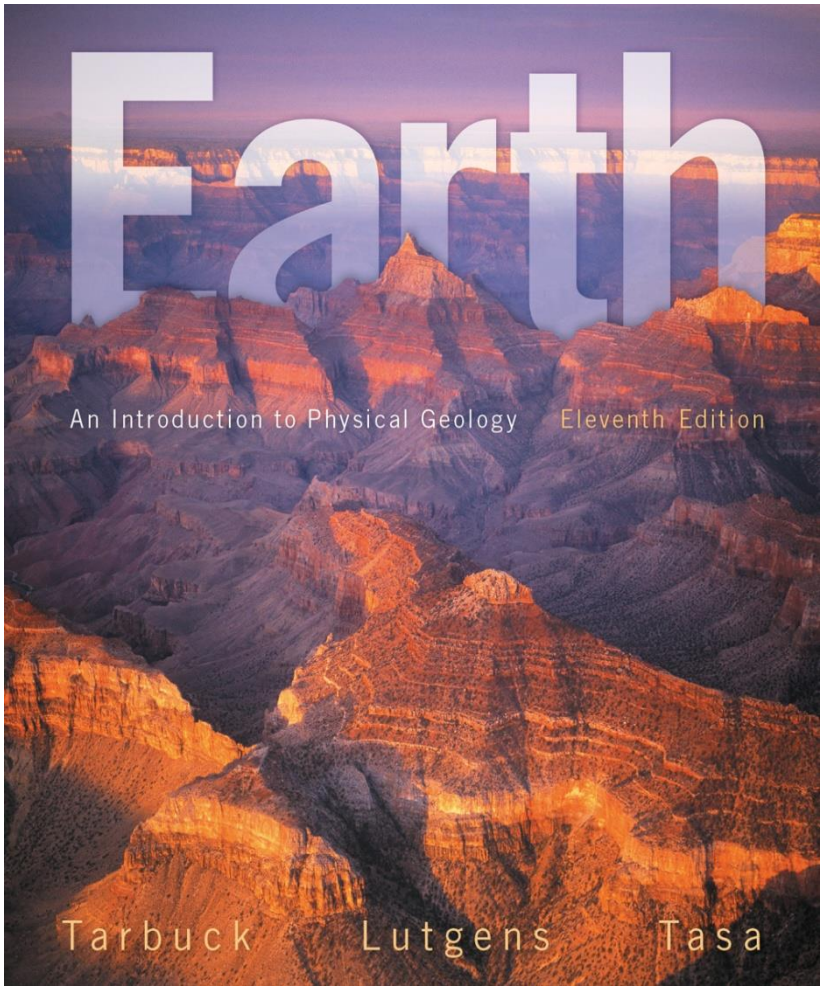
Earth: An Introduction to Physical Geology

Eleventh Edition



Crustal Deformation

Tarbuck and Lutgens

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What Causes Rock to Deform?

- Deformation is a general term that refers to all changes in the shape or position of a rock body in response to stress
- Rock or geologic structures are the features that result from forces generated by the interactions of tectonic plates
  - Includes folds, faults, and joints

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What Causes Rock to Deform?

- Stress: The Force That Deforms Rocks
  - Stress is the force that deforms rocks
    - When stresses acting on a rock exceed its strength, the rock will deform by flowing, folding, fracturing, or faulting
    - The magnitude is a function of the amount of force applied to a given area

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What Causes Rock to Deform?

- Stress: The Force That Deforms Rocks
  - Stress applied uniformly in all directions is confining pressure
  - Stress applied unequally in different directions is called differential stress

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What Causes Rock to Deform?

- Stress: The Force That Deforms Rocks
  - Types of stress
    - Compressional stress squeezes a rock and shortens a rock body
    - Tensional stress pulls apart a rock unit and lengthens it
    - Shear stress produces a motion similar to slippage that occurs between individual playing cards when the top of the stack is moved relative to the bottom

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What Causes Rock to Deform?

- Strain: A Change in Shape Caused by Stress
  - Strain is the change in shape of a rock caused by differential stress
  - Strained bodies lose their original configuration during deformation

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Deformed Trilobite

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How Do Rocks Deform?

- Elastic, Brittle, and Ductile Deformation
  - Elastic deformation: The rock returns to nearly its original size and shape when the stress is removed
  - Once the elastic limit (strength) of a rock is surpassed, it either bends (ductile deformation) or breaks (brittle deformation)

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Rocks Exhibiting Ductile Deformation

These rocks were deformed at great depth and were subsequently exposed at the surface. Vishnu Schist, Grand Canyon National Park, Arizona.

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How Do Rocks Deform?

- Factors That Affect Rock Strength
  - Temperature: Higher temperature rocks deform by ductile deformation whereas cooler rocks deform by brittle deformation
  - Confining pressure: Confining pressure squeezes rocks, making them stronger and harder to break

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How Do Rocks Deform?

- Factors That Affect Rock Strength
  - Rock type: Crystalline igneous rocks generally experience brittle deformation, whereas sedimentary and metamorphic rocks with zones of weakness generally experience ductile deformation
  - Time: Forces applied over a long period of time generally result in ductile deformation

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How Do Rocks Deform?

- Ductile Versus Brittle Deformation and the Resulting Rock Structures
  - Most rocks exhibit brittle behavior in the upper 10 kilometers of the crust
    - Joints are cracks in the rocks resulting from the rock being stretched and pulled apart
    - Faults are fractures in the rocks where rocks on one side of the fault are displaced relative to the rocks on the other side of the fault

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How Do Rocks Deform?

- Ductile Versus Brittle Deformation and the Resulting Rock Structures
  - Folds are evidence that rocks can bend without breaking
    - Usually the result of deformation in high-temperature and pressure environments

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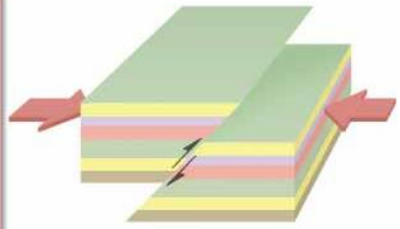
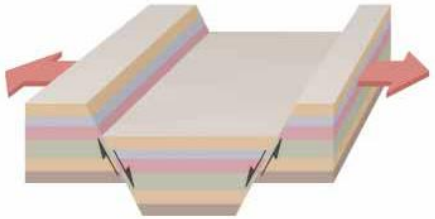
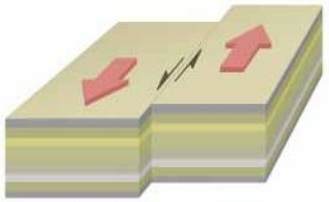
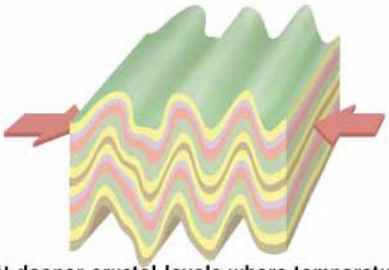
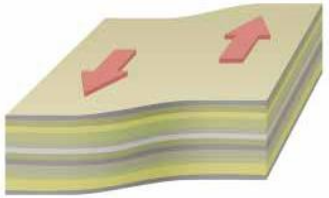
Deformation Caused by Three Types of Stress

