Fundamentals of Earth Sciences (ESO 213A)

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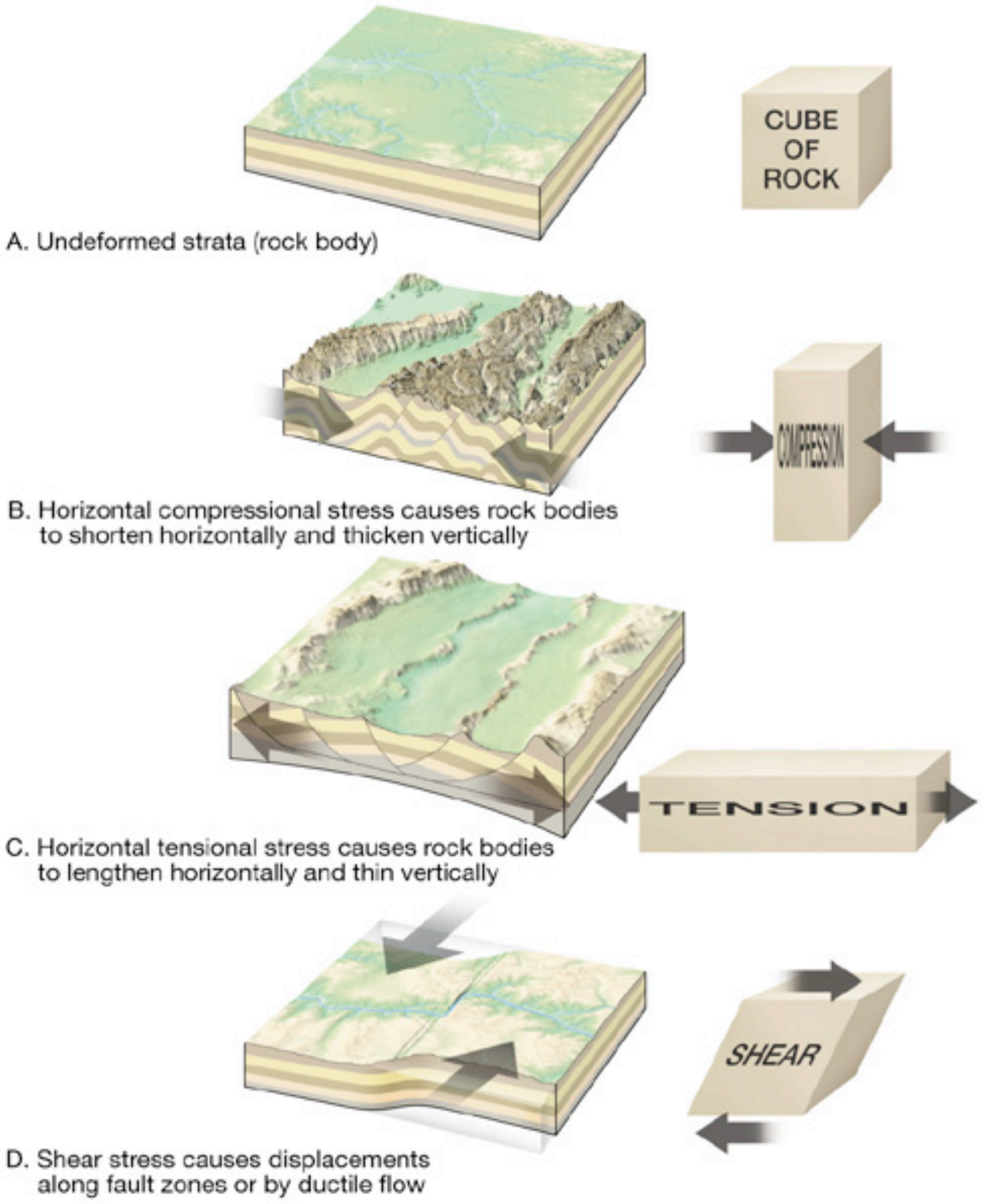
Crustal Deformation (Fold/Fault/Joint)

Previous Class: Crustal deformation

Deformation of the Earth's Crust Caused by Tectonic Forces & Associated Stresses Resulting from the Movement of Lithospheric Plates



At least 6 factors control how rock deforms

e.g. at shallow depth a rock may fracture whereas at depth it may flow.

Factors are:

(1) rock type

(2) Confining and directed pressure

(3) temperature

(4) Fluids

(5) Time

(6) Rate of deformation

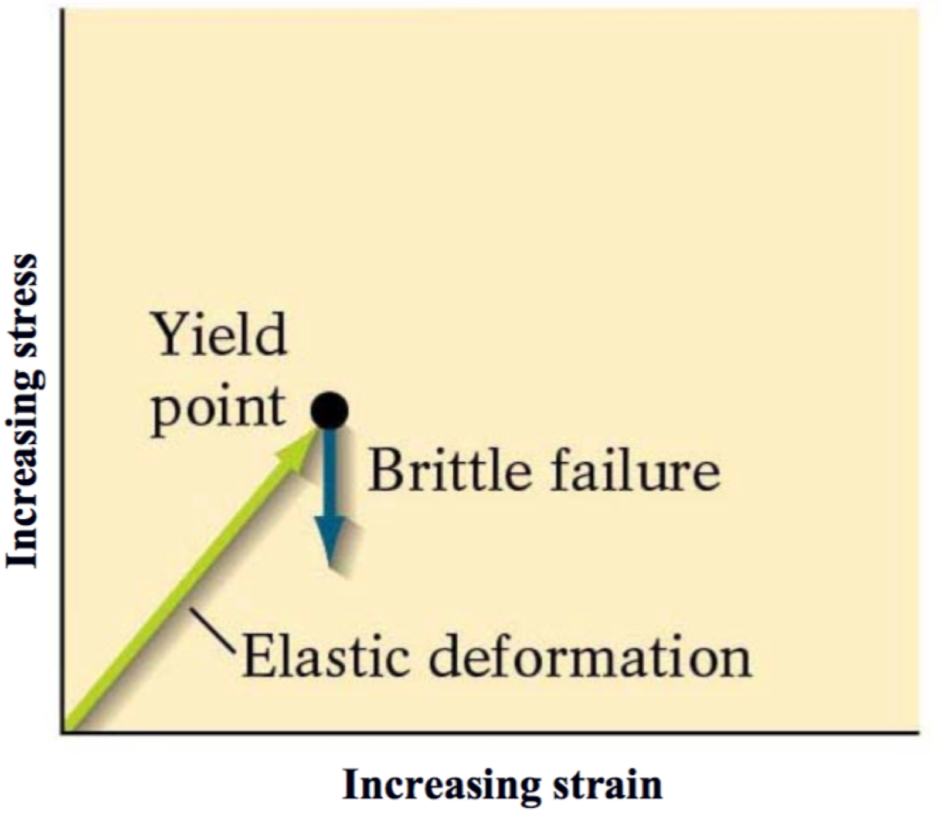
Deformation of Marble Cylinders in the Laboratory Reveals that Rocks Fracture Under Low Confining Pressure, But Flow Plastically Under Higher Pressure

Undeformed	Low Confining Pressure	Moderate Confining Pressure	High Confining Pressure

Types of Deformation: Elastic vs Plastic
Brittle vs Ductile

Brittle Deformation (Rupture)

•When an external force is applied to buried rocks under low confining pressure, such as near the surface of the earth, the rock typically deform by simple fracturing. This is known as **brittle** deformation.

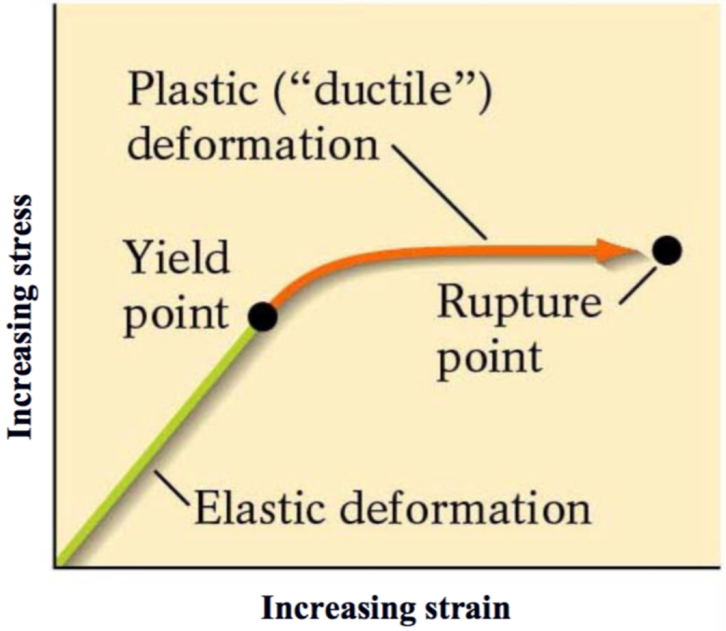


Brittle failure

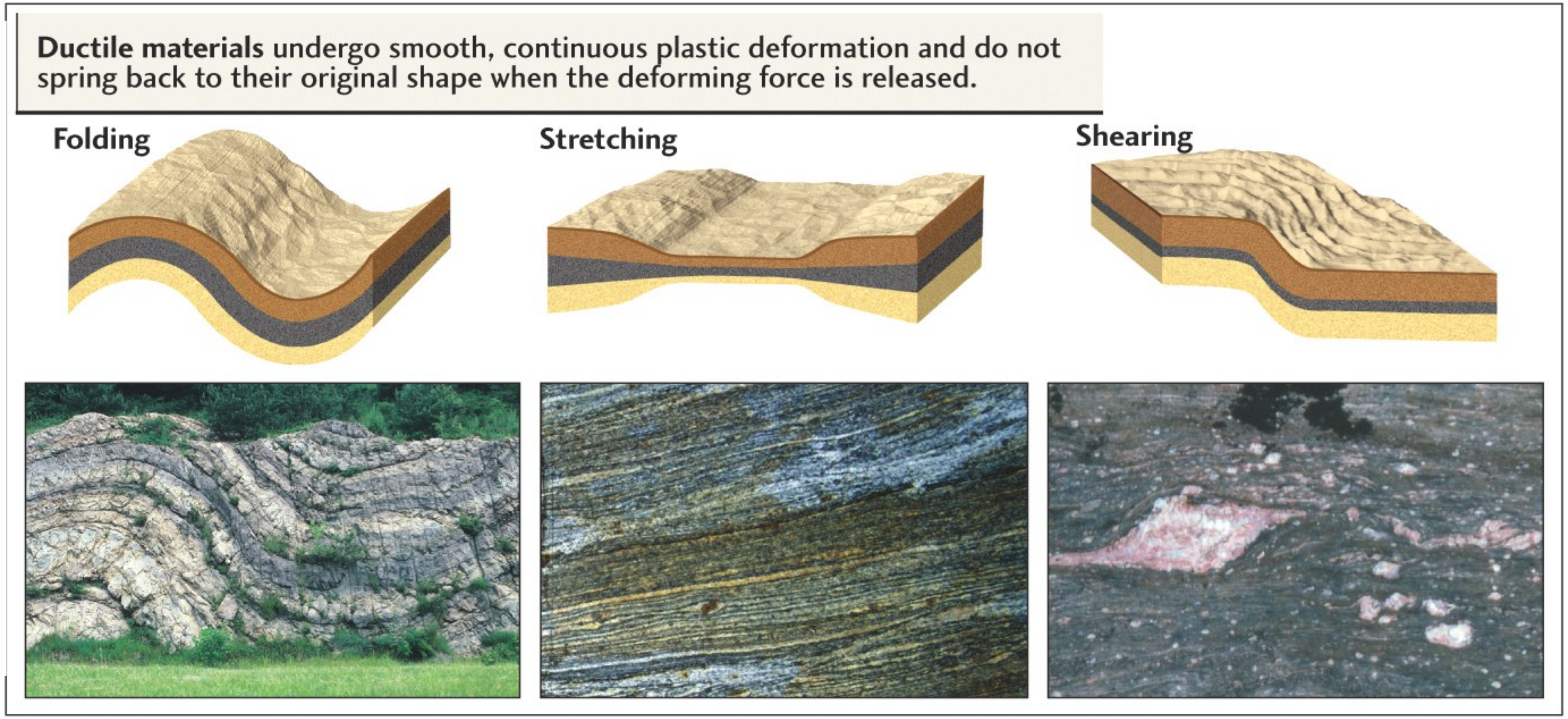
Ductile (Plastic) Deformation

•At higher confining pressures, a similarly directed external force will cause the deeply buried rock to actually flow and deform without fracturing. This is known as **ductile** deformation and the rock is said to behave **plastically**.

•Occurs by the slippage of atoms or small groups of atoms past each other in the deforming material, without loss of cohesion

