

Folding/Faulting: Topographic Expression of Folded Strata

- **Mountains: Orogenesis and Deformation**

- **Folding**
- **Faulting**
- **Joints & Fractures**

- **Domes and Basins**
- **Horst and Graben Rift Valleys**

- **US Examples:**

- **Sierra Nevada**
- **Grand Tetons (Rocky Mountains)**
- **Appalachian Mountains**

Orogenesis

- Orogenesis is the thickening of the continental crust and the building of mountains over millions of years.
- Orogeny encompasses all aspects of mountain formation including plate tectonics, terrane accretion, regional metamorphism, thrusting, folding, faulting, and igneous intrusions.



Photo courtesy of SCGS, SCDNR

South Carolina's Blue Ridge Mountains and Inner Piedmont Region were formed by multiple orogenic events when rocks were uplifted, metamorphosed, folded, faulted, and thrust.

Deformation

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

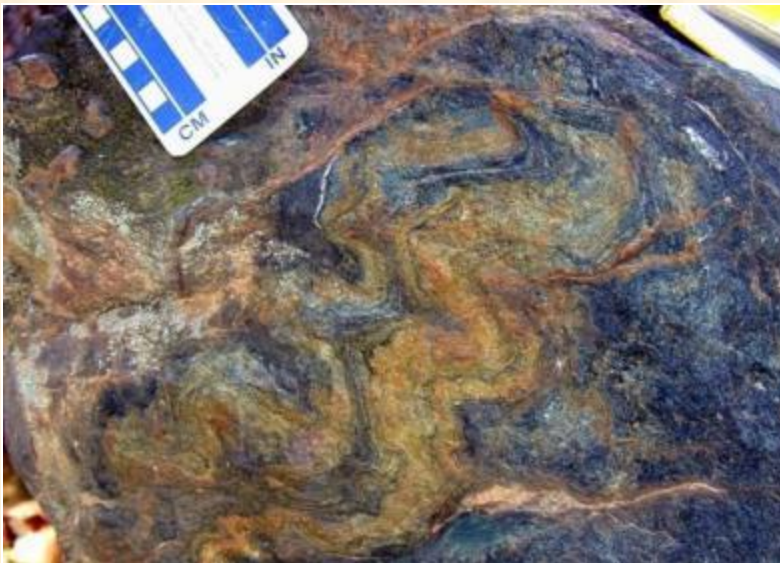


Photo: South Carolina Geological Survey

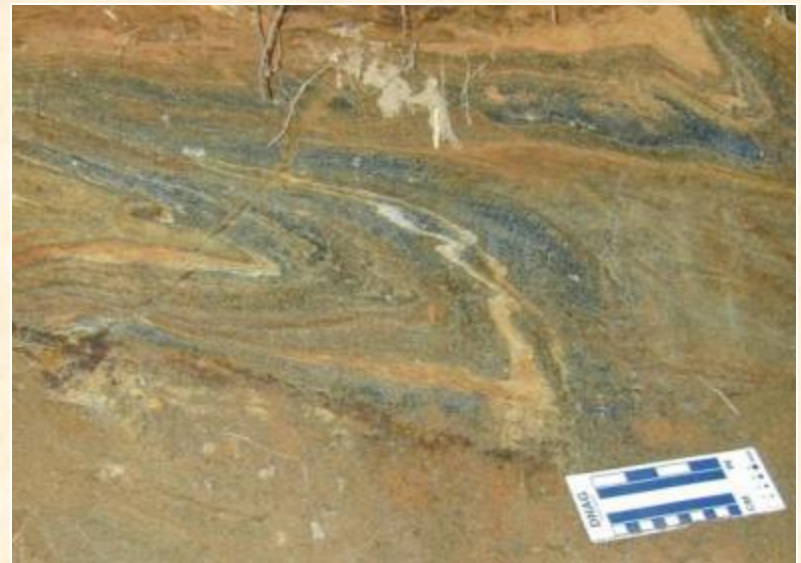


Photo: South Carolina Geological Survey

Deformation

- **Structural Geology**: the branch of geology that studies crustal deformation

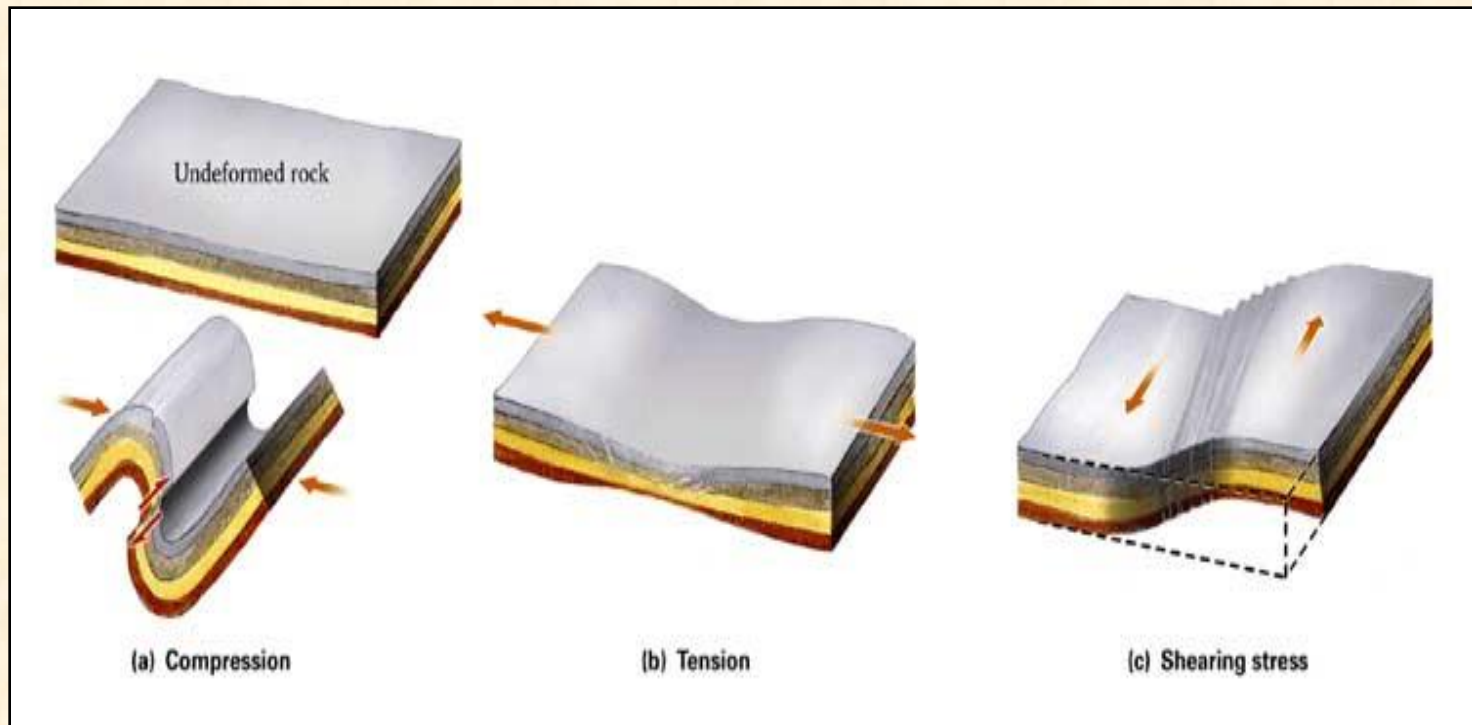


Notes: Folded Sandstone, Martin Bond/Science Photo Library/Photo Researchers, Inc.

Deformation

Stress: the agent of change, units are **pressure** (force/area)

- **Compression**
- **Tension**
- **Shearing**



Deformation

Elastic deformation up to elastic limit

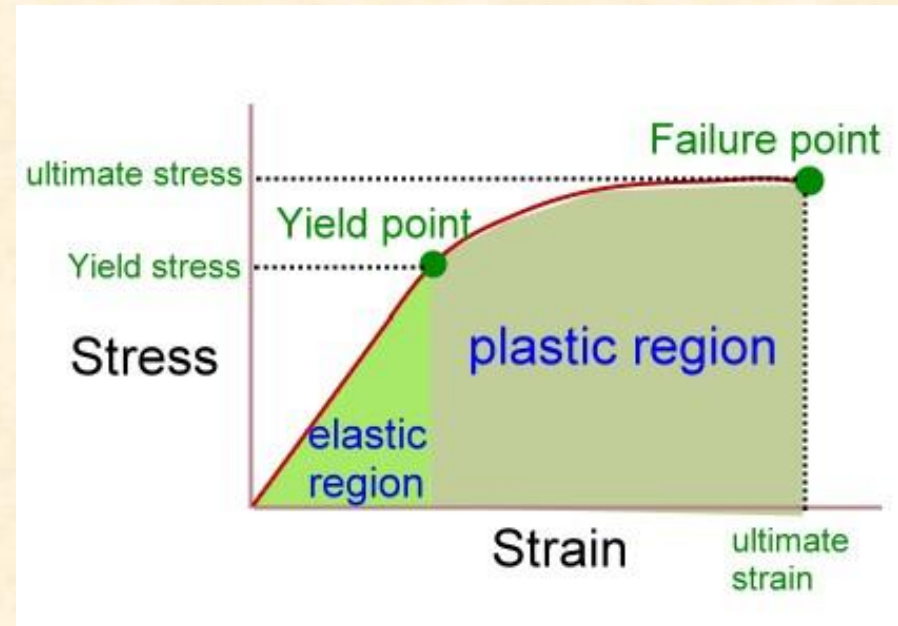
- Springs back to original shape

Brittle failure (it breaks)

- Subjected to great stress that exceeds the elastic limit
- Subjected to sudden stress "impact event"

Plastic deformation

- Does not spring back keeps deformed shape
- High temperature – near melting
- High pressure ... squeezed like a ball of clay



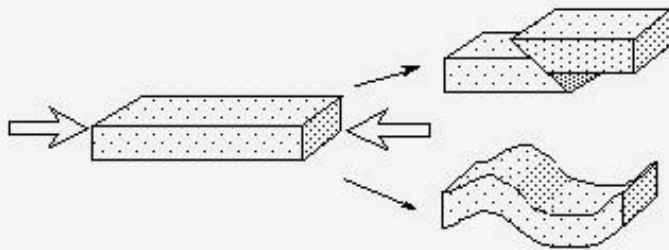
The ratio of change produced in the dimensions of a body by a system of forces, in equilibrium, to its original dimensions is called **strain**.

