches consist of pebbles and cobbles.
- Sediment movement along the beach is referred to as beach drift, and it generally follows long shore currents traveling along a directional trend produced as waves approach the shallower water in the surf zone near the shoreline.

Photo: SCGS

Beaches often stabilize shorelines by absorbing or deflecting wave and current energy. During large storms, such as hurricanes, beaches can experience extensive erosion, and it can be years before they are replenished. Beaches provide numerous recreational activities and are a popular destination for vacationers.

Standards: 3-3.5, 3-3.6, 3-3.8
Standards: 5-3.1, 5-3.4
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Barrier Islands

- Barrier islands, also referred to as barrier beaches, are long, narrow, depositional landforms, that form parallel to the coastline and may or may not connect to the mainland. They are the first line of protection against hurricane storm surge.
- They are generally composed of quartz sands, and they form along coasts where there is a substantial supply of sand entering the ocean from Coastal Plain rivers.
- Barrier islands often form where tidal process are minimal.
- The landward side of the barrier islands may contain tidal flats, marshes, swamps, lagoons, coastal dunes, and beaches.
- Similar to beaches, barrier islands form in relation to, long-shore current processes and overtime adjust to sea-level changes.
- Classic examples of barrier islands include North Carolina's Outer Banks and Texas's Padre Island. Both of these barrier islands have National Park Service lands that preserve natural coastal processes and protect plant and wildlife habitat from human impacts.

Image: NOAA

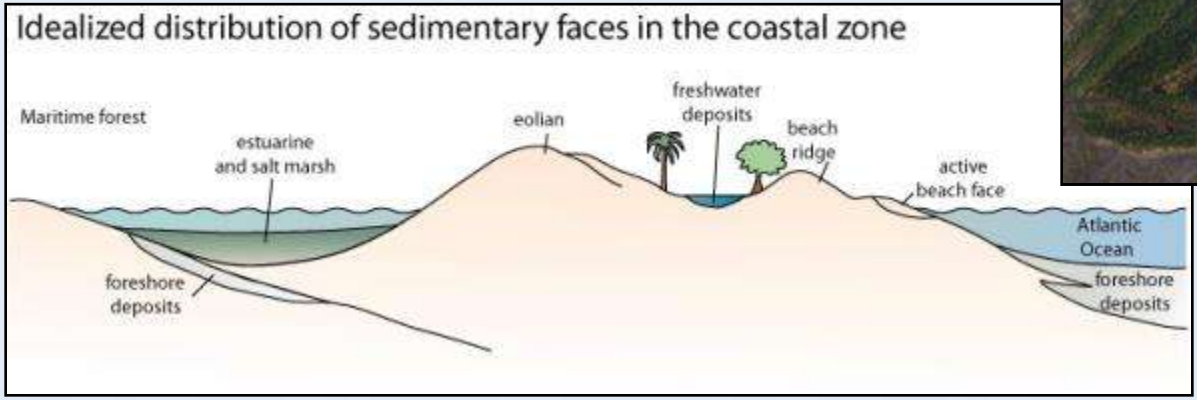
Standards: 3-3.5, 3-3.6, 3-3.8
Standards: 5-3.1, 5-3.4
Standards: 8-3.7, 8-3.9

Beach Ridges

- Beach ridges are wave-deposited ridges that form parallel to the coastline. They are composed of gravel, sands, and shell fragments, and in some cases they may be capped by aeolian sands blown from the beach.
- If sea-level retreat or regional uplifting occurs after the deposition of a beach ridge it is incorporated into the mainland as a raised elevation ridge near the coast. Beach ridges may be deposited one after another or they may be separated by swale like features that form marshes, swamps, and other low-lying wetland environments.

These linear ridges are beach ridge and swale sequences from St. Phillips Island in South Carolina. The green is from dense maritime forest that growing near the coast. The light areas in between the ridges are marshes and the other darker areas between the vegetated ridges are brackish lagoons.Below is a cross section diagram of near-coast deposits, including beach ridges

Source: Google 2008



Standards: 3-3.5, 3-3.6, 3-3.8
Standards: 5-3.1, 5-3.4
Standards: 8-3.7, 8-3.9

Spits

- Spits are elongate depositional landforms that are attached at one end to the coast and extend outward from the coast.
- Spits are formed by a combination of wave and current deposits. As the waves and current lose energy near the mouth of a bay the sediments deposit as elongate spit landforms. The spit may curve slightly back towards land in response to the waves refarction pattern hooking back toward the land at the end of the spit.
- In some cases they may extend outward across the mouth of a bay. If the spit extends enough sediments to eventually cut off the mouth of the bay it becomes a bay barrier and the bay becomes a lagoon.

This spit is growing towards the southwest and slight curves inland at the mouth of the inlet. In addition, there is a slight lagoon forming between the coastal area and the depositional spit landform.

Standards: 3-3.5, 3-3.6, 3-3.8
Standards: 5-3.1, 5-3.4
Standards: 8-3.7, 8-3.9

Deltas

- Deltas form where the mouth of a river meets its ultimate base level at the ocean or sea. As the river's velocity decreases, it looses the capacity to carry its sediment load and the resulting deposits form a delta. Delta shapes and forms vary depending on tidal influences, waves, currents, sediment type and quantity, river discharge, and the stream gradient near the outlet. The most common types of deltas include bird-foot, estuarine, and arcuate.
- Not all rivers form deltas, for example the Amazon deposits its sediment load directly into the ocean onto an underwater seaward sloping continental shelf. The Columbia River in the northwest United States, lacks a delta altogether, because the currents are too strong and erosive for the sediments to deposit.

Mississippi River Delta: Bird-Foot Delta

A bird-foot delta contains a large channel with multiple smaller distributary channels draining off from the main channel and depositing sediments. They generally form with rivers that have a high sediment load and flow into an area with minimal tidal influences. This false-color infrared image provides a satellite view of the Mississippi River delta. This delta has shifted positions several times over the last 5000 years in relation to changes in the Mississippi River. Scientist recognize atleast 7 distinct deltas. The most recent began forming 500 years ago and forms a classic bird-foot delta.

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Deltas

Nile River and Arcuate Delta

The Nile River forms an arcuate fan-shaped delta where it drains into the Mediterranean Sea. It is one of the largest deltas in the world; however, it is currently disappearing because the upstream Aswan High Dam is storing water and sediments and preventing them from being deposited in the delta. As a result the delta is eroding and saltwater is encroaching into freshwater. Other typical arcuate deltas include the Danube River where it enters the Black Sea in Romania, and the Ganges and Indus River Deltas flowing into the Bay of Bengal.

An estuary delta is formed where a river meets the ocean and sediments from the river are filling in the estuary. Estuaries contain a brackish mixture of freshwater and saltwater, and they have a moderate to strong tidal influence. Estuarine deltas are a common deltaic landform and they occur in several rivers along the western and eastern United States coasts, the Seine River in France, and the Tiber River in Italy. The ACE Basin of South Carolina, named for the Ashepoo, Combahee, and Edisto Rivers, protects nearly 150,00 acres of undeveloped estuary habitat.

ACE Basin: Estuarine Delta

Sea Cliffs

- Sea cliffs are erosional landforms formed by the undercutting action of the sea against the coastline.
- The eroded sea cliff becomes notched inland where the waves erode the coastline and eventually the overhanging land collapses into the ocean. This process causes the sea cliff to slowly retreat inland eroding more and more of the coastline.
- In undeveloped areas sea cliff related erosion does not pose a hazard. Unfortunately extensive areas of the California and Oregon coast are developed near sea cliffs that are threatened by the erosive force of the Pacific Ocean.

Source: USGS

These sea cliffs in San Mateo County, California formed from erosive wave action along the Pacific Ocean. While they create spectacular scenery, they pose a large threat to homeowners that live near the retreating sea-cliff edge. The u-shaped seaward extension on either side of the concave eroding sea cliff are referred to as headlands.