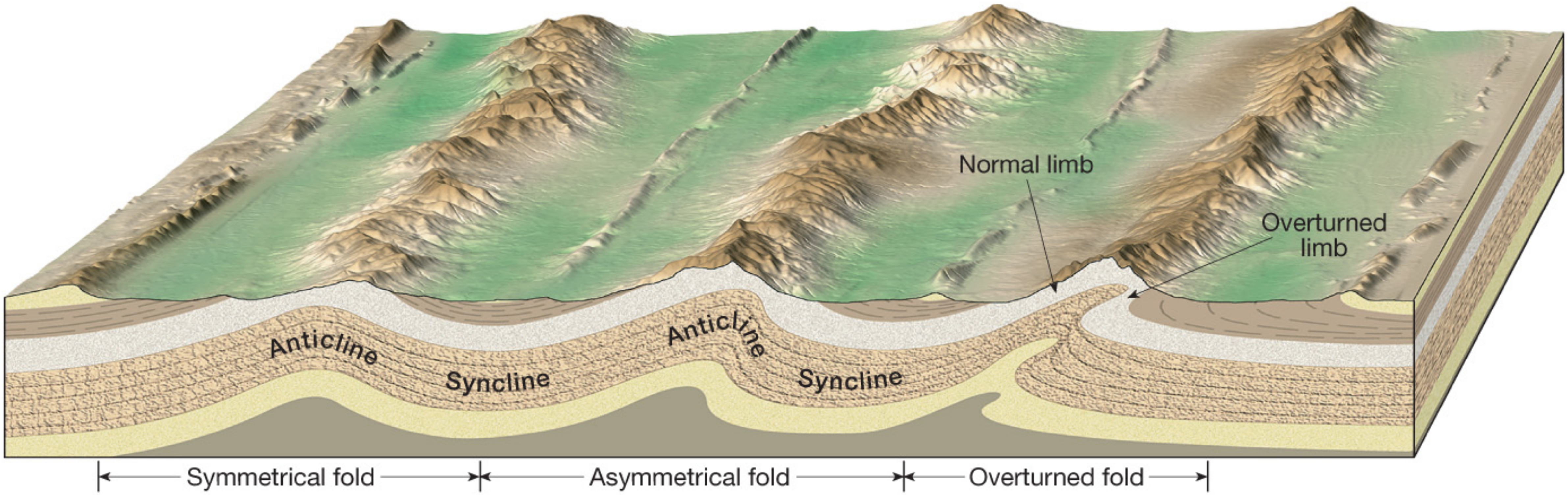


Plastic deformation

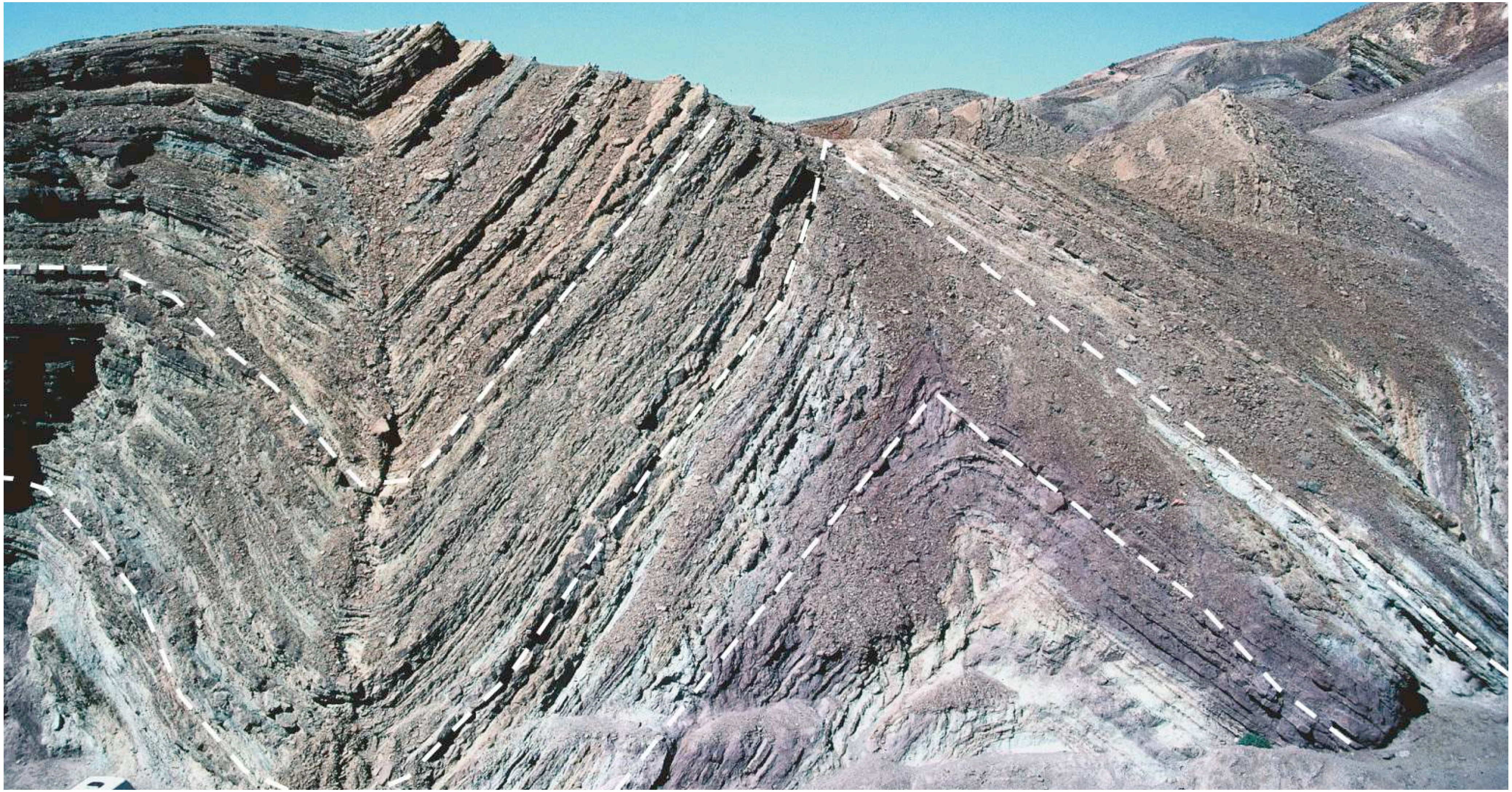


Folds (Ductile Deformation)

- **Along convergent plate boundaries, rocks are often bent into a series of wave-like undulations called folds.**
- **Characteristics of folds**
    - **Most folds result from compressional stresses that shorten and thicken the crust.**

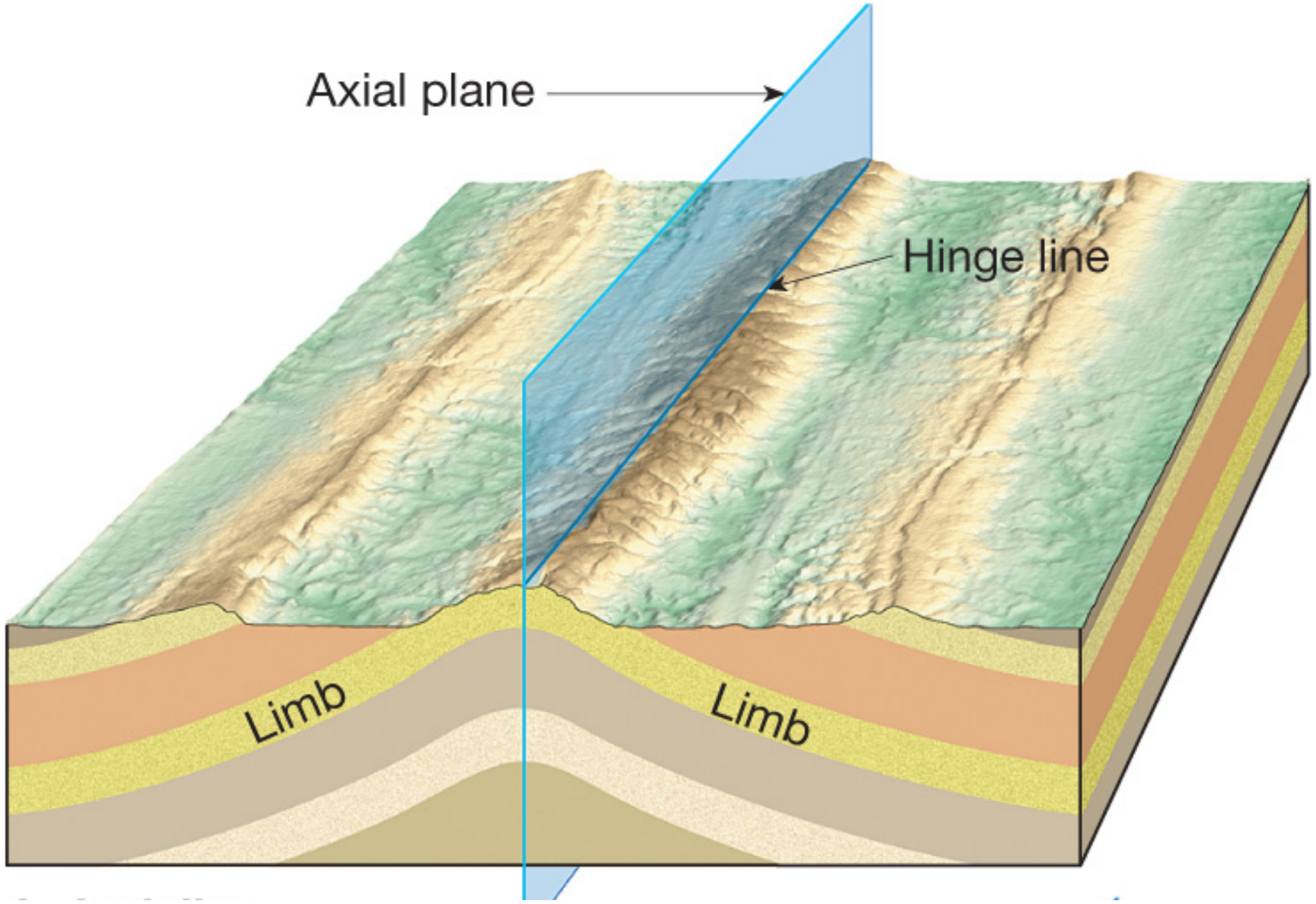


Outcrop Example of a Syncline (Left) and Anticline (Right). Note They Share a Common Limb



Characteristics of folds

- **Parts of a fold**
  - *Limbs* refer to the two sides of a fold.
  - An *axial plane* is an imaginary surface that connects all hinge lines of folded strata
  - A line drawn along the points of max curvature of each layer is the *hinge*

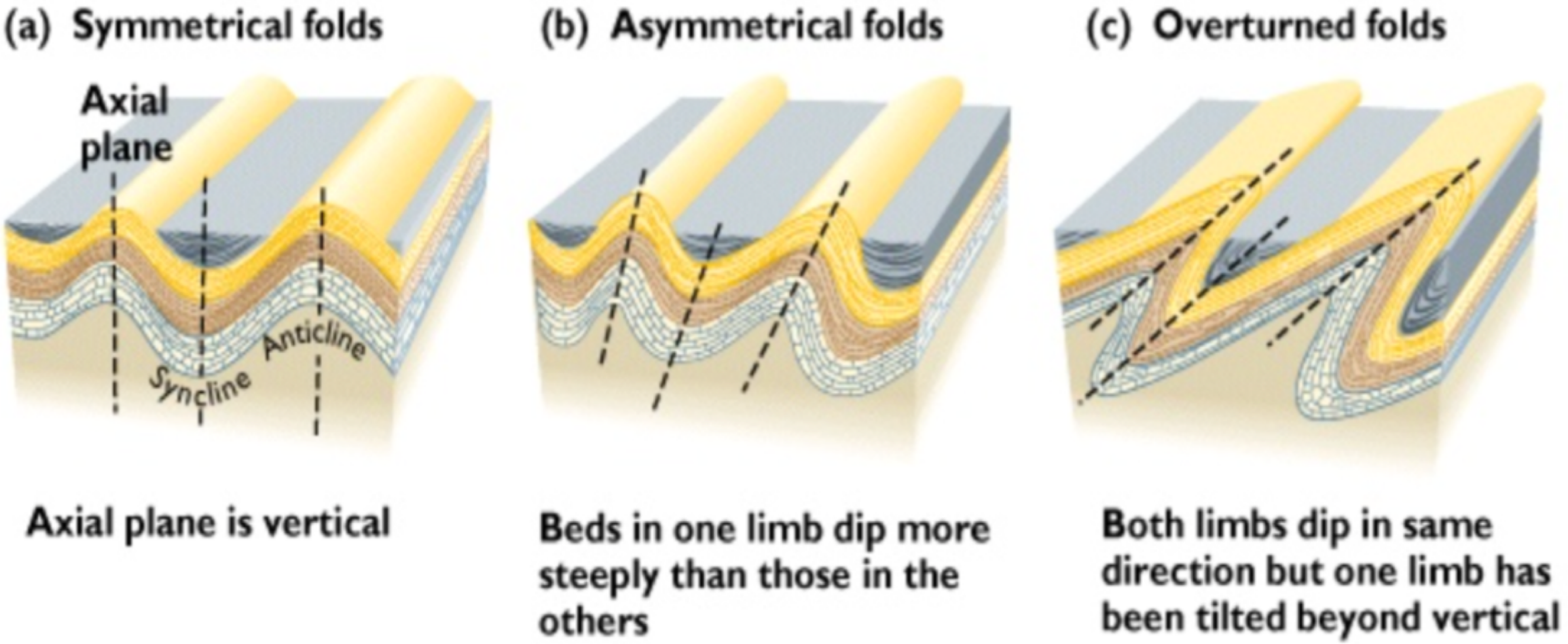


Folds

- Common types of folds (based on age and fold closure)
  - 1. Anticline—older rocks at core
  - 2. Syncline—older rocks away from core

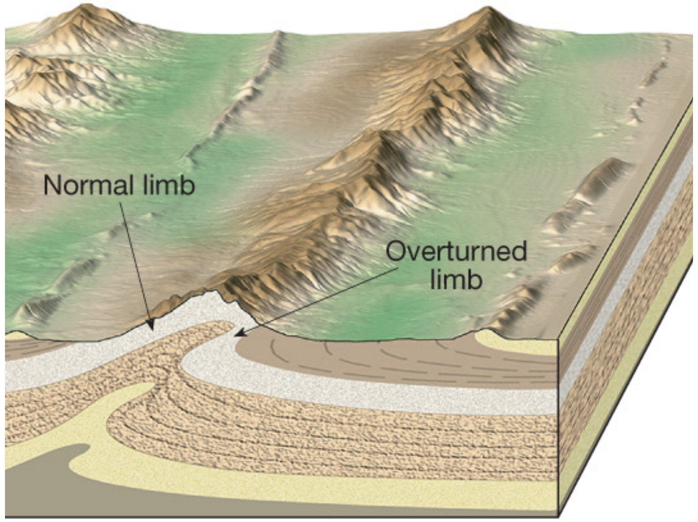
Anticlines and Synclines

- **Depending on axial plane orientation:**
  a) Symmetrical - the limbs are mirror images of each other
  b) Asymmetrical - one limb dips more steeply than the other
  c) Overturned – one or both limbs are tilted beyond vertical and limbs dip same direction and are found in areas with intense deformation



Anticlines and Synclines

Asymetric fold



Overturned fold

Anticlines and Synclines

d) **Recumbent** – a plane extending through the axis of the fold is horizontal (it "lies" on its side)

» Common in highly deformed mountainous regions

Question : This image features a large geologic structure that outcrops in Death Valley National Park, California.

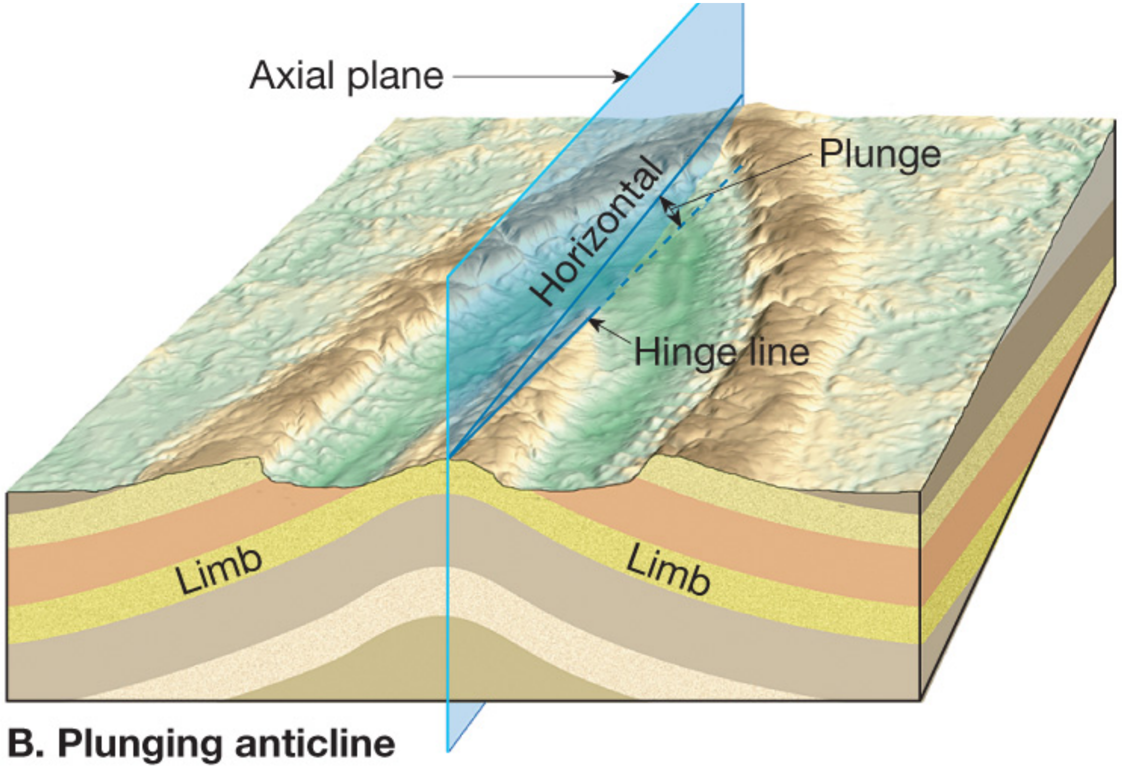
Q1: What name would you give to this geologic structure?

Q2: Based on this image, would you describe this fold as symmetrical or asymmetrical?