How Rocks Respond to Differential Stress

Type of stress	COMPRESSION (Compression causes shortening)	TENSION (Tension causes stretching)	SHEAR (Shear distorts rock)
At shallow depths rocks exhibit brittle fracture	 At shallow depths shortening occurs by brittle deformation along faults where one rock mass is thrust over another.	 At shallow depths tensional stresses cause rocks to fracture and pull apart.	 At shallow depths shear stress causes offsets in crustal blocks along faults.
At deeper crustal depths rocks deform by ductile flow	 At deeper crustal levels where temperatures are high, compressional forces squeeze and fold rock masses.	 At deeper crustal levels where temperatures are high, tensional forces stretch and elongate crustal materials by ductile flow.	 At deeper crustal levels where temperatures are high, shear stress distorts rock masses by ductile flow, usually along shear zones.

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Folds: Rock Structures Formed by Ductile Deformation

- During crustal deformation, rocks are often bent into a series of wave like undulations called folds
- Characteristics of folds
  - Most folds result from compressional stresses that result in a shortening and thickening of the crust

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Folds: Rock Structures Formed by Ductile Deformation

- Anticline and Synclines
  - Anticlines are upfolded or arched sedimentary layers
    - Oldest strata are in the center
  - Synclines are downfolded or troughs of rock layers
    - Youngest strata are in the center

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Folds: Rock Structures Formed by Ductile Deformation

- Anticline and Synclines
  - Depending on their orientation, anticlines and synclines can be described as:
    - Symmetrical—the limbs of the fold are mirror images of each other
    - Asymmetrical—the limbs of the fold are not identical
      - Overturned (recumbent)—one or both limbs are tilted beyond vertical
      - Plunging—the axis of the fold penetrates the ground

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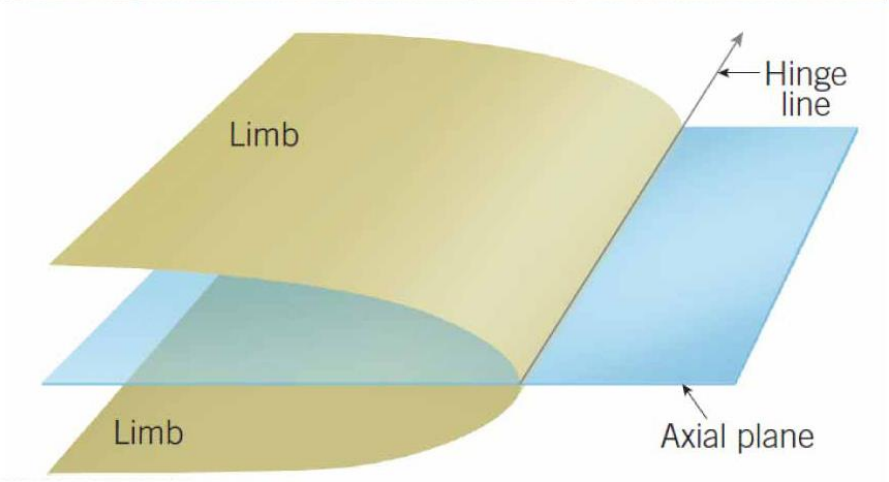
Common Types of Folds



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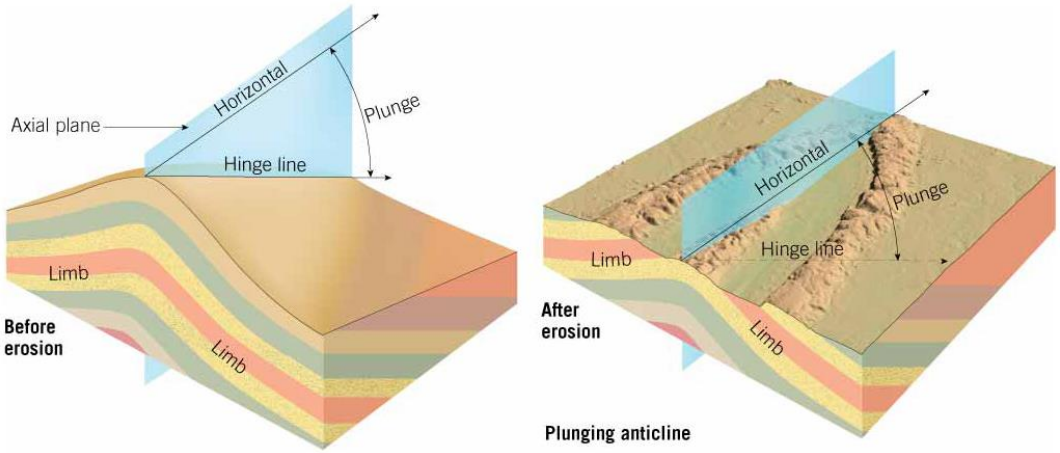
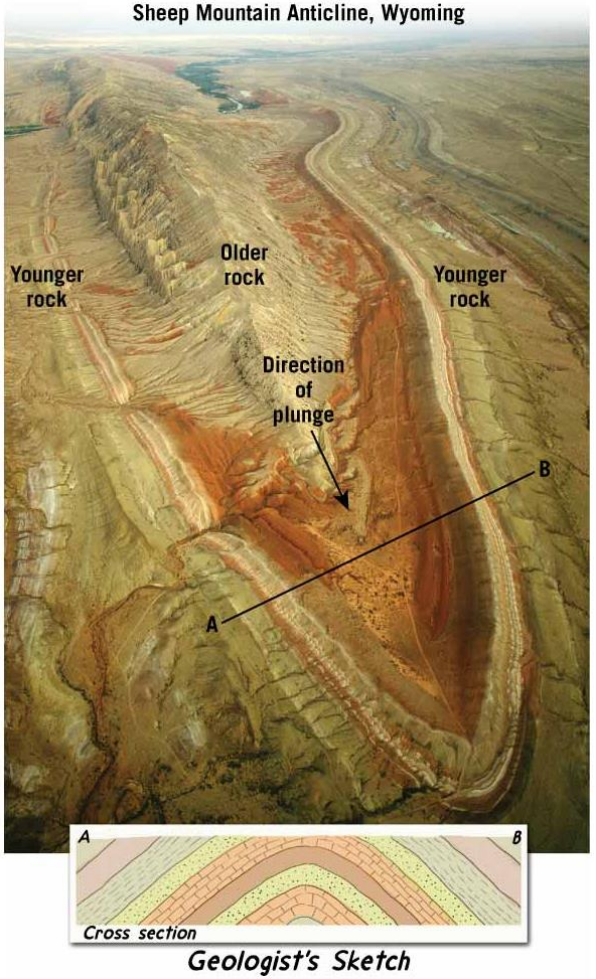
Plunging Anticline