Standards: 3-3.5, 3-3.6, 3-3.8
Standards: 5-3.1, 5-3.4
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Sea Arch

- Sea arches form by erosive wave refraction on opposite sides of a headland.
- The abrasion from both sides erodes an arch by opening a passageway through the headland.
- If the arch erodes to the top of the headland, the seaward extension of the headland becomes isolated from the coastline and forms a sea stack.
- In the Hawaiian islands, sea arches maybe linked by pre-existing lava tubes that form weakness in the headlands, which erode forming a sea arch.
- In other places, sea arches may form along weaknesses or jointing in the bedrock.

Sea arch from the Hawaiian Islands

Photo: SCGS

Wave-Cut Scarps and Platforms

- Wave cut scarps are erosional cliff-like features formed by sea waves breaking against a base of a higher-elevation coastline.
- The wave-cut platform is a relatively flat bench-like surface that is deposited by the eroded coastline.
- Wave-cut scarps and platforms often form in a progressive series, relative to long-term environmental changes, such as sea-level change and or tectonic uplift.

This wave-cut scarp and platform near Brigden, South Wales was formed by the erosive action of the sea's waves. The smaller terraces between the scarp and the current sea-level may eventually form another high-standing platform.

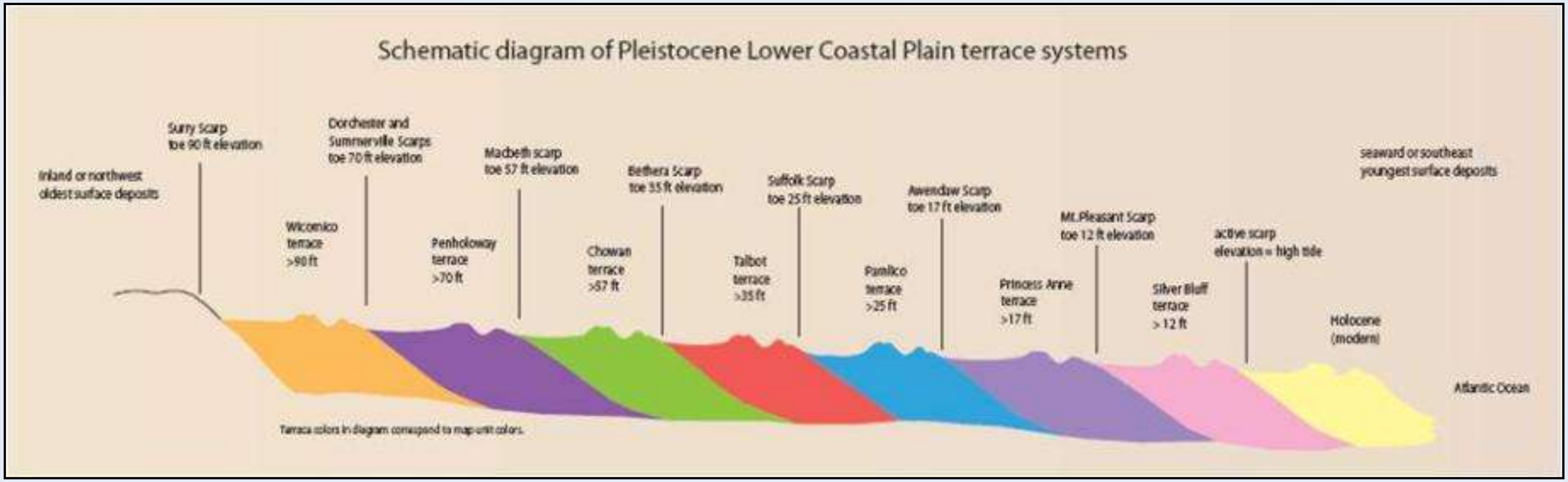
Source: Wikimedia Commons

Standards: 3-3.5, 3-3.6, 3-3.8
Standards: 5-3.1, 5-3.4
Standards: 8-3.7, 8-3.9

Marine Terraces

- Marine terraces are wave-cut platforms that form a series of terraces that progressively increase in elevation and age away from the modern coastline.
- Marine terraces usually form as a result of either sea-level changes, tectonic uplifting, or a combination of both processes.
- Marine terrace are composed of shallow to deep marine deposits and often contain fossil remains which provide a method for relative age dating.
- Scarps form the boundaries between successive marine terraces and often mark some indicator of landscapes response to environmental changes.

The figure below illustrates the sequence of eight marine terraces which form the Lower Coastal Plain of South Carolina. The oldest terrace sits at an elevation of about 90 feet and the youngest terrace is bound by an active scarp that is being eroded by high-tide and rising sea-level.



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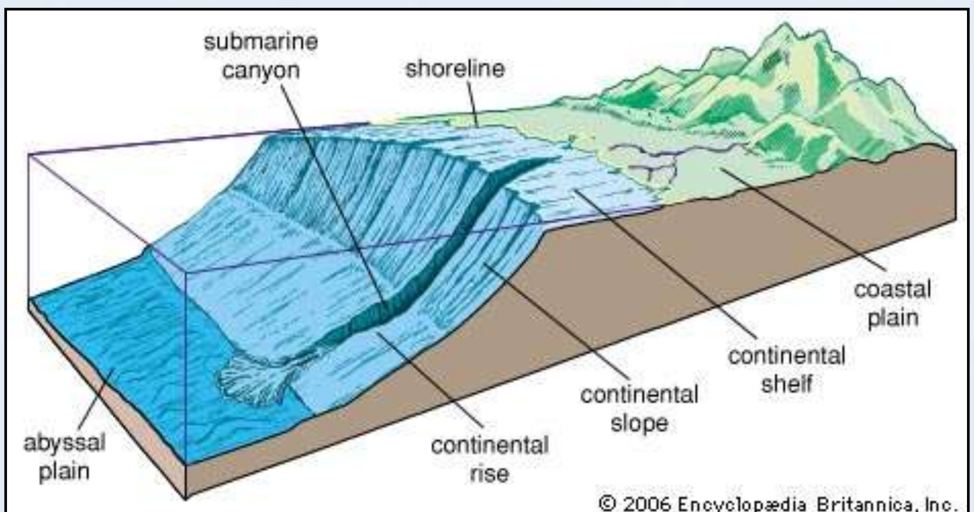
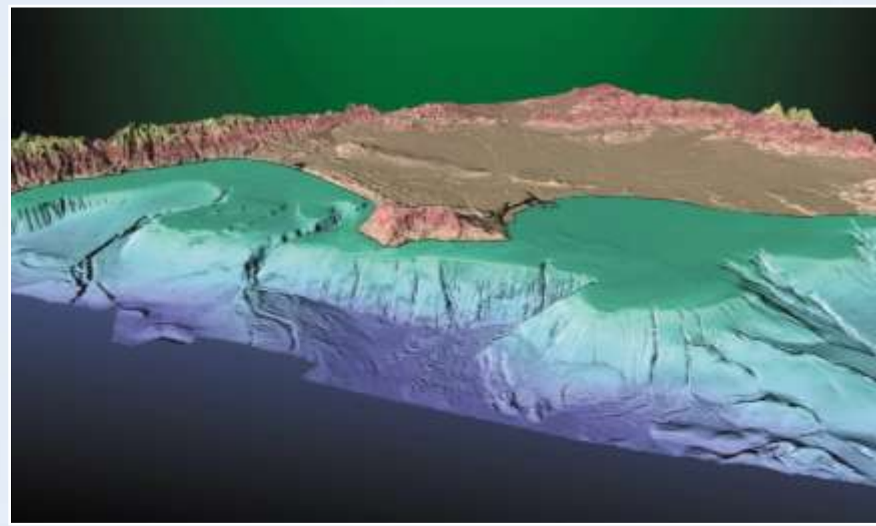
Continental Shelf and Slope

- The continental shelf is a submerged extension of the continental crust that slopes gently outward from the modern shoreline to the deep ocean basin.
- The continental shelf varies in width from being almost non-existent along some continental margins to extending outward for nearly 1500 kilometers (930 miles) in other places. On average it extends outward for about 80 kilometers (50 miles) and has an average slope of about 1 degree (2 meters/kilometer or 10 feet/mile).

