

**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
  - Most occurs at or near plate boundaries
- **Rock or geologic structures** are the features that result from forces generated by the interactions of tectonic plates
  - *Folds, faults, and joints*
  - *Foliation and rock cleavage*

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- **Stress: 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
    - Uniformly in all directions = **confining pressure**
      - Does not change the shape or orientation of a rock body
    - Unequally in different directions = **differential stress**
      - Compressional
      - Tensional
      - Shear

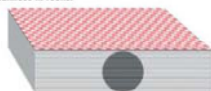
**What Causes Rock to Deform?**

- 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

### What Causes Rock to Deform?

- **Strain:** A Change in Shape Caused by Stress
  - Strained bodies lose their original configuration during deformation

By sliding the top of the deck relative to the bottom, we can illustrate the type of shearing that commonly occurs along closely spaced planes of weakness in rocks.



Shear stress causes the circle in this deck of cards to become an ellipse, which can be used to measure the amount and type of strain.



### 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
  - When stress is applied *gradually*, rocks *initially* respond by deforming elastically
  - Once the elastic limit (strength) of a rock is surpassed, it either bends (**ductile deformation**) or breaks (**brittle deformation**)

### Rocks Exhibiting Ductile Deformation



### How Do Rocks Deform?

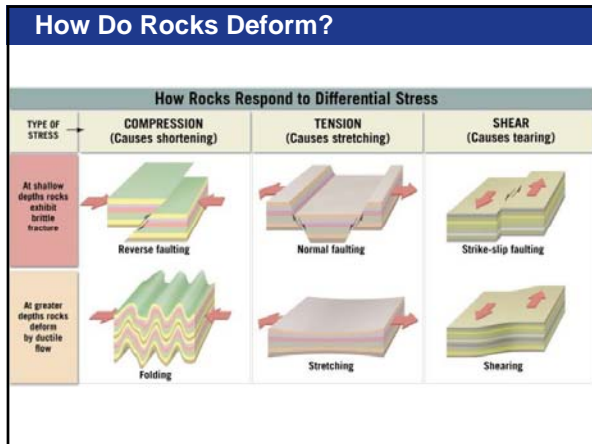
- Factors That Affect Rock Strength
  - **Temperature:** Higher temperature rocks tend to deform by ductile deformation whereas cooler rocks tend to deform by brittle deformation
  - **Confining pressure:** Confining pressure squeezes rocks, making them stronger and harder to break—these tend to undergo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

### How Do Rocks Deform?

- Factors That Affect Rock Strength
  - **Rock type:**
    - Crystalline igneous and some metamorphic rocks, composed of minerals with strong chemical bonds generally experience brittle deformation
    - Sedimentary and metamorphic rocks with zones of weakness generally experience ductile deformation
  - **Time:** Forces applied gradually over a long period of time generally result in ductile deformation

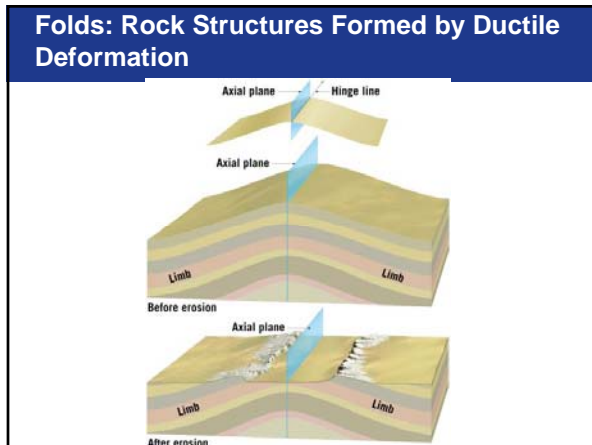
### How Do Rocks Deform?

