

**Geology and Art, Fall 2004**  
**Structure, Lecture 5**  
Dynamic Earth, Chapter 9

**Structures**

The dynamic nature of plate tectonics creates stress in the Earth's crust. The Earth makes adjustments to accommodate this stress, these adjustments are folds and faults.

relationship of folds and faults with plate boundaries  
divergent boundaries  
convergent boundaries  
transform boundaries

**Structural geology:** the branch of geology that studies crustal deformation

**Rock Mechanics:** stress and strain

**Stress:** the force that a rock is subject to (mechanical force)

stress = force per unit area

force = mass x acceleration

1 kg x 9.8 m/sec<sup>2</sup> (acceleration of gravity) = 9.8 newtons (N)

weight is a force

pressure measured in bars (1 bar = 1 atmosphere, 1 bar = 10 N/cm<sup>2</sup>)

**Strain:** the deformation (change in shape and size) that a stress causes

**Uniform stress:** the stress is the same in all directions

**Differential stress:** the stress is not the same in all directions. This is produced by tectonic forces PICTURE

tension: vertical stress is greater than horizontal stress (extension)

compression: horizontal stress is greater than vertical stress

shear: stresses are not equal and opposite

Types of Deformation:

**Elastic Deformation:** rocks return to original size and shape after stress is removed (no permanent deformation)

**Yield Point** (elastic limit): limit to elastic deformation

Brittle failure: rupture occurs (fault). Tends to occur at low temperatures and pressure, high rate of deformation

Plastic (ductile) deformation: folding occurs. Tends to occur at high temperatures and pressure, low rate of deformation

Deformation often proceeds: elastic → yield point → plastic → brittle

**Factors:**

Temperature: higher temperature increases ductile deformation

**Confining stress:** higher pressure increases ductile deformation and decreases brittle fractures

**Time or rate of strain:** higher the strain rate, the more chance for fracturing.

**Composition:** kinds of minerals and water content (enhanced ductile deformation by acting as a lubricant).

Low confining pressure, low temperature, high strain rate (upper crust) = brittle fracture

High confining pressure, high temperature, low strain rates (deep crust and mantle) = ductile deformation

Brittle-ductile transition occurs at about 15km

**Folds:** an individual bend or warp in a layered rock caused by plastic deformation

**Synclines:** concave, trough-like folds (inner rocks are youngest)

**Anticlines:** convex, arch-like folds (inner rocks are oldest)

**Monocline:** region of inclined strata in region of horizontal strata

**Limbs:** sides of a fold

**Axial plane:** imaginary plane through the middle of a fold

**Axis:** intersection of the axial plane and the bedding planes

Types of folds:

**Symmetrical** (open) fold: near-vertical axial plane with limbs dipping gently away.

**Isoclinal fold:** limbs are parallel with each other

**Asymmetrical fold:** axial planes are inclined. Directed pressure can cause folds to rotate:

    overturned: **limbs dip in the same direction**

    recumbent: axial planes are essentially horizontal

    plunging: axis is not horizontal

**Faults:** fractures (breaks in the rock) through rock that has experienced differential movement

**Joints:** systematically oriented fractures (joint set) that have no significant movement

**Offset:** displacement of planer (strata) or linear features

**Slickensides:** surface polished by moving rock (fault plane)

**Fault breccia:** a tectonic breccia that develops along faults

**Hanging wall:** the block above the fault

**Foot wall:** the block below the fault

Types of faults: defined by relative motion

**Normal fault:** caused by tension (extension) which tends to pull the crust apart

Hanging wall moves down relative to foot wall

**Reverse (thrust) fault:** caused by compression

**Thrust faults** are low-angle reverse faults (dips less than  $15^\circ$ )

Hanging wall moves up relative to the foot wall

**Strike-slip fault:** movement is parallel to the strike of the fault

Left-lateral and right-lateral

Oblique strike-slip (also normal or reversed)

Transpression: strike slip and reverse

Transtension: strike slip and normal

**Earthquakes:** Earthquakes occur when energy stored in (elasticity) strained rock is suddenly released. The more energy released, the stronger the earthquake.

**Focus:** the location that the energy is released (may be a region)

**Epicenter:** location of the earth's surface above the focus

**Seismic waves:** energy transmitted from the focus (vibrations)

**Body waves:** move through the solid Earth

**Compressional waves:** move by compression-expansion. They can move through liquids (density differences) and move at the greatest velocity of seismic waves (6 km/s). P (primary) waves

**Shear waves:** move by shear motion. They cannot move through liquids (need elastic strength) and have a velocity of about 3.5 km/s. S (secondary) waves.

**Surface waves:** pass around the Earth but do not travel through it. Slowest seismic waves

**Magnitude of earthquakes:**

the amount of elastic energy stored along a fault can be huge

$10^{17}$  Joules released in the 1906 San Francisco

$10^{17}$  Joules released by a hydrogen bomb

**Richter Magnitude Scale:** based on the amplitudes of seismic waves. The maximum amplitude of P and S waves 100 km from the epicenter. It is measured in log scale, each magnitude represents a 10x increase in the amplitude of the wave signal.

Energy is a function of amplitude and duration of a single wave oscillation, generally each magnitude represents about a 30x increase in energy highest magnitude (possible) is 9.0

Distribution of earthquakes

Foci are rarely deeper than 100 km (except within descending plates, 700 km)

Convergent boundaries:

Subduction:

Benioff zone: zone where the “cold” oceanic crust is subducting  
location of the foci map the angle of subduction.

Normal faults in the upper part of the descending plate.

Thrust fault between plates (100 km depth).

Normal or reverse faults within the subducting slab

Collisional:

Thrust faults that can have foci up to 300 km deep (strong)

Spreading centers:

Normal faults due to the movement of the plates, low magnitude and shallow foci.

Transform boundaries:

Strike-slip faults with shallow foci (100 km) and high magnitude