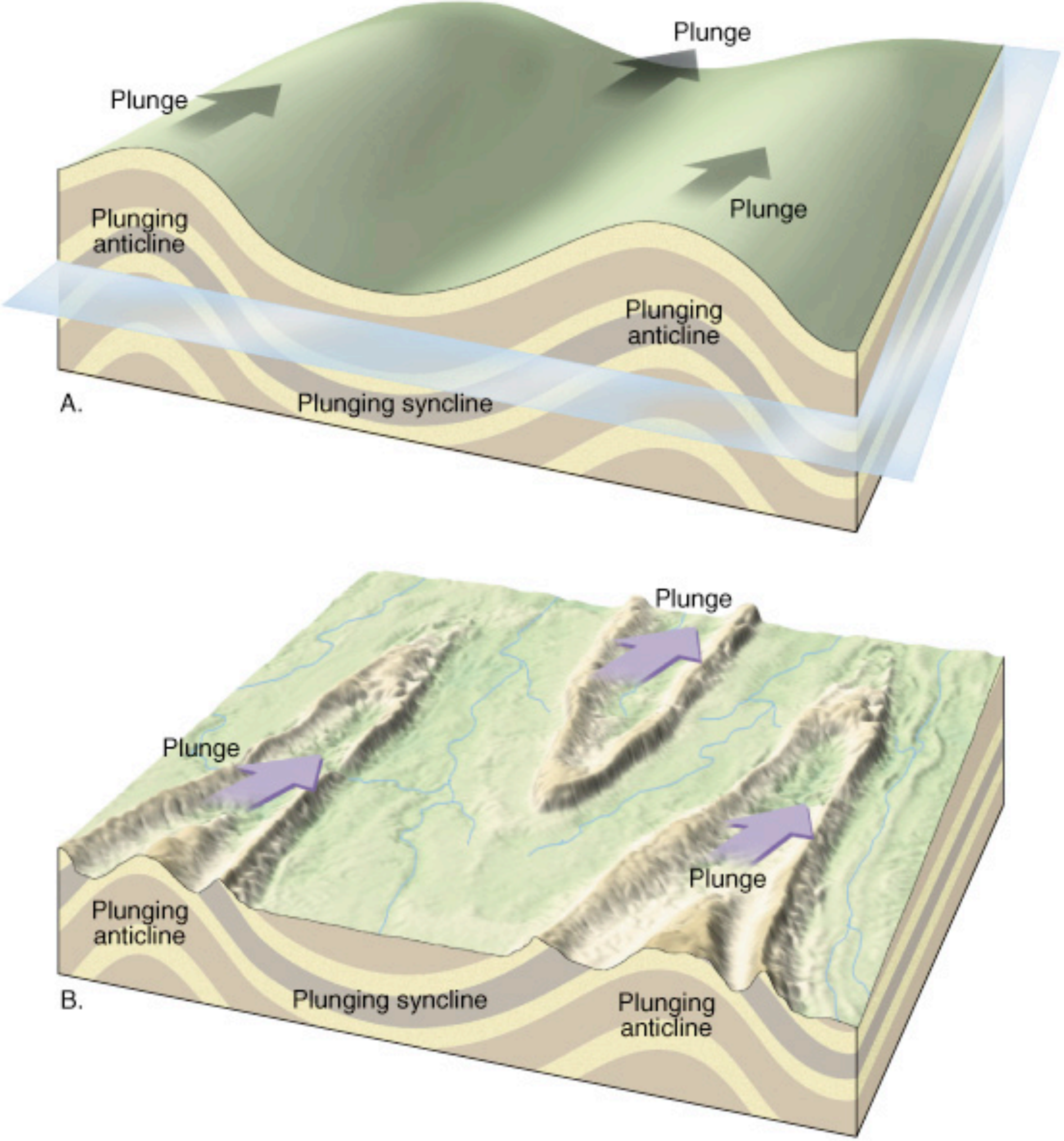
Q3: Do these rock units mainly display ductile deformation or brittle deformation?

Anticlines and Synclines

- **Depending on the fold axis:**
  - Plunging – the axis of the fold penetrates the ground



Sheep Mountain, Wyoming, A Doubly Plunging Anticline (It Dips into the Subsurface on Both Ends)



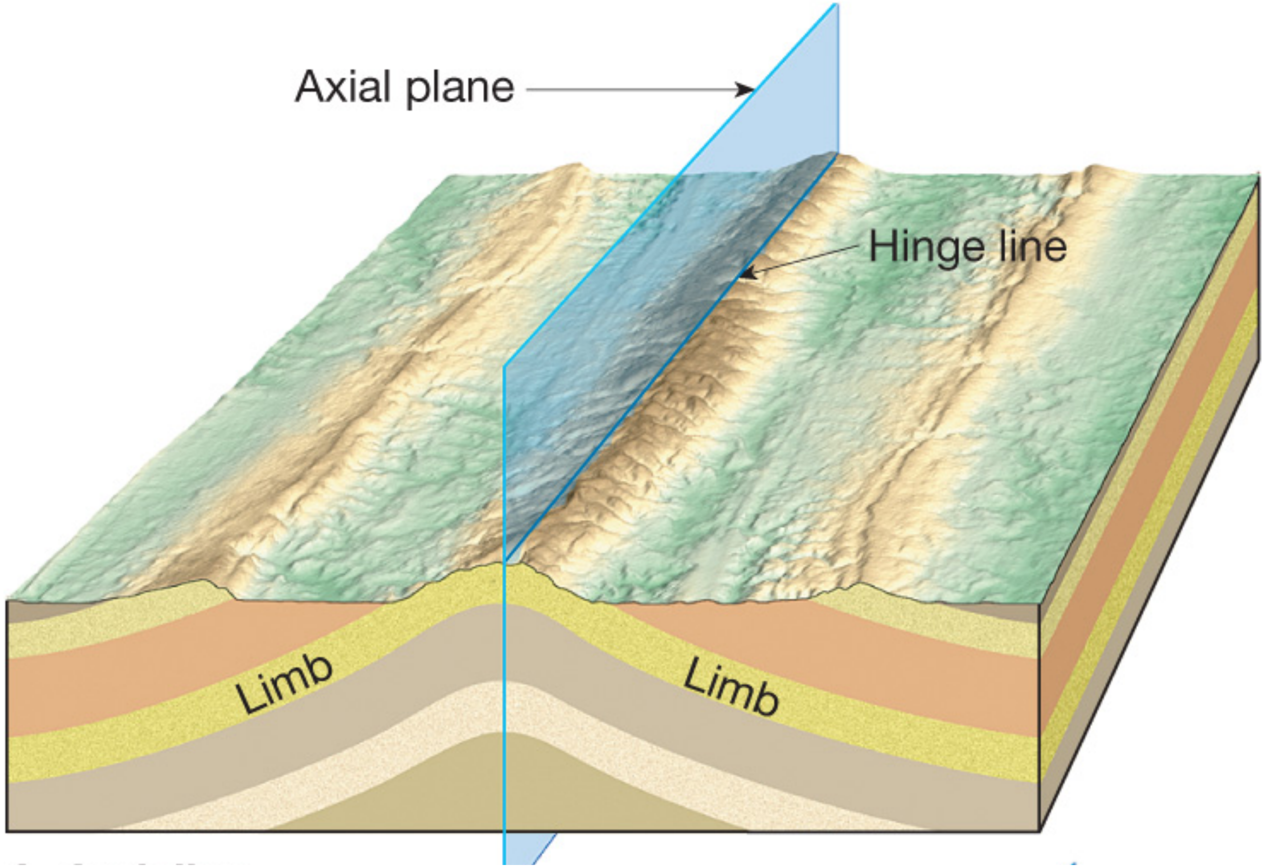
Plunging Folds

A. An Idealized View

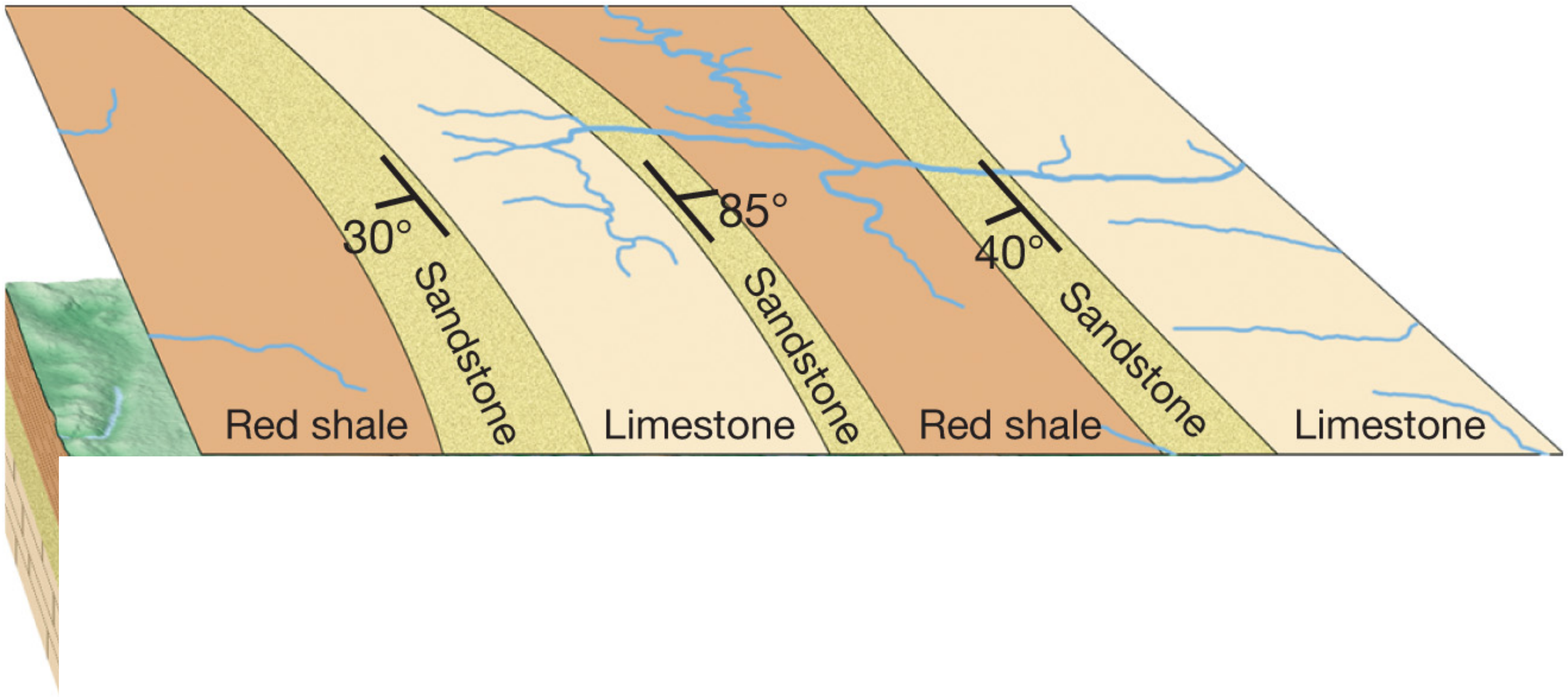
B. What the Same Structures Would Look like on the Surface After Erosion. (Note that in Anticlines the Outcrop Points in the Direction of Plunge, in Synclines it Points Opposite to Plunge)

Anticlines and Synclines

- **Depending on the fold axis:**
  - **Non-plunging – the axis of the fold is horizontal**



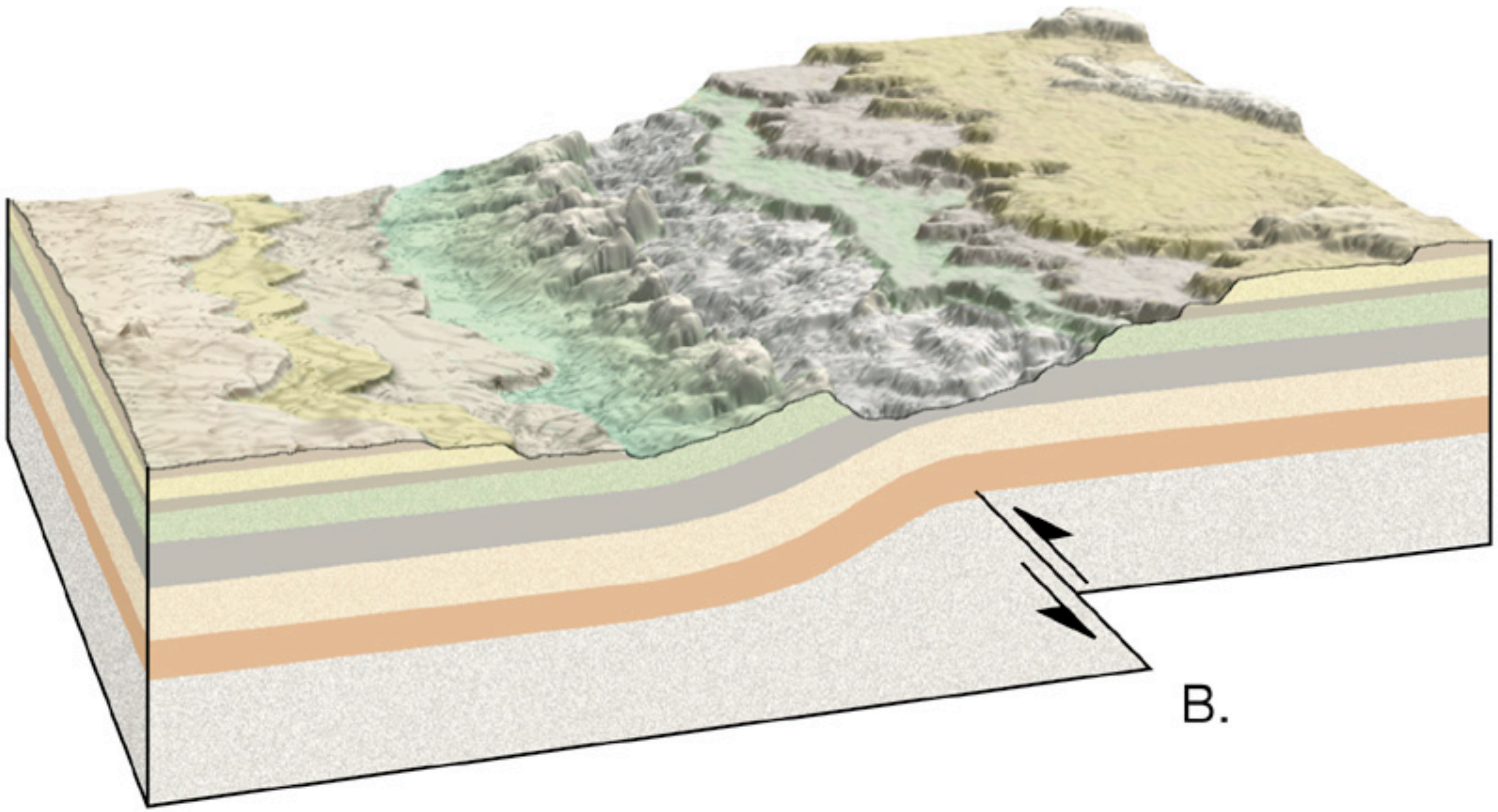
Question



A Geologic Map Showing the Strike and Dip of Structures:
Q1: Identify the Anticline and Syncline
Q2: What will be the nature of the anticlines?