- 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
    - **Folds** are evidence that rocks can bend without breaking
      - Usually the result of deformation in high-temperature and pressure environments



### Folds: Rock Structures Formed by Ductile Deformation

- Characteristics of folds
  - Most folds result from compressional stresses that result in a shortening and thickening of the crust
  - Each rock layer is bent around an imaginary axis: the *hinge line*
    - Hinge lines can be horizontal or inclined
  - The *axial plane* is a surface that connects all hinge lines of the folded strata

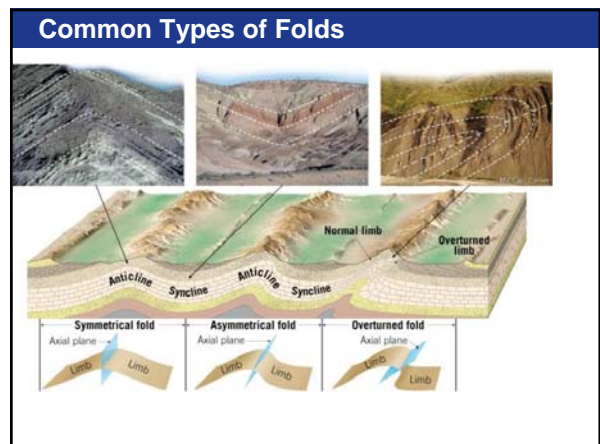


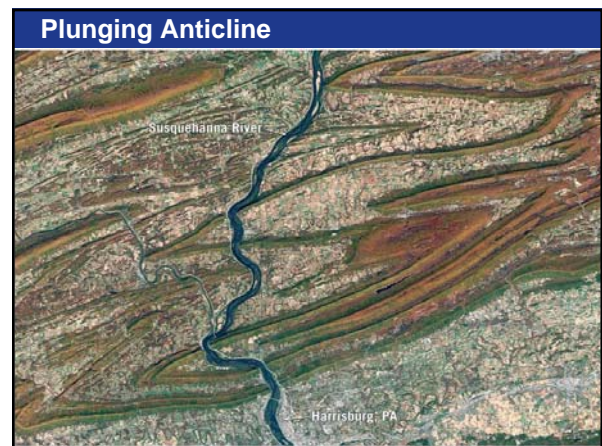
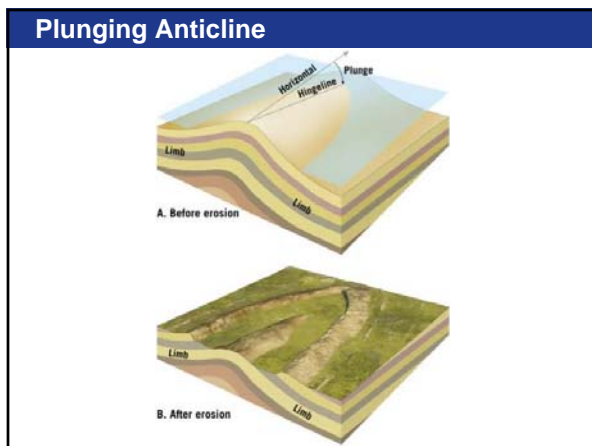
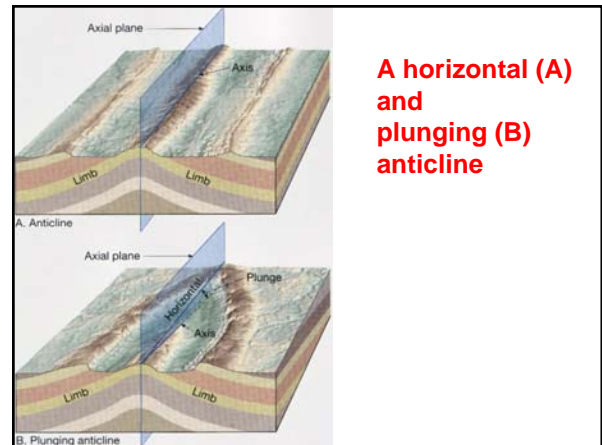
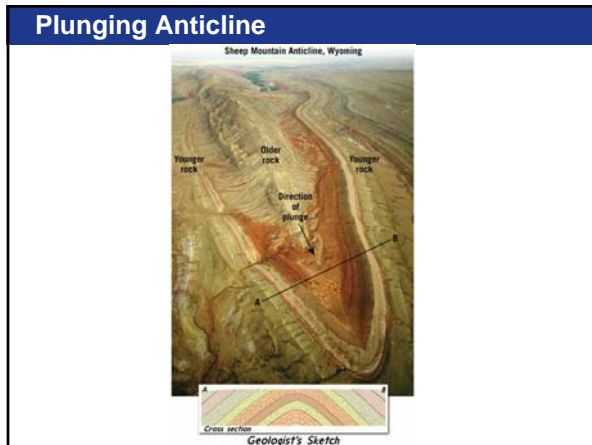
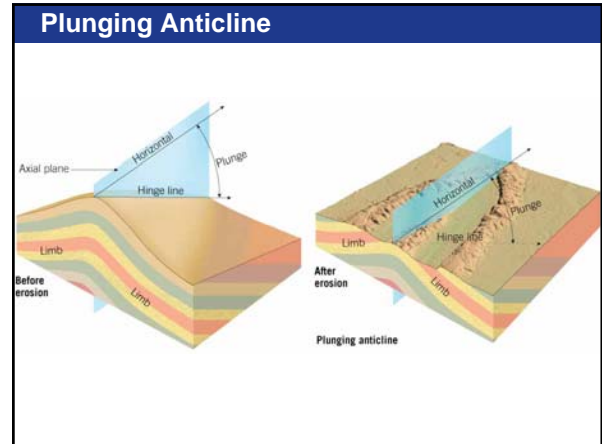
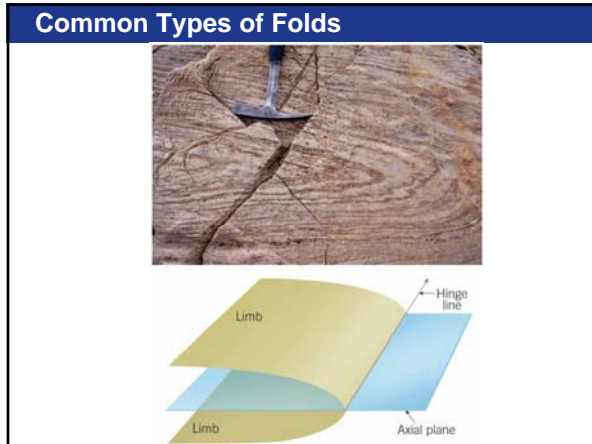
### Folds: Rock Structures Formed by Ductile Deformation