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Folds: Rock Structures Formed by Ductile Deformation

- Domes and Basins
  - Domes are upwarped circular features
    - Oldest rocks are in the center
  - Basins are downwarped circular features
    - Youngest rocks are in the center

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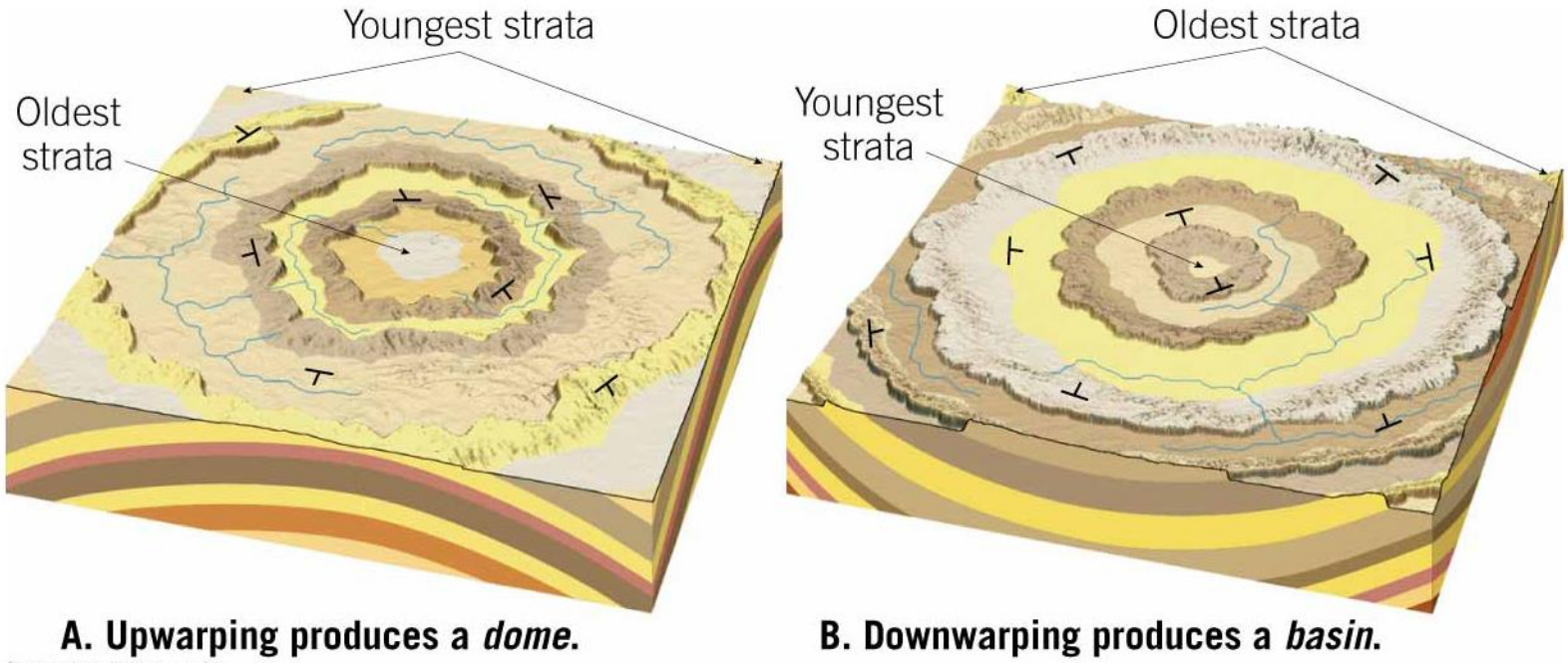
Domes Versus Basins



A. Upwarping produces a *dome*.

B. Downwarping produces a *basin*.

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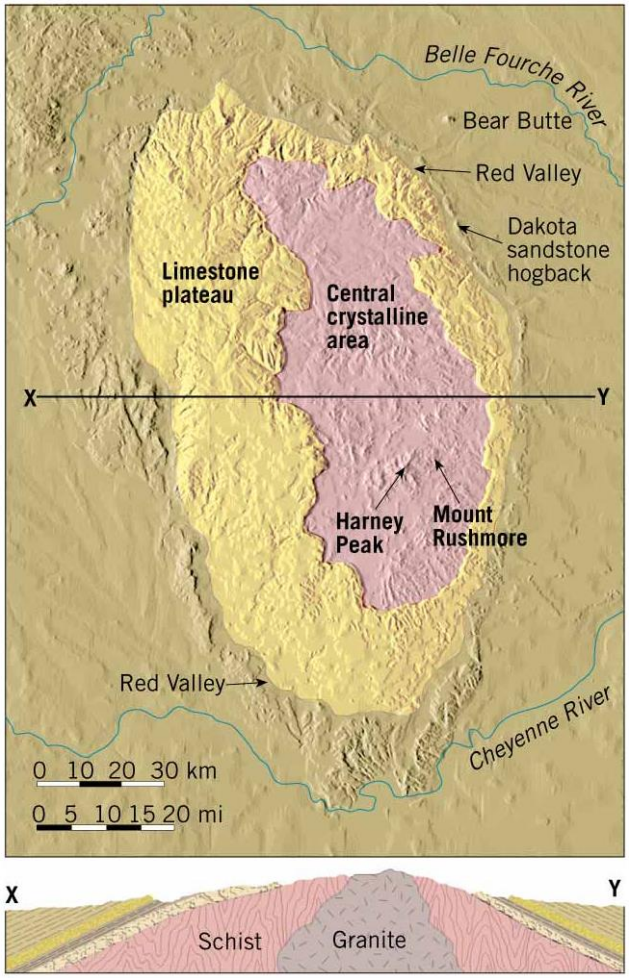
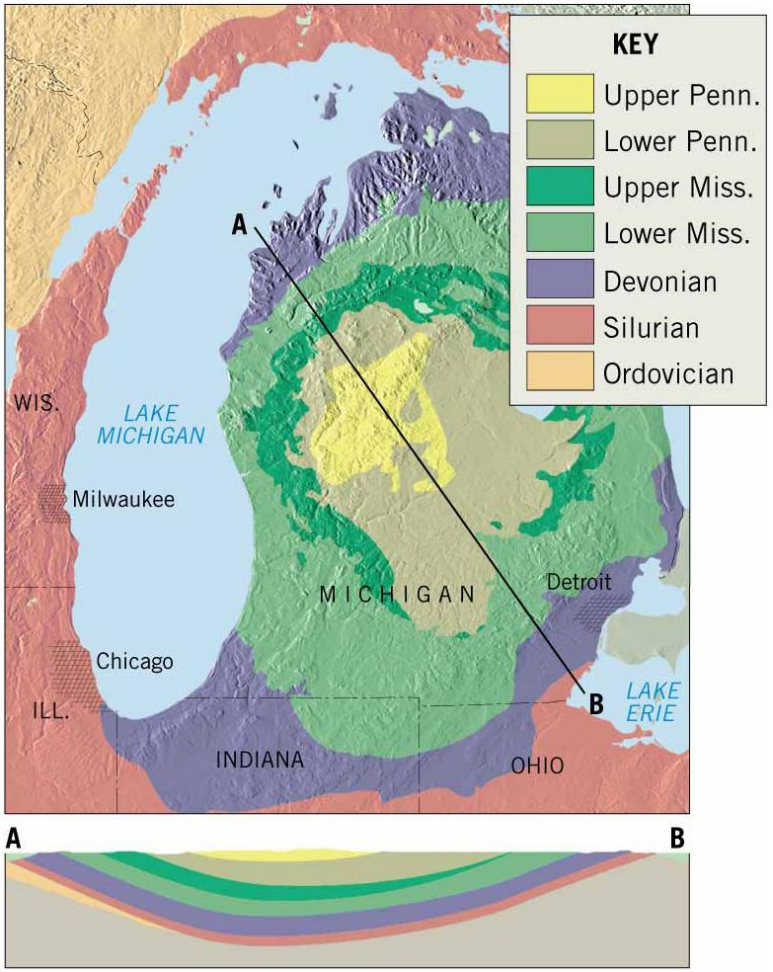
Domes Versus Basins