Ocean floor features including continental shelf and slope. This diagram provides a good illustration of how the shelf is a shallow extension of the continental crust.





Source: NASA, Visible Earth

A digital elevation model (DEM) of the continental shelf and slope near Los Angeles, California.

Standards: 3-3.5, 3-3.6
Standards: 5-3.1, 5-3.2
Standards: 8-3.7, 8-3.9

Deep-Ocean Basin

- The deep ocean basins includes all areas of the ocean beyond the continental shelf and slope, and excluding mid-ocean ridges. The average depth is 3800 meters (12,500 feet), but varies considerably on account of shallow volcanic seamounts and deep trenches.
- The Pacific Ocean contains the largest ocean basins and accounts for nearly 50% of all salt water on the Earth. The Atlantic Ocean contains the next largest ocean basins, located on either side of the Mid-Atlantic Ridge, and also contains many shallow seas including the Caribbean, Gulf of Mexico, Baltic, and Mediterranean. The Arctic and Indian Ocean contain the smallest basins.
- The deep ocean basin covers about 30% of Earth's surface. Trenches, volcanic seamounts, and abyssal plains are all part of the deep ocean basin.

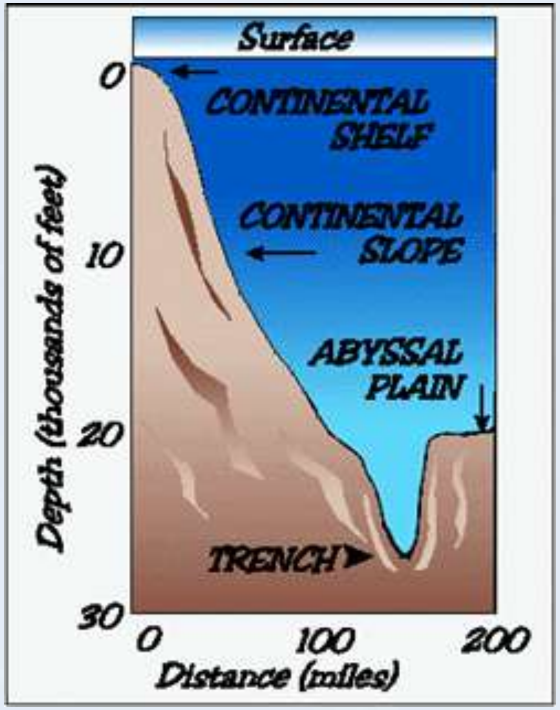
This map includes a few of the ocean basins in southern hemisphere of the Atlantic Ocean. The Brazil and Argentina Basin are separated from the Angola Basin by the Mid-Atlantic Ridge. On the west coast of South America the Pacific Ocean Basin includes the Peru-Chile Trench, formed by convergent boundary between the oceanic and continental subduction zone.

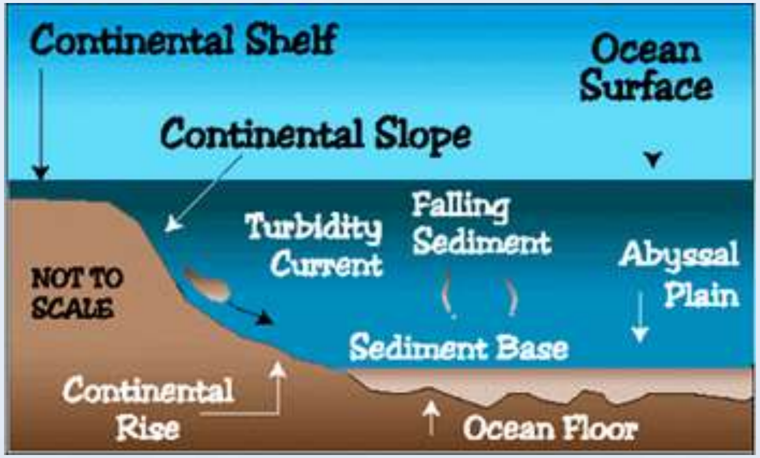
[Standards: 3-3.5, 3-3.6](#)
[Standards: 5-3.1, 5-3.2](#)
[Standards: 8-3.7, 8-3.9](#)

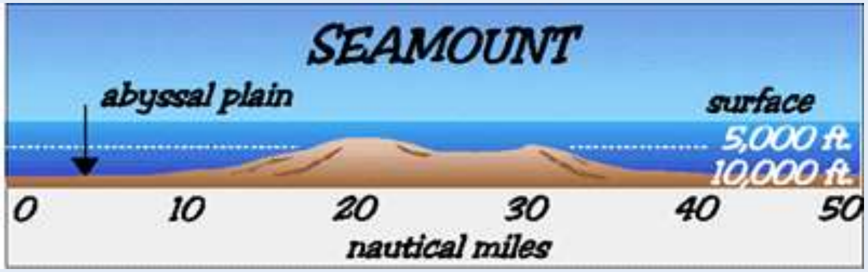
Deep-Ocean Basin Features

- **Abyssal plains** are nearly flat feature-less surfaces and may be the most level areas on Earth. They are very flat because they consist of massive accumulations of sediment, deposited over the ocean floor that bury the underlying topography.
- **Volcanic seamounts** are submerged volcanic mountains, either active or inactive. The occasionally protrude above the surface, exposing their peaks.
- **Trenches** are deep ocean features were plates are submerging into the mantle. Trenches are associated with volcanic island arcs and areas of intense earthquake activity. Marianas Trench in the South Pacific Ocean is the deepest trench, and is more than 35,000 feet (10,668 meters), or almost 6.6 miles (10.6 kilometers) deep. The Navy dove into the deepest part of this trench in January 1960!

The US Navy created this series of cartoon topography to illustrate abyssal plains, trenches, and seamounts.