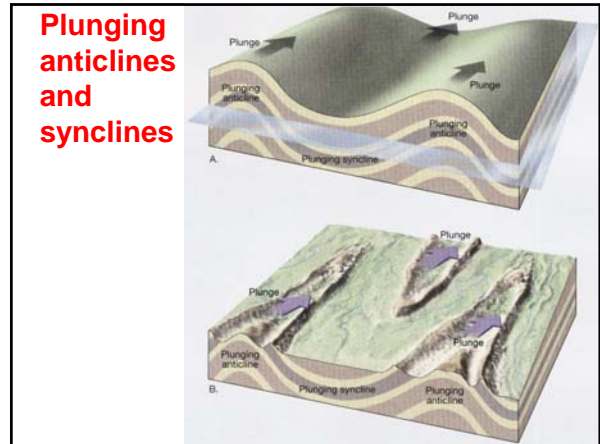
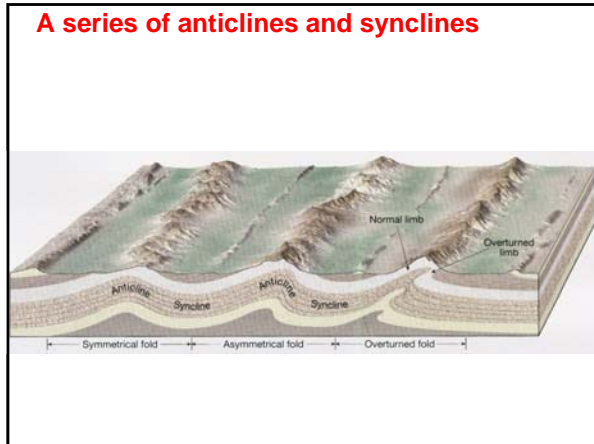
- Anticline and Synclines
  - **Anticlines** are upfolded or arched sedimentary layers
    - Oldest strata are in the center
  - **Synclines** are downfolded or troughs of rock layers
    - Youngest strata are in the center