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Folds: Rock Structures Formed by Ductile Deformation

- Monoclines
  - Monoclines are large, steplike folds in otherwise horizontal sedimentary strata
    - As blocks of basement rocks are displaced upward, the ductile sedimentary strata drape over them

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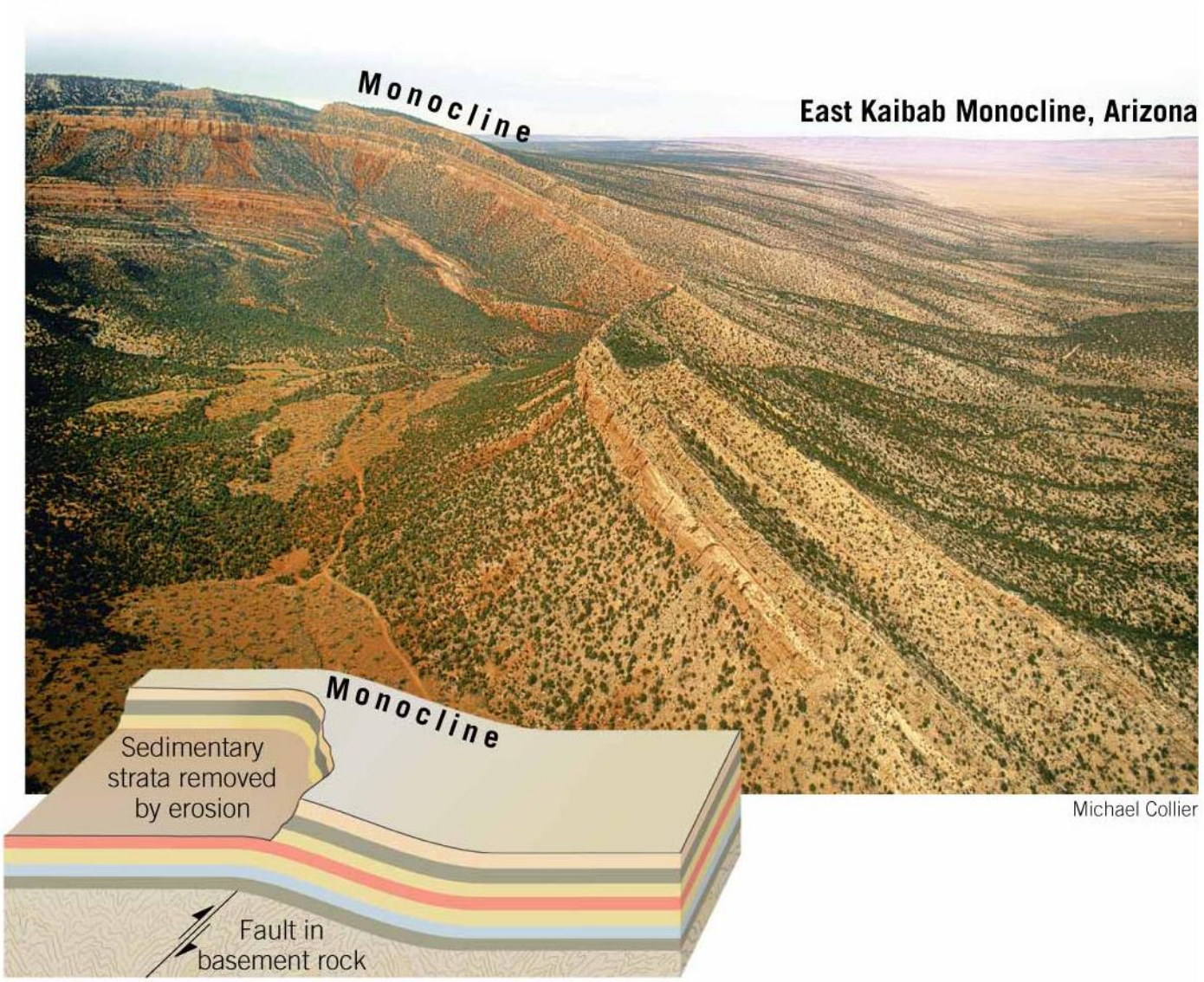
The East Kaibab Monocline, Arizona



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Faults and Joints: Rock Structures Formed by Brittle Deformation

- Faults are fractures in rocks, along which displacement has occurred
- Sudden movements along faults are the cause of most earthquakes
- Polished, smooth surfaces, called slickenslides, provide evidence for direction of movement along the fault

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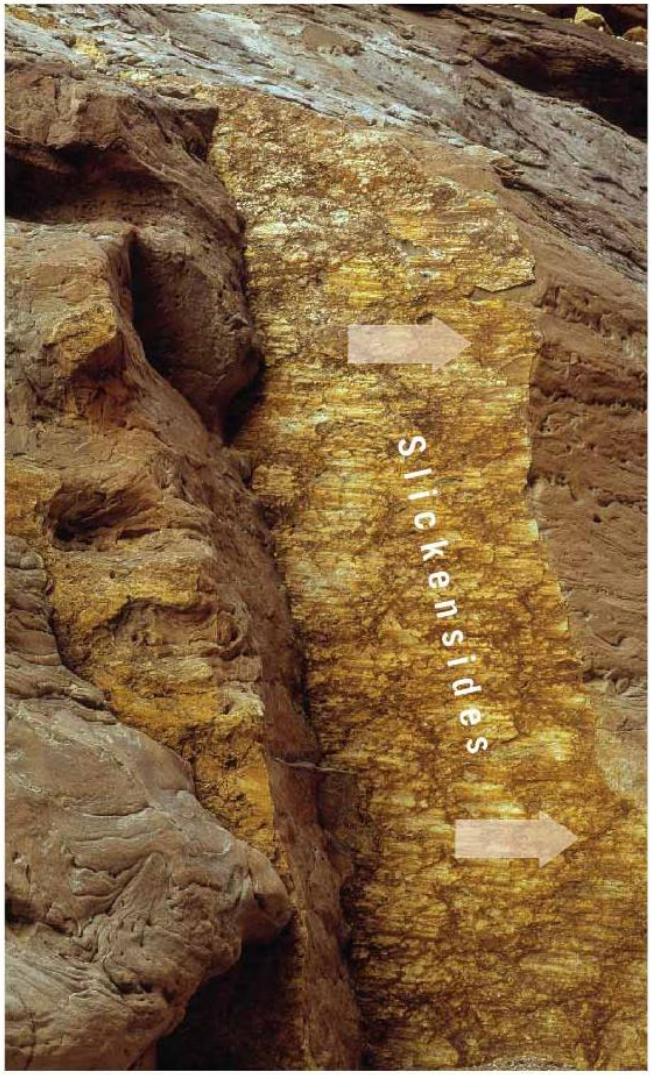
Slickenslides