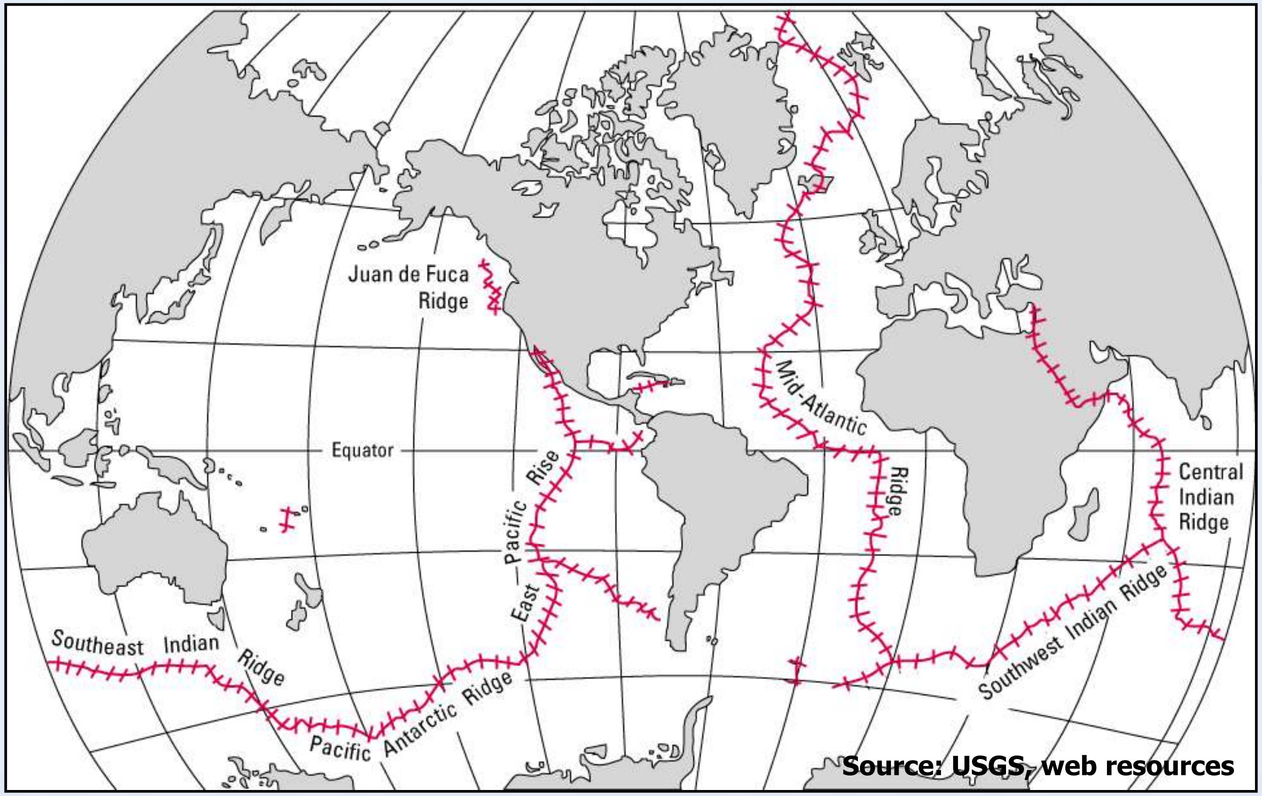




Source: US Navy, author: Captain Neil F. O'Connor, USN (Ret.)

Mid-Ocean Ridges

- Mid-ocean ridges are areas of sea-floor spreading along divergent plate boundaries. New oceanic crust is formed along the narrow ridge crest, where magma rises and solidifies.
- Mid-ocean ridges are characterized by linear, high elevation ridges, extensive faulting, and occasionally volcanic activity.
- The Mid-Atlantic Ridge extends almost the entire length of the North and South Atlantic Ocean and is one of the most prominent subterranean ocean floor features. It rises 3000 meters above the ocean basin floor and is closely monitored by scientists.
- The Mid-Indian Ridge is another prominent feature, and it is actually a continuance of the Mid-Atlantic Ridge system, stretching from below South Africa up to India and Egypt.



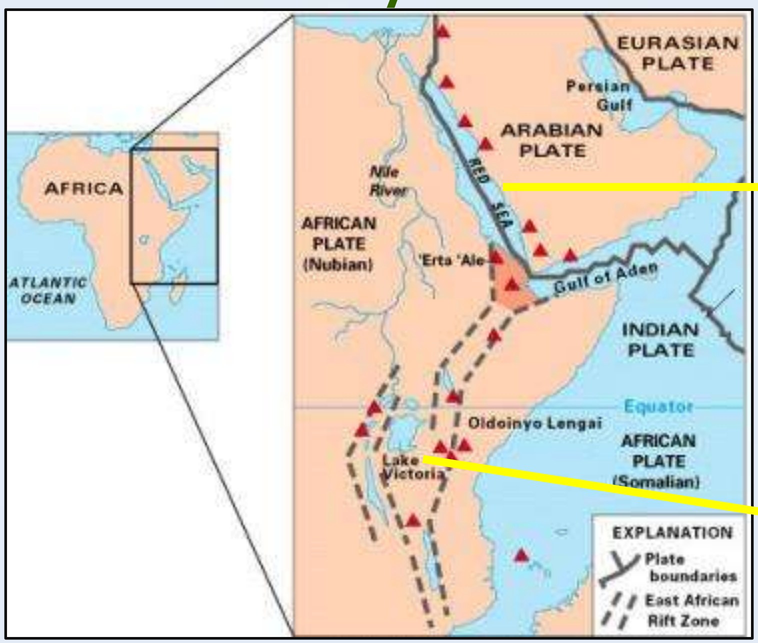
Source: USGS, web resources

The USGS created this "baseball" graphic to illustrate the locations of the major mid-ocean ridge systems. The continuous line marks the location and orientation of the ridge, and the cross-stitching represents potential fault patterns along the ridges. Because the ridges mark plate boundaries they are more or less continuous, but are differentiated by name relative to ocean basin or continental proximity.

Rift Zone

- Rift zones are fault structures formed by normal faults along active boundaries.
- Rising magma below the crust upwells, forcing the lithosphere to fracture, as it fractures and cracks, one or more faults occur causing the rock layers to separate forming a rift valley.
- Rift valleys can eventually form lakes or seas such as the Red Sea, which separates Africa from the Arabian Peninsula.

Rift Valleys in Africa



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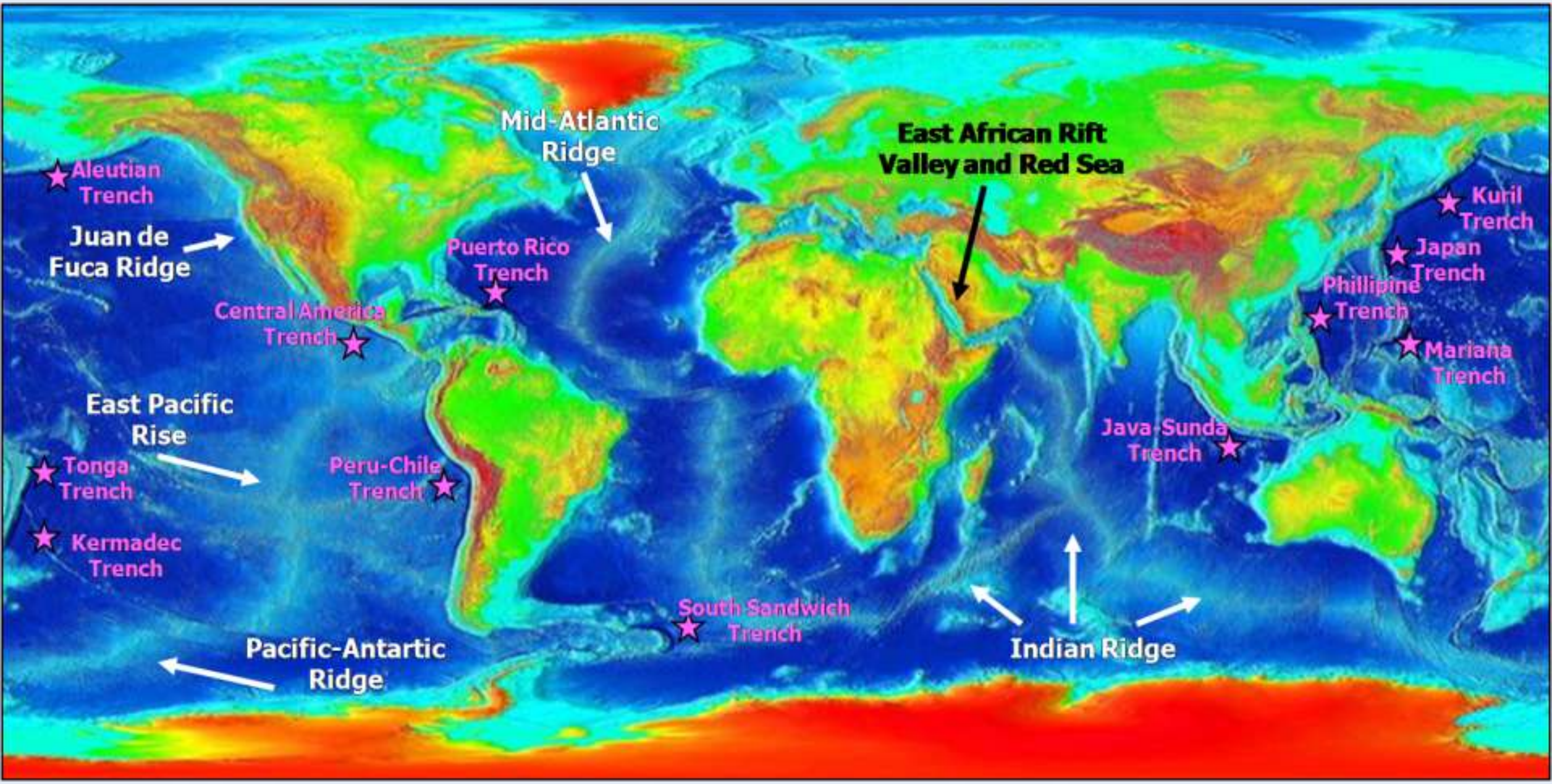
Standards: 8-3.7, 8-3.9