### 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
      - *Overtured (recumbent)*—one or both limbs are tilted beyond vertical
      - *Plunging*—the axis of the fold penetrates the ground

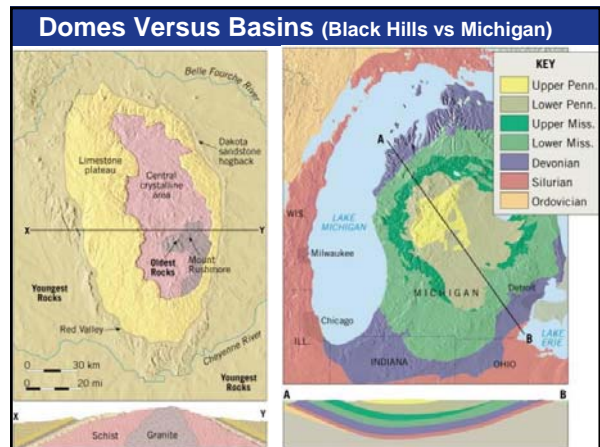
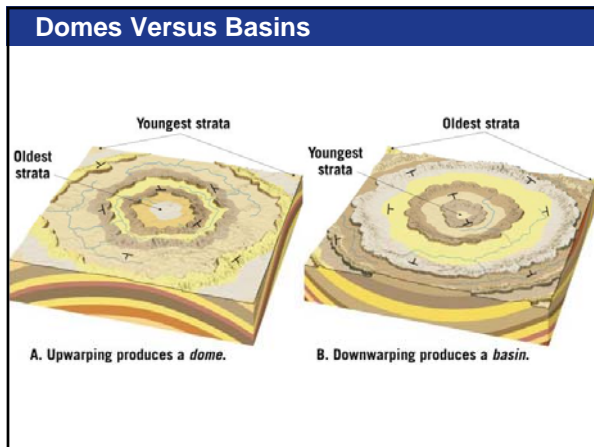






**Folds: Rock Structures Formed by Ductile Deformation**

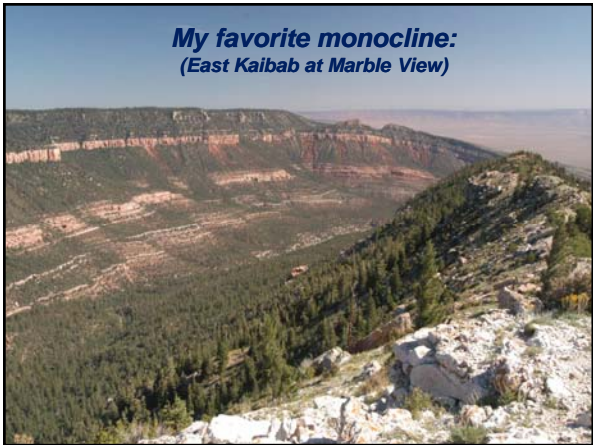
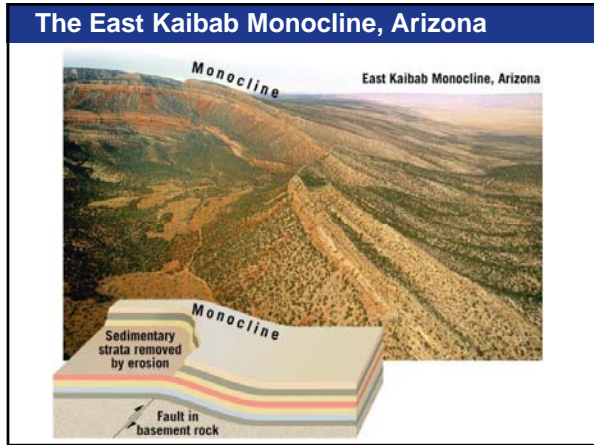
- Domes and Basins
  - **Domes** are upwarped circular features
    - Oldest rocks are in the center
    - Can form due to intrusion of a laccolith
  - **Basins** are downwarped circular features
    - Youngest rocks are in the center
    - Can form from subsidence of large sedimentary basins