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Faults and Joints: Rock Structures Formed by Brittle Deformation

- Dip-Slip Faults
  - Dip-slip faults occur when movement is parallel to the inclination
    - The hanging wall is rock surface above the fault
    - The footwall is the rock surface below the fault
  - The vertical displacement along the fault produces long, low cliffs called fault scarps

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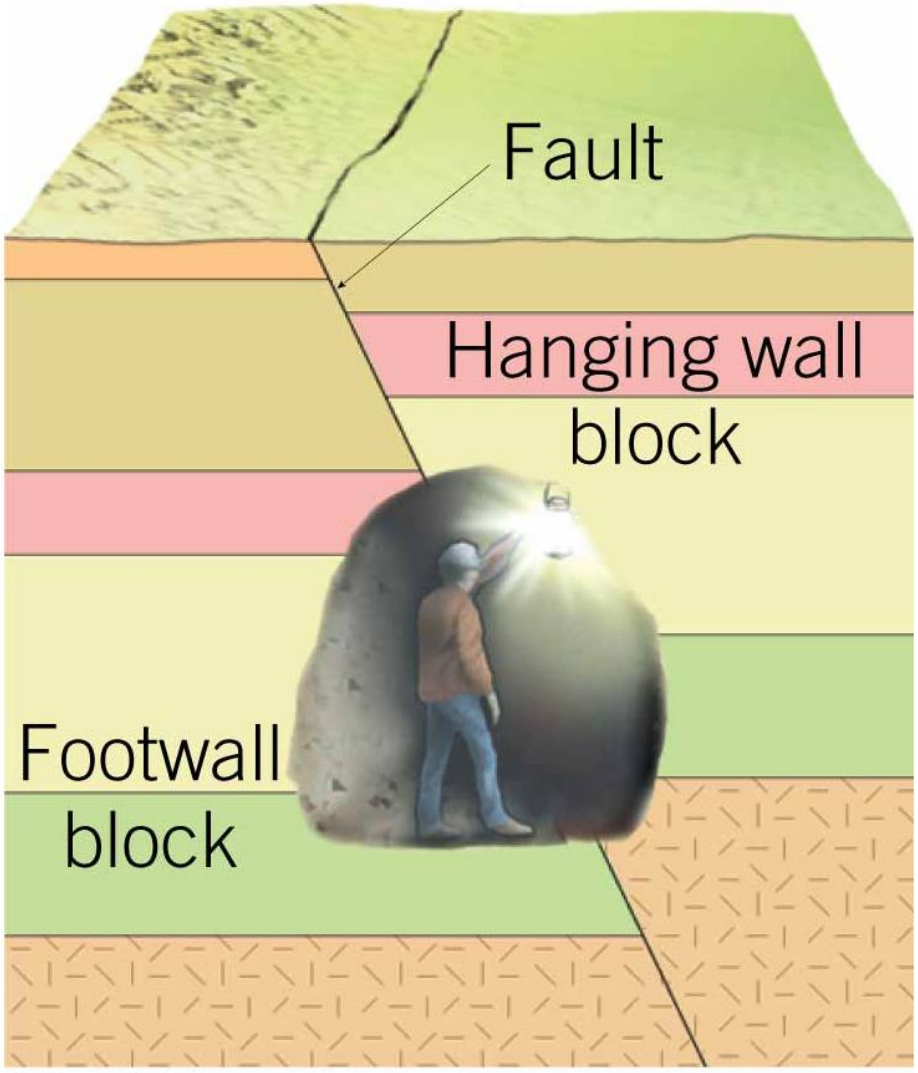
Hanging Wall Block and Footwall Block



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Faults and Joints: Rock Structures Formed by Brittle Deformation

- Dip-Slip Faults
  - Normal faults are characterized by the hanging wall moving down relative to the footwall
    - Associated with tensional stress as the rocks pull apart
  - Larger scale normal faults are associated with fault-block mountains
    - Example: Basin and Range Province
    - Uplifted blocks are called horsts
    - Down-dropped blocks are called grabens

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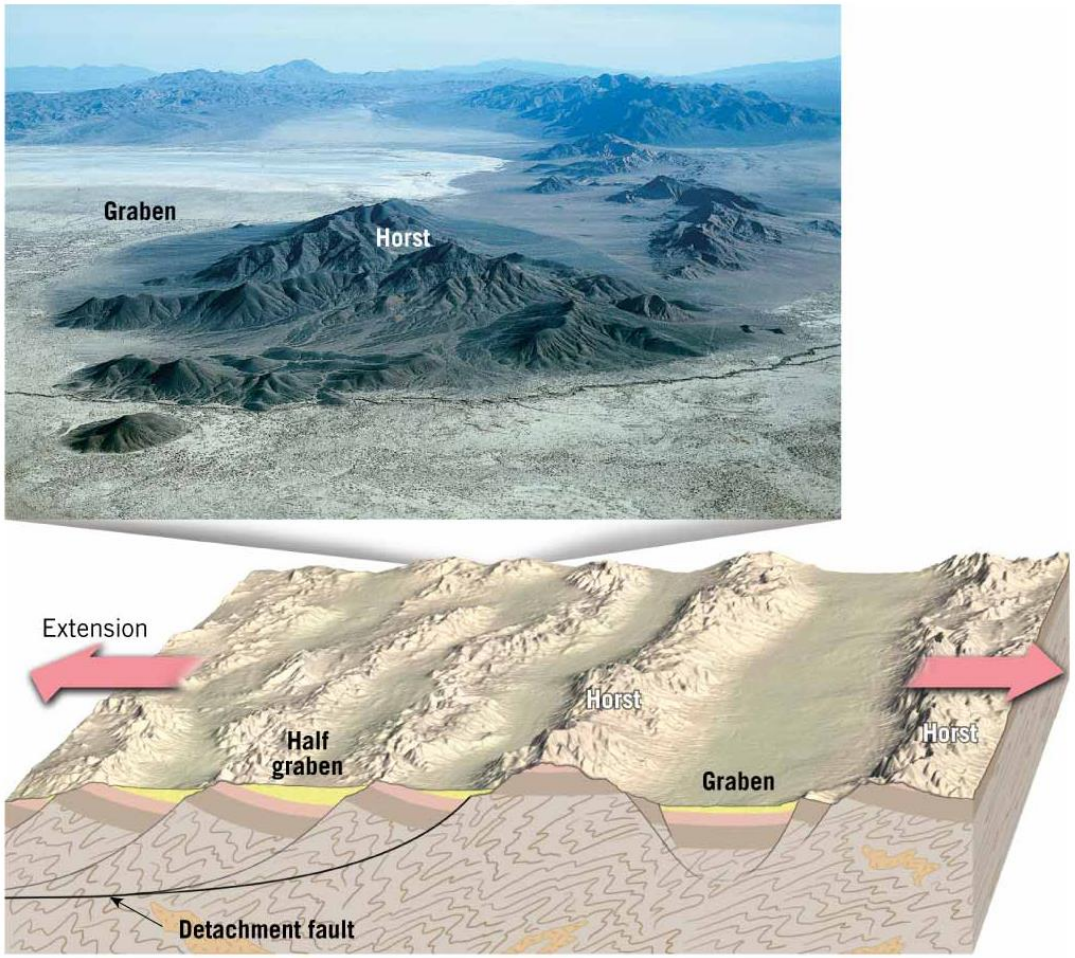
Normal Faulting in the Basin and Range Province