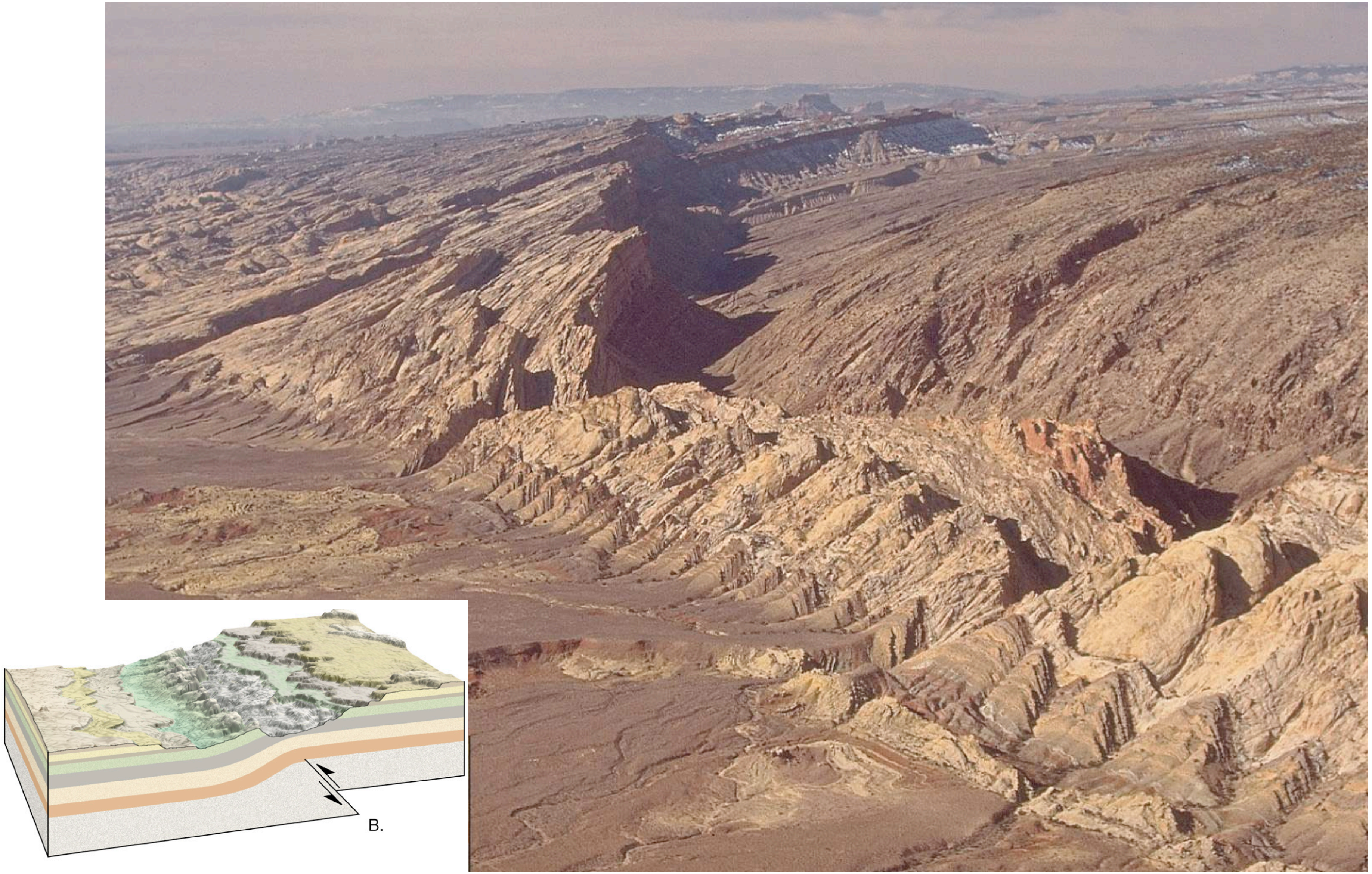
 B. Block diagram

- **Monoclines** – large, step-like folds in otherwise horizontal sedimentary strata



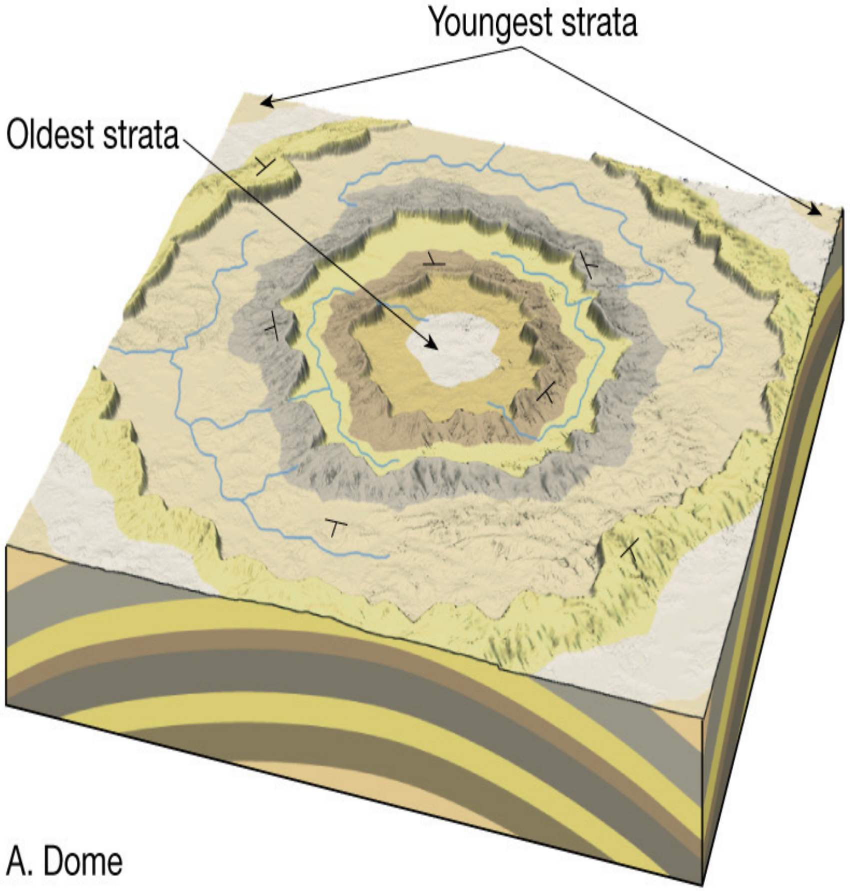
Monoclines (Structures that Are Folded on Only One Side) Are Often Produced by Faulting in the Underlying Strata

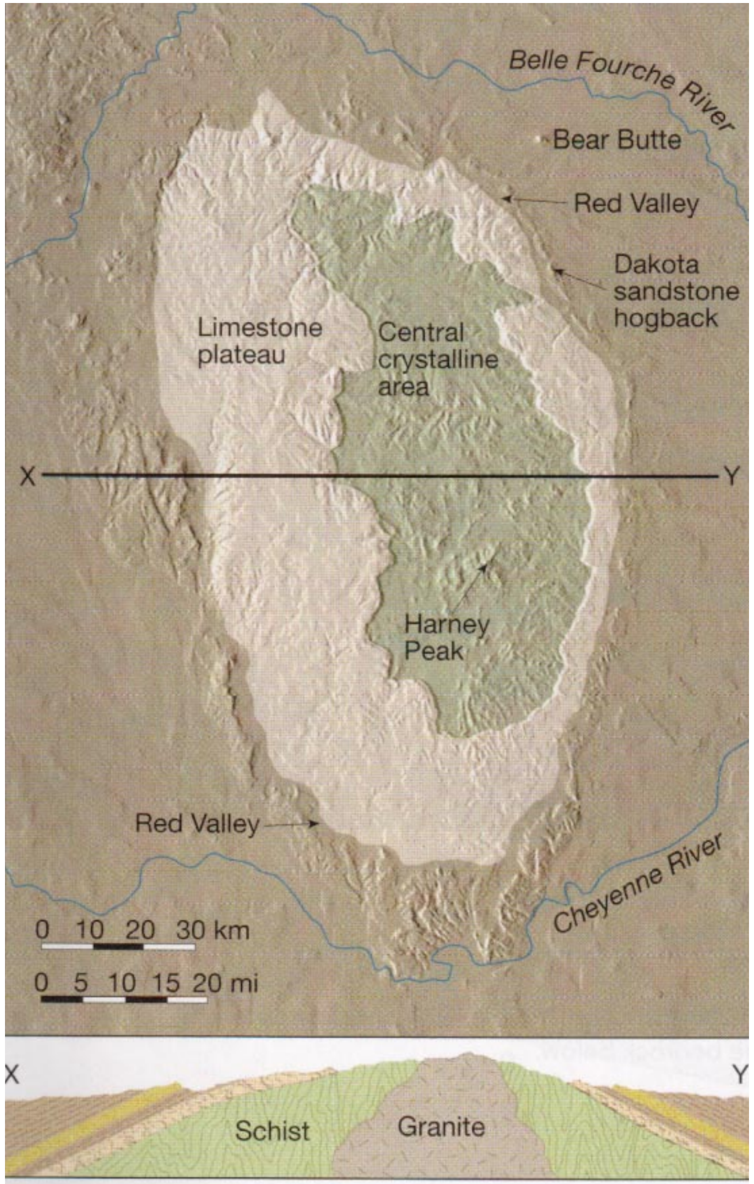
The San Rafael Swell (Utah) Shows the Edge of a Monocline (Dips on One Side Only).



- **Other types of folds**
  - **Dome**
    - **Upwarped displacement of rocks**
    - **Circular or slightly elongated structure**
    - **Oldest rocks in center, younger rocks on the flanks**

A Dome Exhibits a Circular Outcrop Pattern with the Oldest Rocks in the Center

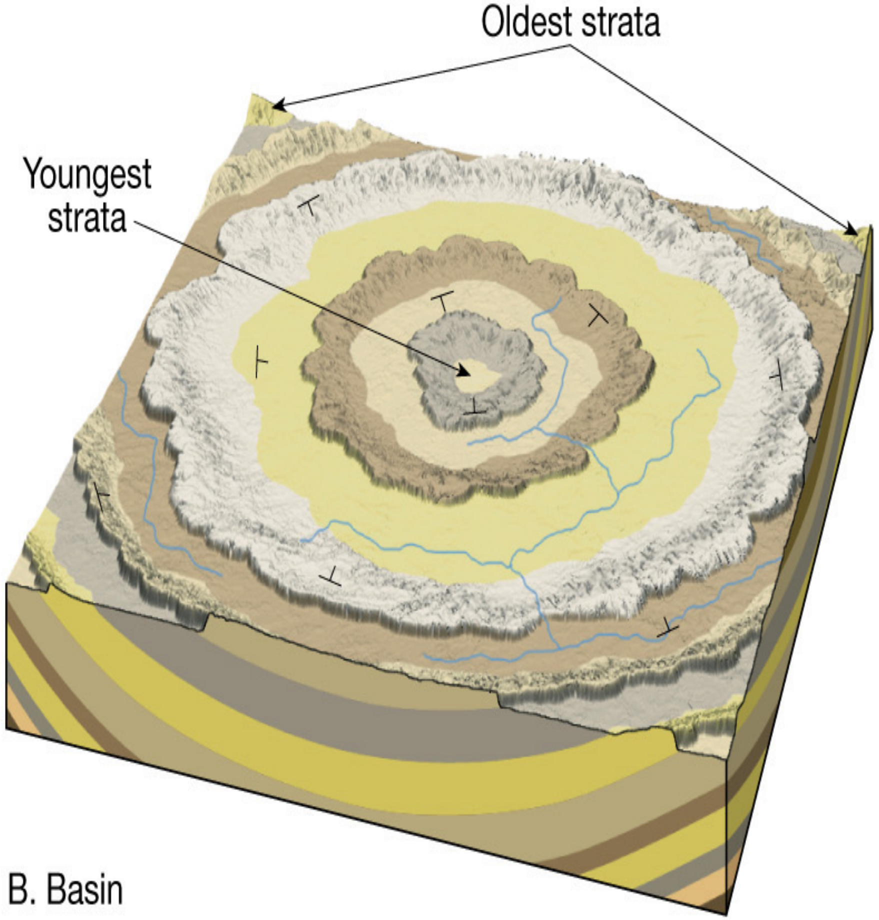




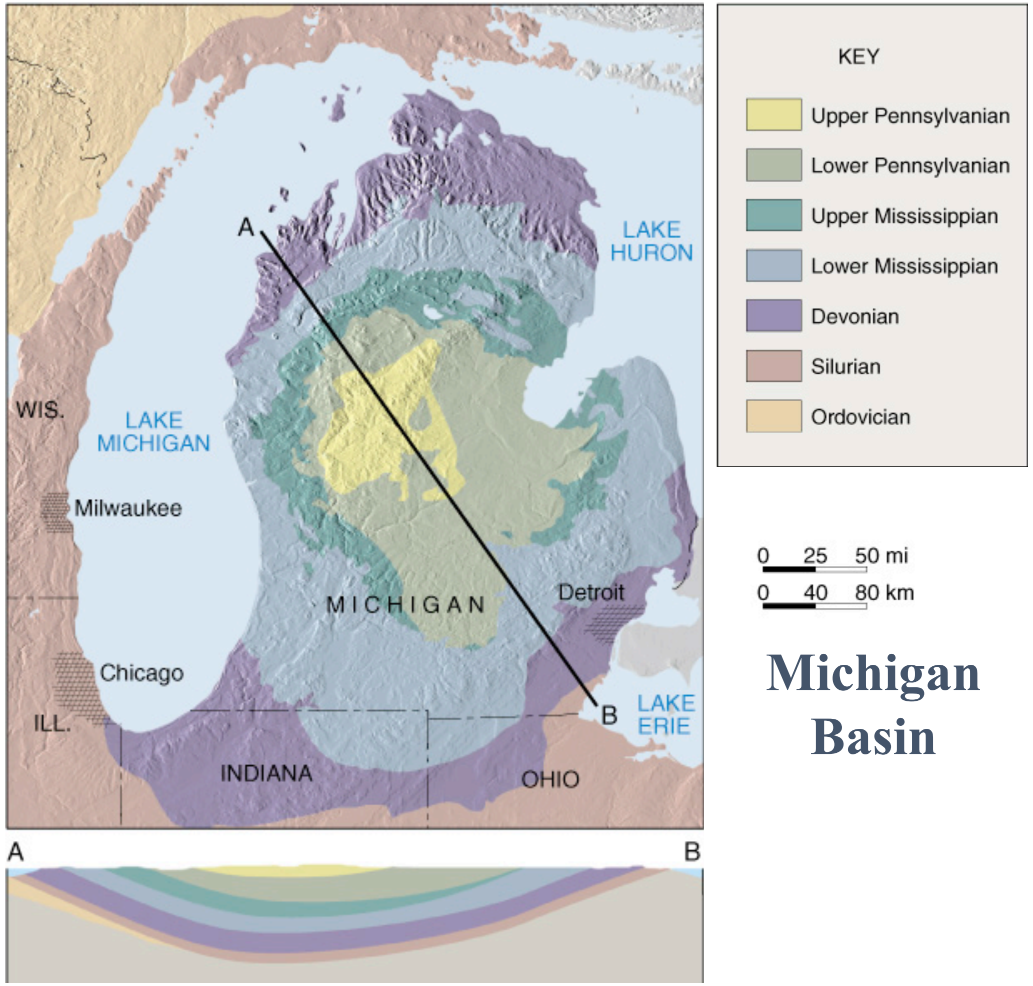
The Black Hills of South Dakota Are a Good Example of a Dome

- **Other types of folds**
  - **Basin**
    - **Circular or slightly elongated structure**
    - **Downwarped displacement of rocks**
    - **Youngest rocks are found near the center, oldest rocks on the flanks**

A Basin Exhibits a Circular Outcrop Pattern with the Youngest Rocks in the Center