Continental Shelf and Slope:
areas of turquoise colored continental crust around the continental margins

Mid-Ocean Ridges:
boundary between divergent plate margins, indicates areas of sea-floor spreading



Ocean Basin:
all of the submerged ocean floor beyond continental shelf and slope, but excluding trenches.

Rift Zone:
tectonically active areas of rifting that create new seas

Trenches:
deep, narrow features along active margins, trenches are dark blue markings located on the map next to a pink star " ☆ "

Standards: 3-3.5, 3-3.6, 3-3.8
Standards: 5-3.1, 5-3.5
Standards: 8-3.7, 8-3.9

Glacial Landforms

Glaciers are large masses of moving ice. Because glaciers are "frozen" they are part of the Earth's cryosphere, which accounts for 77 percent of all Earth's freshwater.

Glaciers are very sensitive to the slightest temperature changes. Over Earth's geologic history the spatial extent and size of glaciers has expanded and shrunk numerous times. As a result, glacial landforms can be found in locations that currently have no active glaciers or glaciation processes. Presently, glacial landforms occur in two distinct geographic regions, high latitude polar environments and high altitude mountain environments. In this section we will explore glacial landforms from their present context and from a historic look into the past.

Alpine Valley Glacier in Alaska.

- Ice sheets and Alpine Glaciers
- Ice Field and Ice Caps
- Piedmont Glacier
- Tidal Glaciers and Icebergs
- Glacial U-shaped Valleys
- Fjords
- Hanging Valleys
- Cirques and Cirque Glaciers
- Arêtes, Horns, Cols
- Lateral and Medial Moraines
- End and Terminal Moraines
- Paternoster Lakes
- Kettles
- Erratics
- Drumlins
- Outwash Plain

Standards: 3-3.5, 3-3.6, 3-3.8
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Glaciers

- Glaciers are large masses of "flowing" ice formed by the accumulation and compaction of recrystallized melted snow.
- Glacial landforms are divided into two broad categories which occur in distinct geographic regions: **ice sheets** which occur high latitude polar environments and **alpine glaciers** which occur in high altitude mountain environments.

    - **Ice sheets** are high latitude polar glaciers that cover extensive areas of continental landmasses, for this reason they are also referred to as "**continental glaciers**". Glacial ice sheet formation requires long periods of extremely low temperatures, which allows snow to collect over vast areas covering the underlying terrain. The accumulation of snow forms dense layers that are thousands of meters thick. Antarctica and Greenland are both almost completely covered by glacial ice sheets.
    - **Alpine glaciers** are long, linear glaciers that occupy high altitude mountain valleys, for this reason they are also referred to as "**valley glaciers**". Alpine glaciers flow down valley, and increase in size as they accumulate and absorb smaller tributary glaciers from the mountainous terrain. Alpine glaciers can be found all around the world, and presently occur in may of the major mountain ranges in the world including the Rockies, Andes, and Himalayas. Alpine glaciers may also occur in high-latitude, polar or arctic mountains, such as those in Alaska.

- Geomorphologist's often refer to glaciers as "rivers of ice" because like rivers, continental and alpine glaciers "flow" down-valley through the landscape eroding, transporting, and depositing weathered materials along their the path. It is this combination processes that forms the diverse array of constructive and destructive glacial landforms.

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Standards: 5-3.1, 5-3.5
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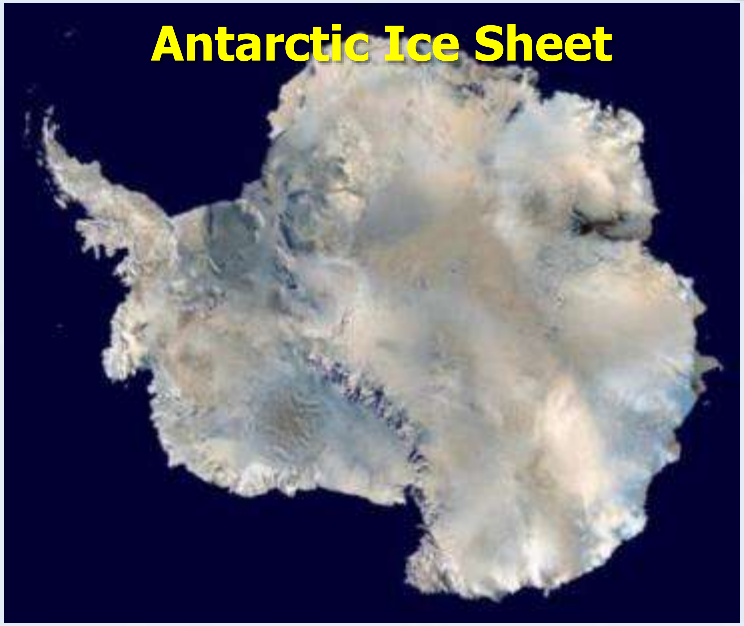
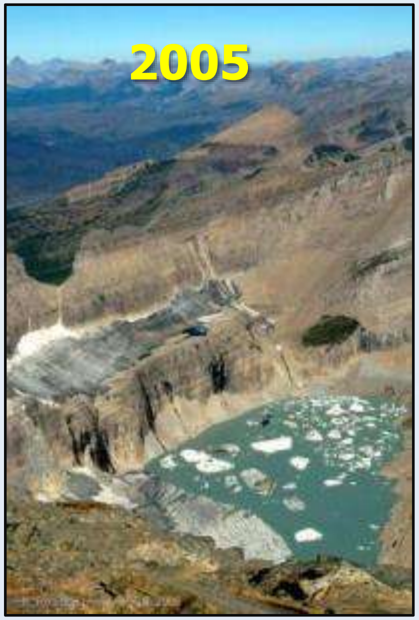
Ice Sheets and Alpine Glaciers



Glacier National Park in the United States has been sculpted by alpine glacial processes over thousands of years. Today, Glacier NP's landscape contains vestiges of past glaciation, with only a few active, high elevation alpine glaciers. Recent temperature increases are melting glaciers at an alarming rate. Scientist predict that by 2030 there may not be any more glaciers in Glacier National Park! The images below taken from the same location, 67 years apart, shows the effects of climate change on glaciers.

An ice sheet is a continuous widespread, mass of glacial ice which blankets the entire landscape, and in their most extensive form, ice sheets may cover an entire continent. It is estimated that 90 percent of Antarctica and nearly 80 percent of Greenland are covered by ice sheets. Both of these ice sheets are so thick, that portions the Earth's crust below them are isostatically depressed, placing the actual landmass thousands of feet below sea-level. As the ice melts and the weight is removed, the landmass will slowly rebound and rise back up to sea-level. Both the Antarctic Ice Sheet and Greenland Ice Sheet are over 9800 feet thick in some places, and the only landmasses exposed are the highest elevation mountain peaks.