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Faults and Joints: Rock Structures Formed by Brittle Deformation

- Dip-Slip Faults
  - Fault Block Mountains
    - Half-grabens are tilted fault blocks
    - Detachment faults represent the boundary between ductile and brittle rock units

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Faults and Joints: Rock Structures Formed by Brittle Deformation

- Dip-Slip Faults
  - Reverse faults are characterized by the hanging wall moving up relative to the footwall
    - Associated with compressional stress as the crust shortens
  - Thrust faults have an angle less than 45º, so the overlying plate moves almost horizontally
    - Most pronounced along convergent plate boundaries
    - Example: Glacier National Park

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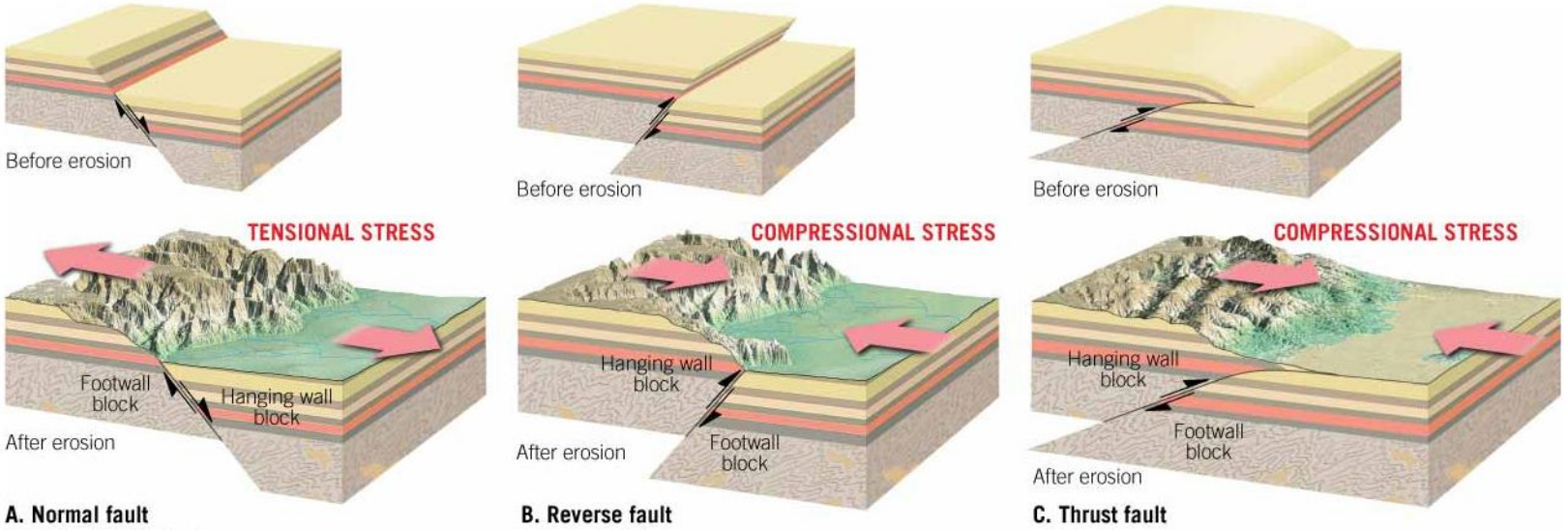
Types of Dip-Slip Faults



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Faults and Joints: Rock Structures Formed by Brittle Deformation

- Strike-slip faults are characterized by placement that is horizontal and parallel to the strike of the fault
  - Types of strike-slip faults
    - Right-lateral—As you face the fault, the opposite side of the fault moves to the right
    - Left-lateral—As you face the fault, the opposite side of the fault moves to the left

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Aerial View of a Strike Slip Fault

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Faults and Joints: Rock Structures Formed by Brittle Deformation

- Strike-Slip Faults
  - Large strike-slip faults that cut through the crust to accommodate plate motion are called transform faults