**Folds: Rock Structures Formed by Ductile Deformation**

- **Monoclines**
  - **Monoclines** are large, step-like folds in otherwise horizontal sedimentary strata
    - Uniquely coupled with faults
    - As blocks of basement rocks are displaced upward, the ductile sedimentary strata drape over them



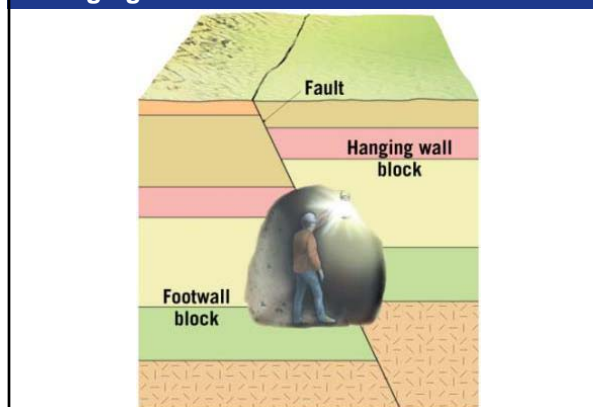
### Faults and Joints: Rock Structures Formed by Brittle Deformation

- **Faults** are fractures in rocks along which displacement has occurred
  - Sudden movements along faults are the cause of most earthquakes
- Fault orientation is described by **strike** and **dip**
  - Strike is the direction of a horizontal line on the inclined surface
  - Dip is the angle of inclination of that surface measured from the horizontal

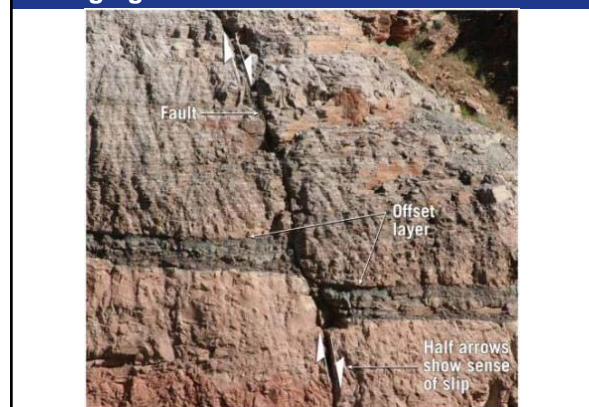
### Faults and Joints: Rock Structures Formed by Brittle Deformation

- Dip-Slip Faults
  - **Dip-slip** faults occur when movement is parallel to the inclination (dip)
    - The **hanging wall** is rock surface above the fault
    - The **footwall** is the rock surface below the fault
  - There are two general types of dip slip faults
    - **Normal**—hanging wall moves down
    - **Reverse**—hanging wall moves up

### Hanging Wall Block and Footwall Block



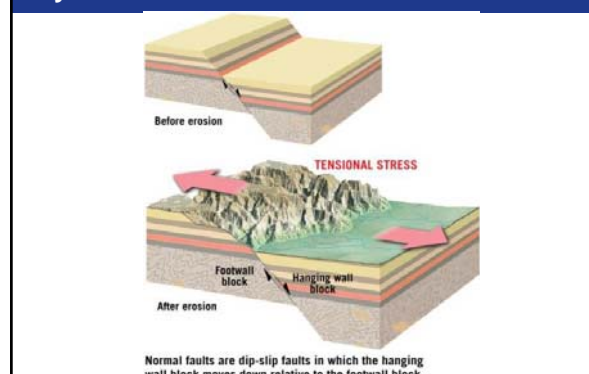
### Hanging Wall Block and Footwall Block