Source: USGS

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Ice Field and Ice Caps

- **Ice fields** are elongate, continuous expanses of glacial ice which follow the topography of mountains. Isolated mountain ridges and peaks often protrude out from the ice field. Ice field may feed alpine glaciers.
- **Ice caps** are circular shaped masses of glacial ice that cover an area less than 50,000 km^2. Ice caps form in mountain regions and they completely bury the underlying topography. Ice caps are similar to ice sheets, only smaller.

Copyright ©Bruce Molnia, Terra Photographics

The high altitude environments in Alaska contain large ice fields that feed alpine glaciers. In this picture, you can see the mountain peaks protruding above the ice field. This image also contains example of crevasses, or cracks, in glacial ice.

Source: wikimedia commons, NASA image

This aerial image of the Vatnajökull Ice Cap in Iceland has several glaciers flowing outward from the ice cap. NASA scientists monitor the effects of global warming on this ice cap using satellite imagery. Notice how the advancing glaciers are slightly darker colored than the ice sheet from the sediments and debris they are transporting.

Standards: 3-3.5, 3-3.6
Standards: 5-3.1, 5-3.5
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Piedmont Glacier

- Piedmont glaciers are formed where multiple valley glaciers flow out from the mountainous terrain and coalesce into a singe large glacier, spreading over the lowland topography.
- Piedmont glaciers continue to grow as long as they are fed by valley glaciers. Piedmont glaciers often source rivers and streams that form from glacial melt water and till deposits.

This piedmont glacier is part of the Malaspina Glacier in Alaska and is the largest piedmont glacier in the United States. The Mount Saint Elias mountains in the background are the source that feed this piedmont glacier. The dark bands in the photo mark the lateral and medial moraines where the valley glaciers merged together.

Standards: 3-3.5, 3-3.6
Standards: 5-3.1, 5-3.5
Standards: 8-3.7, 8-3.9

Tidal Glaciers and Icebergs

- Tidal glaciers are the portion of either alpine or continental glaciers which spill out into the sea and float on the surface of the saltwater.
- The glacial ice over the water breaks by calving off into large icebergs.
- Icebergs are large floating blocks of ice that calved off from tidal glaciers.
- Icebergs usually calve off along crevasses or cracks in the ice, but can also fail from a combination of melting and gravitational pull.
- Icebergs vary in size and thickness, and some reach heights more than 100 feet!

The icebergs in the front of the photo calved of from the tidal glacier in the background. The portion of the icebergs exposed above the water is often only a third of their entire size, the other two-thirds is submerged below the water.

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Glacial “U-Shaped” Valleys

- Glacial valleys are formed by the abrasive action of glacial ice as it slowly carves a “u-shaped” path through the mountainous valleys.
- Prior to the formation of the glacier, most valleys are initially formed as a “v-shaped” stream valley eroded by flowing water. Once the valleys becomes occupied by the glacier, the glacial ice spreads from one side of the valley to the other, completely filling in the valley floor and up the hill slopes. As the glaciers moves down-valley it abrasively erodes the pre-formed “v-shaped” stream valley into a “u-shaped” glacial valley.

The Alaska's Woodworth Glacier, on the left is beginning to retreat and expose a glacial u-shaped valley beneath the melting ice. The Sierra Nevada landscape with Yosemite Valley pictured below, presently only contains glaciers in the highest elevations, but many of the prominent u-shaped valleys, reveal past evidence of glacial erosion.

Source: Wikimedia Commons

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Fjords

- Fjords are flooded troughs that form where glacial u-shaped valleys intersect the ocean and the sea floods inland filling up the valley.
- Fjords can form during active glaciation or post-glaciation depending on sea-level.
- When a glacier intersects the ocean, the glacier can continue to erode and carve the valley below sea-level. The water that fills in above the glacier and floods the valley forms a fjord.
- Fjords can also form post-glaciation by rising sea-level or changes in elevation along the coastline from melting ice.

On the left is a glacier intersecting a fjord in the Pacific Ocean off Estero de las Montanas in Chile, South America. Below is an aerial view of the Prince William Sound and Cascade Glacier fjord in Alaska.

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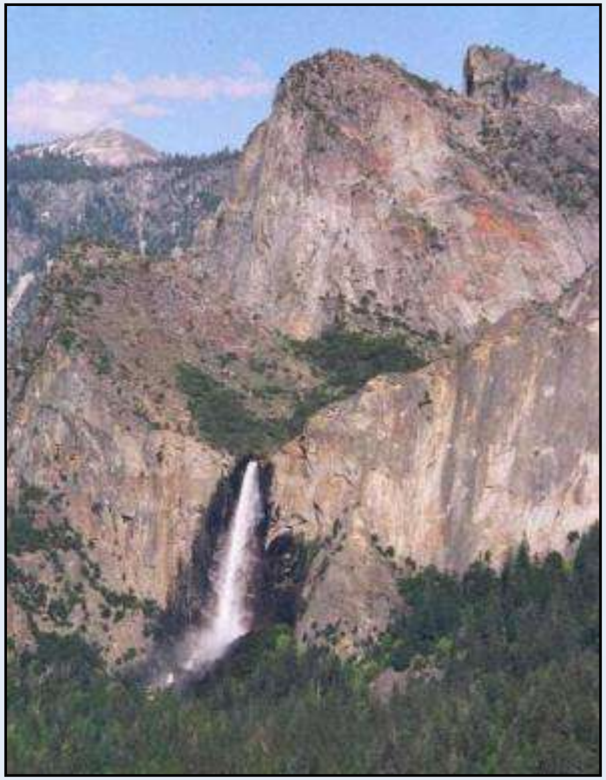
Standards: 5-3.1, 5-3.5
Standards: 8-3.7, 8-3.9

Hanging Valleys

- Hanging valleys are abrupt, cliff-like features that are formed at the confluence where smaller tributary glaciers merge with larger valley glaciers.
- The scour of the larger glacier carves the valley into a u-shape, removing the original gradient of the tributary confluence, as a result the tributary valley is left stranded or “hanging” above the larger valley.
- Hanging valleys are only visible after the glacier melts and reveals the underlying topography. Hanging valleys are often the sight of dramatic plunging waterfalls.

These images show hanging valleys in two different periods. Below the tributary glacier is retreating and a waterfall begins to form. The image on the right is of a post-glacial hanging valley, Bridal Falls in Yosemite National Park.



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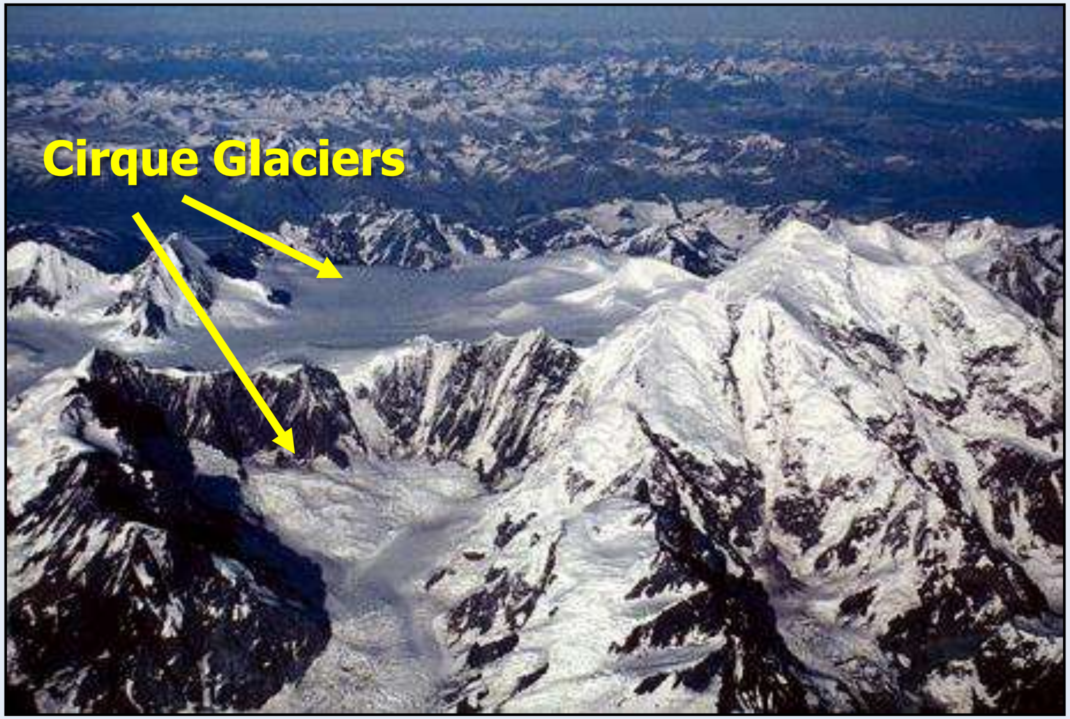
Standards: 3-3.5, 3-3.6
Standards: 5-3.1, 5-3.5
Standards: 8-3.7, 8-3.9