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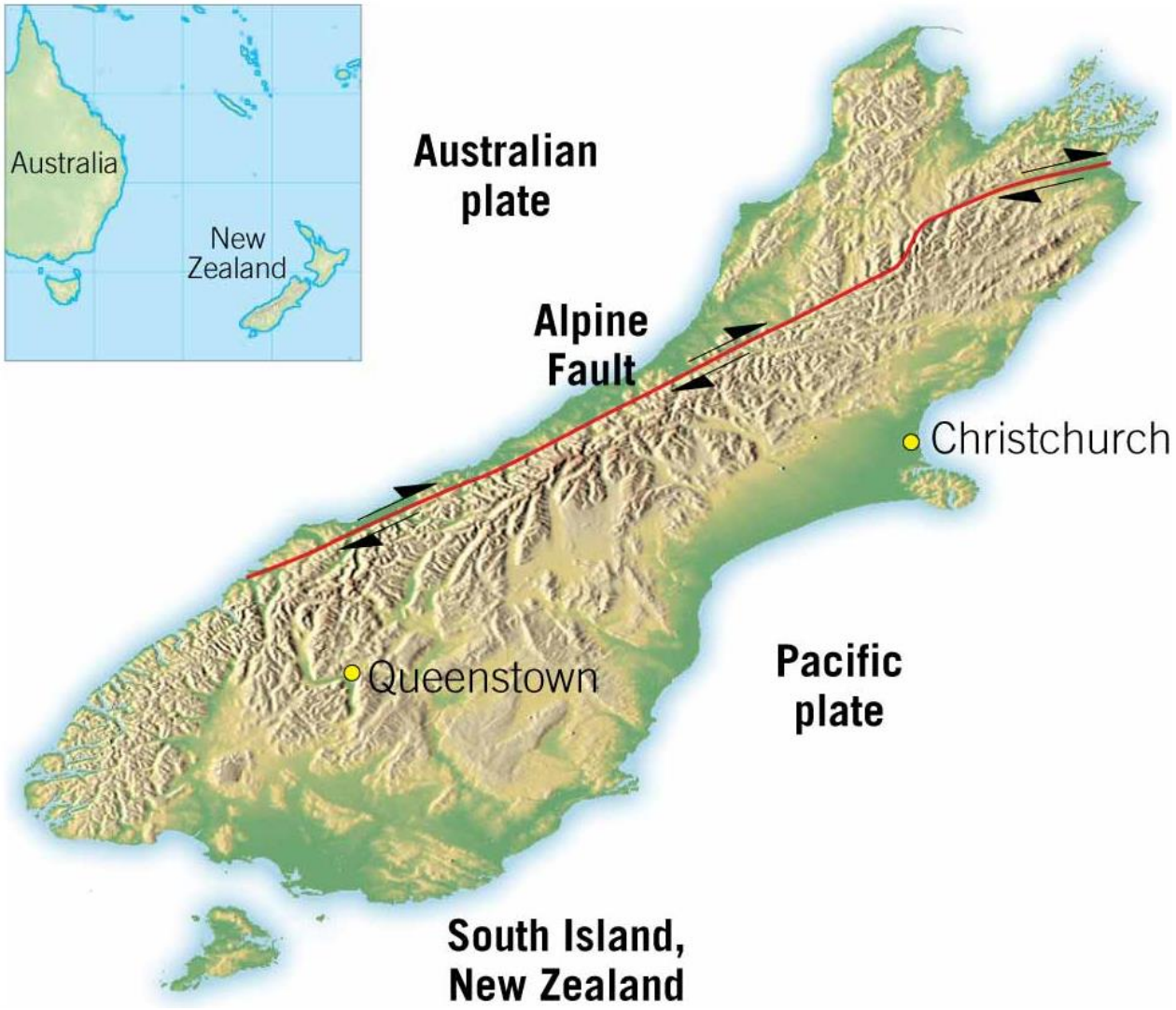
The Alpine Fault, New Zealand



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Faults and Joints: Rock Structures Formed by Brittle Deformation

- Oblique-slip faults exhibit both a strike-slip and a dip-slip movement
- Joints are fractures in a rock where there has been no rock movement
  - Most joints appear in parallel groups

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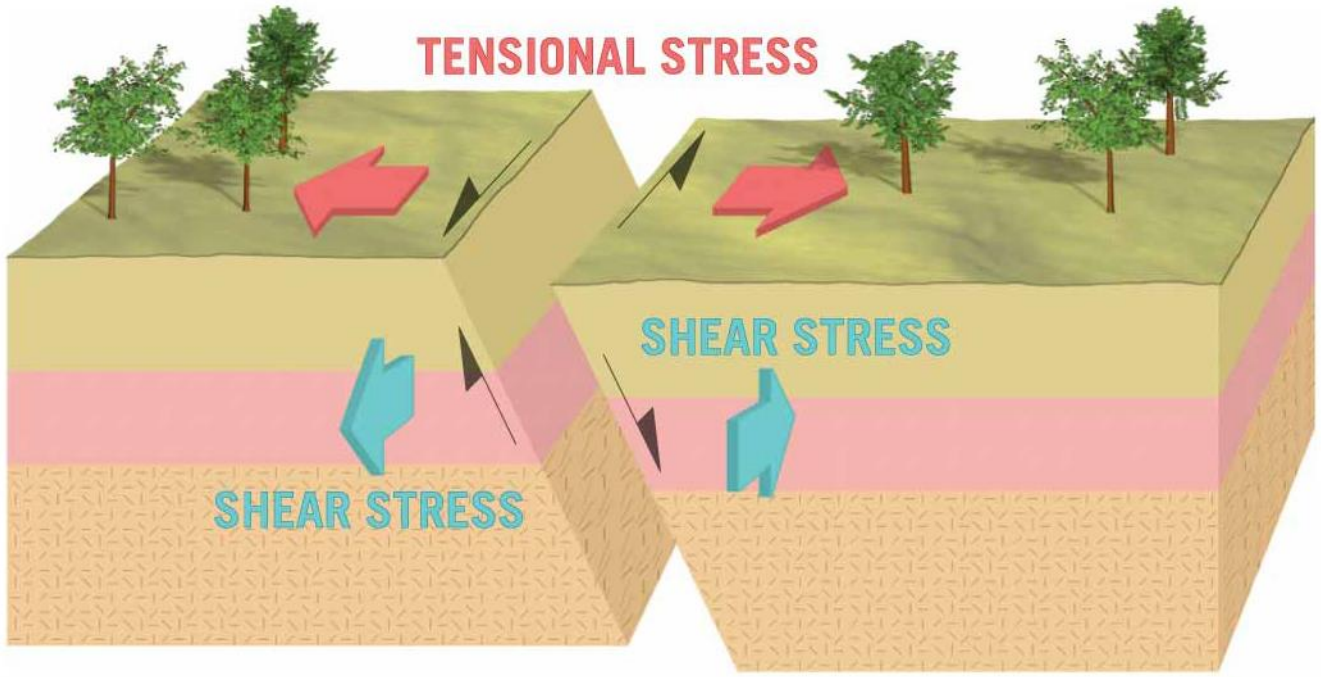
Oblique-Slip Faults



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Parallel Joints

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Mapping Geologic Structures

- A geologist identifies and describes the dominant rock structures in a region
  - Using a limited number of outcrops (sites where bedrock is exposed at the surface)
  - Work is aided by aerial photography, satellite imagery, global positioning systems (GPS), and seismic reflection profiling

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Mapping Geologic Structures

- Strike and Dip
  - Sedimentary rocks that are inclined or bent indicate that the layers were deformed following deposition
    - Strike
      - The compass direction of the line produced by the intersection of an inclined rock layer or fault with a horizontal plane
      - Generally expressed as an angle relative to north

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Mapping Geologic Structures

- Strike and Dip
  - Dip
    - The angle of inclination of the surface of a rock unit or fault measured from a horizontal plane
    - Includes both an inclination and a direction toward which the rock is inclined