Strain = Change in Dimension / Original Dimension

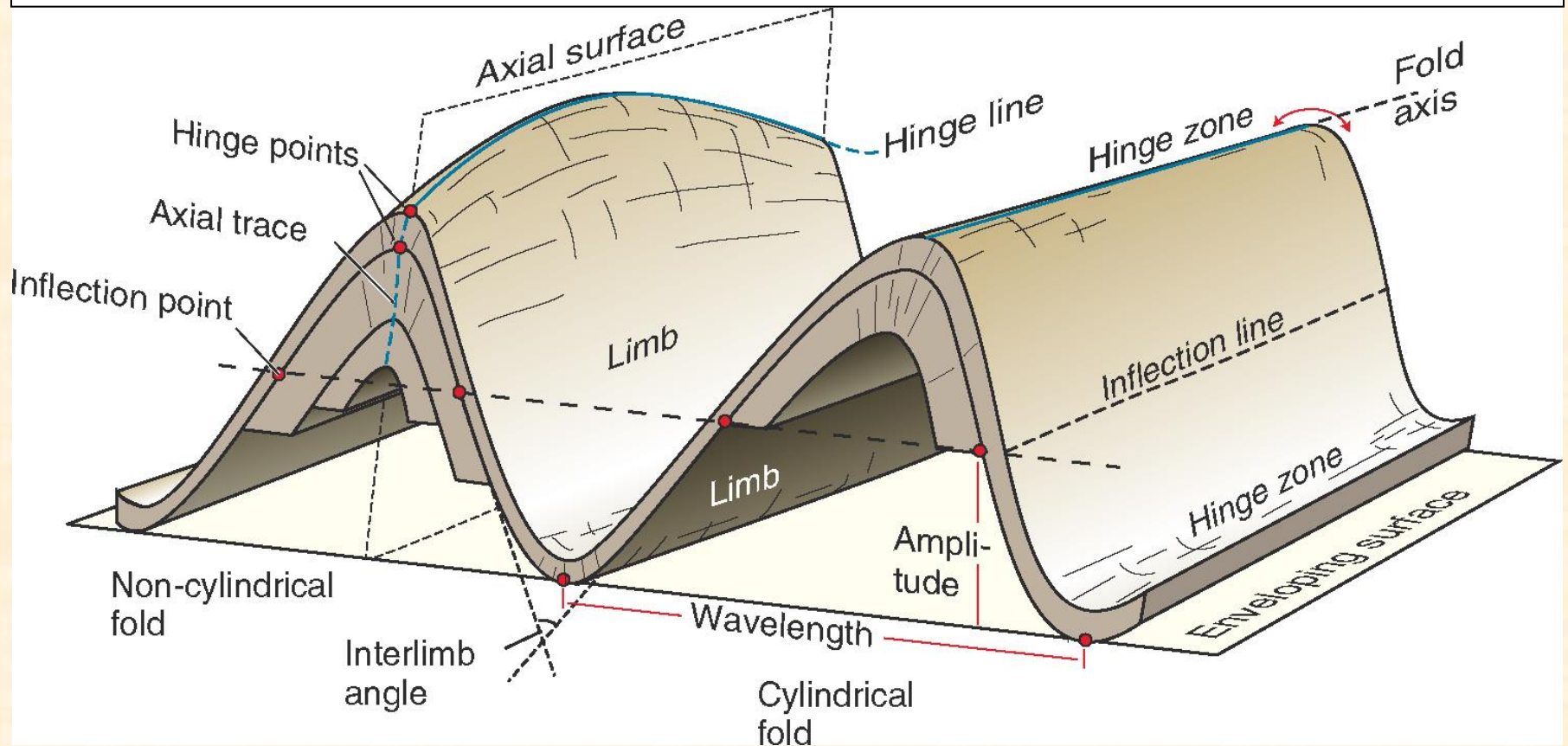
Factors Affecting Rock Deformation

- Intensity of applied stress
- Heat –Temperature of the Rock
- Amount of Time the Stress is applied
- Rock Composition

<i>Type of deformation</i>	<i>Typical action</i>	<i>Geologic result</i>	<i>Favorable geologic environment</i>	<i>Favorable rock types</i>	<i>Favorable strain rate</i>
Brittle	Breakage	Faults	Near surface (Low P & T)	Sandstone, Limestone, Igneous Rocks	Fast
Ductile	Bending & flowing	Folds	Deep (High P & T)	Salt, Shale, Slate, Schist	Slow



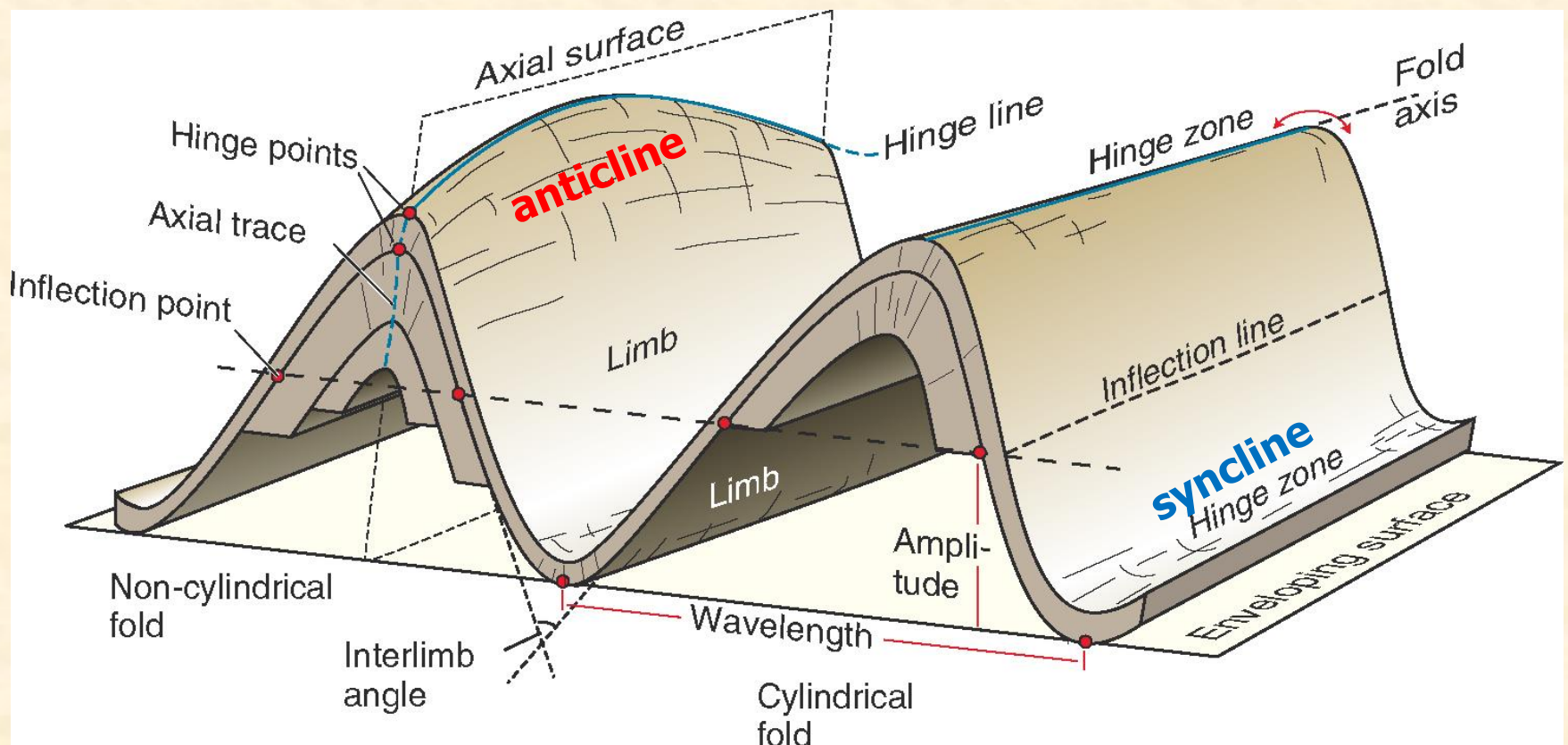
Folding



Folding

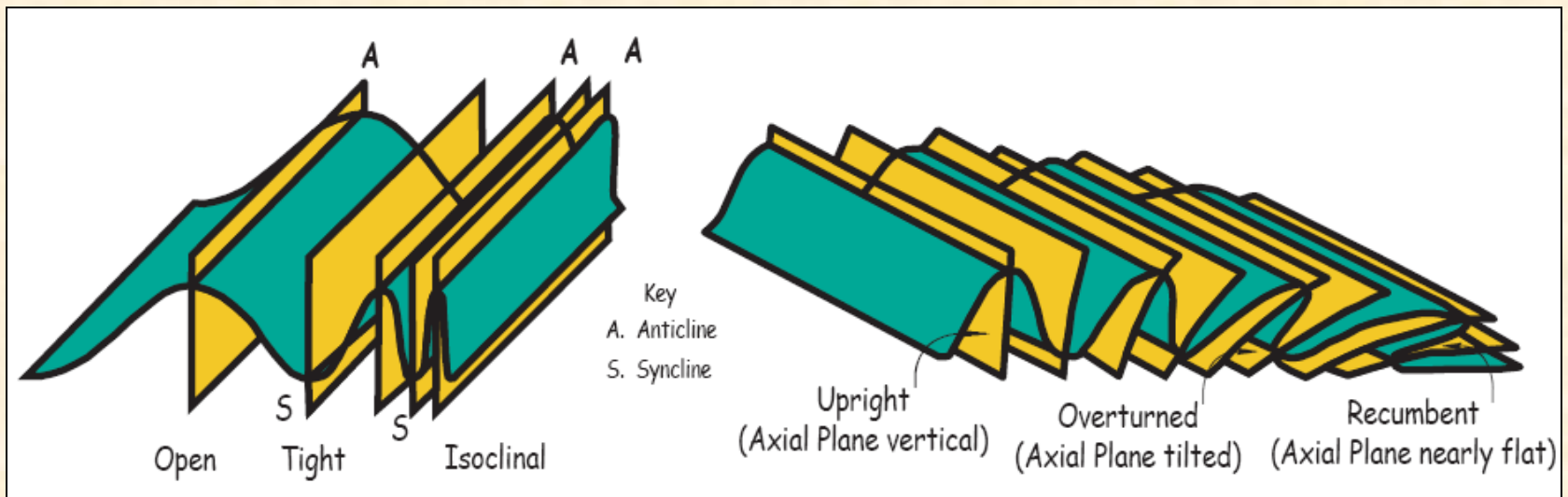
The crest of the fold, where the rock layers slope downward form the **anticline**.

The valley of the fold where the layers slope toward the lower axis form the **syncline**.

