Rock: Bend, Buckle, and Break

Why Is Rock Deformed?

• Tectonics forces continuously squeeze, stretch, bend, and break rock in the lithosphere
• Energy source: Earth’s internal heat
  – transformed into mechanical energy

Stress

• Force per unit area
• Units:
  – Pounds per square inch
  – Bars, kilobars, megabars
  – Pascals, MPa, GPa
• Differential vs confining stress
  – Different stress in different directions
  – “pressures”

Strain

• Fractional change in dimension
  – Length
  – Angle
  – Volume
• Units: dimensionless
**strain-rate**: fractional change in dimension per time
- \(10^{-2}\) sec\(^{-1}\) meaning:
  - 1% length change in a second
- Geologic Strain Rates: \(10^{-14}\) to \(10^{-17}\) sec\(^{-1}\)
  - at \(10^{-14}\) sec\(^{-1}\): 100,000 years to get 3% strain

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**Elastic response**

- Strain proportional to stress
  - “Hooke’s Law”
- Reversible

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**Ductile (Plastic)**

- Irreversible change
- Stressed beyond “Elastic limit”
Brittle Behavior

• Fracture when stressed beyond elastic and plastic limit

Rock Behavior

• Elastic-plastic-brittle deformation depends on strain-rate, pressure, temperature, and composition
  – More ductile at:
    • Low strain rate
    • High pressure
    • High temperature
Composition

- The composition of a rock has pronounced effects on its properties.
  - Quartz, garnet, and olivine are very brittle.
  - Mica, clay, calcite, and gypsum are ductile.
- The presence of water in a rock reduces brittleness and enhances ductile properties.
  - Water affects properties by weakening the chemical bonds in minerals and by forming films around minerals grains.

General Behavior:

- Rock are brittle at low pressure and temperature and high strain rate
- Rocks are brittle at the Earth’s surface
• By about 1300°C, rock strength is very low.
• Brittle deformation is no longer possible. The disappearance of all brittle deformation properties marks the lithosphere-asthenosphere boundary.
• In the crust large movements happen so slowly (low strain rates) that they can be measured only over a hundred or more years.

**Abrupt Movement**

- Abrupt movement results from the fracture of brittle rocks and movement along the fractures.
  - Stress builds up slowly until friction between the two sides of the fault is overcome, when abrupt slippage occurs.
    - The largest abrupt vertical displacement ever observed occurred in 1899 at Yakutat Bay, Alaska, during an earthquake. A stretch of the Alaskan shore lifted as much as 15 m above the sea level.
    - Abrupt movements in the lithosphere are commonly accompanied by earthquakes

**Gradual Movement**

- Gradual movement is the slow rising, sinking, or horizontal displacement of land masses.
  - Tectonic movement is gradual.
  - Movement along faults is usually, but not always, abrupt.
Evidence Of Former Deformation

- Structural geology is the study of rock deformation.
- The law of original horizontality tells us that sedimentary strata and lava flows were initially horizontal.
- If such rocks are tilted, we can conclude that deformation has occurred.

Dip and Strike

- The **dip** is the angle in degrees between a horizontal plane and the inclined plane, measured down from horizontal.
- The **strike** is the compass direction of the horizontal line formed by the intersection of a horizontal plane and an inclined plane.
Deformation By Fracture

- Rock in the crust tends to be brittle and to be cut by innumerable fractures called either joints or faults.
- Most faults are inclined.
  - To describe the inclination, geologists have adopted two old mining terms:
    - The **hanging-wall block** is the block of rock above an inclined fault.
    - The block of rock below an inclined fault is the **footwall block**.

Classification of Faults

- Faults are classified according to:
  - The dip of the fault.
  - The direction of relative movement.
Normal faults

- Caused by tensional stresses that tend to pull the crust apart, as well as by stresses created by a push from below that tend to stretch the crust
- The **hanging-wall** block moves down relative to the footwall block

Reverse faults

- Caused by compressional stresses
- Movement on a reverse fault is such that a hanging-wall block moves up relative to a footwall block.
- Reverse fault movement shortens and thickens the crust
• Thrust faults are low-angle reverse faults with dip less than 15°.
  – Such faults are common in great mountain chains.
• Strike-slip faults are those in which the principal movement is horizontal and therefore parallel to the strike of the fault.
  – Strike-slip faults arise from shear stresses.
  – The San Andreas is a right-lateral strike-slip fault.
    • Apparently, movement (more than 600 km) has been occurring along it for at least 65 million years.