Rock Deformation Structures and Mountain Building

Earth

Portrait of a Planet

Fifth Edition

Chapter 11

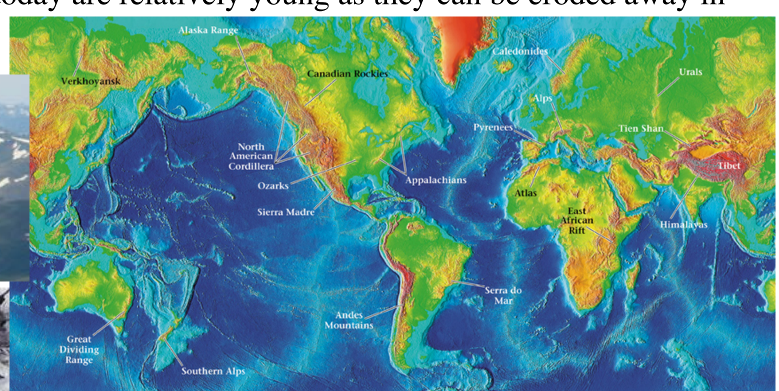
Mountain Belts

Last lecture, the term "***Orogeny***" was introduced.

Orogeny = Mountain Building = Plate Convergence; process = ***Orogenesis***.

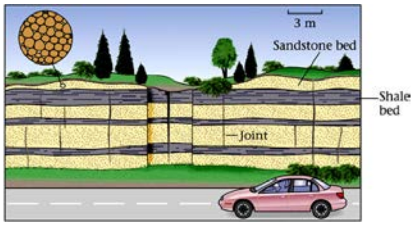
Mountains, unless a volcano above a hotspot, occur in curvilinear belts.

The mountain belts of today are relatively young as they can be eroded away in as little as 50 m.y.

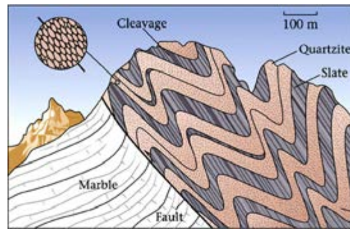


Mountain building involves numerous geologic processes, including deformation, jointing, faulting, folding, partial melting, foliation, metamorphism, glaciation, erosion, and sedimentation.

Deformation & Strain



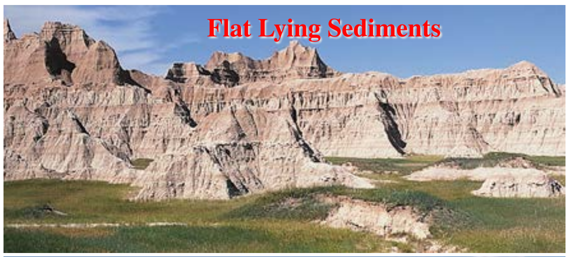
Undeformed

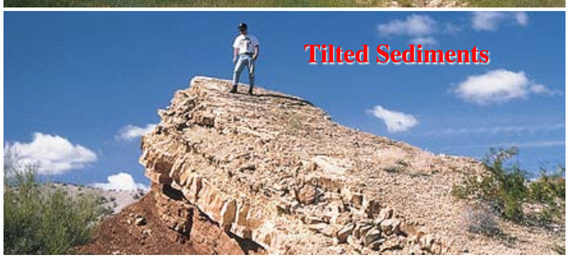


Deformed

Folding, Faulting, Foliation. Brittle & Ductile.

Slaty cleavage (metamorphism) developed - flattening of clay minerals.



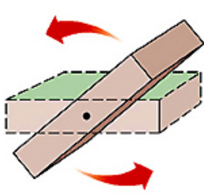


Orogenesis applies force to rocks, causing deformation (bending, breaking, shortening, stretching, and shearing). Change in shape via deformation is called strain.

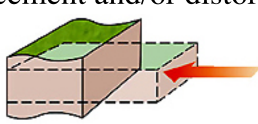
Deformation & Strain

Changing location

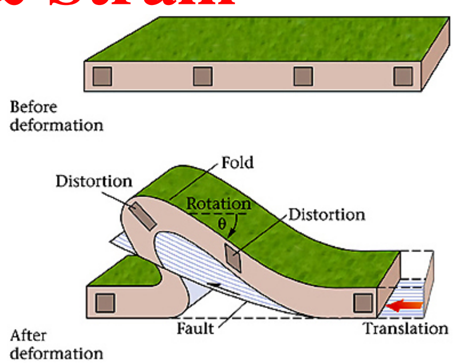
Deformation results in displacement and/or distortion



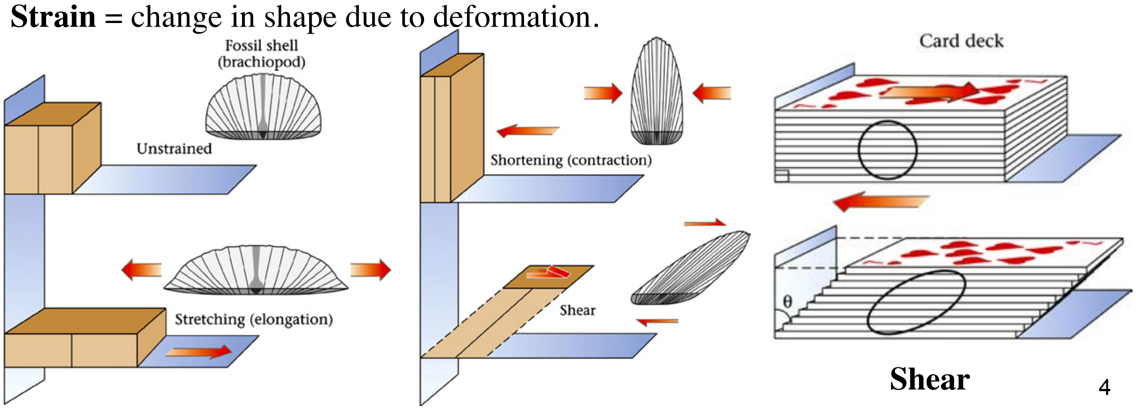
Changing orientation



Changing shape



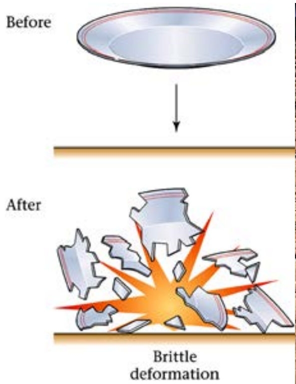
Strain = change in shape due to deformation.



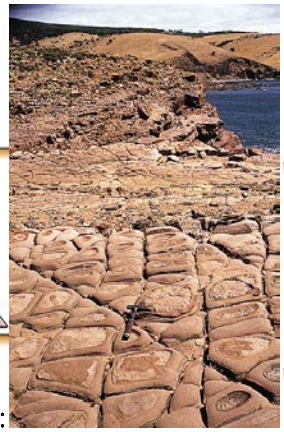
Shear

Brittle & Ductile Deformation

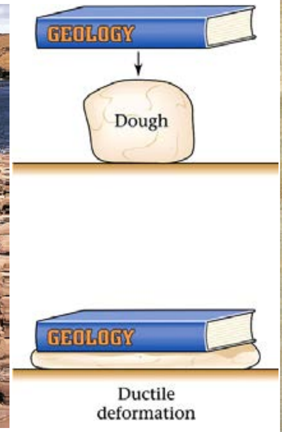
Brittle: material breaks.



Joint formation:



Ductile: material flows.



Behavior depends on:

- Temperature;
- Pressure (effectively prevents rocks from separating into fragments);
- Deformation Rate;
- Composition (same P-T, different behavior).

General Rule: brittle deformation <10-15 km; ductile deformation >10-15 km.
Brittle deformation produces earthquakes.

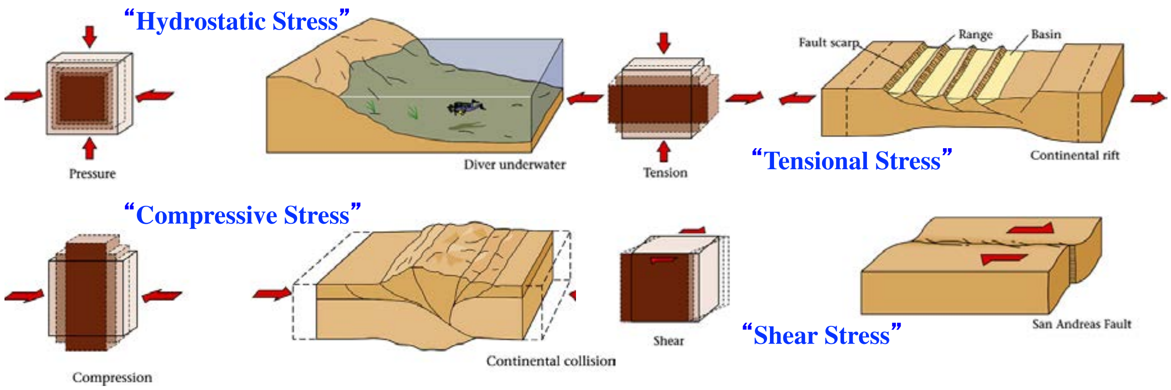
Deformation: Force & Stress

FORCE = MASS x ACCELERATION

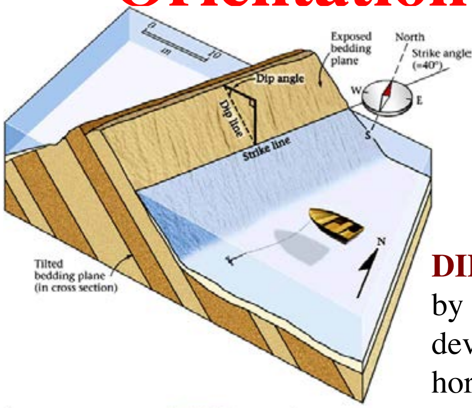
In Geology, Stress = Force.