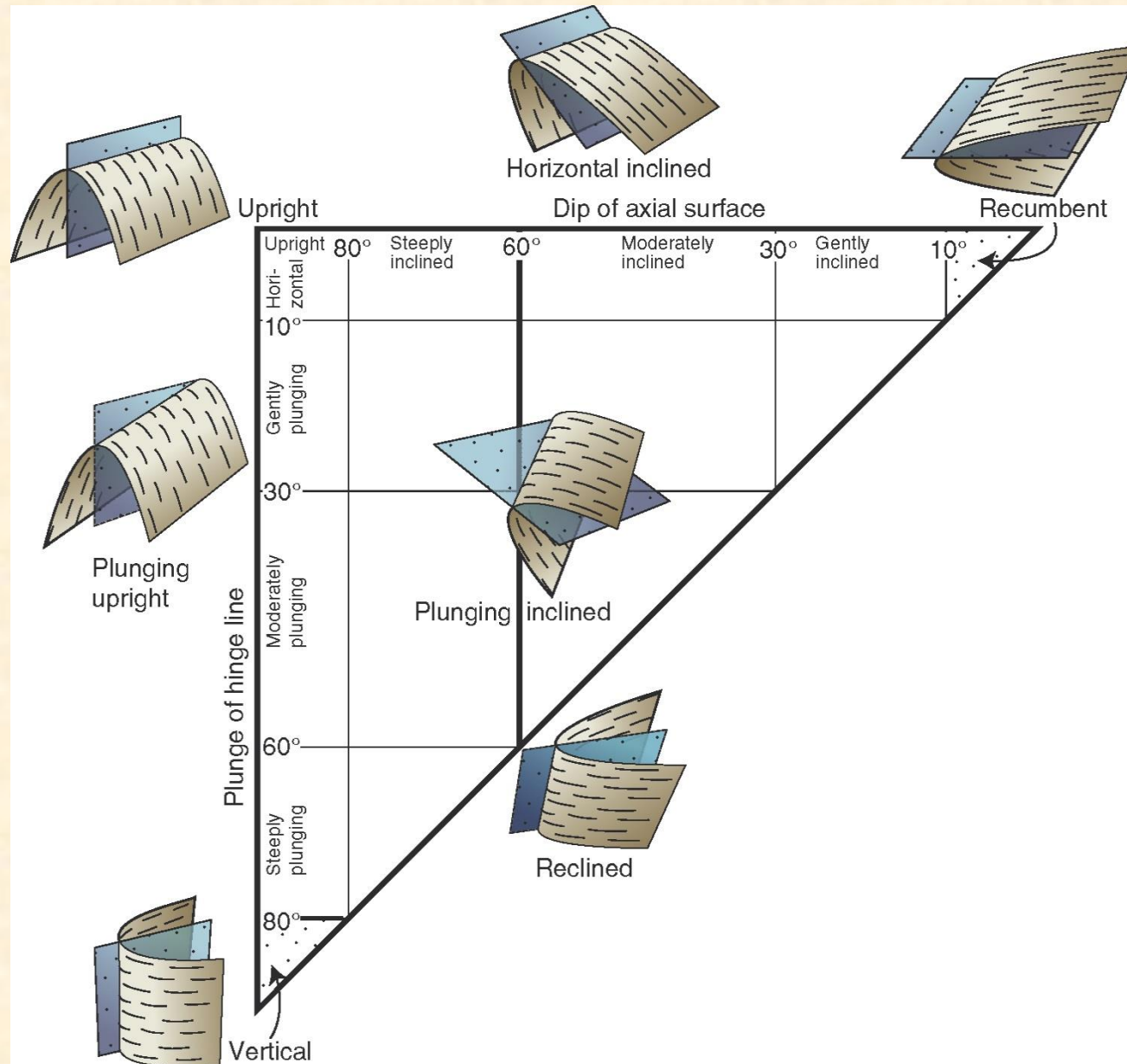


Folding

- 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**.



Fold Geometry



Folding: Scale Continuum

Anticline exposed along NJ Route 23 near Butler NJ.



Copyright ©USGS

Overtuned folds in the Table Rock gneiss in South Carolina's piedmont.



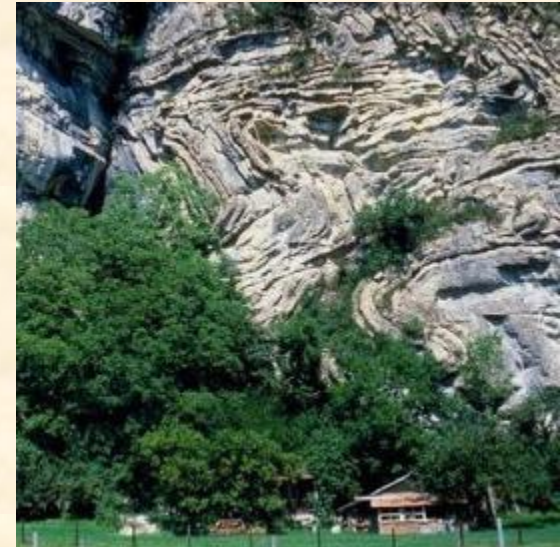
SCGS photo

Syncline valley between mountain peaks.



Copyright ©Michael Lejeune

Recumbent folds in limestone.



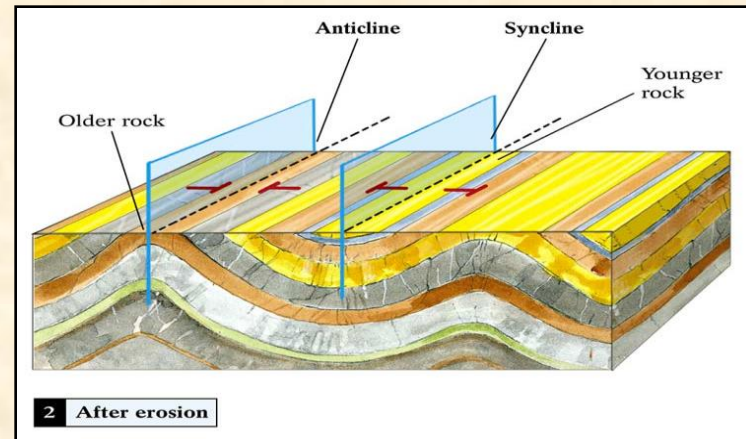
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Folding

Syncline (downfold) innermost rocks youngest

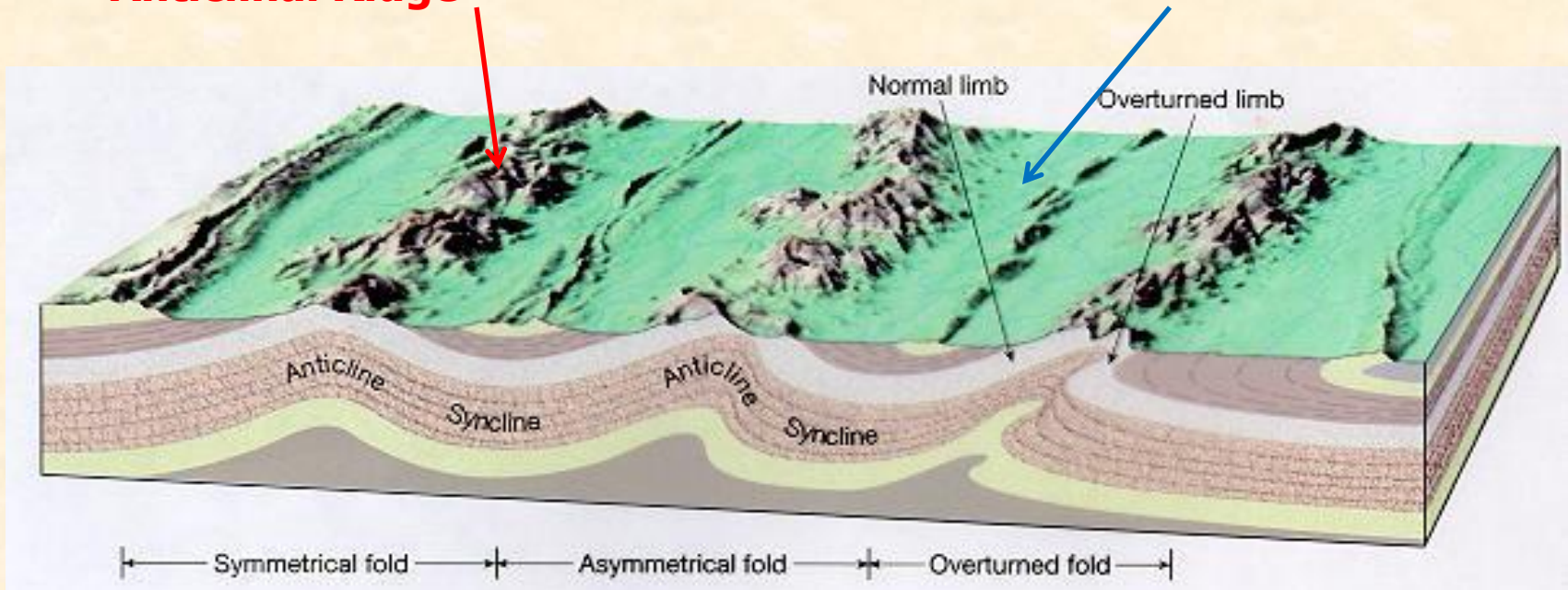
Anticline (upfold) innermost rocks oldest