B. Basin



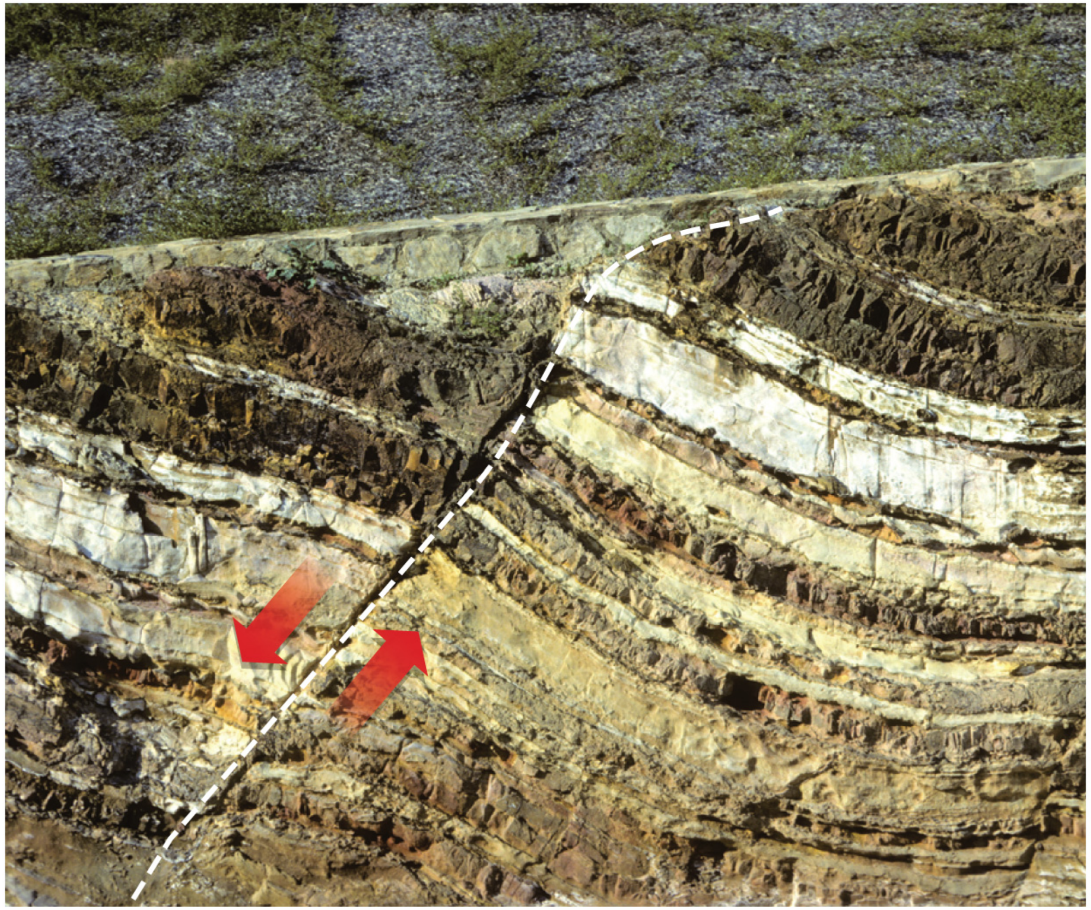
Michigan Basin

Fractures

- ***Most common Brittle response to stress***
- ***With displacement or slip = Fault***
- ***Without displacement or slip=Joint***

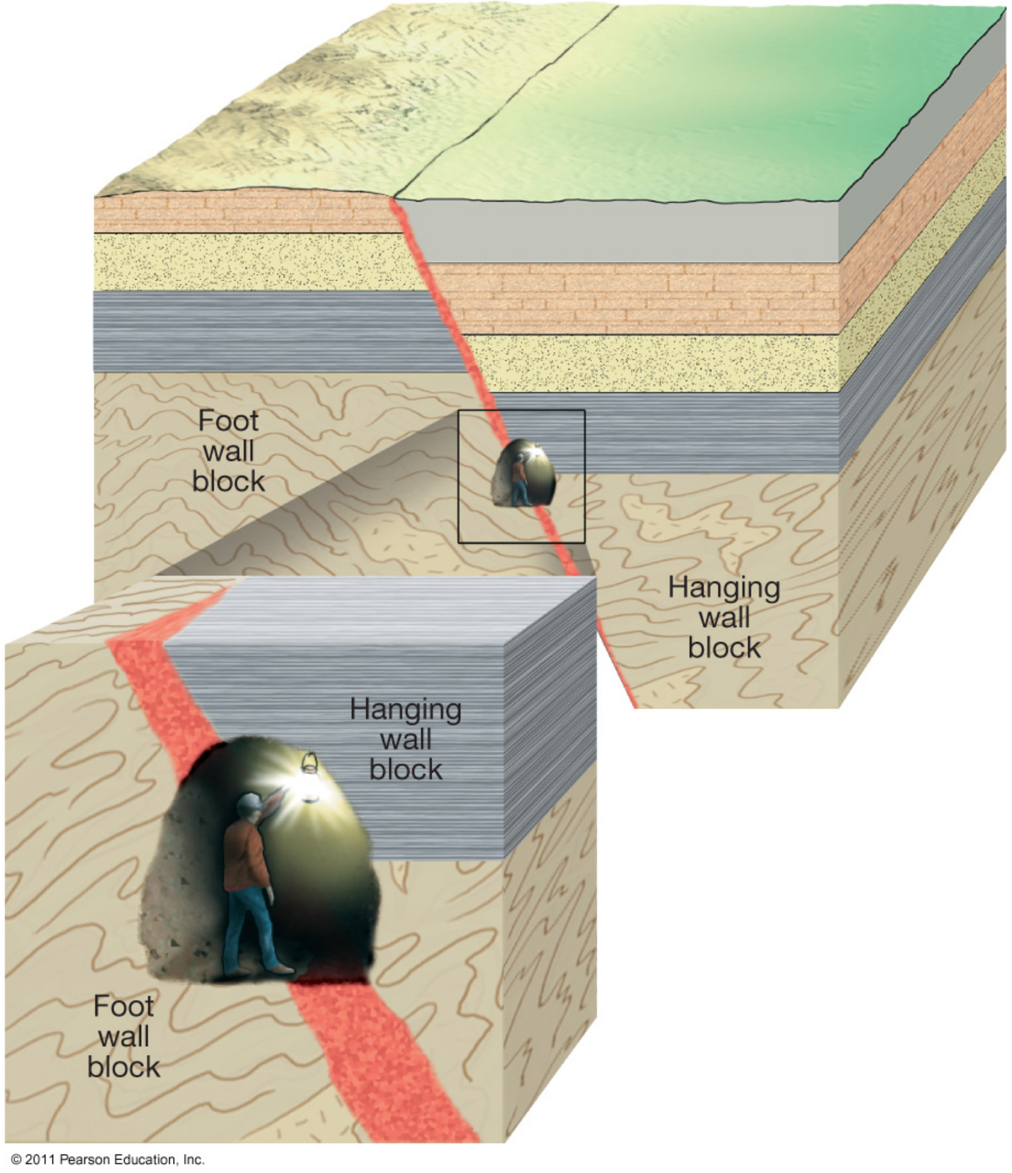
Faults

- **Faults are fractures in rocks along which appreciable displacement has taken place.**
- **Sudden movements along faults are the cause of most earthquakes.**
- **Classified by their relative movement, which can be horizontal, vertical, or oblique.**



Faults

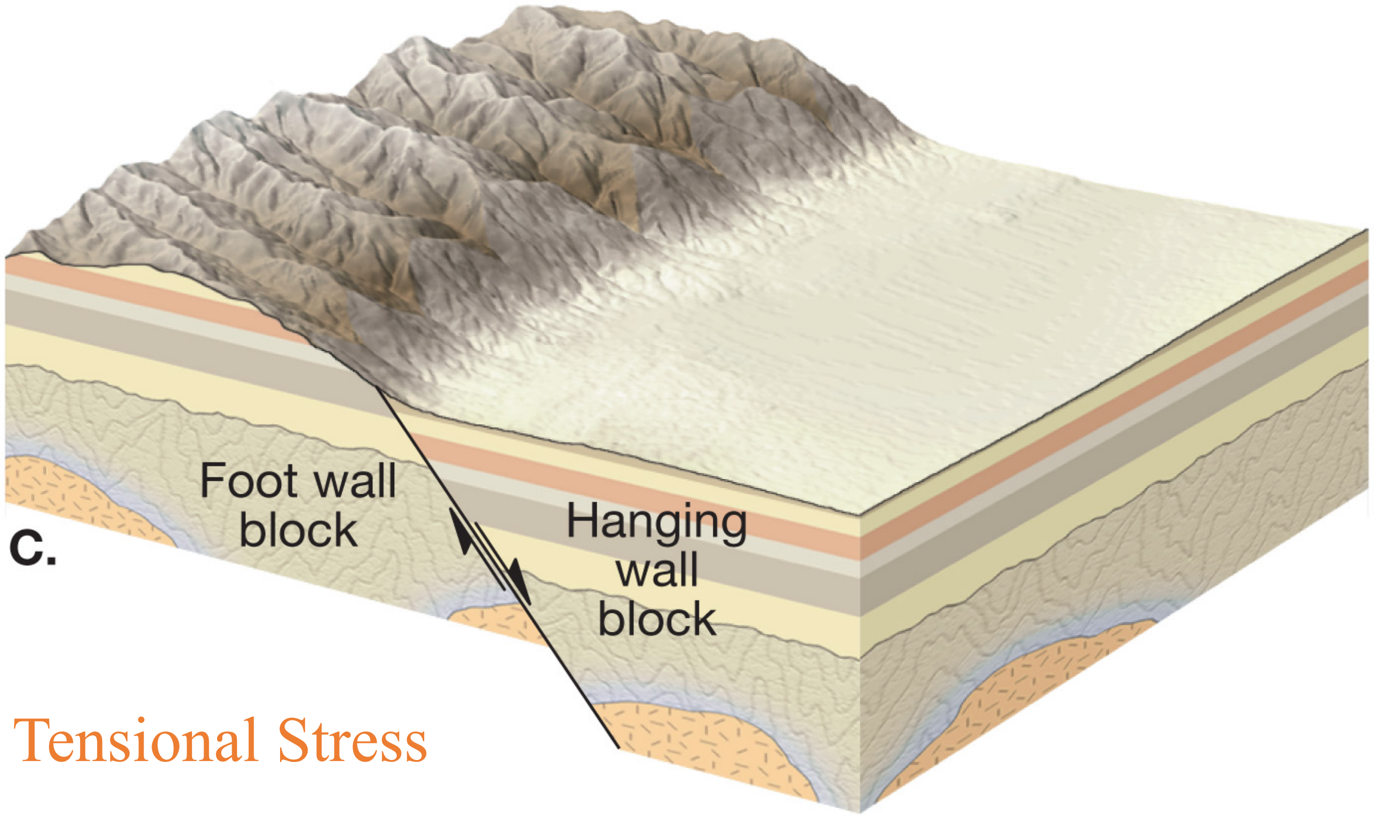
- **Types of faults**
    - **1. Dip-slip faults**
        - **Movement is mainly parallel to the dip (inclination) of the fault surface**
        - **Parts of a dip-slip fault include the hanging wall (rock surface above the fault) and the footwall (rock surface below the fault)**



Hanging Wall and Footwall Along a Dip-Slip Fault Surface

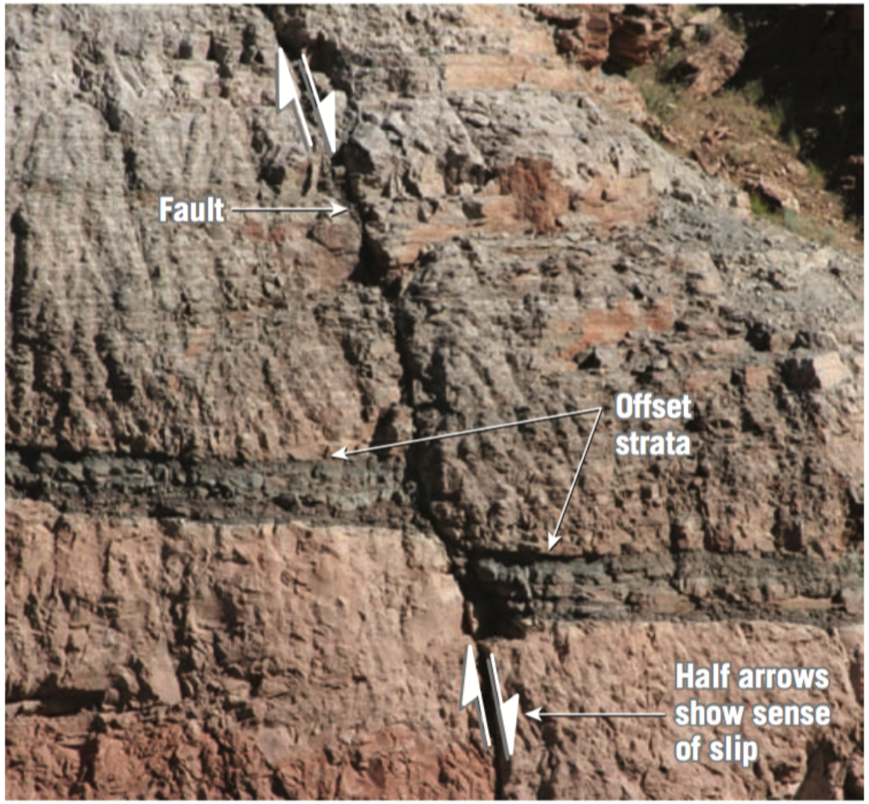
Dip-Slip Faults

- **Types of dip-slip faults**
  - **a) Normal faults**
    - **The hanging wall moves down relative to the footwall.**
    - ***Accommodate lengthening or extension of the crust***
    - **Most are small with displacements of 1 meter or so.**