Stress: force per unit area.

Strain: change in shape.



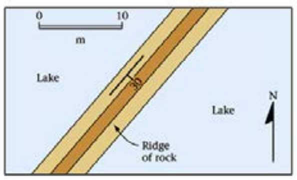
Orientation of Structures/Beds



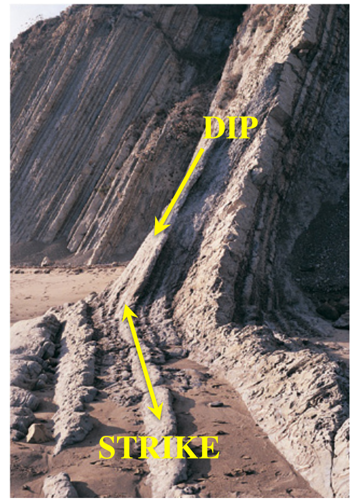
Strike, Dip, and Plunge

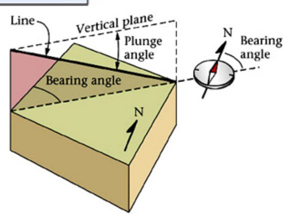
Means of recording bed orientation and orientation of other planar features.

STRIKE: angle between true north and the *horizontal* line contained in any planar feature.



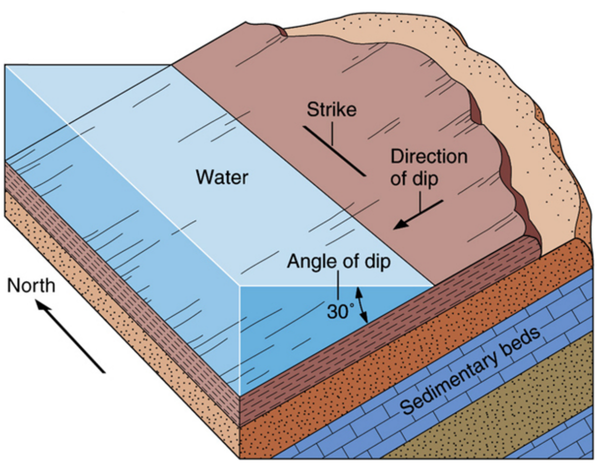
DIP: The maximum angle by which a planar feature deviates from the horizontal, <u>always</u> measured in the plane *perpendicular* to the strike. Orientation where dip is zero.

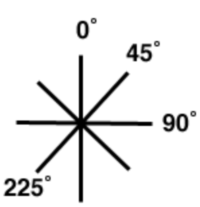


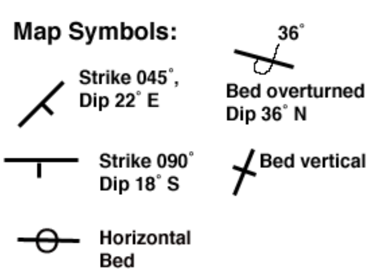


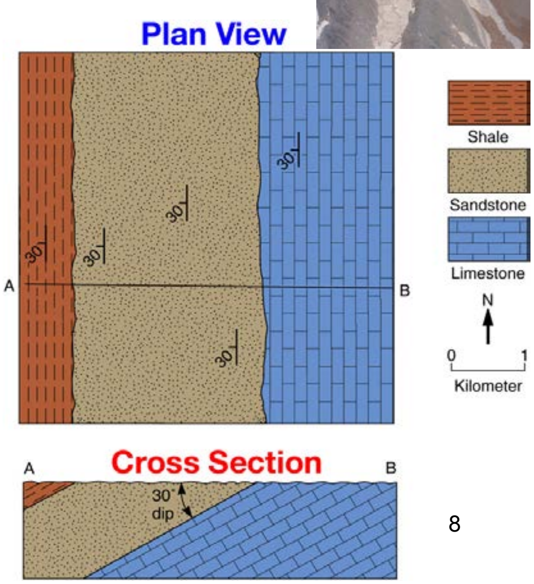
PLUNGE: angle between a line and horizontal (0˚). Vertical = 90˚.

Orientation of Structures/Beds









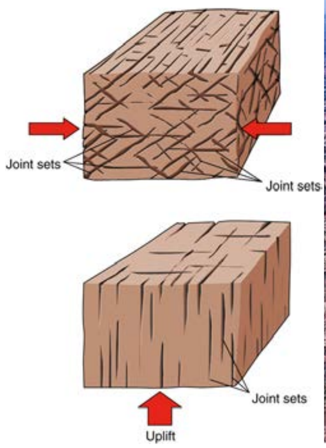
Joints

Fractures along which there has been no movement.

Joints develop because of tension. Tension can be produced by cooling (contraction), pressure release, bending, compression, etc.

Systematic Joints: planar cracks that occur regularly throughout a rock body. A group of systematic joints = ***Joint Set***.

Nonsystematic Joints: randomly spaced with a variety of orientations.



Joints

In sedimentary rocks, systematic joints are typically vertical.

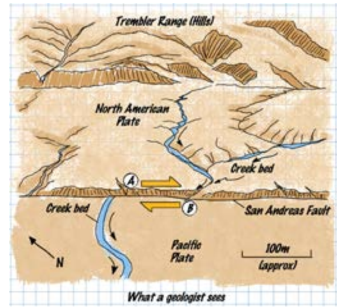
Veins: Joints filled with minerals precipitated from groundwater.

Geotechnical engineers avoid joints - allow water to flow and decrease rock strength.

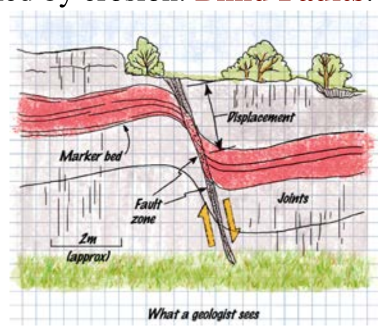
Faults

Faults, like joints, are planar features - can be represented by dip and strike.

Faulting causes offset at the Earth's surface – i.e., movement along the fault plane.

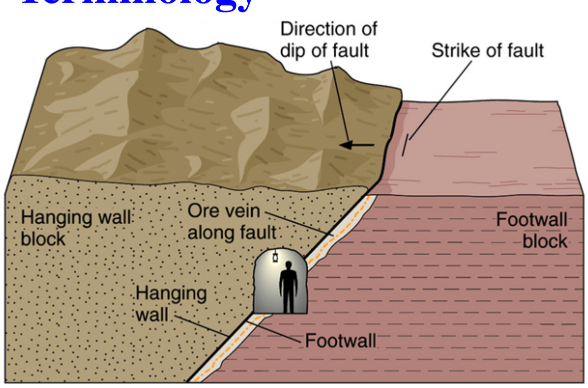


Some faults do not reach the surface until revealed by erosion: **Blind Faults**.



Faults

Terminology

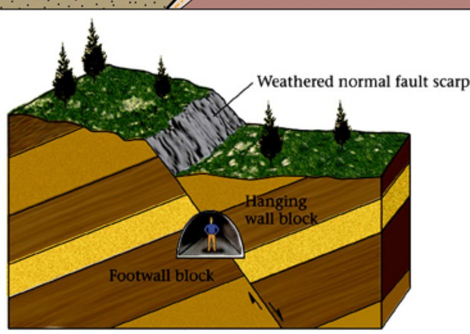


Dip-Slip Faults.

Strike-Slip Faults.

Oblique-Slip Faults.

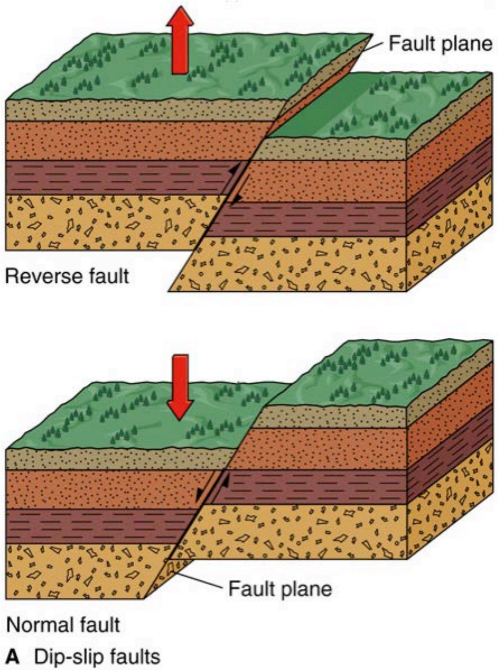
On a dipping fault, the blocks are classified as the hanging-wall block above the fault, and the footwall block below the fault.



Dip-slip faults are characterized by blocks that move parallel to the dip of the fault. In strike-slip faults, blocks move parallel to fault plane strike. Oblique-slip faults have components of both dip-slip and strike-slip faults.

Faults

Fractures through rocks along which movement has occurred.