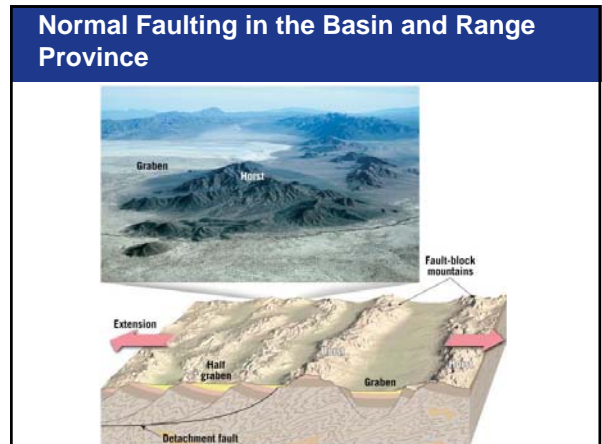
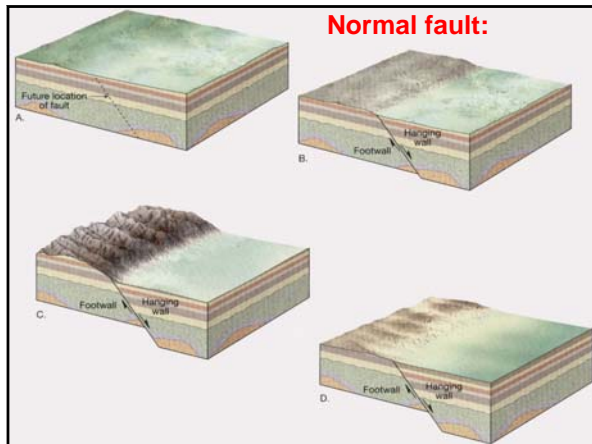


### Faults and Joints: Rock Structures Formed by Brittle Deformation

- **Normal faults** are characterized by the hanging wall moving down relative to the footwall
  - Associated with **tensional stress** as the rocks pull apart, lengthening the crust
- 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**