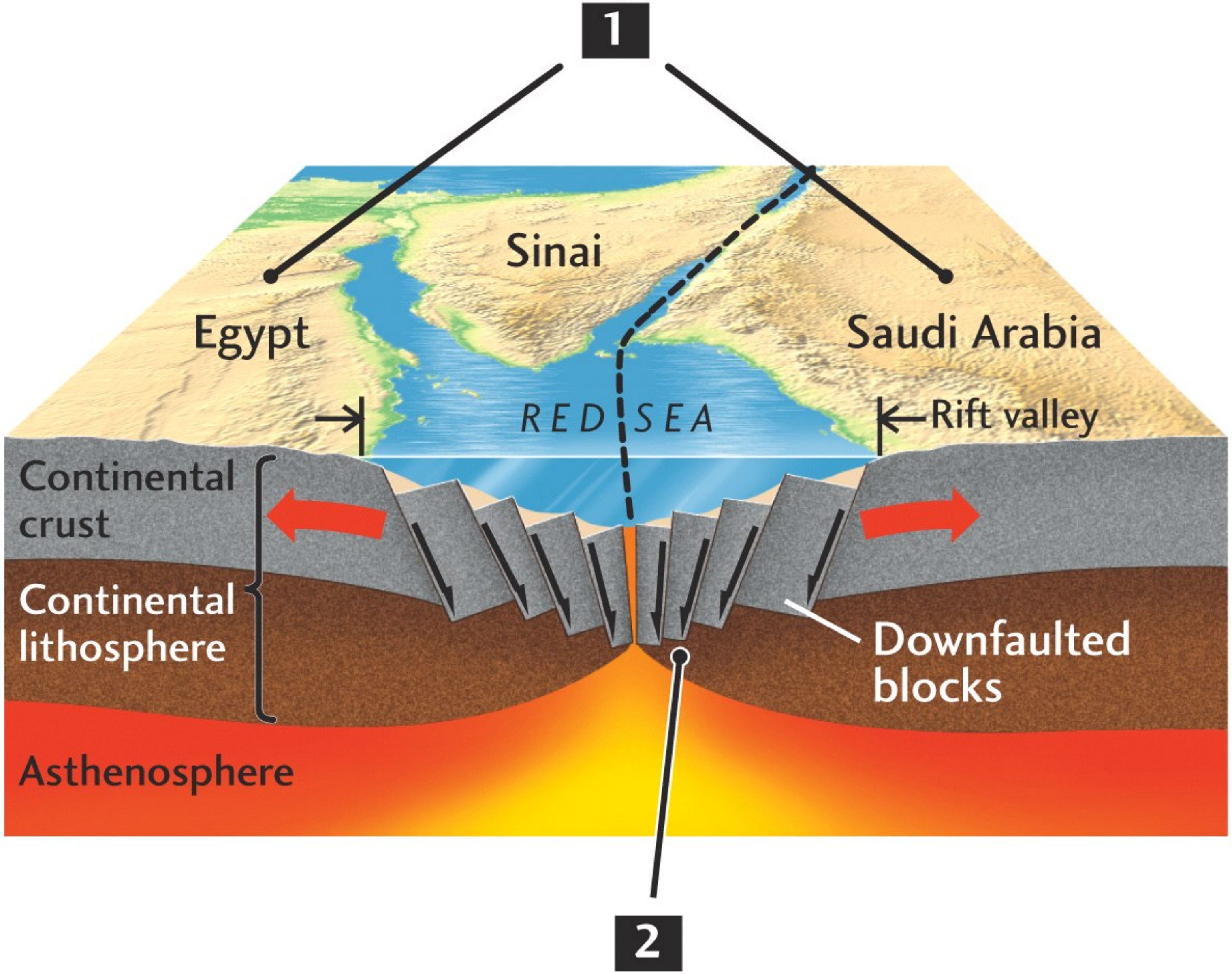


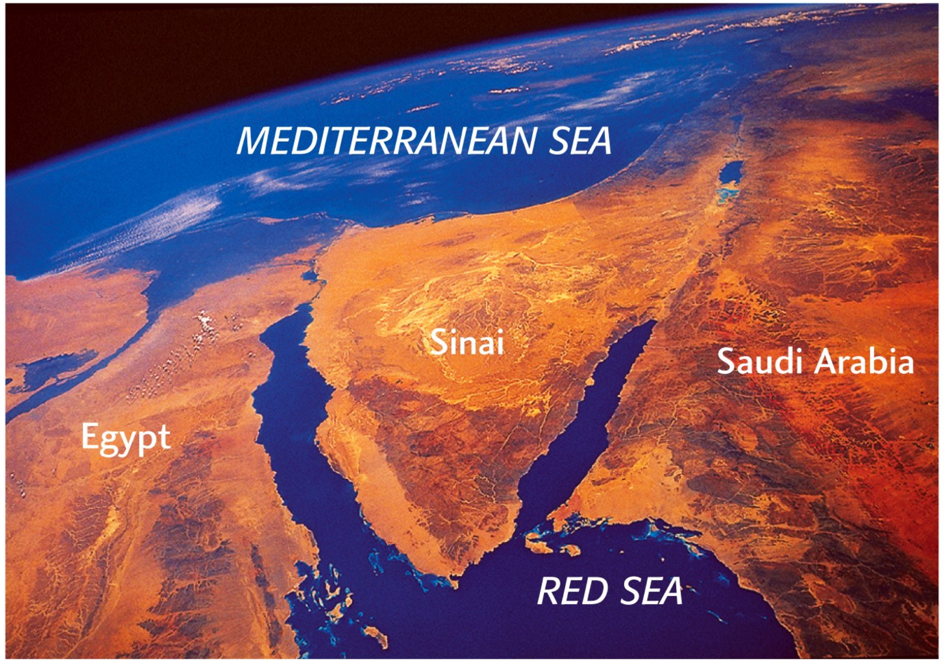
Tensional Stress

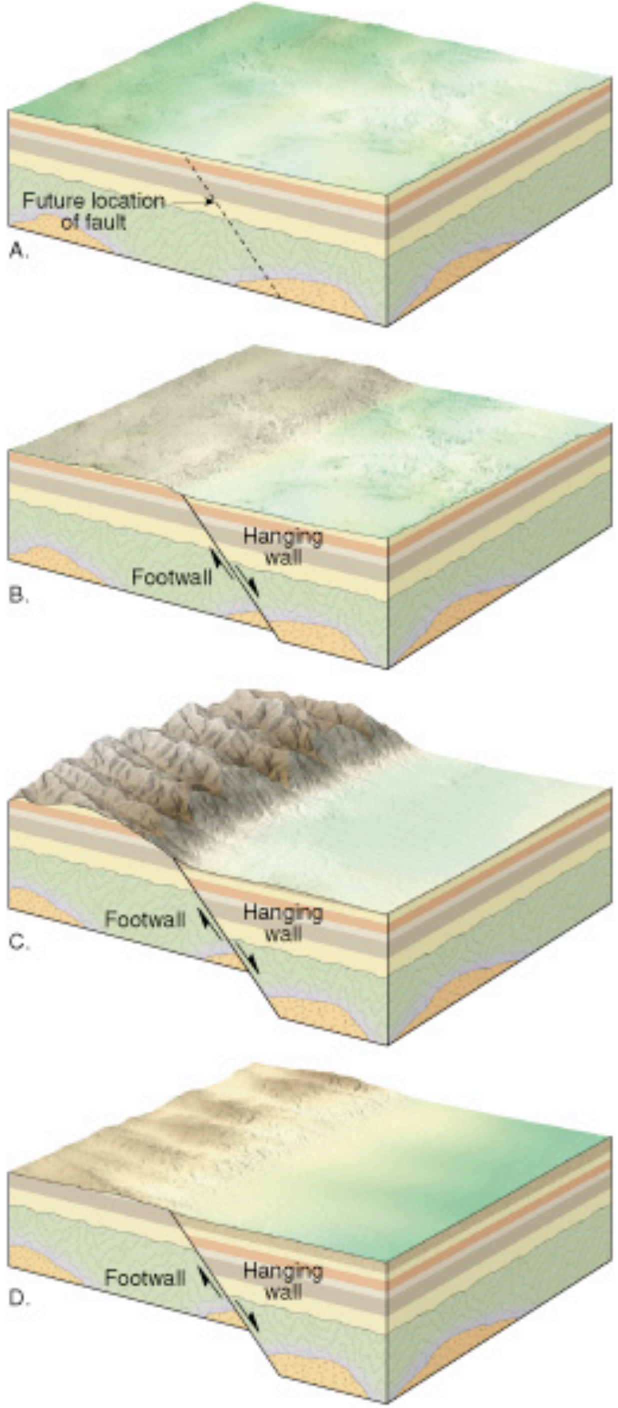
"Normal" Dip-Slip Fault (Hanging Wall Moves Down)



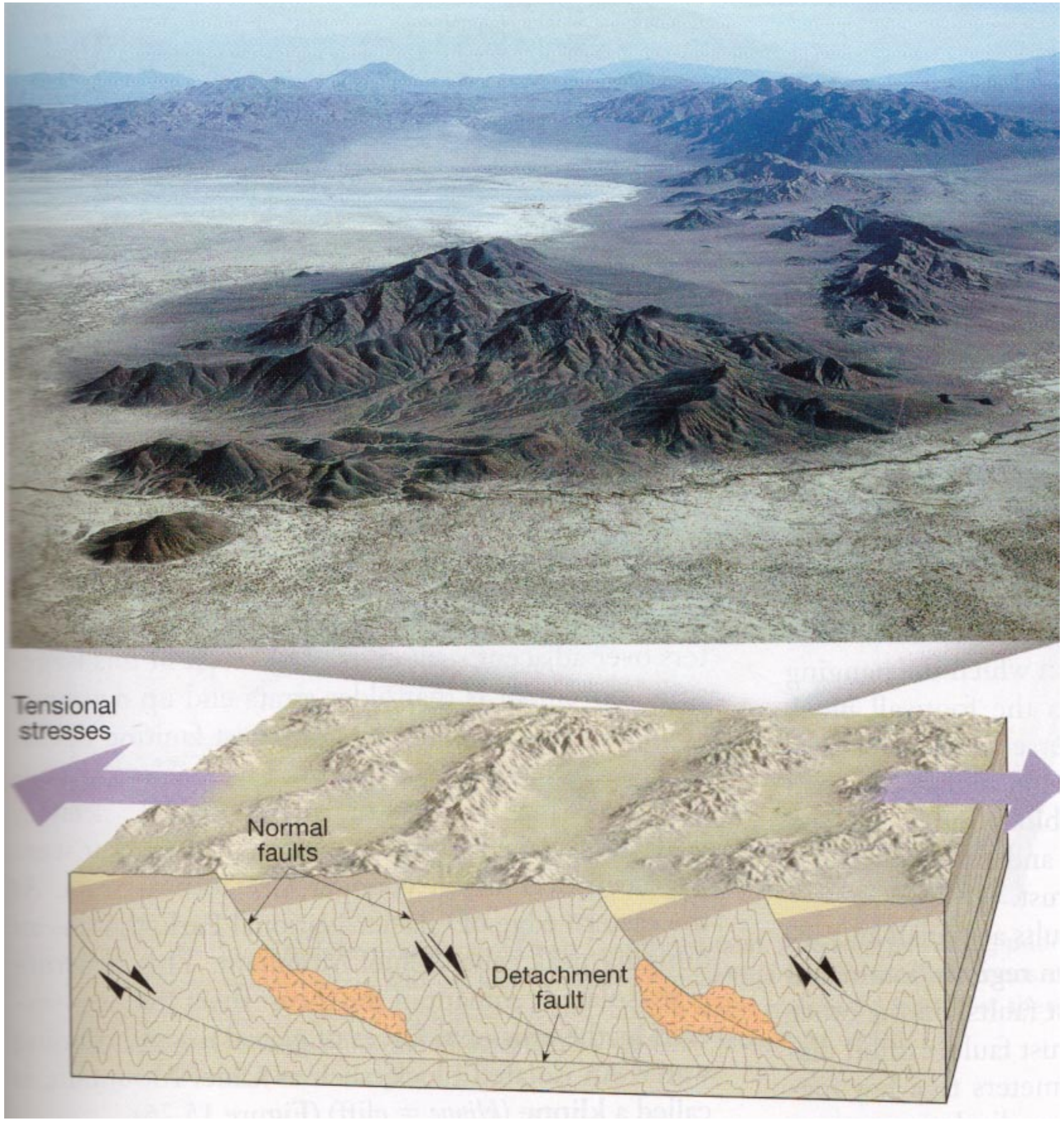
Example


1
Sinai
Egypt
Saudi Arabia
RED SEA
Rift valley
Continental crust
Continental lithosphere
Asthenosphere
Downfaulted blocks
2


MEDITERRANEAN SEA
Sinai
Saudi Arabia
Egypt
RED SEA



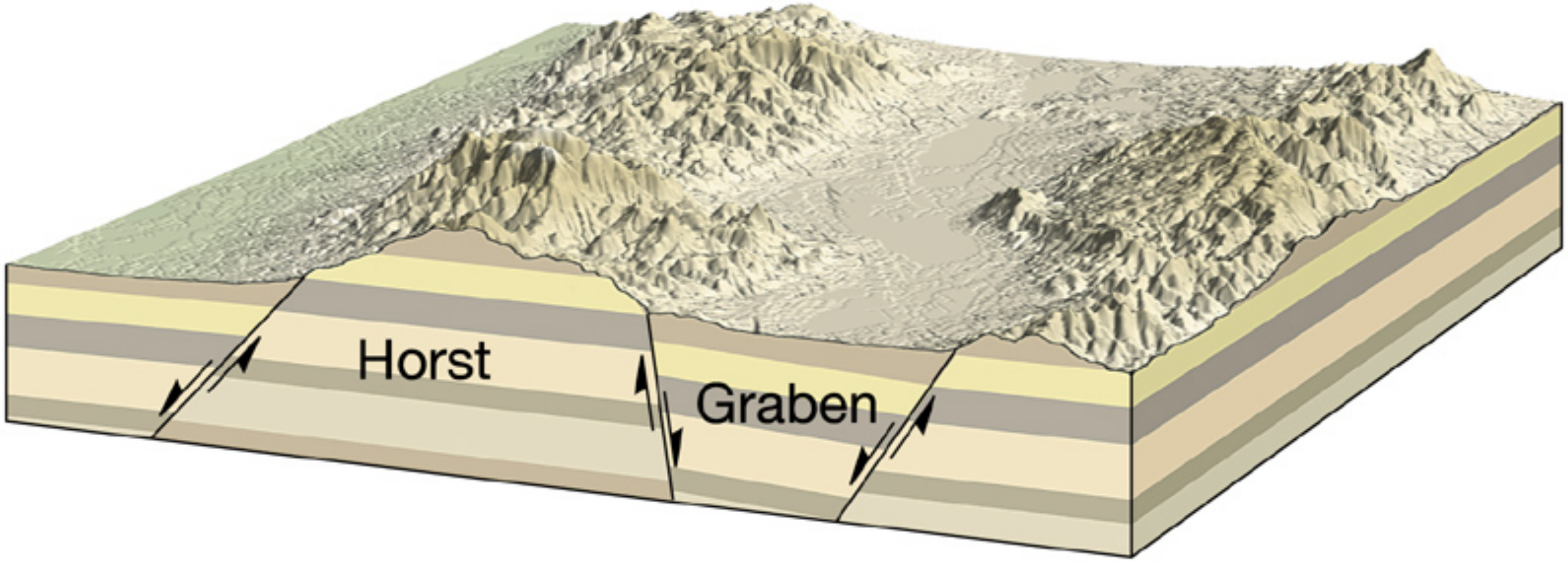
Block Diagrams Illustrating the Movement on a Normal Dip-Slip Fault. Subsequent Erosion Can Often Produce Mountains on the Upthrown Side of a Normal Fault



At brittle-ductile transitions

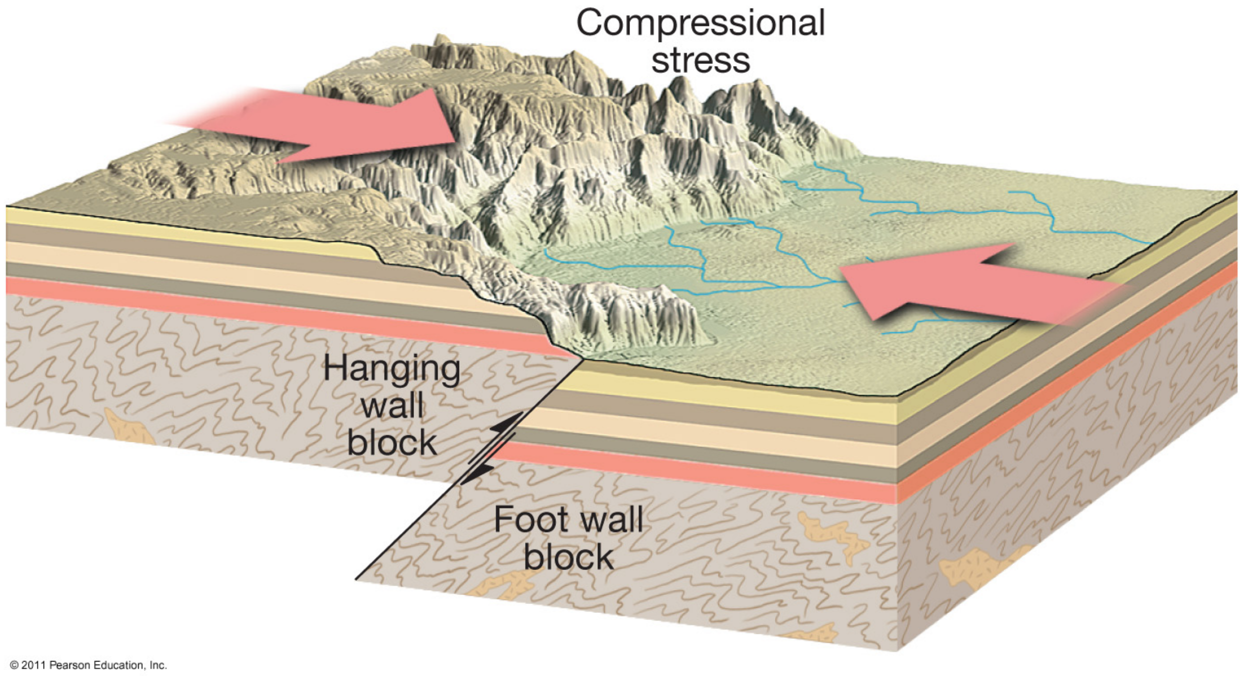
Typical "Block Faulting" (Normal Faulting) Creates the Basin and Range Topography in Parts of the Western United States