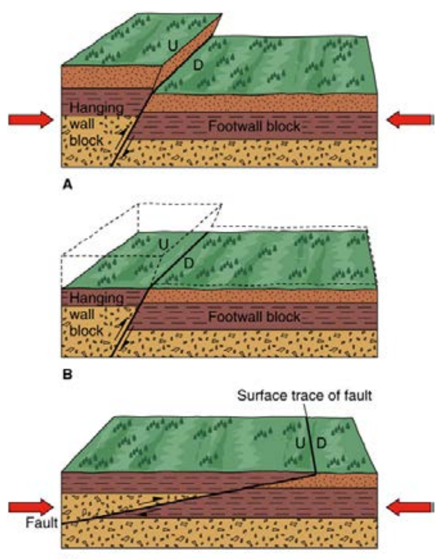


Dip-Slip Faults: Subdivided into normal (extensional) or reverse (compressional).

Reverse: older strata over younger - hanging wall moves up relative to footwall (causes a repetition of strata).
Normal: Younger strata over older - hanging wall moves down relative to footwall.

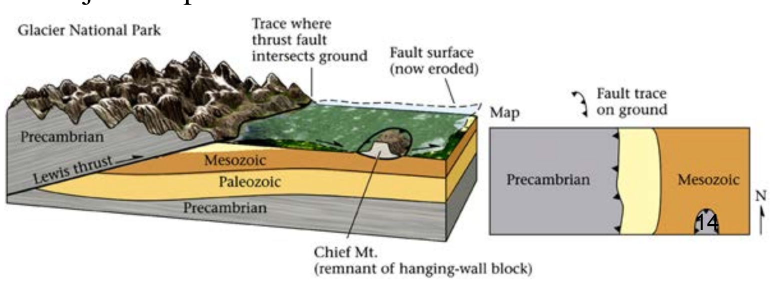
Faults

Reverse faults: high angle (>35˚) compression.

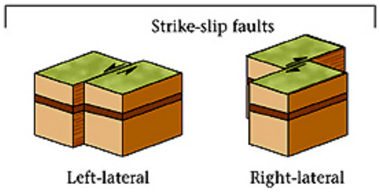


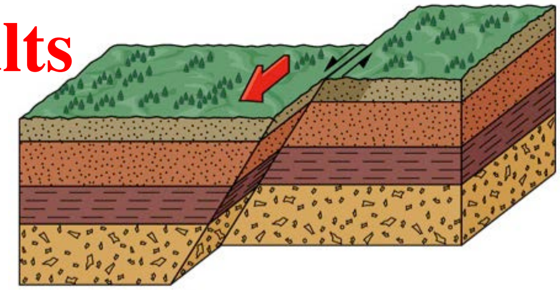
Low angle (<35˚) reverse faults – **thrust** faults. Can juxtapose old rock on top of younger rock – common during orogenies. These can move parcels of rocks 100s of km. Major compression.

Thrust faults can transport sheets of rock hundreds of kilometers and are common features at the leading edge of orogenic deformation



Faults

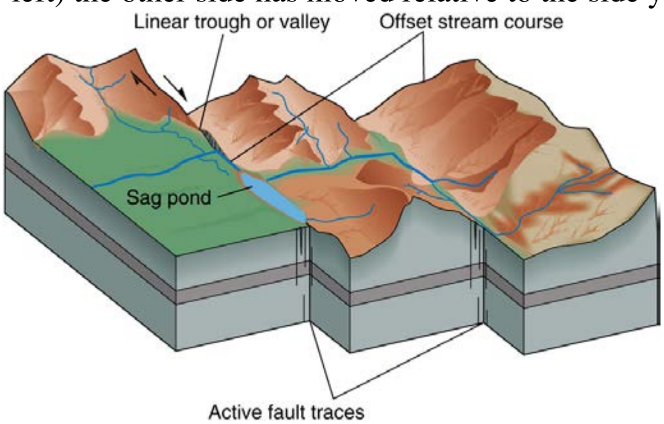


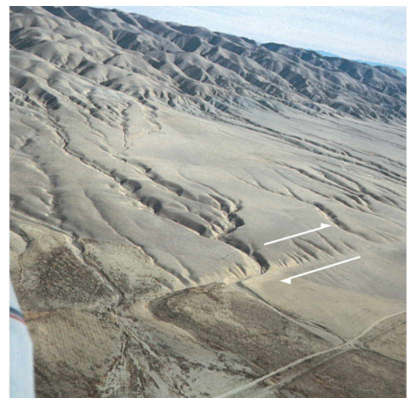


B Strike-slip faults

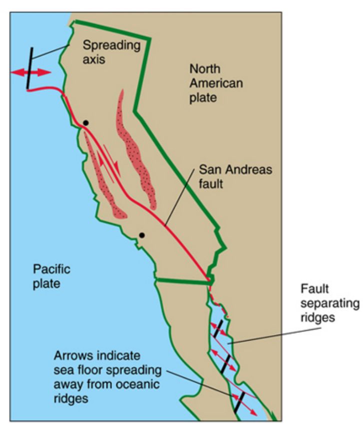
Strike-Slip faults: dips ~90˚

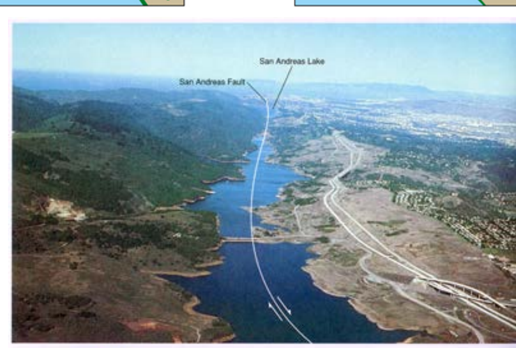
Divided into right-lateral (e.g., San Andreas) and left-lateral faults.
Named by standing on one side of the fault line and seeing which way (right or left) the other side has moved relative to the side you are standing on.





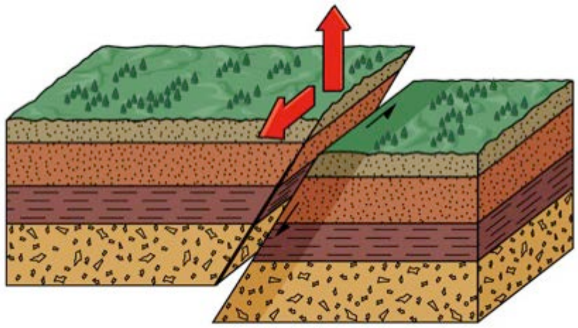
Faults



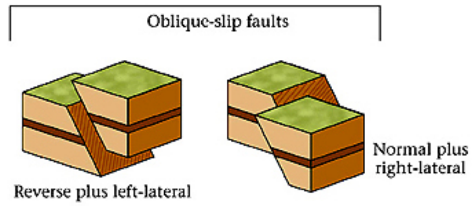


Box 15.3 — FIGURE 2
Part of the San Andreas fault. View northward toward San Francisco. Lakes occupy the fault zone. Hills to the left of the fault are moving northward.

Faults



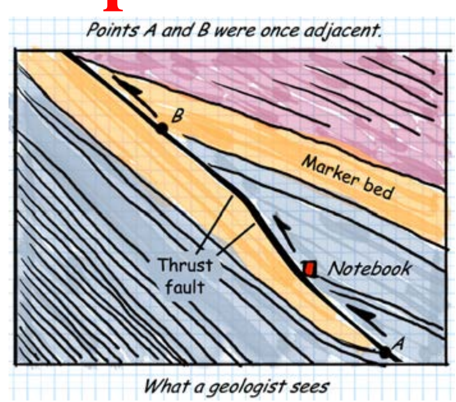
C Oblique-slip fault



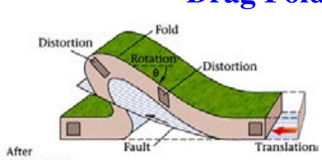
Oblique-slip Faults: Contain major components of movement parallel to both strike and slip.

Recognizing Displacement

How far has the fault moved?



Folding prior to faulting = **Drag Folds**.

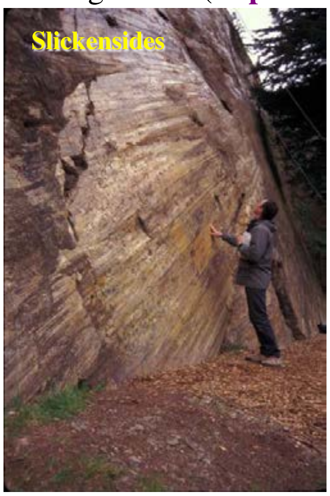


Faults can juxtapose rocks of different strengths and produce a **Fault Scarp**. They can also create valleys.

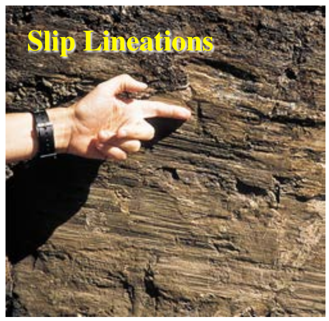
Recognizing Displacement

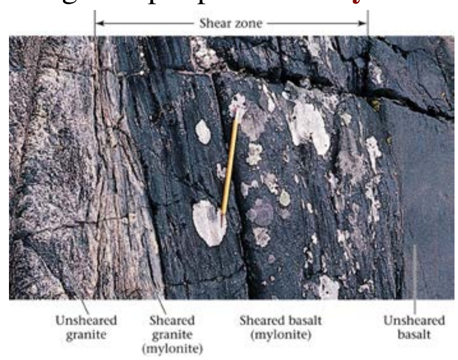
Faulting grinds up material along the fault plane. Can produce a **Fault Breccia**, or if the material is finely ground, **Fault Gouge**.

Some fault surfaces are polished (**Slickensides**) and grooved (**Slip Lineations**).