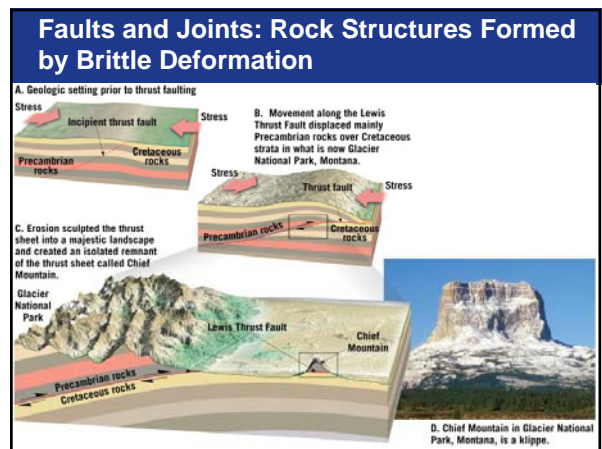
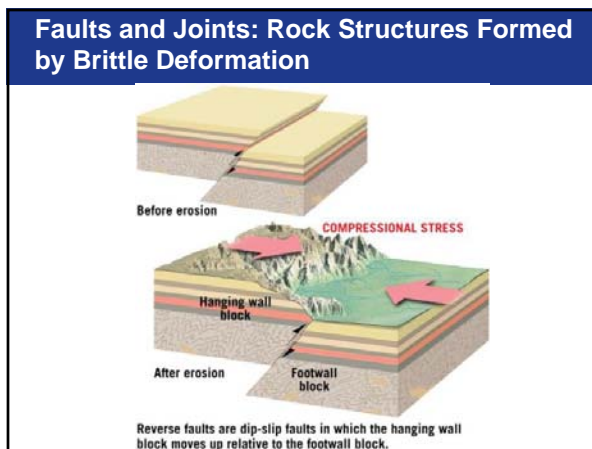
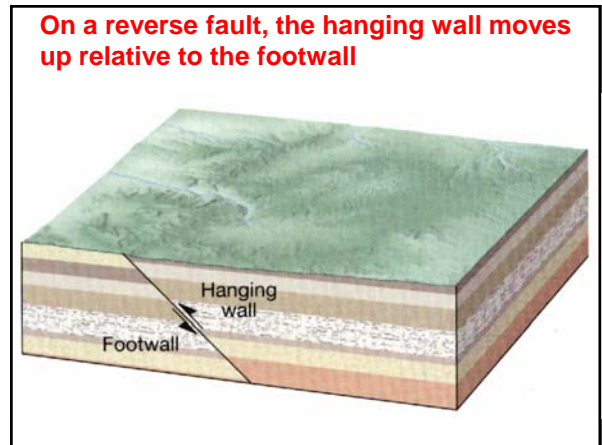
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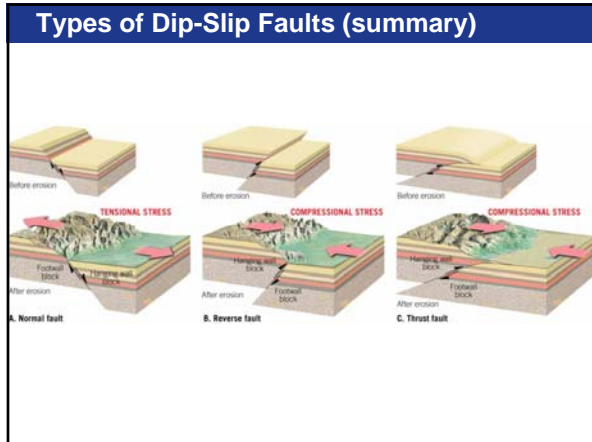




**Faults and Joints: Rock Structures Formed by Brittle Deformation**

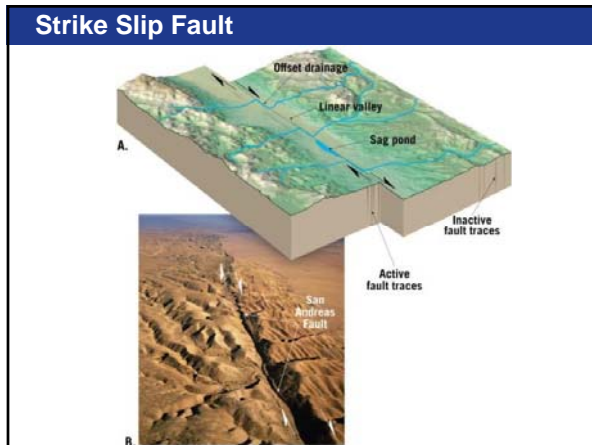
- **Reverse faults** are characterized by the hanging wall moving up relative to the footwall
  - Associated with **compressional stress** as the crust shortens
- **Thrust faults** have an angle less than 45°, so the overlying plate moves almost horizontally
  - Most pronounced along convergent plate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