Cirques and Cirque Glaciers

- Cirques are bowl-shaped eroded, depressions near-mountain top ridges where snow accumulates and forms the head of an alpine glacier.
- Glaciers in this early phase of formation are often referred to as cirque glaciers. The confluence of multiple cirque glaciers merges to form a valley glaciers. Cirque glaciers feed valley glaciers a relatively steady source of new snow.
- When glaciers retreat, the cirque is often the last part of the glacier to melt.



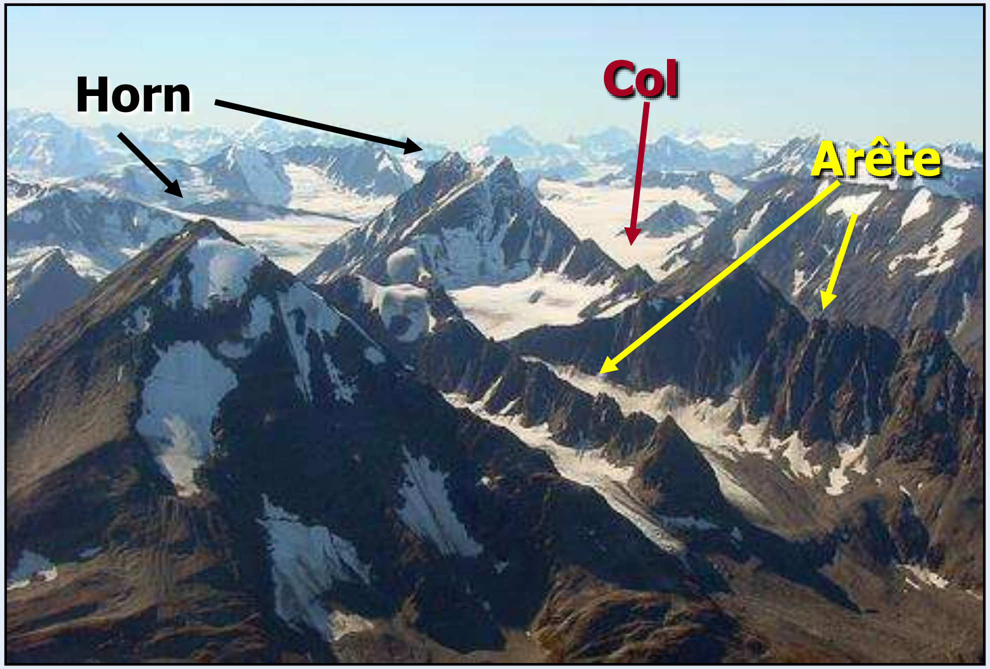
Mount Fairweather in Alaska contains several cirques glaciers that feed into valley glaciers that descend down the mountain. This image shows two different cirque glaciers of varying sizes feeding different valley glaciers separated by cols and arêtes. In post glacial landscapes, cirques may fill with water to form cirque lakes.

Standards: 3-3.5, 3-3.6
Standards: 5-3.1, 5-3.5
Standards: 8-3.7, 8-3.9

Arêtes Cols and Horns

- **Arêtes** are saw-tooth, serrated ridges in glacial mountains. Arêtes separate adjacent cirques and adjacent valleys. Arête is French for "knife-edge", and the ridges are appropriately named!
- **Cols** form when two cirque basins on opposite sides of the mountain erode the arête dividing them. Cols create saddles or passes over the mountain.
- **Horns** are a single pyramidal peak formed when the summit is eroded by cirque basins on all sides. Horns form majestic mountain peaks and create many challenges for adventurous climbers. Matterhorn, in the Swiss Alps, is a well known horn.

On the left is a classic set of glacial landforms in the Chugach Mountains, Alaska. Many of the glaciers in this range are currently retreating and exposing the erosive action of the glacial ice on the landscape. Below is the famous Matterhorn in the Swiss Alps.



Source; Wikimedia commons

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Standards: 3-3.5, 3-3.6
Standards: 5-3.1, 5-3.5
Standards: 8-3.7, 8-3.9

Lateral and Medial Moraines

- Moraines are formed by the deposition of glacial till as the glacier melts. Moraines are defined by where the glacial till was deposited relative to the moving, melting glacier.
- The four most common moraine types are **lateral**, **medial**, **end**, and **terminal** moraines.

- **Lateral moraines** are long linear ridges of glacial till deposited along the side of the glacier parallel to its direction of movement.
- **Medial moraines** are long linear ridges that form along the contact where tributary glaciers with lateral moraines merge to join larger valley glaciers. Medial moraines form were the glaciers merge together the till deposits become incorporated as dark ridges of sediment oriented down valley and aligned parallel through the middle of the glacier.

Kennicott Glacier shows off multiple medial moraines as it descends Mount Blackburn in the Wrangell-St. Elias National Park in Alaska.

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Standards: 3-3.5, 3-3.6
Standards: 5-3.1
Standards: 8-3.7, 8-3.9

Terminal and End Moraines

- **Terminal moraines** are linear, concave, arc-shaped depositional ridges that form at the terminus of a glacier. The terminal moraine is formed by the deposits of glacial till that mark the outward expanse or limit of glacial movement . Even if the glacier is no longer advancing forward, it continues to transport ice and sediments to the terminus, where the ice melts and the sediments bound up in the ice are deposited as the terminal moraine.
- **End moraines**, also referred to as recessional moraines, are concave arc-shaped ridges deposited by the melting glacier. They are similar to terminal moraines, except that they are generally smaller, and they mark the gradual retreat of the glacial ice after it has already deposited its terminal moraine.

View of the retreating Schwan Glacier in the Chugach Mountains of Alaska. The terminus is marked by an outwash plain and lake formed from the melting snow. This image contains many classic glacial features, including u-shaped valleys, hanging valleys, arêtes, and end, terminal, medial, and lateral moraines.

Standards: 3-3.5, 3-3.6
Standards: 5-3.1, 5-3.5
Standards: 8-3.7, 8-3.9

Paternoster Lakes

- Patternoster lakes are a connected string of small, circular lakes that occur in valleys previously occupied by glaciers.
- Patternoster lakes are post glacial erosional features filled with rainwater or glacial meltwater.
- The depressions where the lakes form are usually the result of either differential erosion of the bedrock, or the creation of small dams formed by glacial till deposits or end moraines.
- Initially, melted glacial ice fills the depressions creating a string of lakes. Over time, precipitation or springs provide a renewable source of freshwater.

This string of patternoster lakes in this u-shaped valley in the Sierra Nevada Mountains of California provides evidence of past glaciations. Glaciers have occupied this valley on and off over the last 2.5 million years during cooler ice age periods. Glaciers may occupy these valleys again in the future.