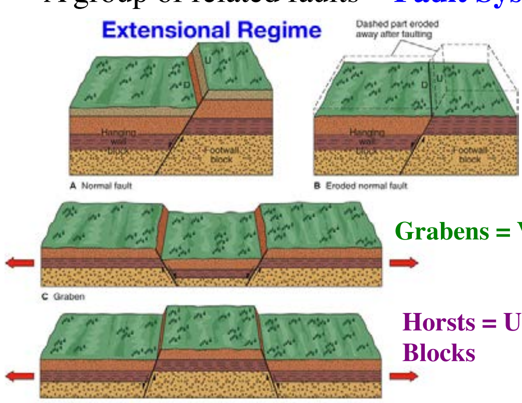
Ductile shearing at depth produces **Mylonite**.





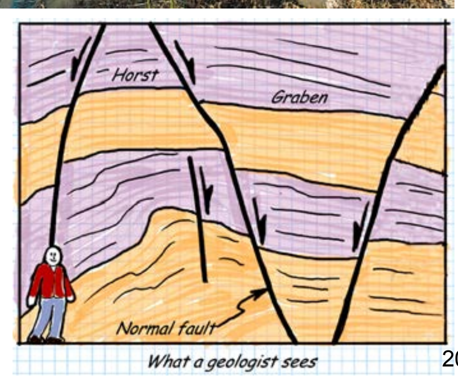
Fault Systems

A group of related faults = **Fault System**. Can form "**Horsts**" and "**Grabens**".



Grabens = Valleys

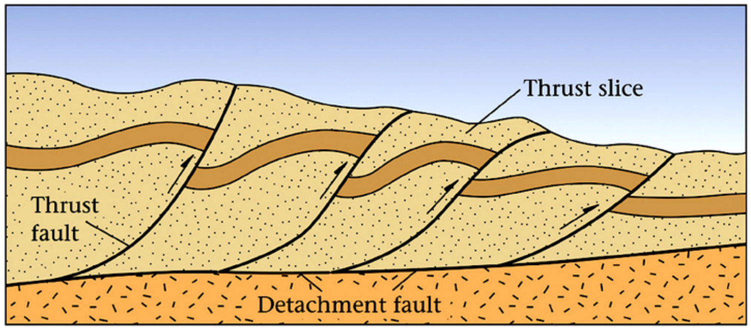
Horsts = Uplifted Blocks



Fault Systems

Faults in a Fault System are related by a "**Detachment Fault**".

Compressional



Extensional

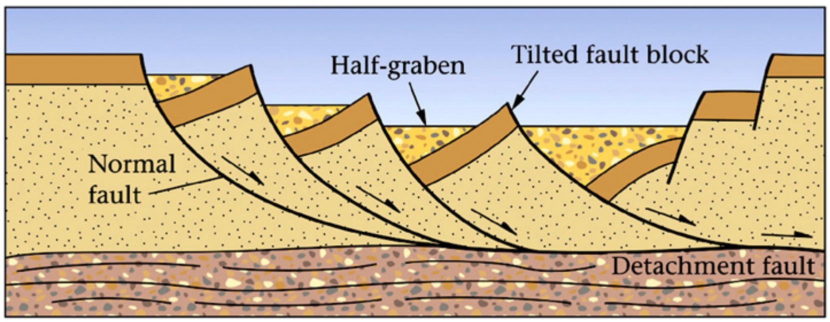


FIGURE 15.10
Folded sedimentary rocks, Lulworth Cove, Dorset, England.

Folds

Different types:

Open folds.

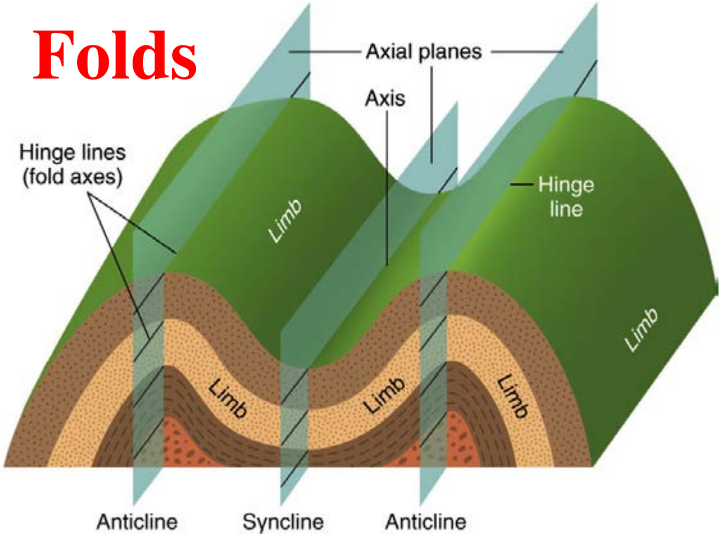
Isoclinal (tight) folds.

Chevron folds.

Tight, overturned folds (one limb upside down).

Recumbent fold (both limbs flat, one upside down).

Folds



Axial Surface: Surface that divides the fold as symmetrically as possible (often called the Axial Plane).

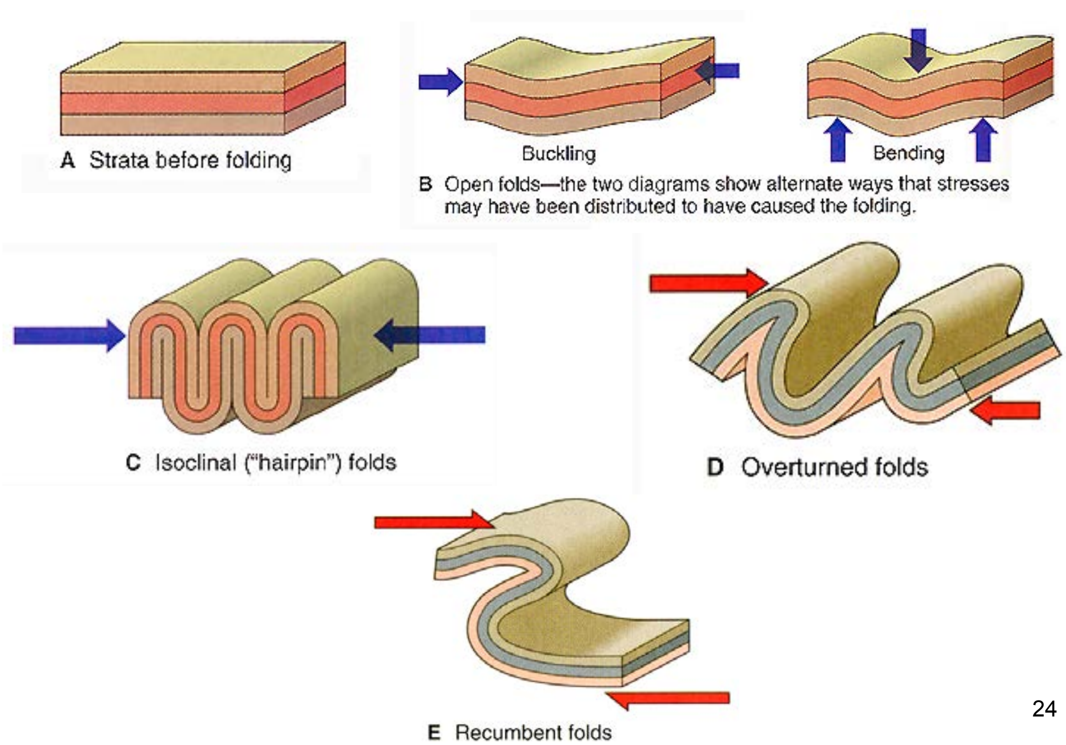
Fold Axis: Line made by the intersection of the axial surface with the beds. If axis is not horizontal it is "plunging".

Hinge Line: Line defining the fold axis (1D – axial plane = 2D).

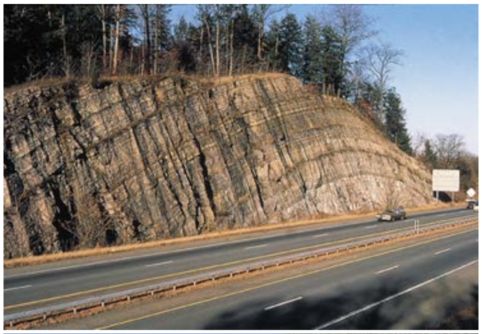
Anticline: oldest rocks in the center, beds dip away from oldest rocks. If the age of the rocks is unknown, the structure is called an "**Antiform**".

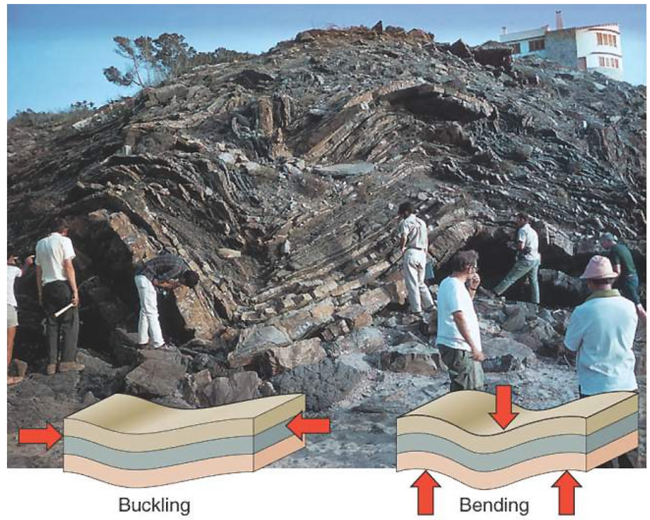
Syncline: youngest rocks in the center, beds dip into youngest rocks. If the age of the rocks is unknown, the structure is called a "**Synform**".