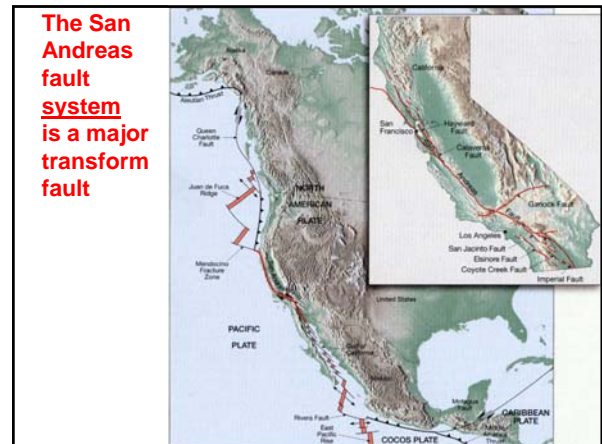
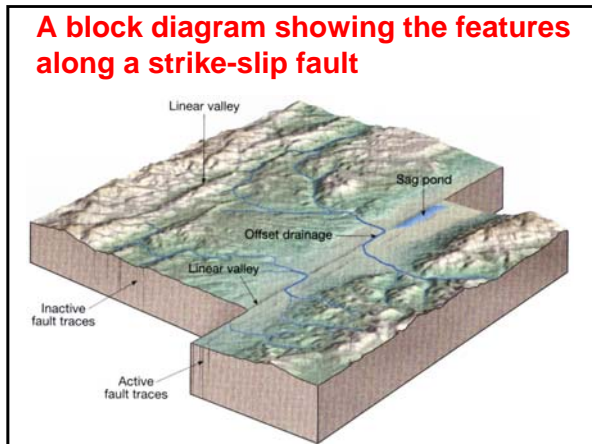
### Faults and Joints: Rock Structures Formed by Brittle Deformation

- **Strike-slip faults** are characterized by displacement 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



### 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**
  - Most continental transform faults consist of a zone of roughly parallel fractures
    - San Andreas Fault



**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

**Faults and Joints: Rock Structures Formed by Brittle Deformation**

- **Oblique-slip faults** exhibit both a strike-slip and a dip-slip movement

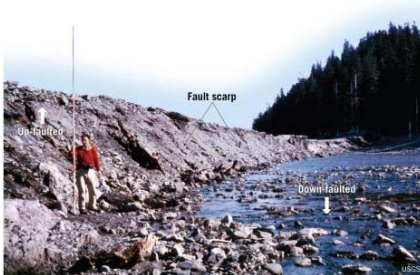
**Faults and Joints: Rock Structures Formed by Brittle Deformation**

- **Faults and Earthquakes**
  - Sudden displacement along a fault can produce an earthquake
  - Some of the most destructive earthquakes occur along strike-slip faults
    - Port-au-Prince, Haiti, 2010
  - Even larger earthquakes occur along low-angle thrust faults, called **megathrust faults**
    - Japan 2011, Sumatra 2004



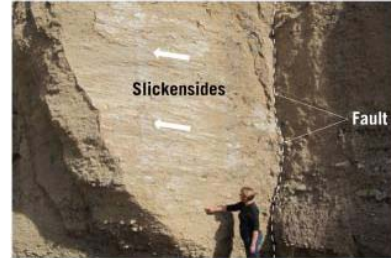
### Faults and Joints: Rock Structures Formed by Brittle Deformation

- **Fault Scarps**
  - Vertical displacement along faults may produce long low cliffs called **fault scarps**



### Faults and Joints: Rock Structures Formed by Brittle Deformation

- **Slickensides**
  - On some fault surfaces the rocks became highly polished and striated (grooved) as crustal blocks slid past each other
  - These surfaces are called **slickensides**



### Faults and Joints: Rock Structures Formed by Brittle Deformation

- **Joints** are fractures in a rock where there has been no rock movement
  - One of the most common rock structures
  - Most joints appear in parallel groups
  - Produced when rocks in the outermost crust are deformed and experience brittle failure

### Parallel Joints



### Mapping Geologic Structures

- A geologist identifies and describes the dominant rock structures in a region
  - Using outcrops of exposed bedrock
  - Work is now aided by
    - Aerial photography
    - Satellite imagery
    - Global positioning systems (GPS)
    - Seismic reflection profiling

### Mapping Geologic Structures

- **Strike and Dip**
  - Sedimentary rocks that are inclined or bent indicate that the layers were deformed following deposition
    - **Strike**
      - The compass bearing 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

### 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
    - Always at a 90° to the strike

### Strike and Dip of Rock Layers

### Strike and Dip of Rock Layers

### A. Map view

A geologic map illustrates the geologic structures of an area

B. Block diagram

### Strike and dip of a rock layer

### Mapping Geologic Structures

A. Study area

B. Geologic map

C. Block diagram