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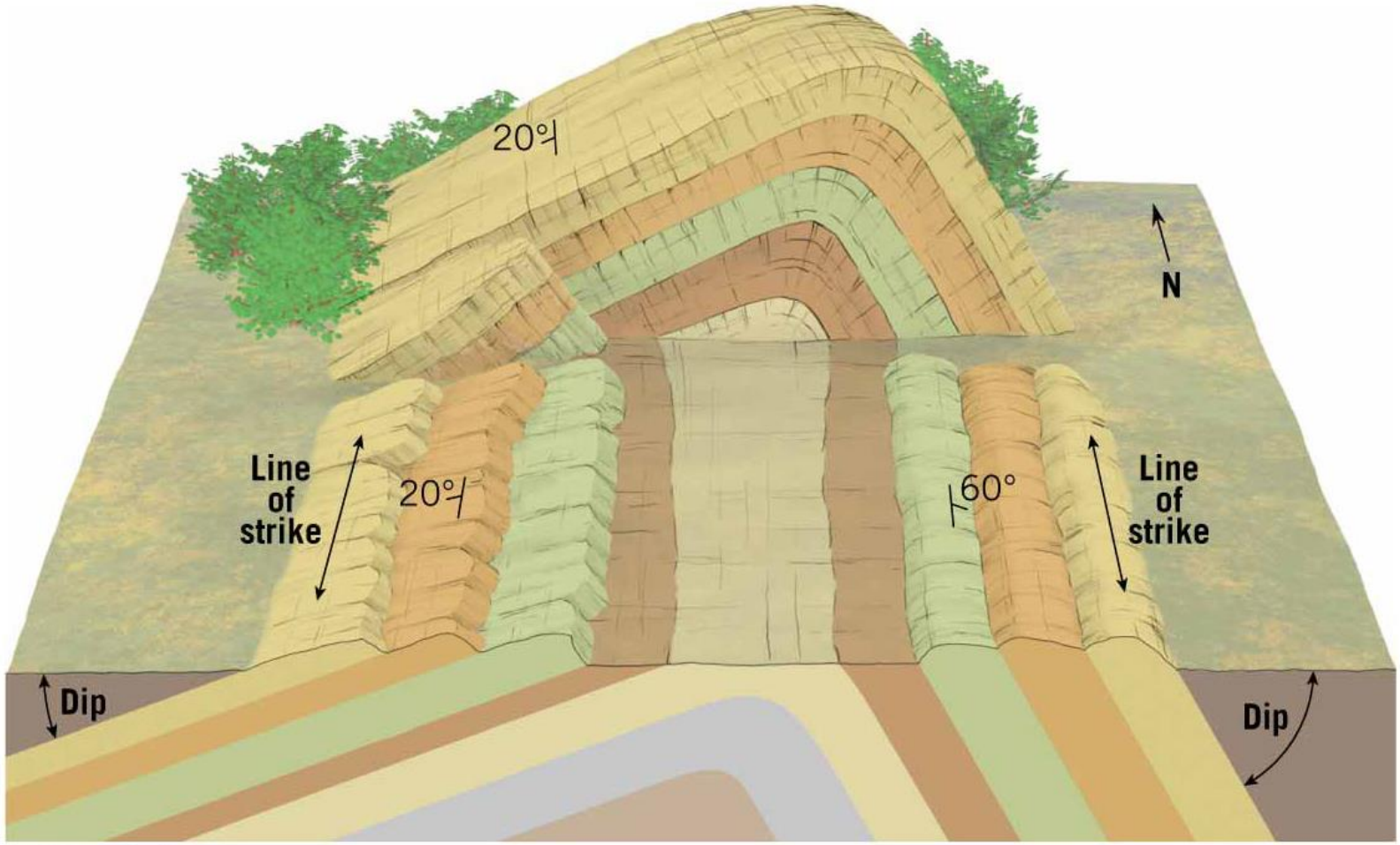
Strike and Dip of Rock Layers



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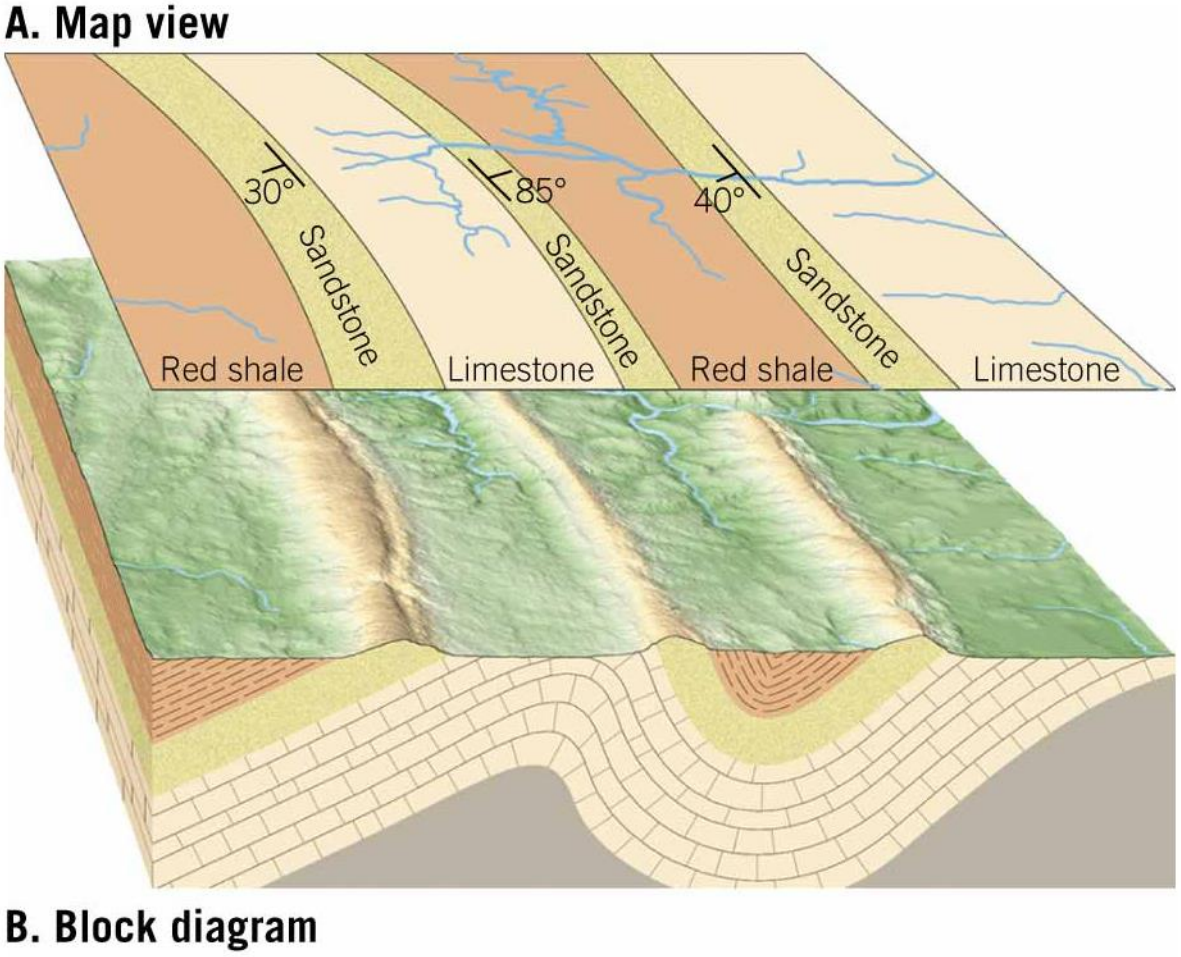
Mapping Geologic Structures



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End of Chapter 10

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