Folds



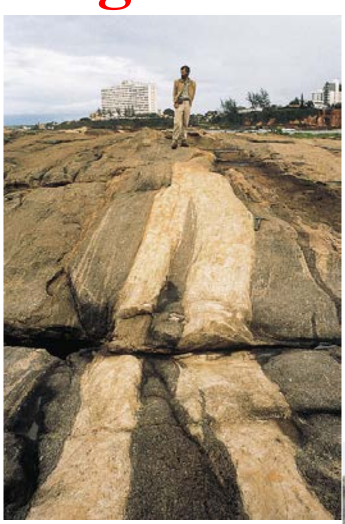
Open Folds



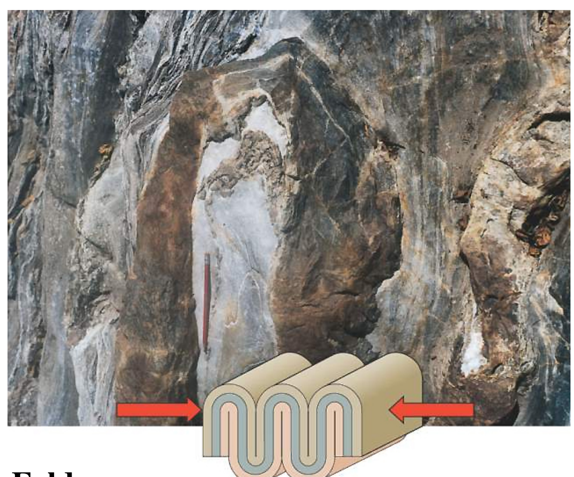


B Open folds—the two diagrams show alternate ways that stresses may have been distributed to have caused the folding.

"Tight" Folds

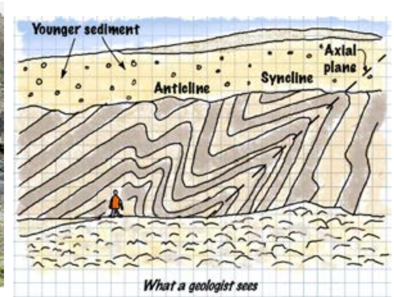


Isoclinal =
Parallel limbs



C Isoclinal ("hairpin") folds

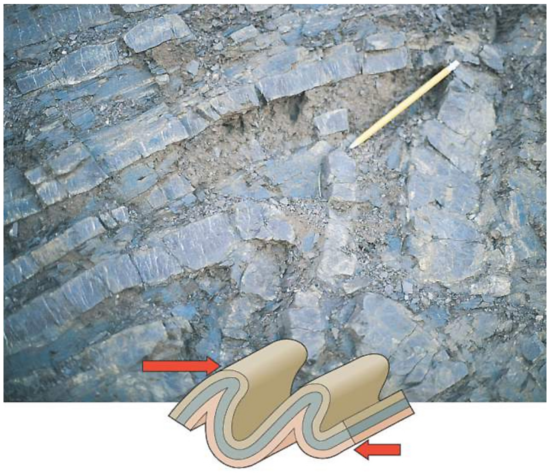
Chevron Folds



Note: Axial Plane is not vertical.

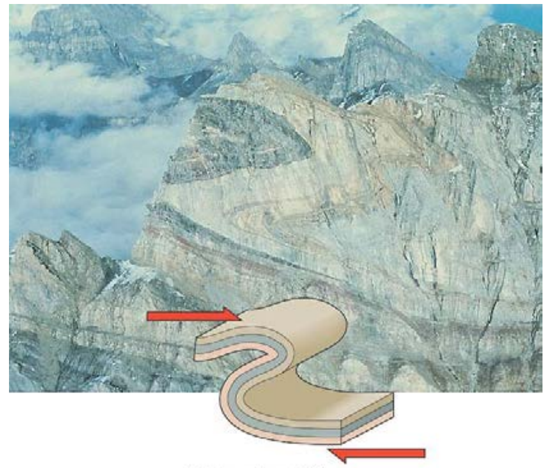
Overturned & Recumbent Folds

Overturned: One limb is now the wrong way up.



D Overturned folds

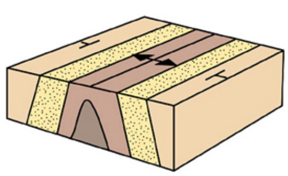
Recumbent: both limbs approach horizontal.

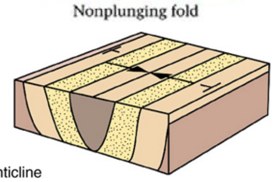


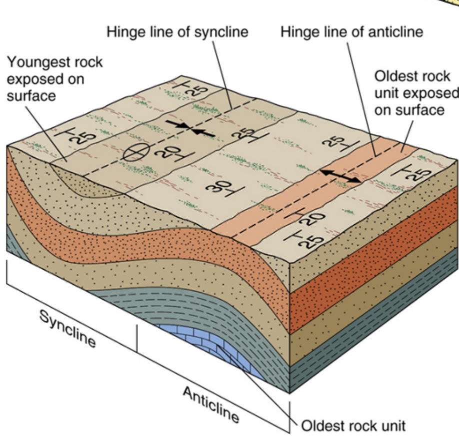
E Recumbent folds

Folds

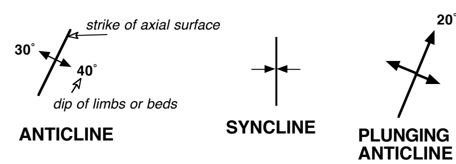
Nonplunging Folds: hinge is horizontal.
Dips switch as you go from limb to limb.



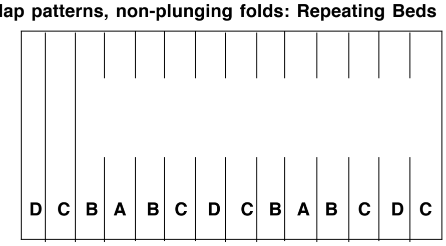




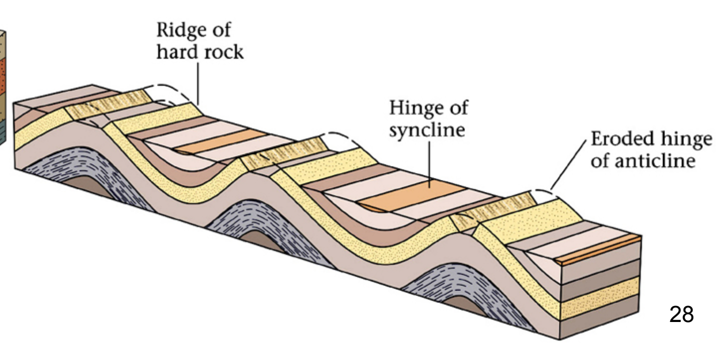
Fold Map Symbols:



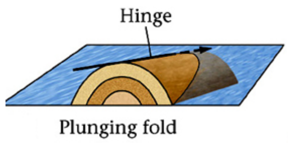
Map patterns, non-plunging folds: Repeating Beds



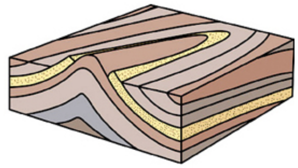
A = OLDEST, D = YOUNGEST



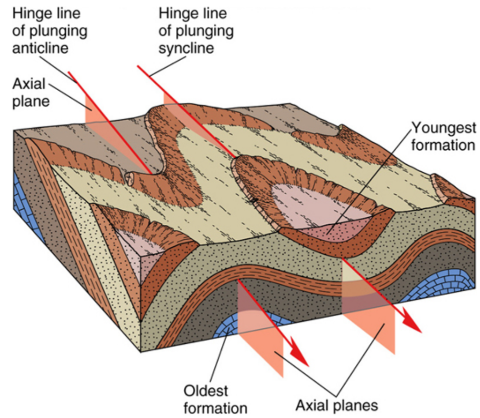
Folds



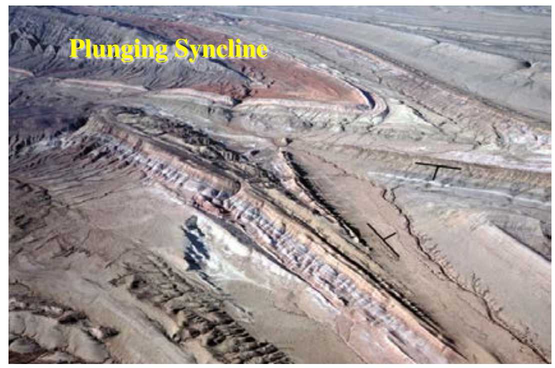
Plunging Folds: hinge is inclined.