Note: anticlines and synclines are structures in rocks, not surface landforms

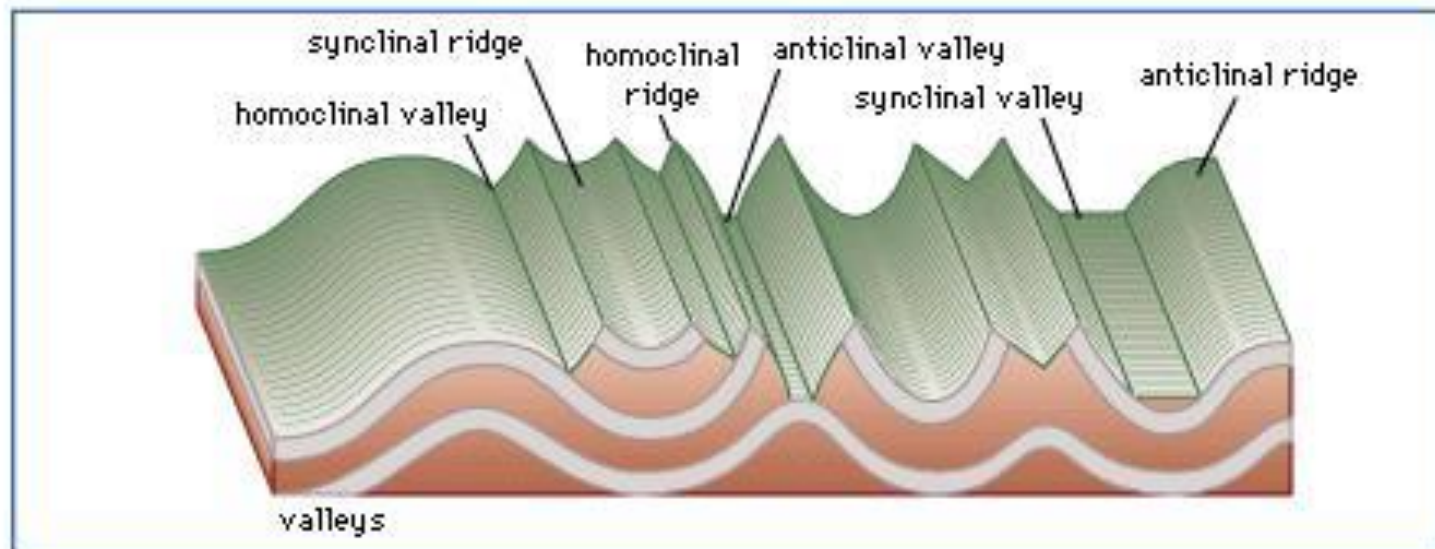
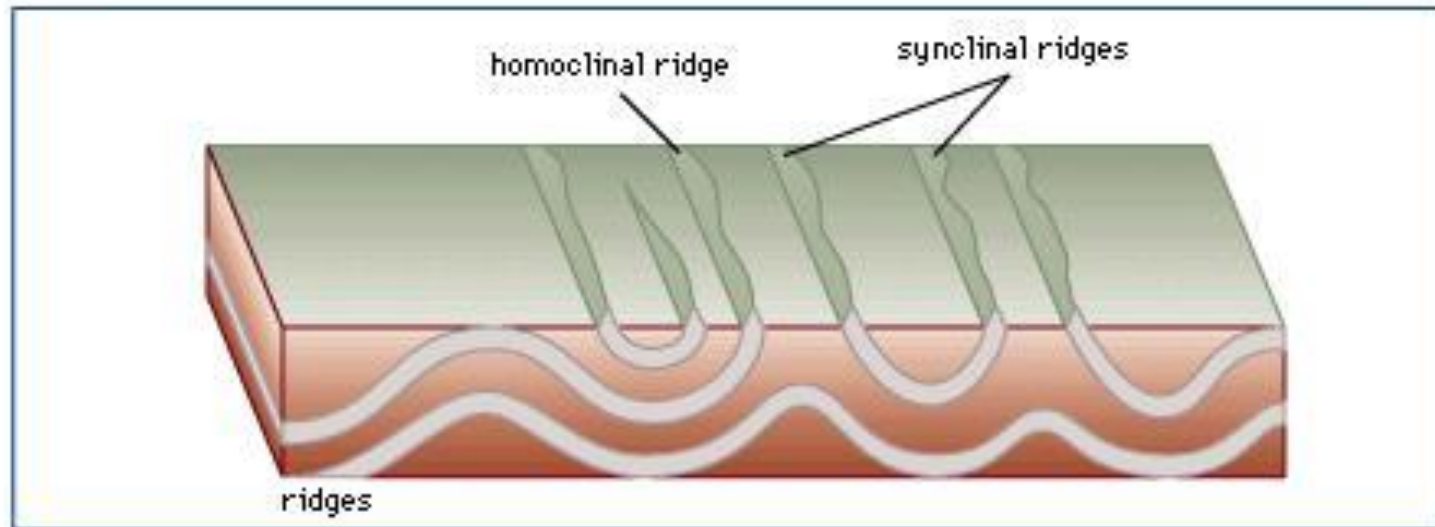


Anticlinal Ridge

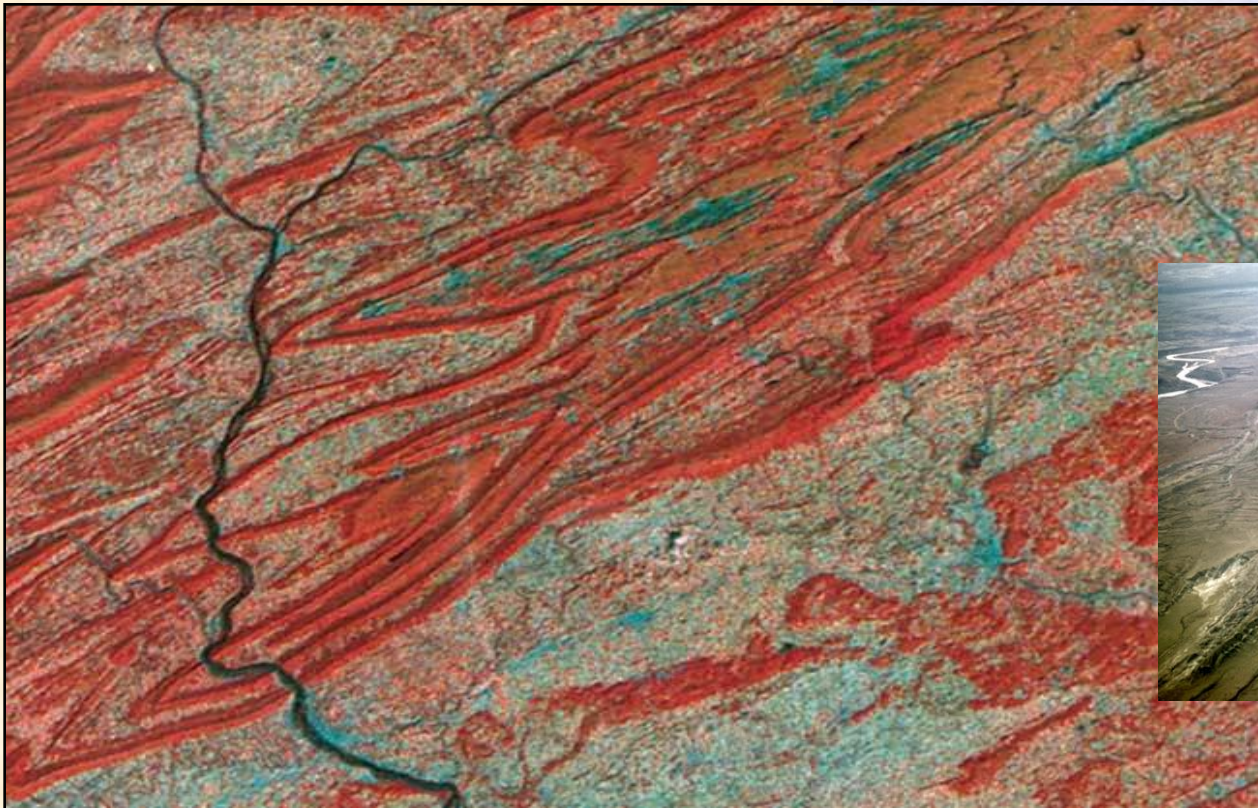
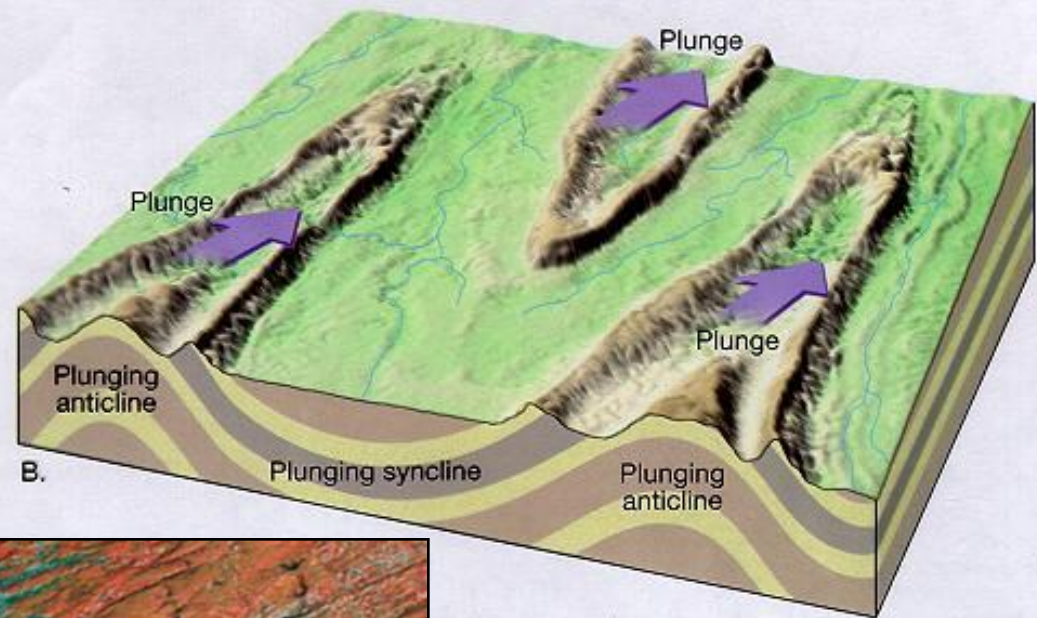
Synclinal Valley



Folded Landforms: Influence of Denundation



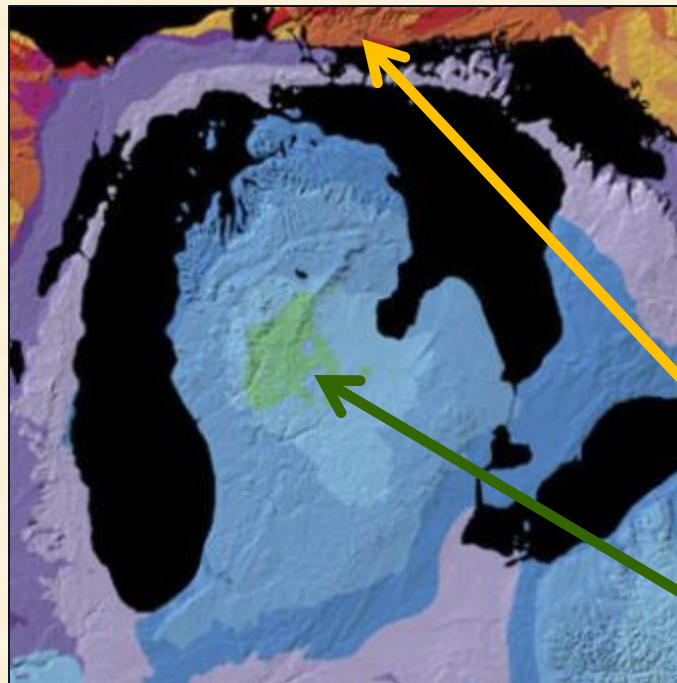
Plunging Folds



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.

- **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.