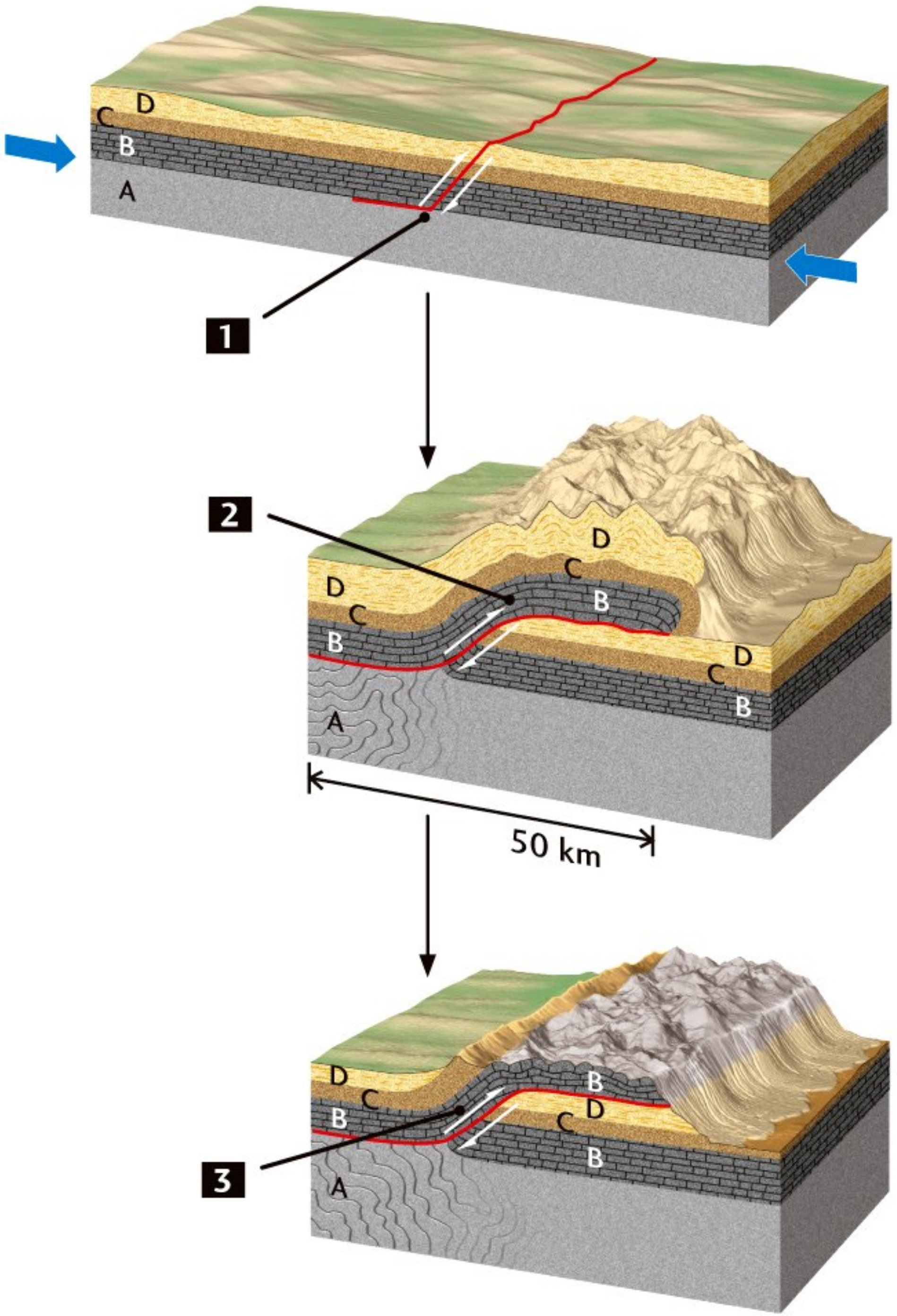
Most Block Faulted Mountains in the Basin & Range Are Actually Horsts and Grabens. The Mountains Are Faulted on Both Sides and Moved "Up" Relative to the Intervening Valleys



Dip-Slip Faults

- **Types of dip-slip faults**
  - **b) Reverse and thrust faults**
    - **The hanging wall block moves up relative to the footwall block.**
    - **Reverse faults have dips greater than 45 degrees and thrust faults have dips less then 45 degrees.**
    - ***Accommodate shortening of the crust***
    - **Strong compressional forces**
    - **Thrust faults are most pronounced along convergent plate boundaries**

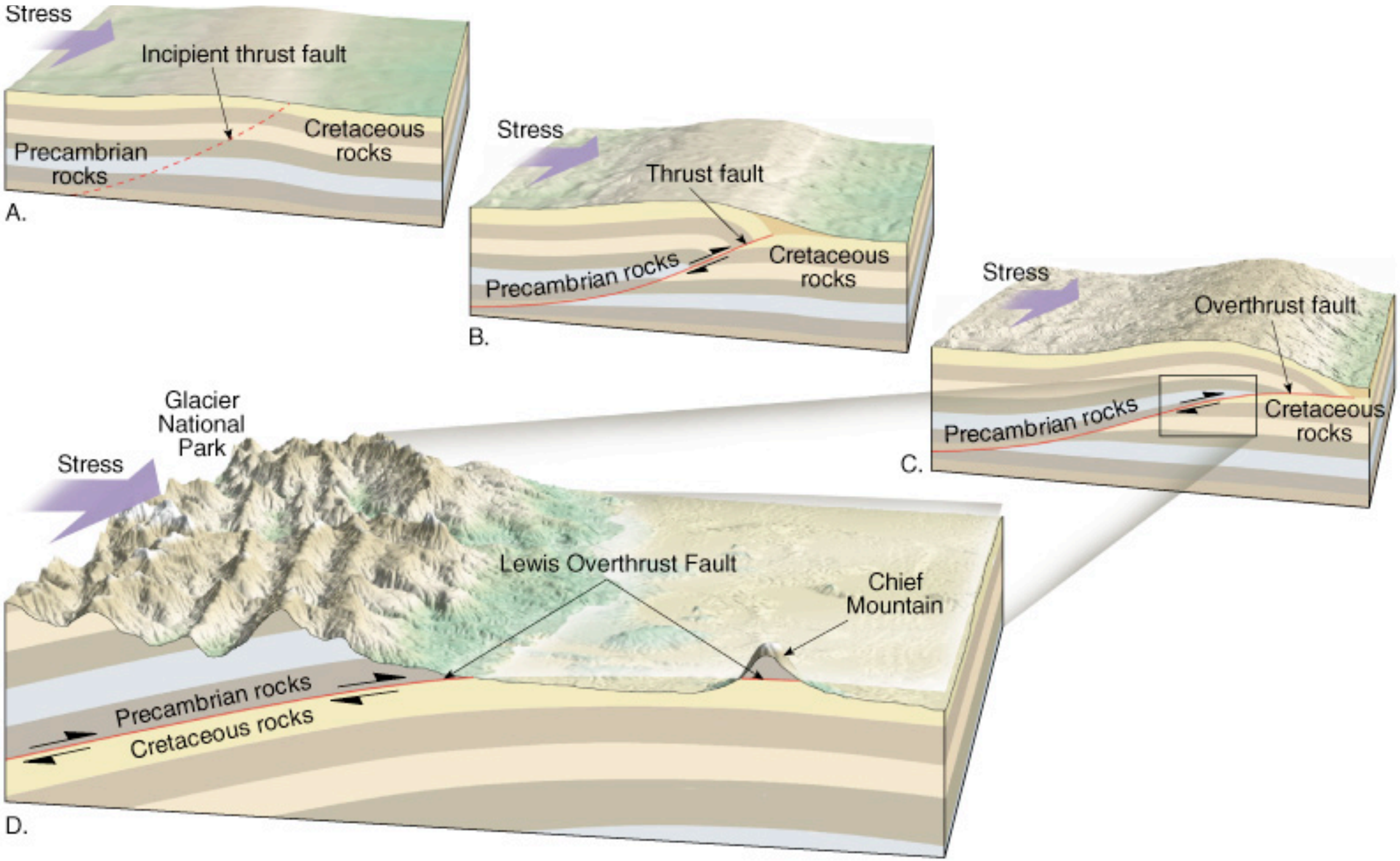




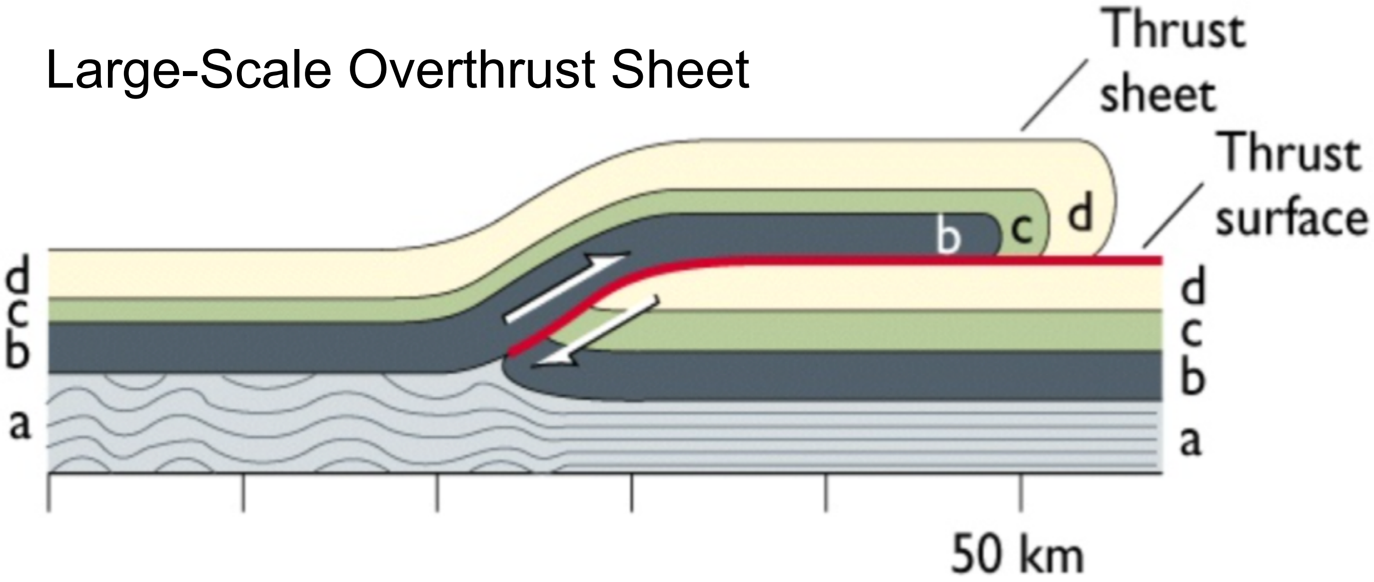
Direction of view in photo

Keystone thrust fault, southern Nevada

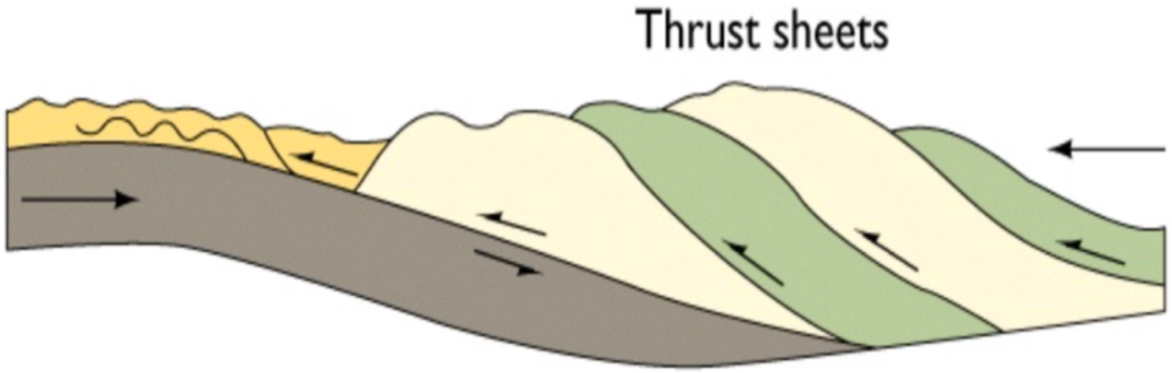
Example : Development of Thrust Faults in Glacier National Park



Large-Scale Overthrust Sheet



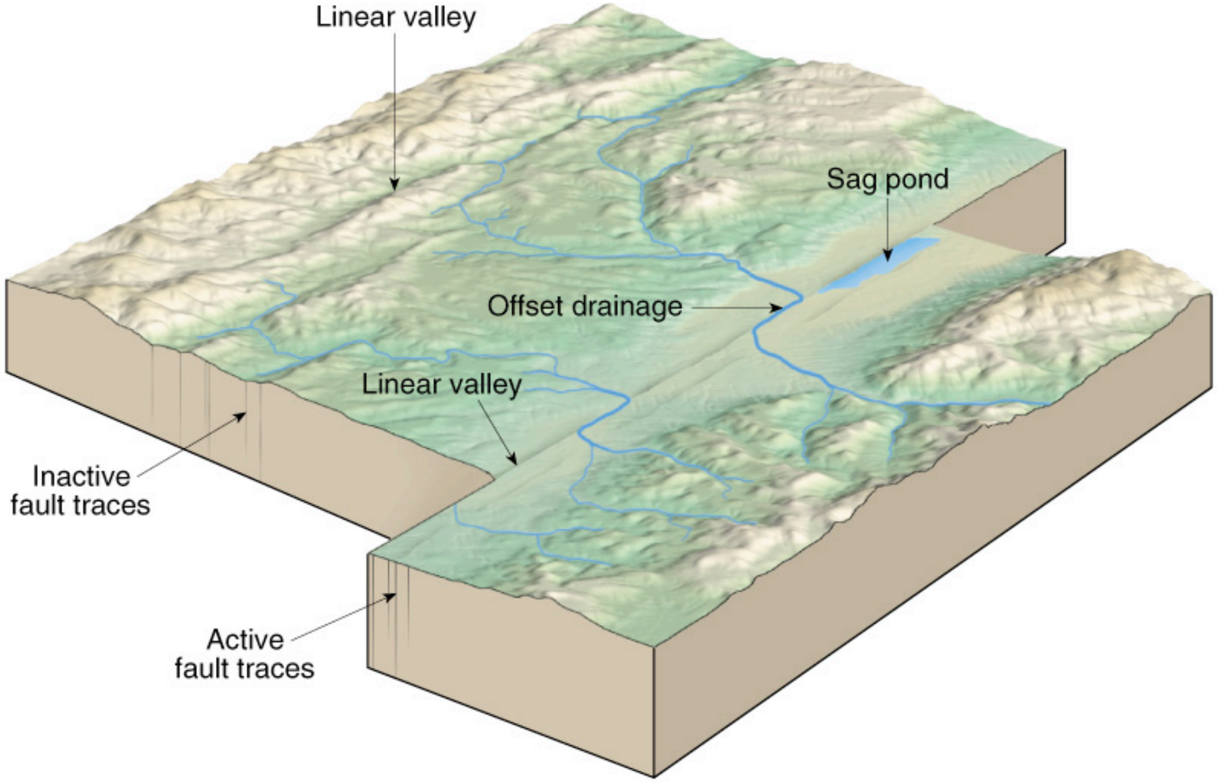
Stacked Sheets of Continental Crust Due to Convergence of Continental plates