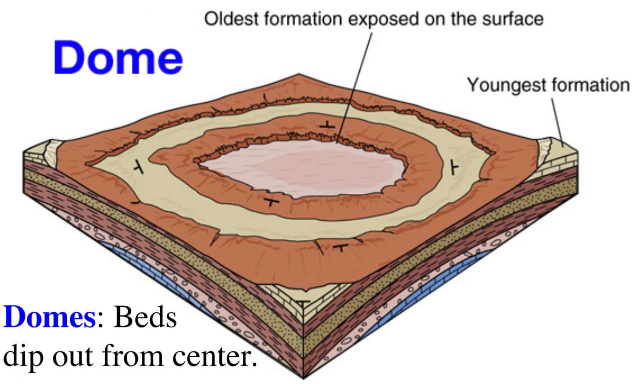
Plunging anticline



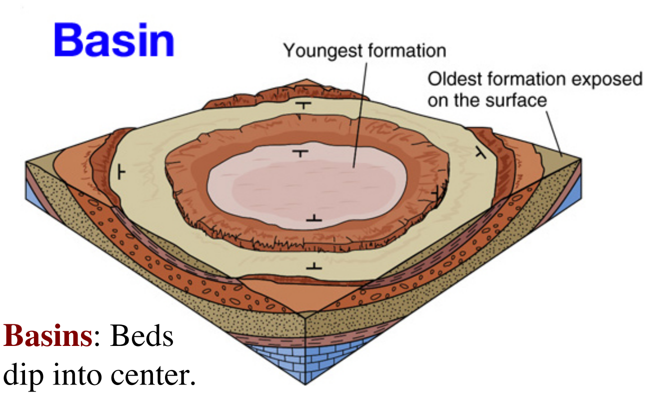
If the folds are plunging, anticlines point in the direction of plunge, synclines point away:



Domes and Basins

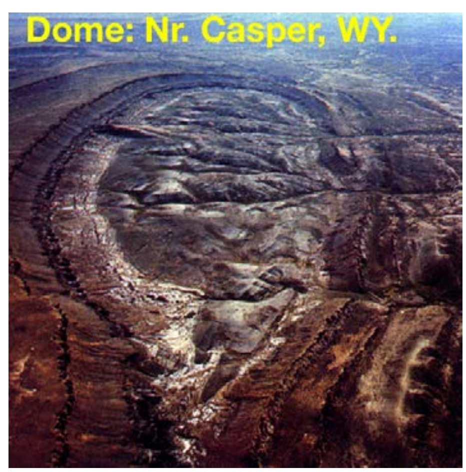


Domes: Beds dip out from center.



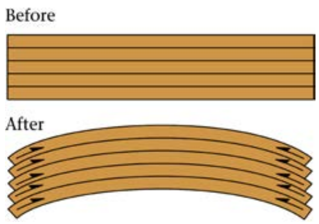
Basins: Beds dip into center.

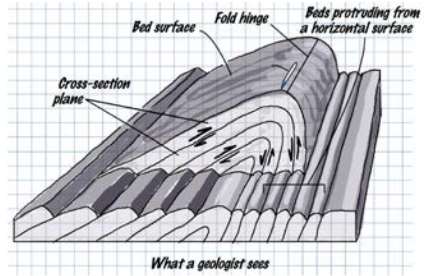
Approximately circular structures in map (plan) view.



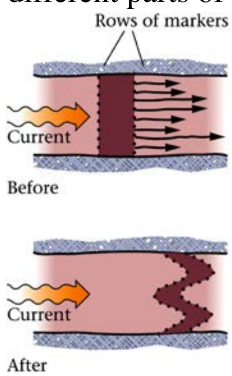
Forming Folds

“**Flexural Folds**”: when a stack of layers bends, slip occurs between the layers.



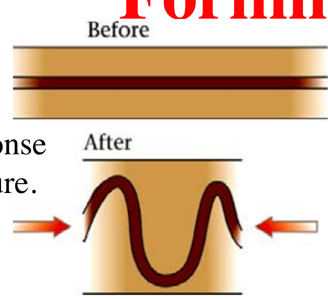


“**Flow Folds**”: rock is soft and behaves like weak plastic - develop because different parts of the body move at different rates.

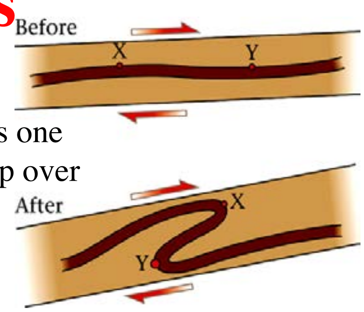


Forming Folds

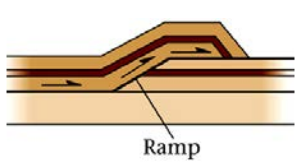
Some layers “wrinkle” or “buckle in response to end-on pressure.



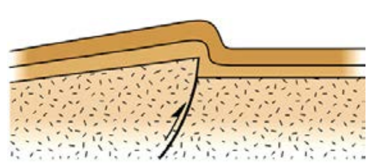
Shear stress can gradually moves one part of a layer up over another part.



Rock layer folds, but “over bends” and a fault is formed.

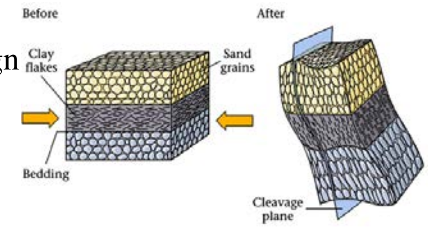


Block of basement moves and bends the overlying strata.



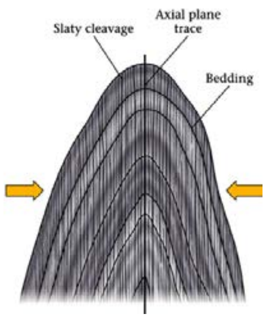
Tectonic Foliation

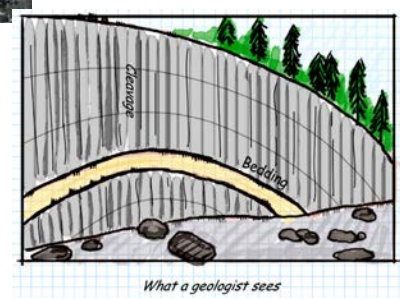
Deformation can create inequant grains and align them parallel with each other. This process produces **Tectonic Foliation**.



Different rock types require different metamorphic conditions in order to produce foliation. Some might not ever produce foliation.

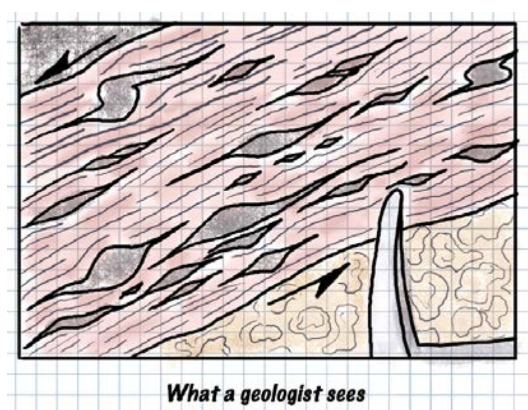
Slaty cleavage: clay minerals align perpendicular to the end-on stress - foliation may be parallel to fold axes.





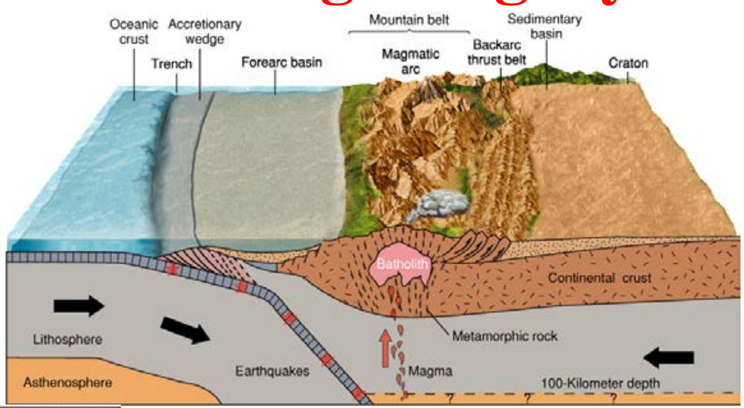
Tectonic Foliation

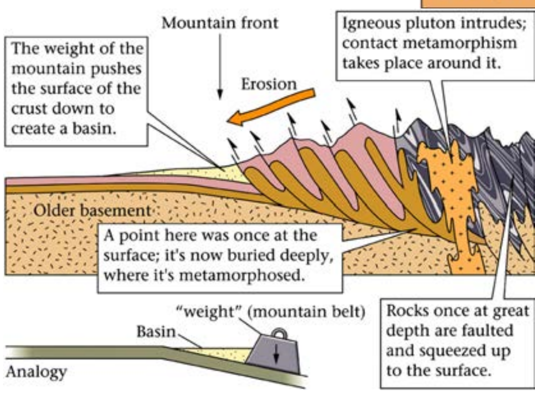
Schists and gneisses are produced by shear - foliation can be parallel to or at a slight angle to the shear direction because shear tends to smear grains out into the plane of shearing.



Rocks Formed During Orogeny

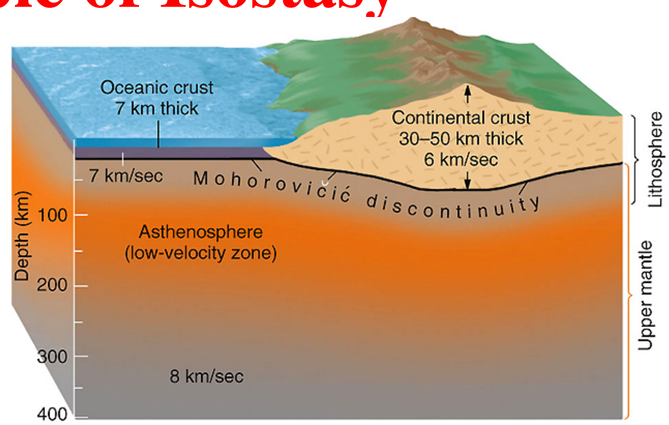
All types: magmatism promoted by subduction.
Metamorphism promoted by temperature and pressure.
Sedimentary rocks formed through erosion of uplifted arc/mountain range.