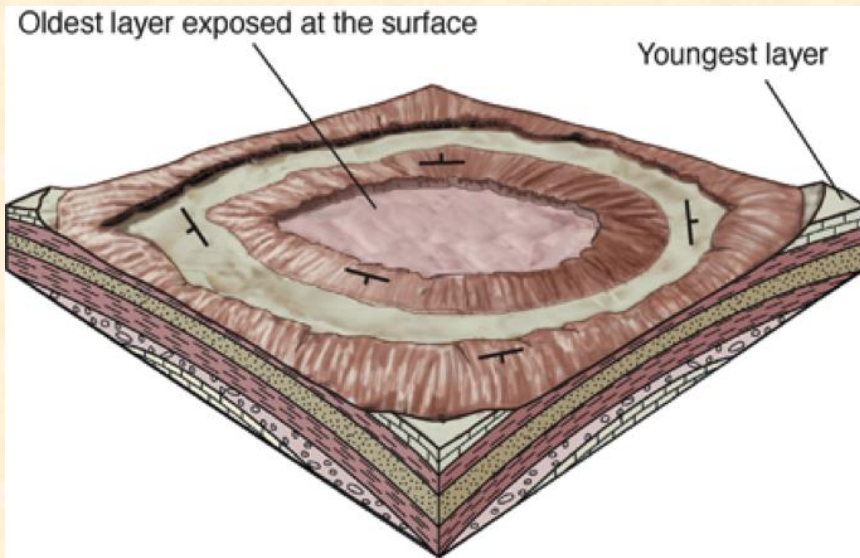


This geologic map of the Michigan Basin illustrates the circular pattern of the sedimentary strata. The green color in the center of the map represents the youngest rocks which are Upper Pennsylvanian; and the rocks progressively increase in age toward the periphery where the reddish-orange colors represent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

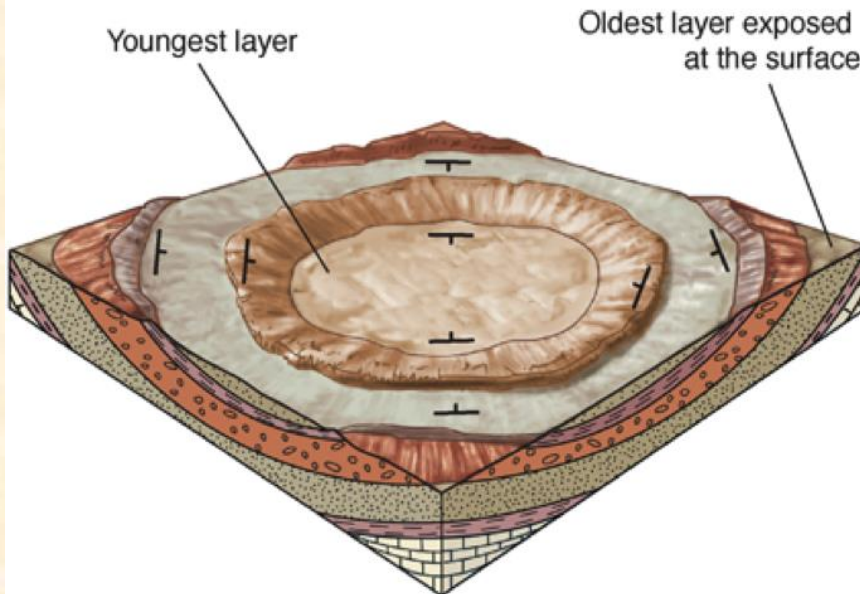
Oldest Rocks (Ordovician and Cambrian)

Youngest rocks (Upper Pennsylvanian)

3D-Folds

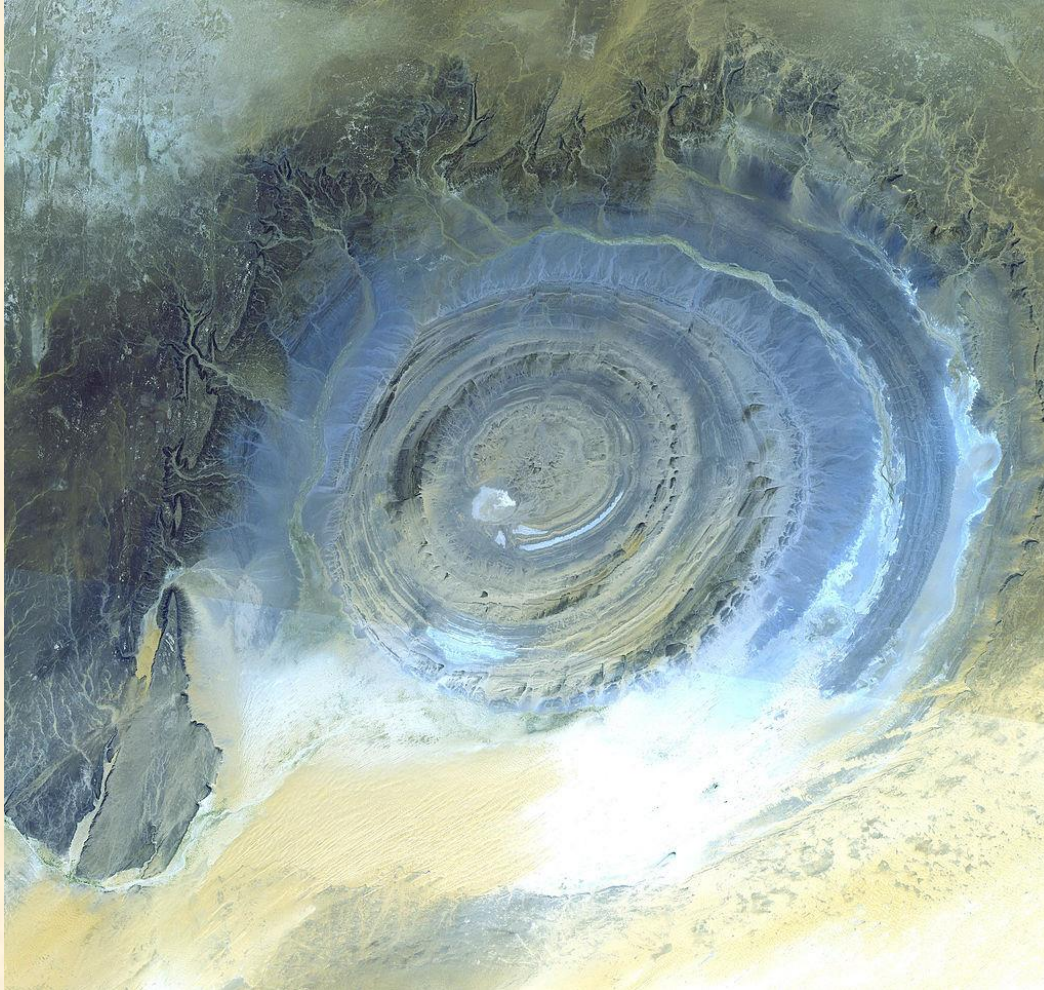


Domes resemble anticlines, but the beds dip uniformly in all directions away from the center of the structure. Domes are caused by compression and uplift.



Basins resemble synclines, but the beds dip uniformly in all directions toward the center of the structure. Basins are caused by compression and downwarping.

3D-Folds



The Richat Strurcture in the Sahara Desert of Mauritania. Long considered to be an impact structure, it is now believed by most to be a structural dome.

Dome Formation:

Impact Structures

Refolding

Diapirism: the process in which an igneous intrusion deforms the overlying more brittle rocks.

Faulting

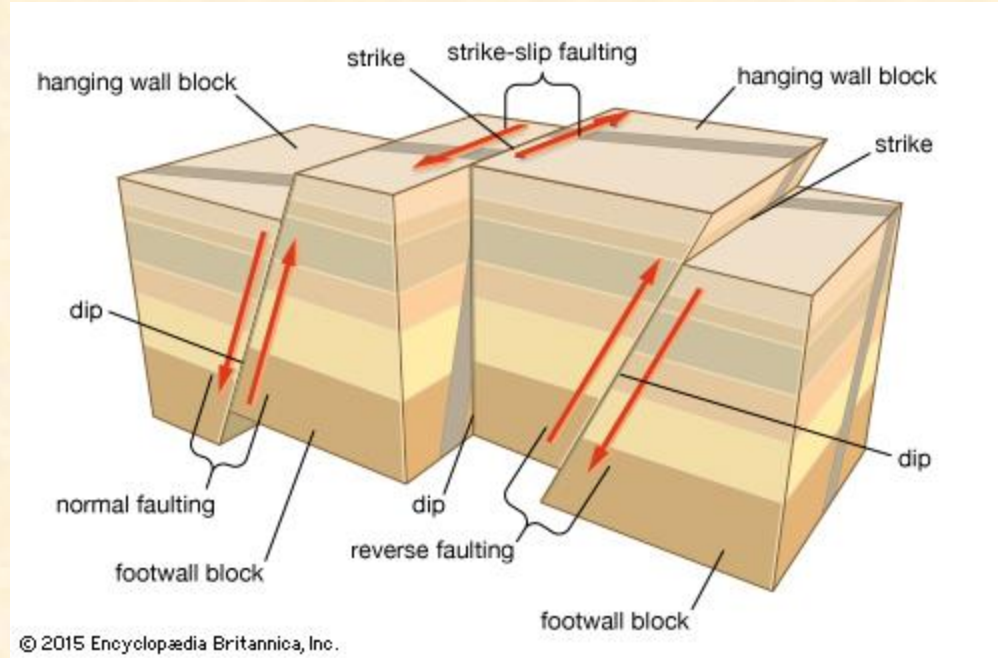
- Faulting occurs when the rocks fail under deformation processes.
- A fault is a planar discontinuity along which displacement of the rocks occurs.

Normal: rocks above the fault plane, or hanging wall, move down relative to the rocks below the fault plane, or footwall.