Standards: 3-3.5, 3-3.6
Standards: 5-3.1, 5-3.5
Standards: 8-3.7, 8-3.9

Kettles

- Kettles are small depressions in the landscape, often filled with water, that form post-glaciation.
- Kettles form when large blocks of ice are left by a retreating glacier and the land surrounding the abandoned ice block accretes from the accumulation of glacial deposits. After the ice block melts, only a void or kettle remains.
- The kettle can also be deepened by the melting and subsidence of the ground below where the ice block previously lay.
- Kettles formation is most common where glaciers retreat from the steep terrain and flow into lower-lying valleys.
- Kettles may or may not form lakes. Those that contain water are often sourced by rainfall or snowmelt.

This small kettle was formed by the melting and retreat of glacial ice from this valley. The kettle is surrounded by a small ridge formed by the deposition of glacial till from the melting ice block. The presence of plants in the forefront of the image suggest that glaciers have been absent from this area for at least a couple decades and maybe longer.

Standards: 3-3.5, 3-3.6
Standards: 5-3.1
Standards: 8-3.7, 8-3.9

Erratics

- Erratics are large, isolated boulders deposited by retreating, melting glaciers. They are post-glacial depositional features that provide evidence of past glaciations.
- As glaciers move across the landscape they pick up sediments by plucking them off the surface. This process incorporates sediments into the glacial ice and transports them down-valley. When the glacier melts, these sediments are deposited. Erratics, are generally the largest rocks left behind by the retreating glaciers. They are generally smooth from glacial abrasion and appear “misplaced” in the landscape.

Yosemite Valley is littered with glacial erratics, like the example below, perched on Lambert Dome. This erratic is quite angular suggesting it was only transported by the glacier for a short distance or amount of time.

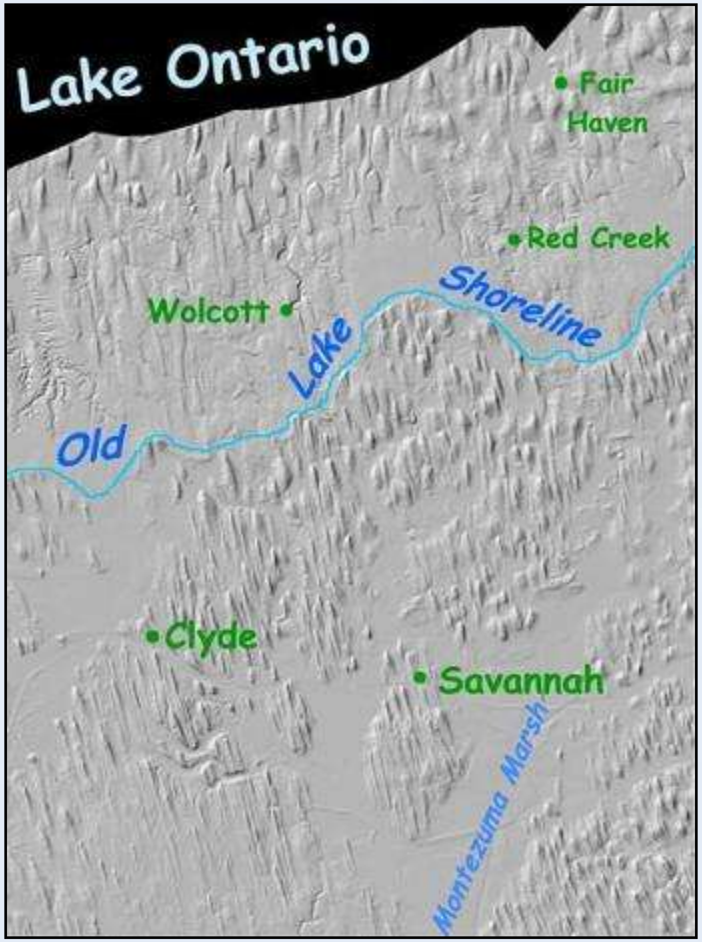
Source: Wikimedia Commons

The image above is from a recently deposited glacial erratic. Notice how the erratic is still perched atop glacial ice, and there is a glacier retreating in the lower right corner of the image. The person in front of the erratic provides a relative scale for size.

Standards: 3-3.5, 3-3.6, 3-3.8
Standards: 5-3.1
Standards: 8-3.7, 8-3.9

Drumlins

- Drumlins are long, linear hills of glacial till deposited by ice sheets. The term "drumlin" comes from the Irish word "druim" which translates to ridge.
- Drumlins are similar to medial and lateral moraines, except that they are usually smaller and may be irregular shaped relative to the direction of glacial movement. Drumlin fields are areas with numerous drumlins.



Source: Wikimedia Commons

The digital elevation model (DEM) on the right shows a large drumlin field with numerous drumlins all oriented in the same direction. Below is a photo of a drumlin overgrown with vegetation. Both of these examples are from New York, where extensive glacial ice sheets once covered the northeast United States.

Source: Wikimedia Commons

Outwash Plains and Eskers

- Glacial outwash plains are extensive stratified deposits of glacial till below a glacier that usually form braided streams. They are choked with glacial till and are fed by melt-water flowing from the base of the glacier.
- Outwash plains form a complicated network of braided channels, flowing through a mess of glacial till sediment deposits. The streams partially sort the mess of sediments, transporting the finer materials further downstream and leaving behind the coarser till deposits.
- Eskers form along melt water channels that are emerging from tunnels beneath the glacier. They are depositional ridges of sands and gravel that mark the "course" of the melting glacier or course of the melt water tunnel.
- Eskers form interesting sinuous ridges across a landscape marking the location of a melt water tunnels from a glacier.

The outwash plain below this glacier in the left image heads a braided river that flows through the glacial till deposits. The image below contains recently formed eskers exposed by the melted glacier.

South Carolina Earth Science Education Standards: Grade 3

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. (Earth Science).

Indicators:

3-3.5: Illustrate Earth's saltwater and freshwater features (including oceans, seas, rivers, lakes, ponds, streams, and glaciers).

3-3.6: Illustrate Earth's land features (including volcanoes, mountains, valleys, canyons, caverns, islands) by using models, pictures, diagrams, and maps.

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 Earth Science Education Standards: Grade 5

Landforms and Oceans:

Standard 5-3: The student will demonstrate an understanding of features, processes, and changes in Earth's land and oceans. (Earth Science)

<u>Indicators:</u>

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.

5-3.2: Illustrate geologic landforms of the ocean floor (including the continental shelf and slope, the mid-ocean ridge, rift zone, trench, and ocean basin).

5-3.4: Explain how waves, currents, tides, and storms affect the geologic features of the ocean shore zone (including beaches, barrier islands, estuaries, and inlets).

5-3.5: Compare the movement of water by waves, currents, and tides.

South Carolina Earth Science Education Standards: Grade 8

Earth's Structure and Processes

Standard 8-3: The student will demonstrate an understanding of materials that determine the structure of Earth and the processes that have altered this structure. (Earth Science)

<u>Indicators:</u>

8-3.7: Illustrate the creation and changing of landforms that have occurred through geologic processes (including volcanic eruptions and mountain building forces).

8-3.9: Identify and illustrate geologic features of South Carolina and other regions of the world through the use of imagery (including aerial photography and satellite imagery) and topographic maps.

Table of Contents

Resources and References

- Christopherson, R. W. 2004. Elemental Geosystems. 4th Ed. Prentice Hall. Upper Saddle River, New Jersey.
- Lutgens, F. K. and E. J. Tarbuck 2003. Essentials of Geology, 8th Ed. Prentice Hall. Upper Saddle River, New Jersey.
- Smith, G. A. and Pun, A. 2006. How does Earth Work? Physical Geology and the Process of Science. Prentice Hall. Upper Saddle River, New Jersey.