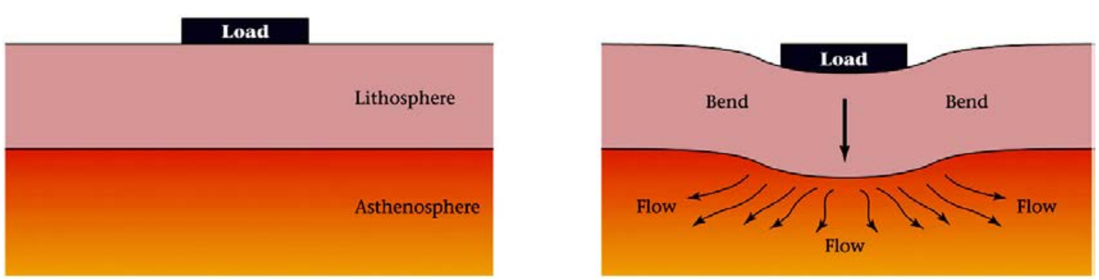




Principle of Isostasy

Mountain ranges commonly have a root that protrudes into the mantle.
Orogeny shortens crust, but thickens it.
If no root, mountain ranges would not be as high - ***Principle of Isostasy***.

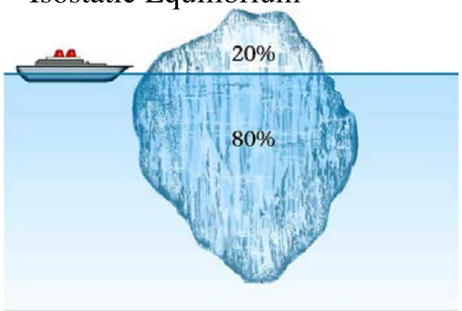


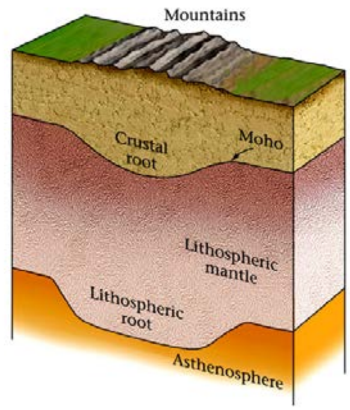


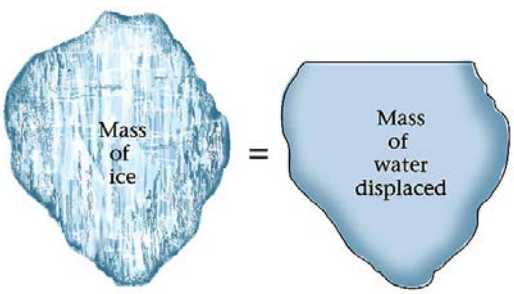
Lithosphere bends, but asthenosphere flows

Principle of Isostasy

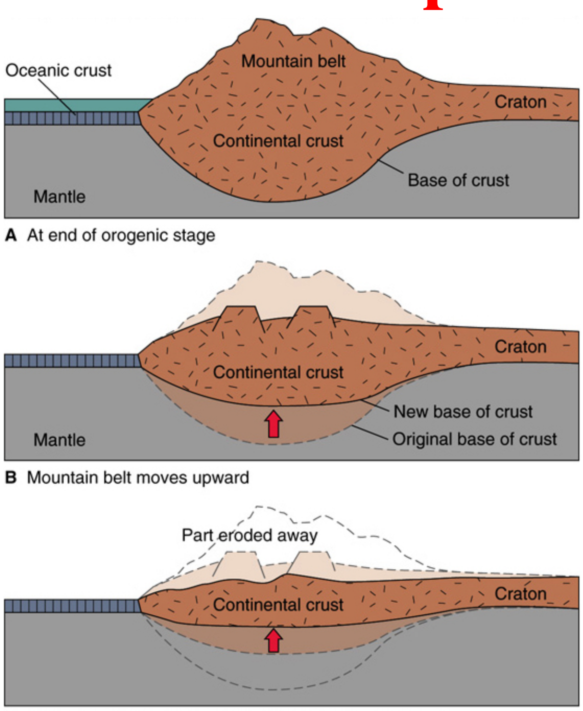
= Isostatic Equilibrium







Principle of Isostasy



A At end of orogenic stage

B Mountain belt moves upward

C Erosion and renewed uplift continue until crust beneath mountain belt is the same thickness as that of the craton

After plate convergence stops, relaxing the compressive force, there is a long period of uplift and erosion.

Isostasy:. Concept – lighter, less dense continental crust "floats" higher on the mantle than the denser oceanic crust.

Mountains still rise after collision is over.

Mountain Shape

Mountains are shaped by weathering and erosion and depends upon:

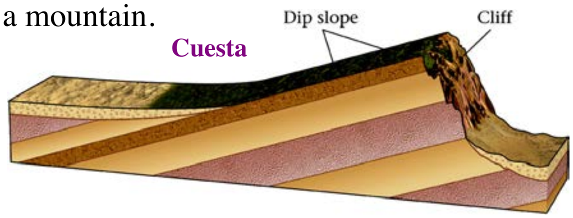
Rock type, Climate, Geologic Structure, Time.

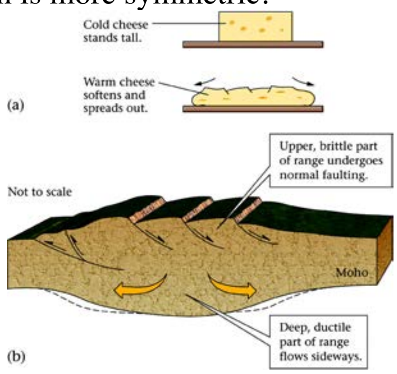
Mountains are erosional features.

Geologic structure can affect the shape of a mountain.

Cuesta: asymmetric ridge underlain by dipping strata.

Hogback: strata are more steeply dipping so the mountain is more symmetric.



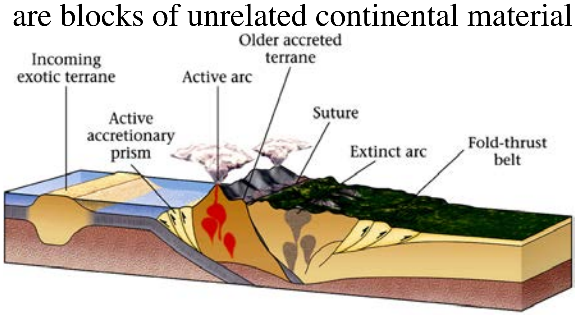


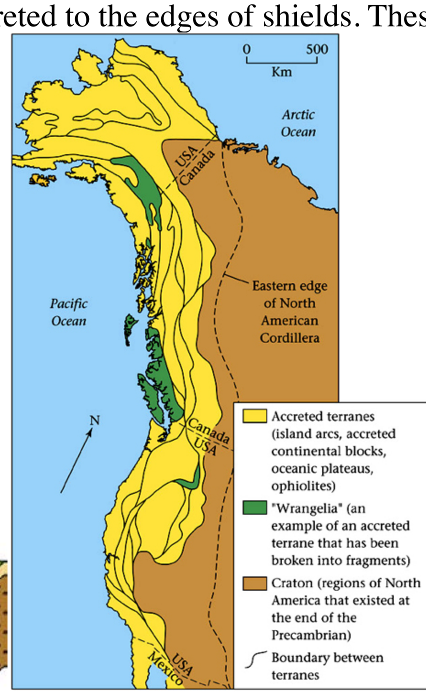
Orogenic Collapse: Weight of mountain causes warm crust at depth to flow laterally. This takes time because rock are slow to heat up.

This, together uplift and erosion, forms the process of "***exhumation***" that brings metamorphic and plutonic rocks to the surface.

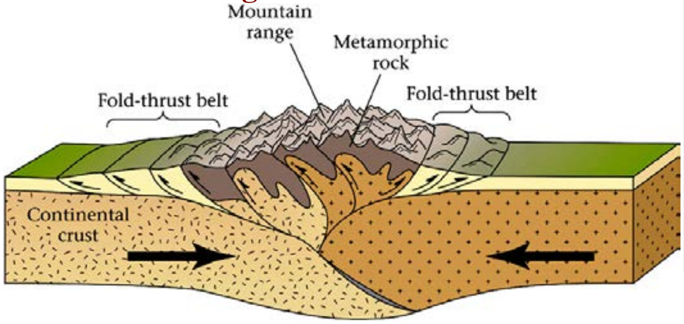
Mountain Building

Accretionary Orogens: Exotic terranes are accreted to the edges of shields. These are blocks of unrelated continental material.



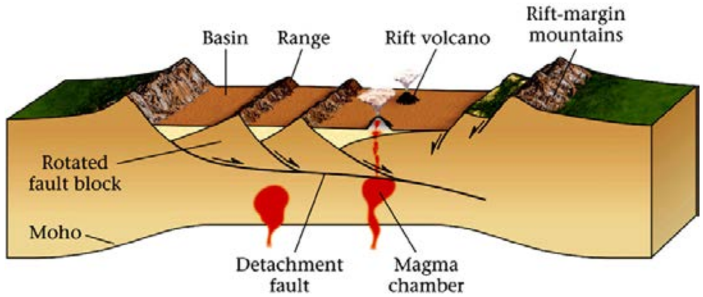


Collisional Orogen: Two continents collide.