Reverse: rocks above the hanging wall moves up relative to the footwall

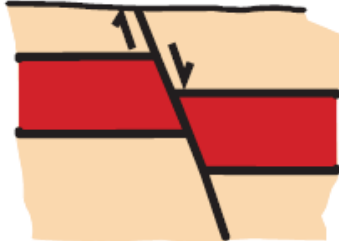
Strike-slip: rocks on either side of a nearly vertical fault plane move horizontally

Oblique-slip: normal or reverse faults have some strike-slip movement, or when strike-slip faults have normal or reverse movement

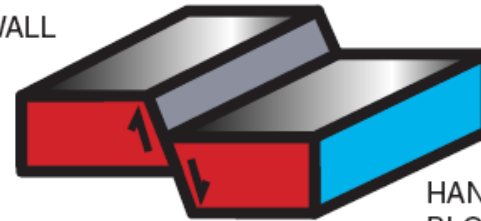


Faulting

NORMAL FAULT
(CROSS SECTION)

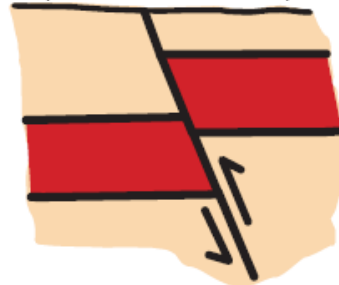


FOOTWALL
BLOCK

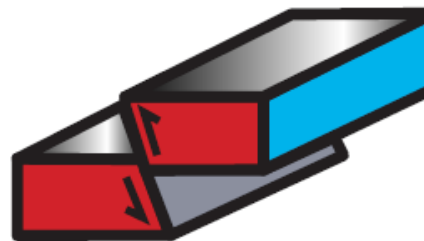


HANGING WALL
BLOCK DOWN

REVERSE FAULT
(CROSS SECTION)

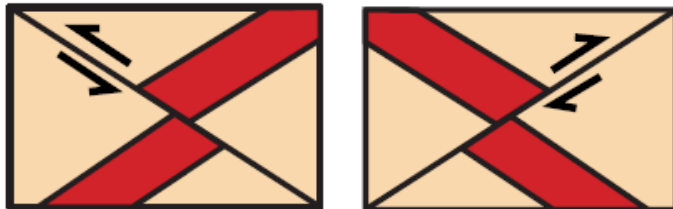


FOOT WALL
BLOCK



HANGING WALL
BLOCK UP

STRIKE-SLIP FAULT
(PLAN VIEW)



LEFT-LATERAL FAULT

RIGHT-LATERAL FAULT

SINISTRAL
(LEFT-LATERAL)



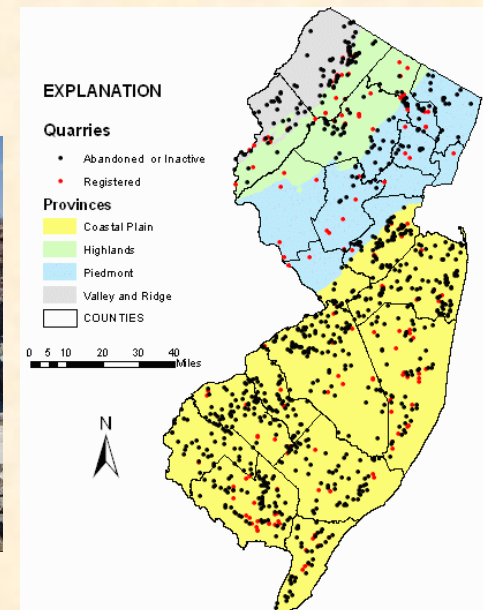
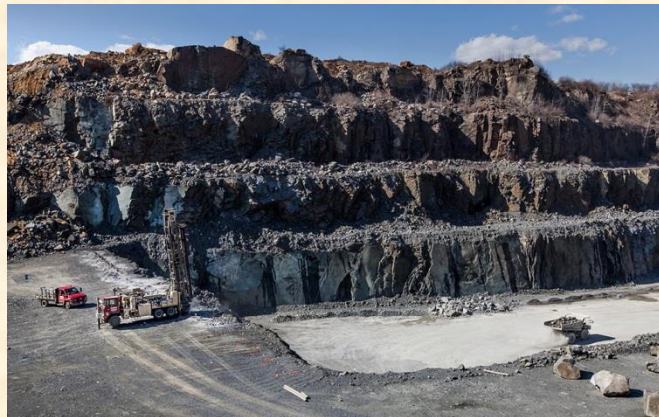
DEXTRAL
(RIGHT-LATERAL)



Note: Movement determined by which side of the fault moves toward an observer looking along the fault plane.

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.
- **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.



Fractures and Joints

- 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.



Jointing

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



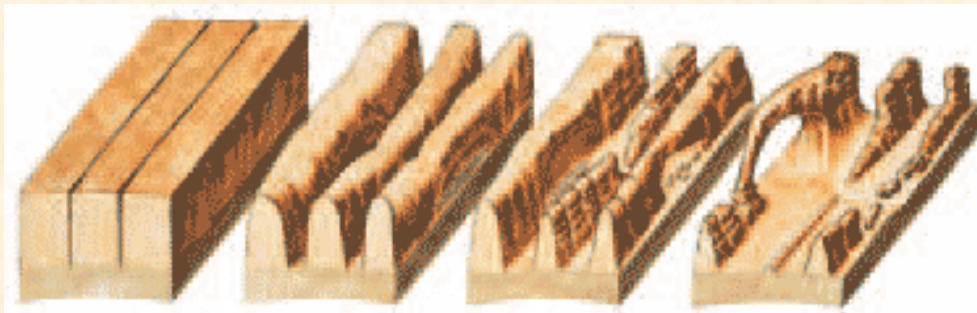
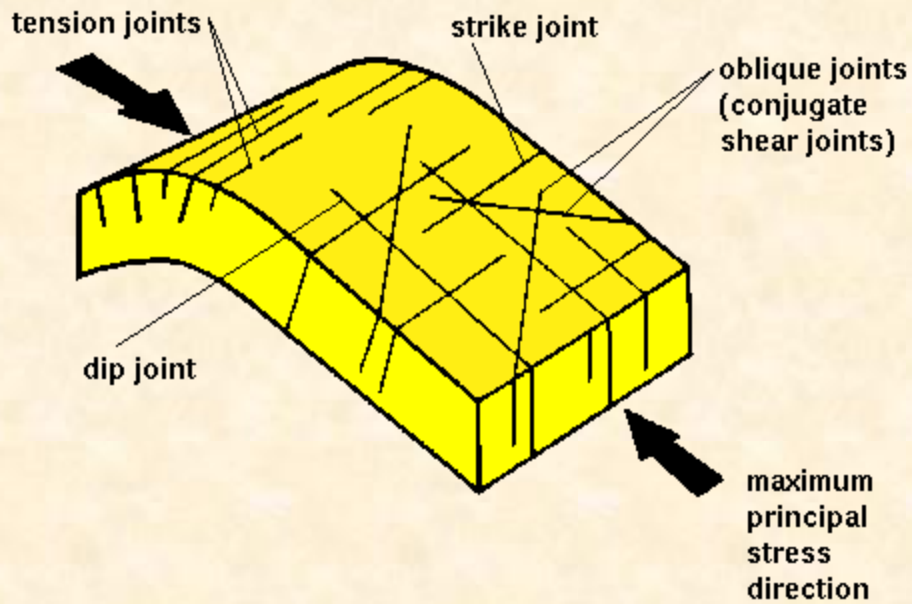
Copyright Larry Fellows, Arizona Geological Survey

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.



Jointing



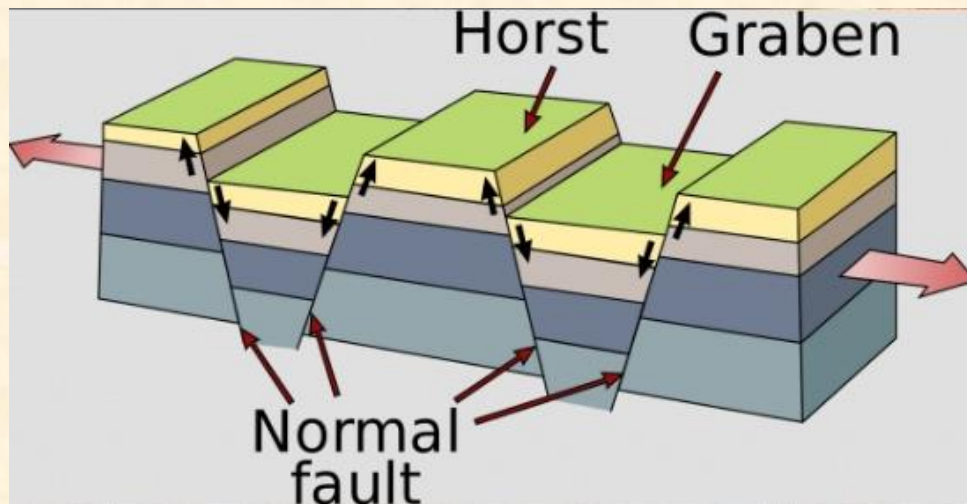
Model for Arches National Park

Rock Fins



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**.



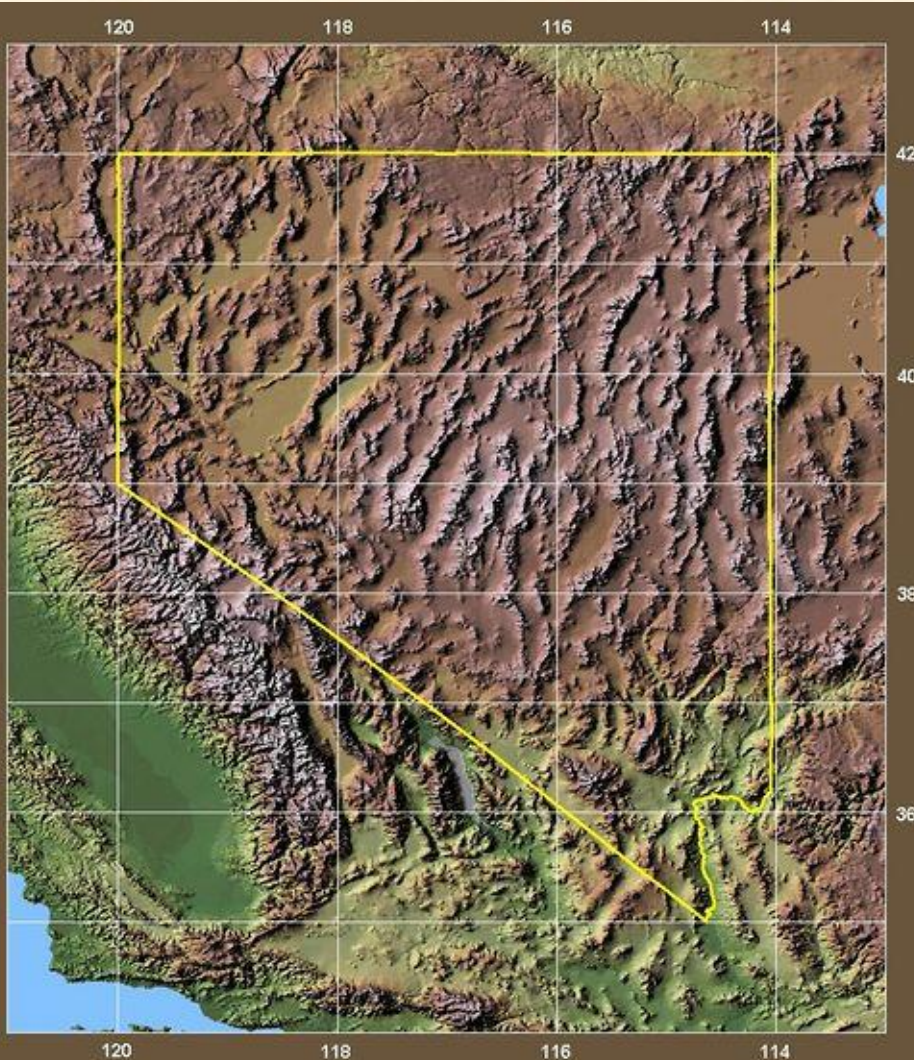
Basin and Range topography, Nevada.