(e) Thrust

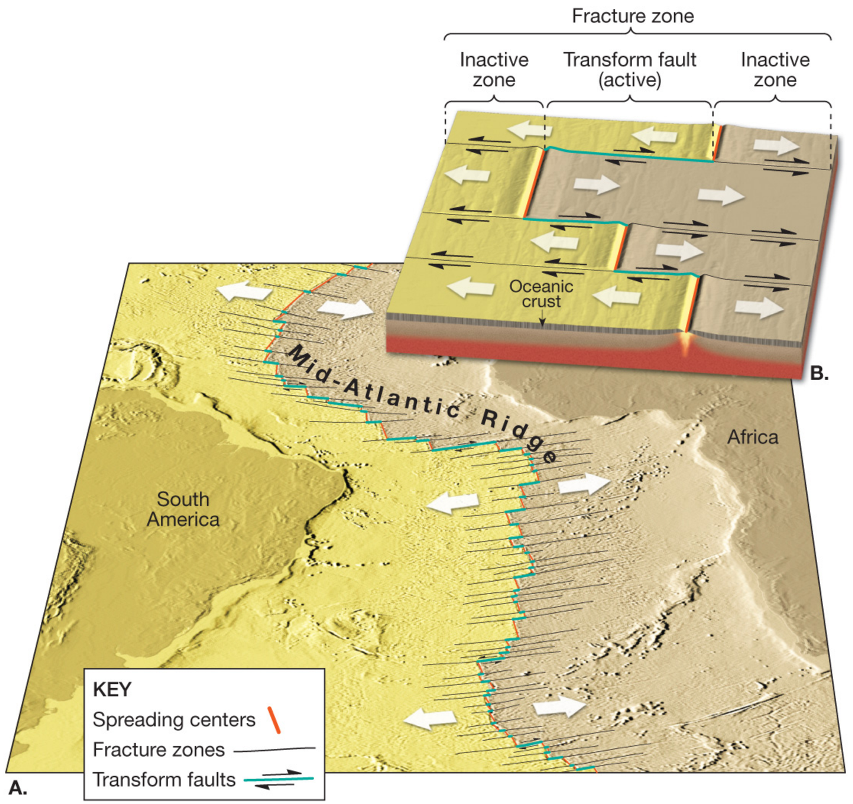
Overlapping Thrust Faults, Himalaya

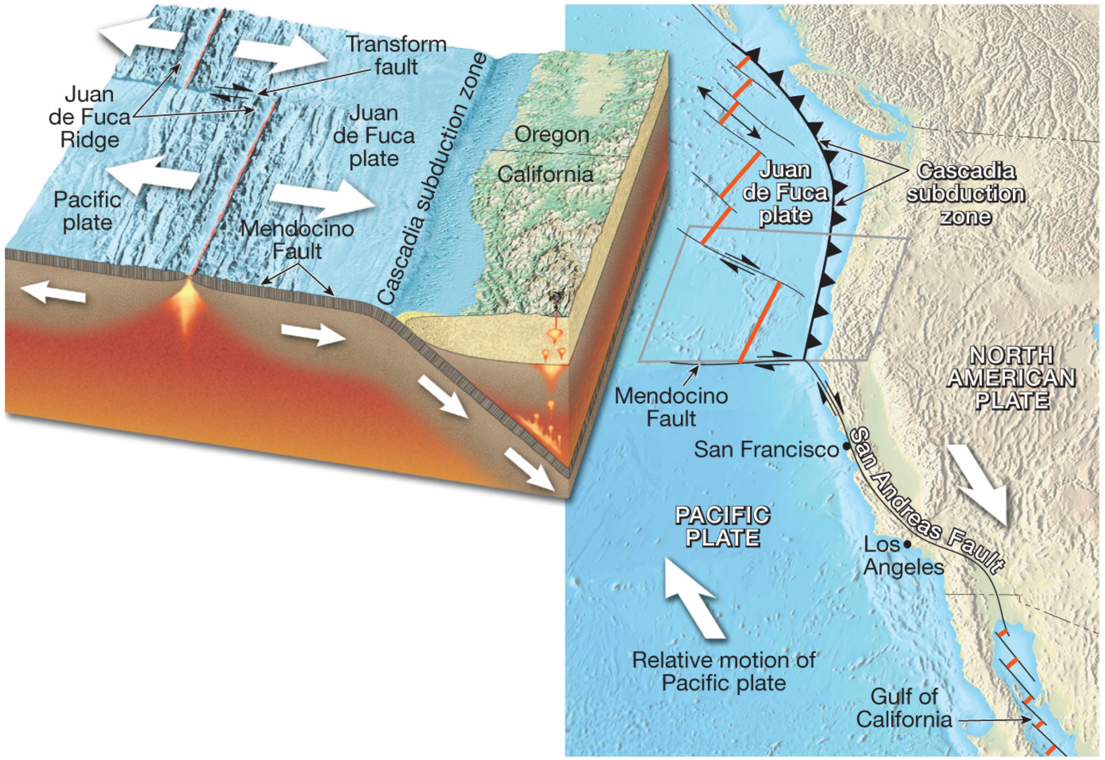
- Strike-slip fault
  - Dominant displacement is horizontal and parallel to the strike of the fault
  - Types of strike-slip faults
    - Right-lateral – as you face the fault, the block on the opposite side of the fault moves to the right
    - Left-lateral – as you face the fault, the block on the opposite side of the fault moves to the left



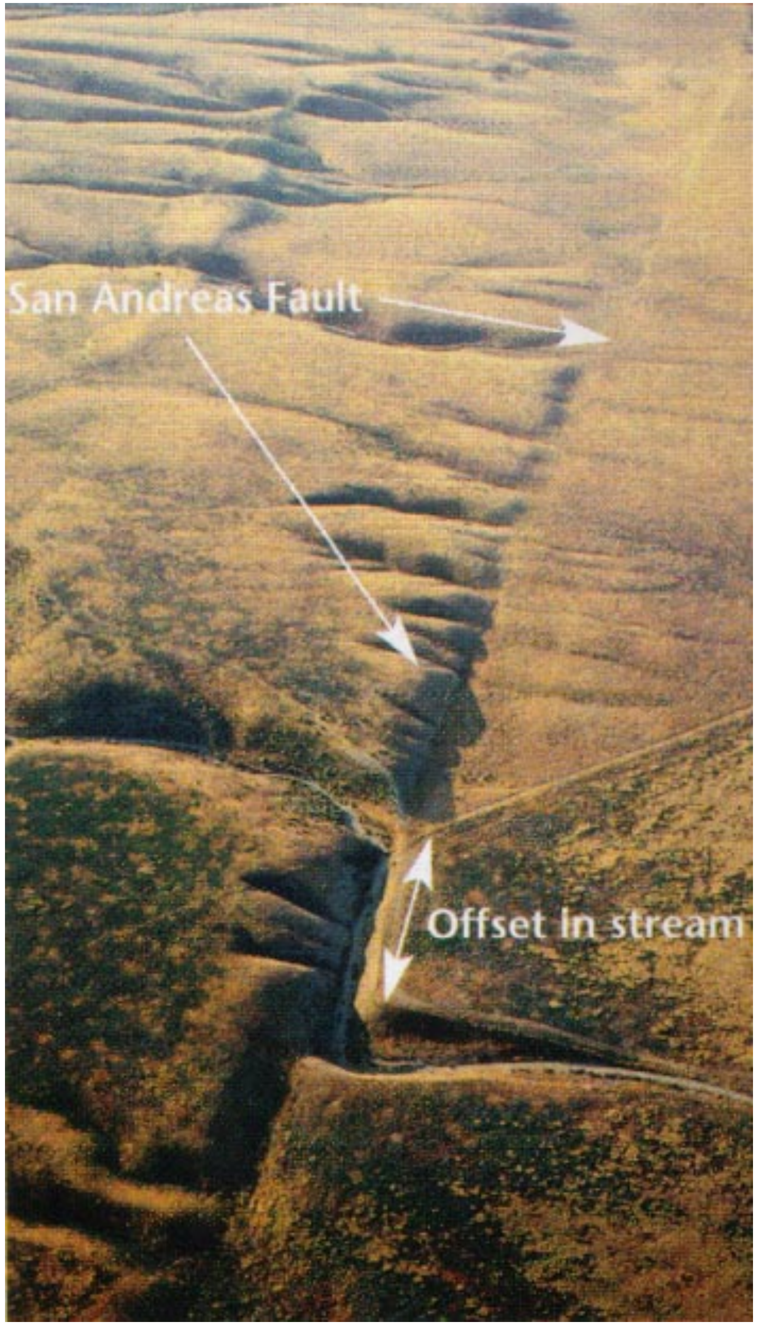
Aerial View of a Right Lateral Strike-Slip Fault in Nevada

- **Strike-slip faults**
  - **Transform faults**
    - **Large strike-slip faults that cut through the lithosphere**
    - **Accommodate motion between two large crustal plates**
    - **Many cut the oceanic lithosphere and link spreading ridges**
    - **Others accommodate displacement between continental plates that move horizontally with respect to each other**





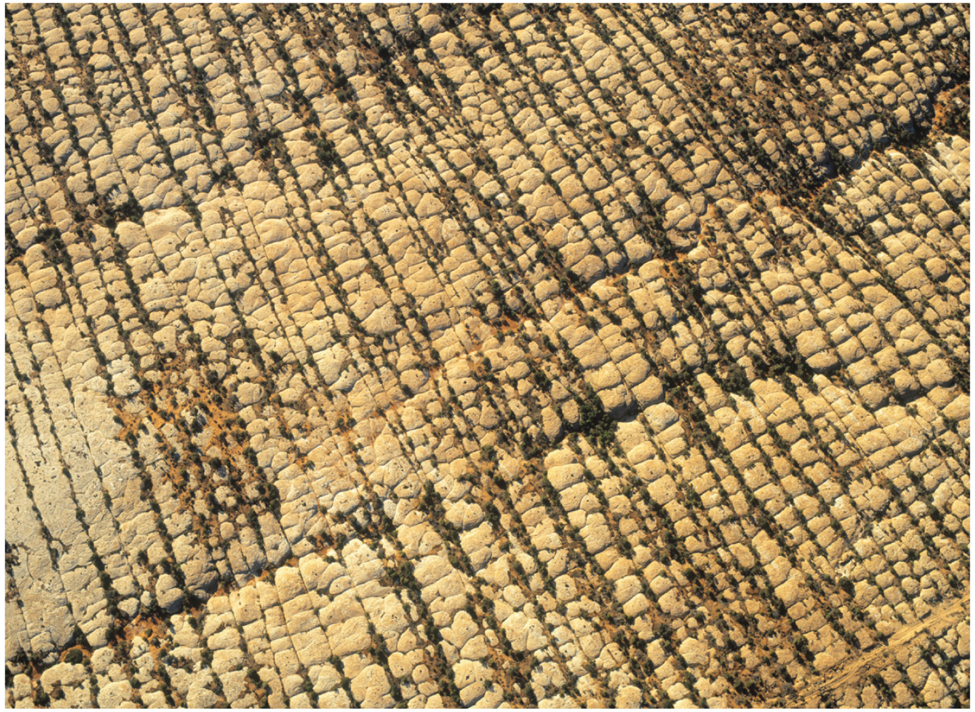
The San Andreas Fault System



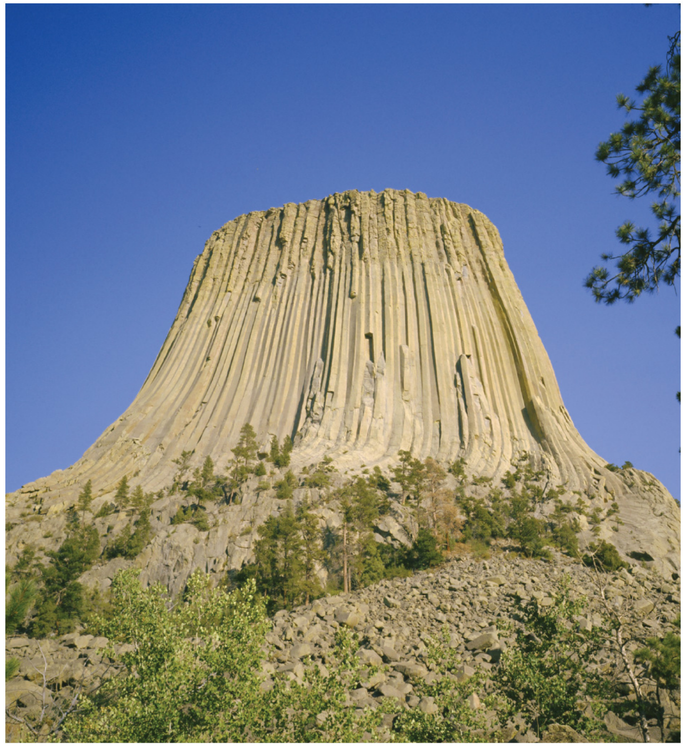
Aerial View of Offset Along the San Andreas Fault

Joints

- **A joint is a fracture with no appreciable displacement**
- **When tectonic forces cause upwarping of the crust, rocks near the surface are stretched and pulled apart to form fractures**
- **Due to cooling of volcanic rocks**
- **Most occur in roughly parallel groups**
- **Chemical weathering tends to be concentrated along joints**



Arches Natl. Park, UT



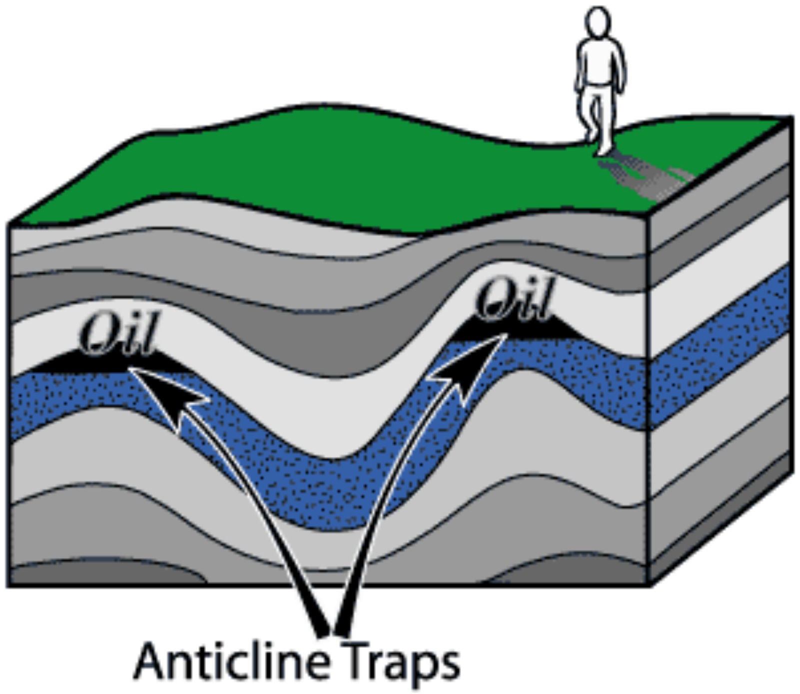
Devil's Tower, WY

Columnar Jointing in Basalt, Giants Causeway, Ireland

Petroleum Exploration

- Significance of folds/faults/joints
    - Folds and faults are good petroleum reservoirs
    - Many economically important mineral deposits are emplaced along joint systems (important for Cu, Ag, Au, Zn, Pb, and U).
    - Chemical weathering tends to be concentrated along joints.

Structural traps are primarily the result of folding and (or) faulting, or both.



A cross section of the Earth showing typical Anticline Traps. Reseroir rock that isn't completely filled with oil also contains large amounts of salt water.