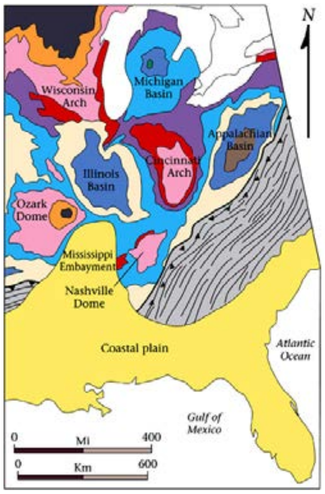


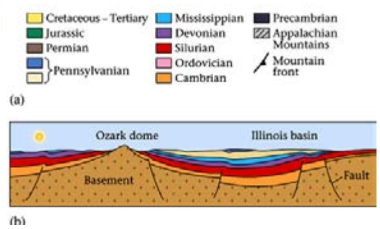
Mountain Building

Rifting: produces fault-block mountains through normal faulting with half grabens in between.



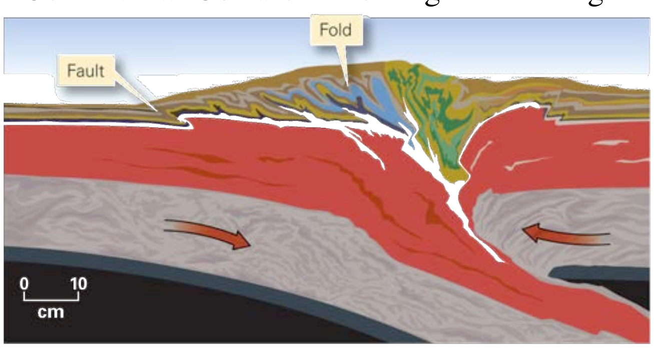
Regional Basins and **Regional Domes**: Broad areas that gradually sank and rose, respectively. Process that generate these huge (but "gentle") broad vertical movements in mid-continents = "***epeirogeny***".

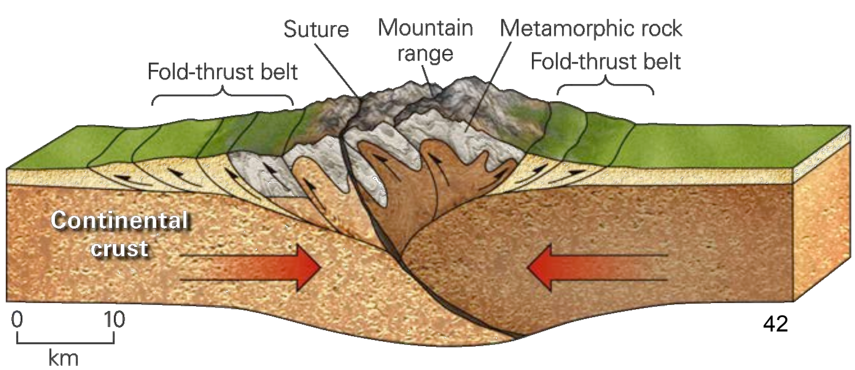




Mountain Building

Continental Collision – folding and faulting – crustal shortening/thickening





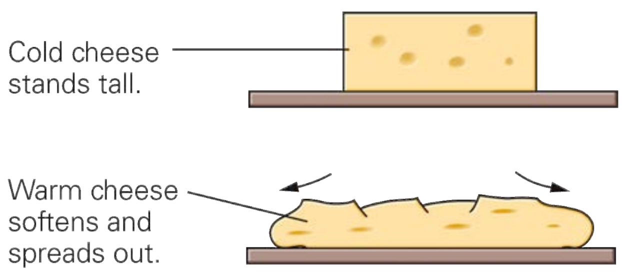
What Goes Up…..

Mountains reflect a balance between uplift and erosion. Mountains are steep and jagged due to high rates of erosion.

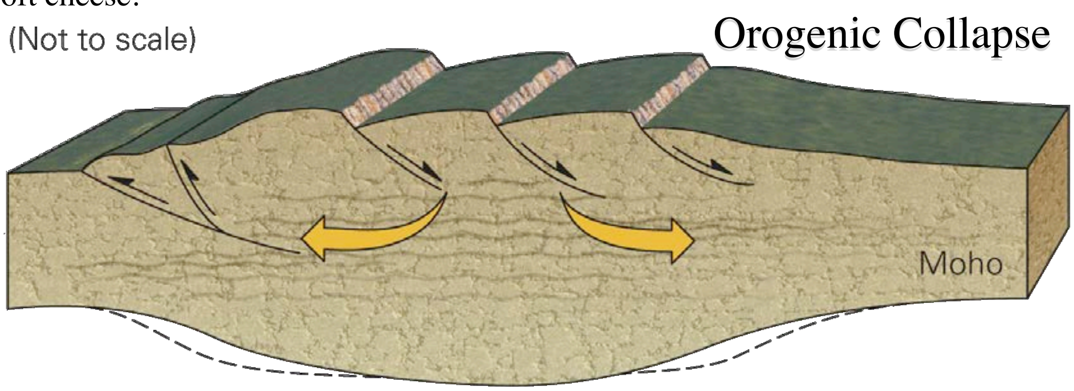
When tectonic uplift slows or ceases, or rates of erosion exceed rates of uplift, mountains are reduced in elevation. Eventually, mountains may be eroded back to sea level.

……Must Come Down!

The weight of mountains eventually overwhelms the strength of hot ductile rock in the lower crust. Ductile rock eventually flows out from beneath high mountains, which then settles downward like soft cheese.

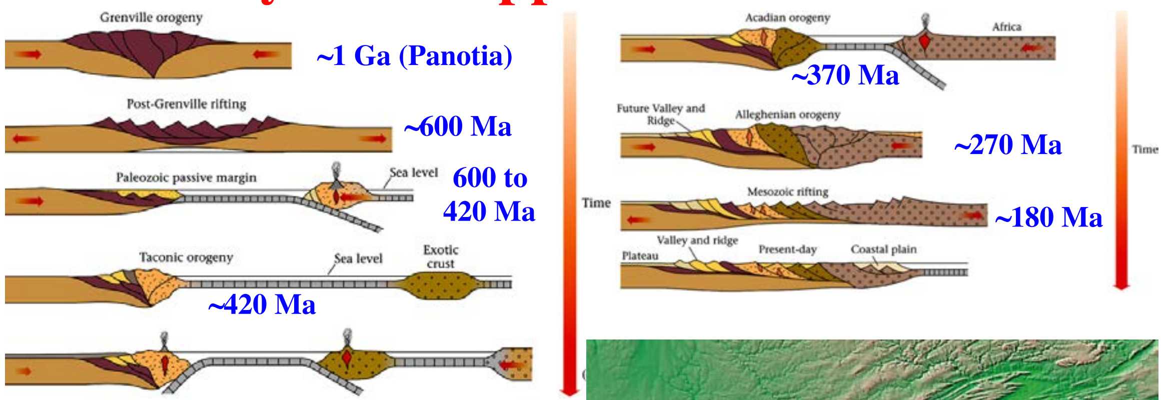


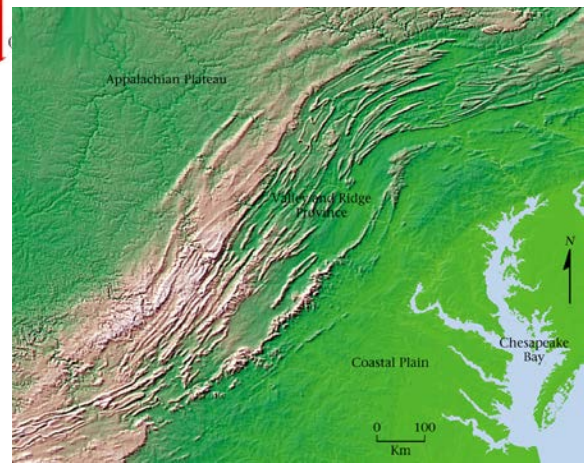
Orogenic Collapse



The upper brittle crust breaks into faults. This process, which leads to destruction of the mountains, is known as **Orogenic Collapse**.

History of the Appalachian Mountains





Summary

Mountain Belts.

Deformation & Strain: Folding, Faulting, Foliation, Translation, Tilting, Stretching, Shortening, Shear.

Brittle & Ductile Deformation.

Force & Stress: Hydrostatic, Compressive, Tensional, Shear.

Strike, Dip, Plunge.

Joints: Systematic and Nonsystematic, Veins.

Faults: Blind, Dip-Slip, Strike-Slip, Oblique-Slip.

Dip-Slip: Normal, Reverse (>35˚), Thrust (<35˚).

Strike-Slip: Left Lateral, Right Lateral.

Recognizing Displacement: Drag Folds, Fault Scarp, Fault Breccia, Fault Gouge, Slickensides, Slip Lineations, Mylonite.

Fault Systems: Horst, Graben, Detachment Fault.

Summary (cont.)

Folds: Open, Isoclinal (Tight), Chevron, Overturned, Recumbent, Fold Axis, Axial Surface/Plane, Hinge Line, Anticline, Syncline.

Plunging & Nonplunging Folds.

Domes & Basins.

Flexural Folds & Flow Folds.

Tectonic Foliation.

Principle of Isostasy.

Mountain Shape: Rock Type, Climate, Structure, Time, Cuesta, Hogback, Orogenic Collapse, Exhumation.

Mountain Building: Accretionary Orogens, Collisional Orogens, Rifting, Regional Basins, Regional Domes, Epeirogeny.

History of the Appalachians.