Horst and Graben: Basin and Range

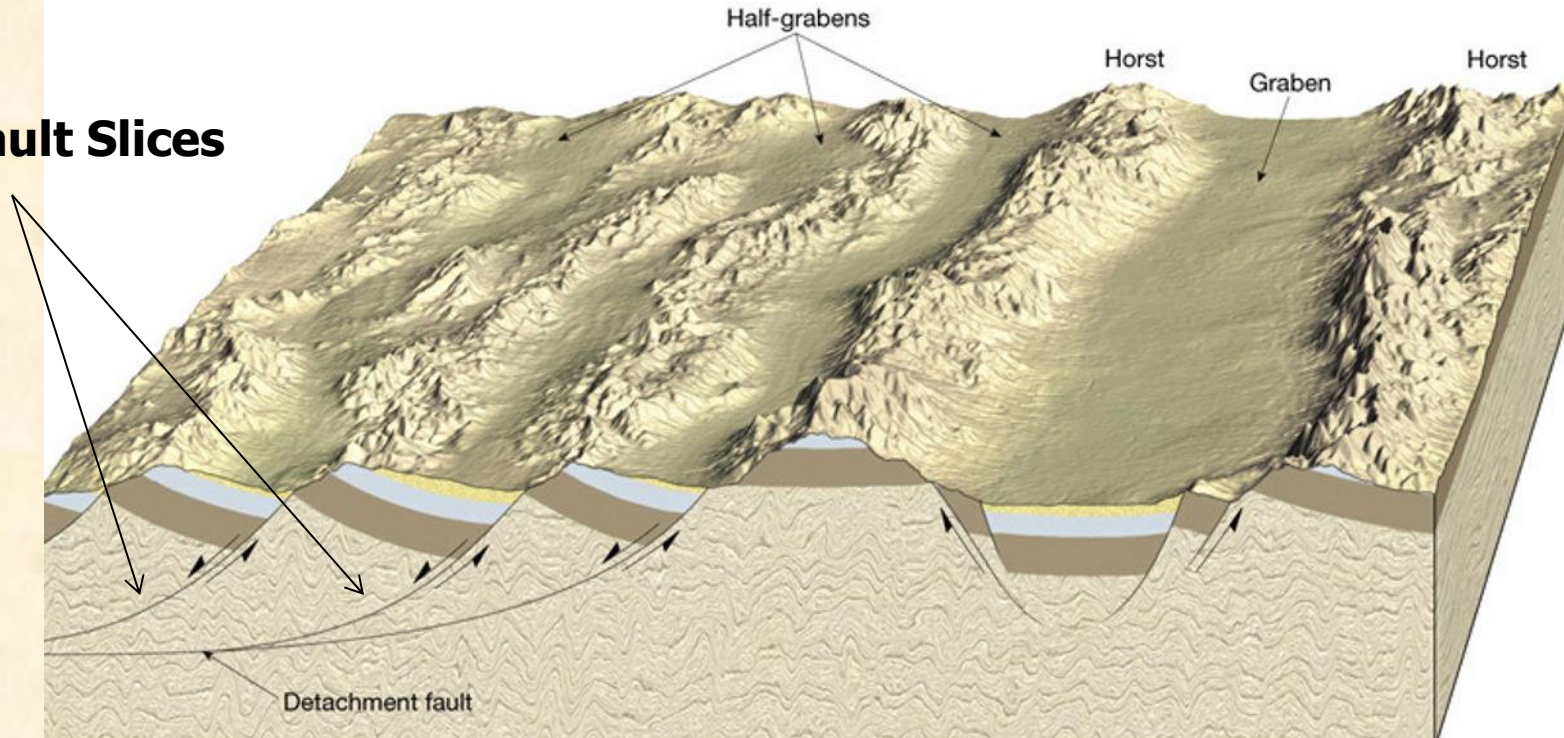
- Some horsts may tilt slightly producing asymmetric, tilted terrane or mountain ranges.
- In the Western United States, horst and graben fault sequences are described as “**Basin and Range**” topography.

Basin and Range topography, Nevada.

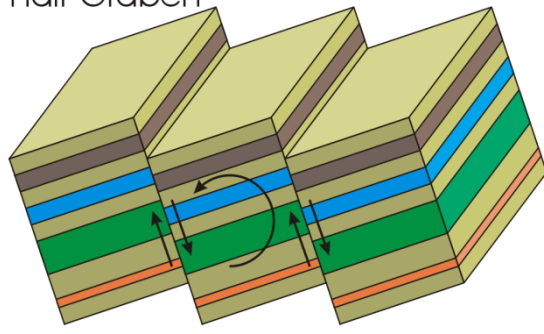


Faulting: Rotation

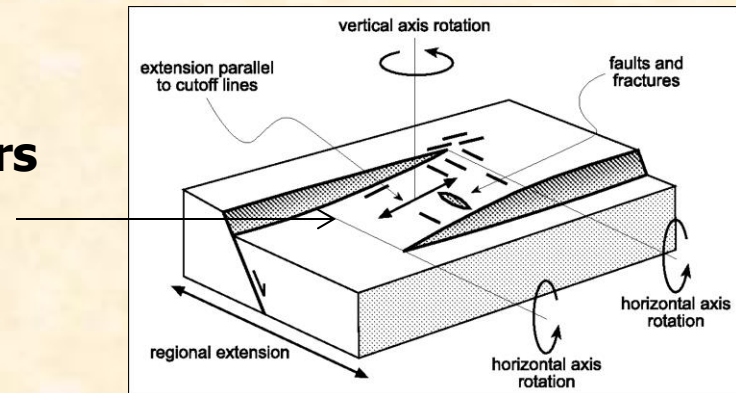
Fault Slices



Half-Graben



Fault Splinters



Faulting: Strike-Slip

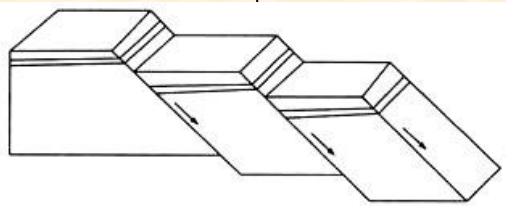
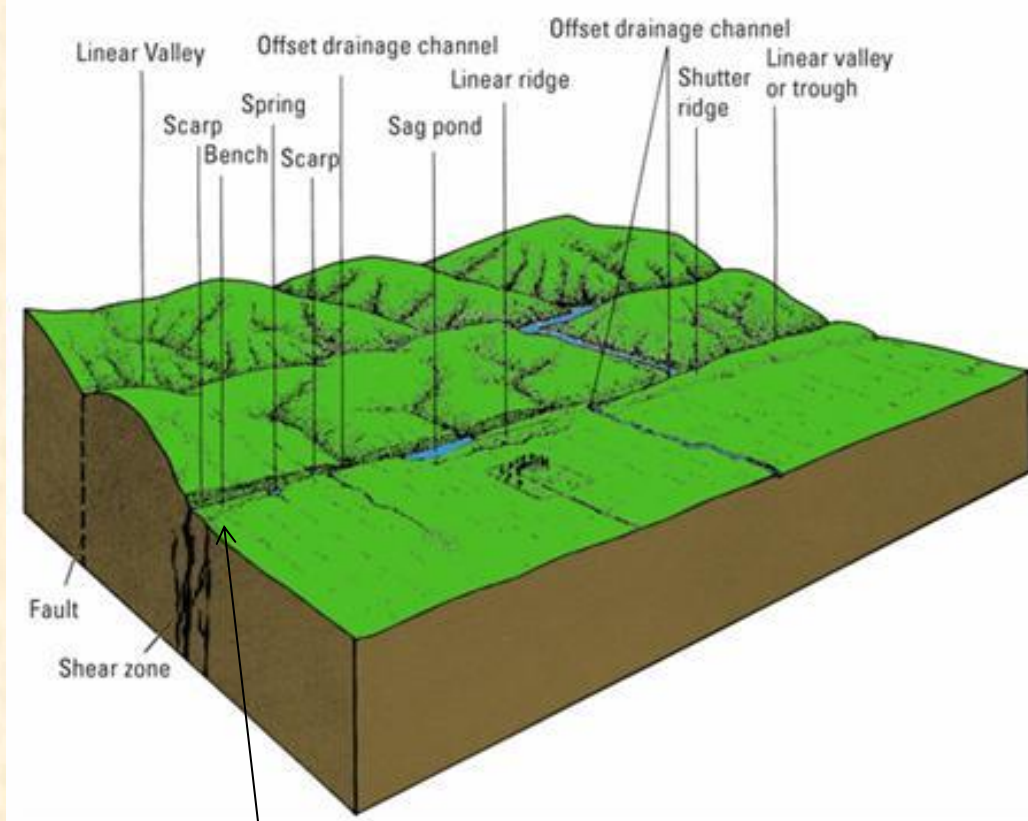
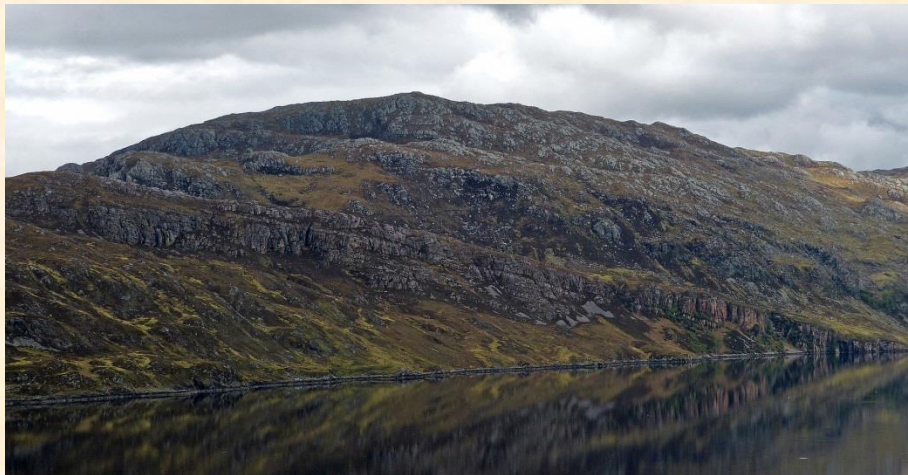
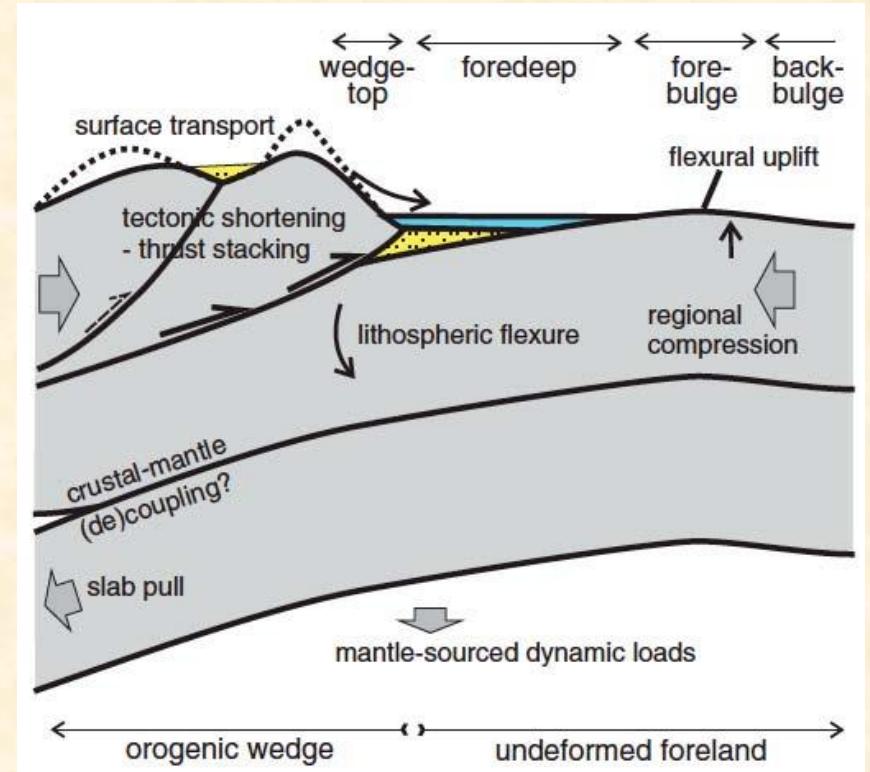
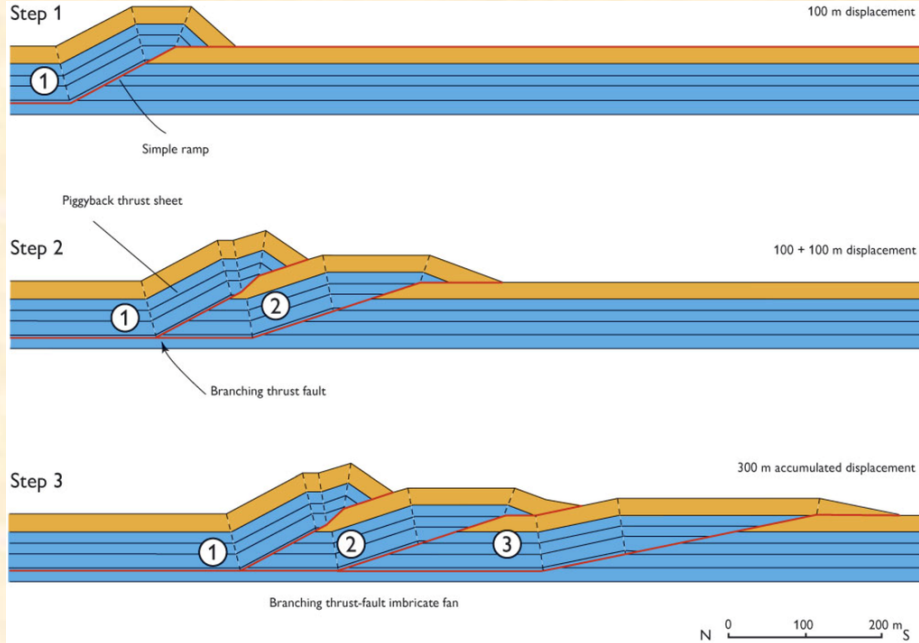


Fig. 17.33 Step fault



Reverse Faulting



Glencoul Thrust, Scotland

- Common along convergent boundaries.
- Often involves sedimentary environments
- Accretionary Wedges
- Fold & Thrust Mnts, Himalayas, Appalachians, Alps
- Often low angle thrusts

Tilted Fault Block Mnts

Sierra Nevada



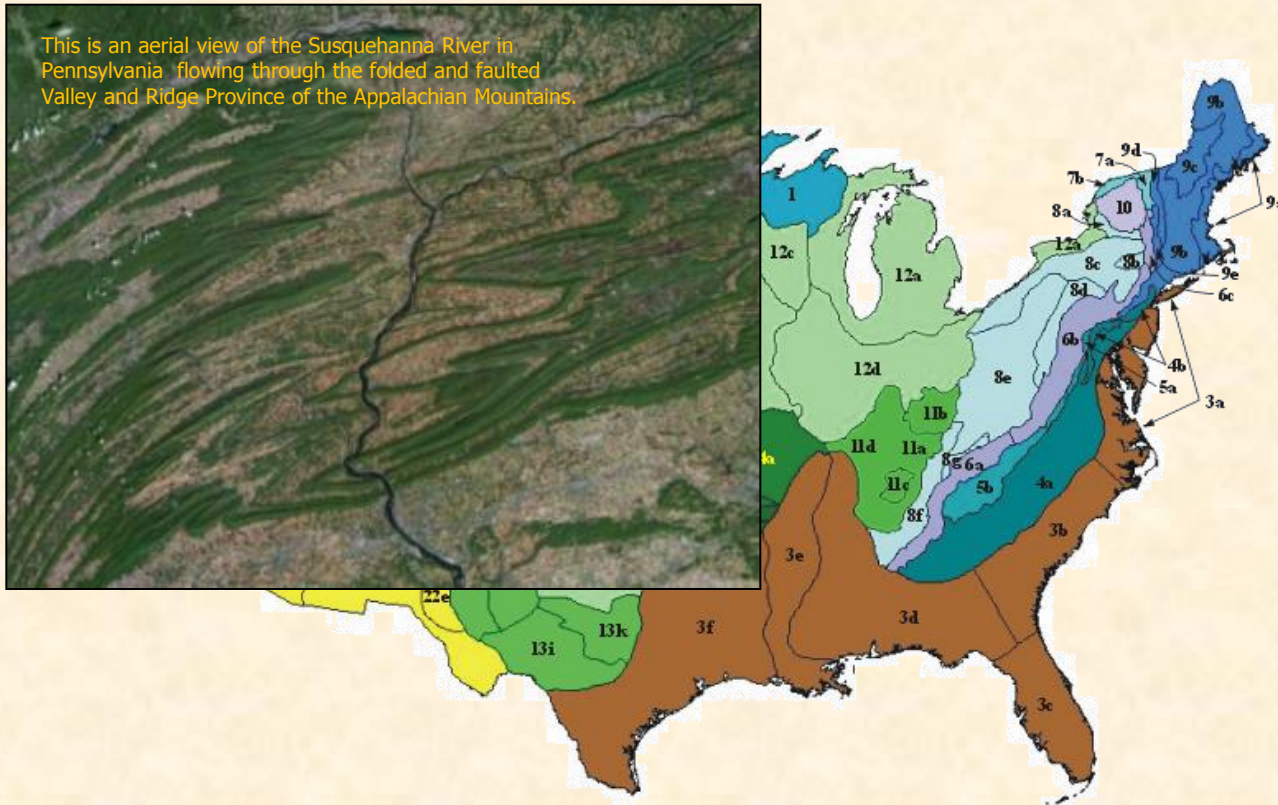
Grand Tetons

Basin & Range Province



Appalachian Mountains

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.



Laurentian Upland

Atlantic Plain

Appalachian Highlands

Interior Plains

1 Superior Upland

3 Coastal Plain

4 Piedmont province

5 Blue Ridge province

6 Valley and Ridge province

7 St. Lawrence Valley

8 Appalachian Plateaus

9 New England province

10 Adirondack province

11 Interior Low Plateaus

12 Central Lowland

13 Great Plains province

Interior Highlands

Rocky Mountain System

Intermontane Plateaus

Pacific Mountain System

14 Ozark Plateaus

15 Ouachita province

16 Southern Rocky Mountains

17 Wyoming Basin

18 Middle Rocky Mountains

19 Northern Rocky Mountains

20 Columbia Plateaus

21 Colorado Plateaus

22 Basin and Range province

23 Cascade-Sierra Mountains

24 Pacific Border province

25 Lower California province

- Extend Alabama to Maine in the US, and through the southeastern provinces of Canada to Newfoundland.
- Formed during the **Paleozoic Era** from several orogenic episodes,
 - Taconic Orogeny (Ordovician ~480 mya)
 - Acadian Orogeny (Devonian ~400 mya)
 - Alleghany Orogeny (Permian ~ 300 mya).
- Each of these major orogenic episodes involved multiple events of folding, faulting, metamorphism, emplacements of igneous intrusions, and uplift.

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.
- Major orogenic events involved recumbent folding and thrust faulting of crystalline basement rocks.



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

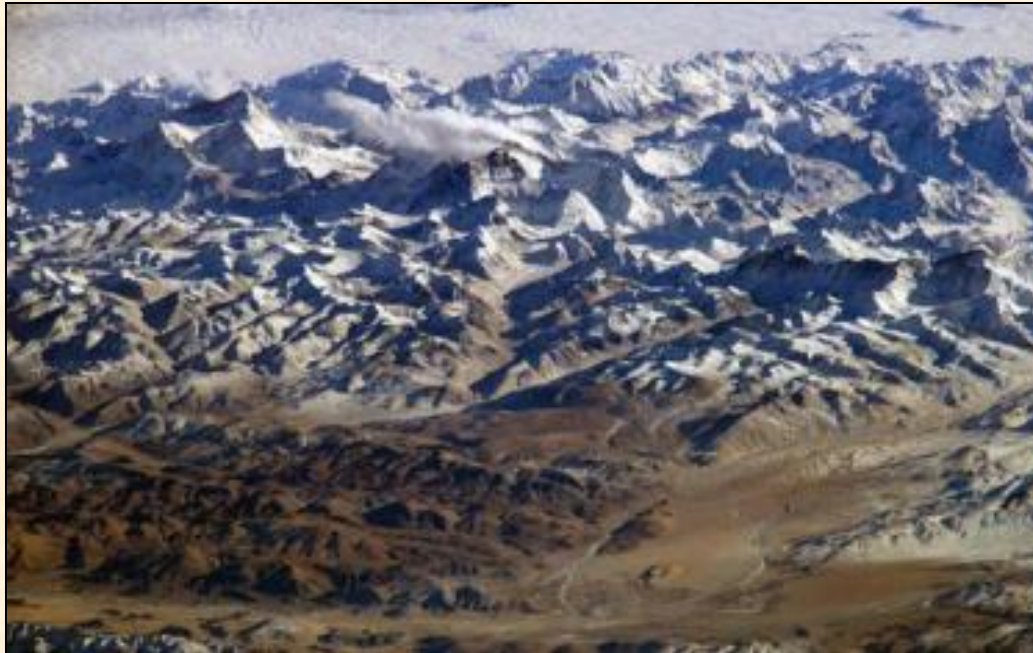


<http://en.wikipedia.org/wiki/Matterhorn>

The Matterhorn, on the border between Switzerland and 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.

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, overthrust, uplifted forming an extensive continental mountain range.



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