Stress and Strain

Fractures and Joints
FORCE

► A push or pull acting upon an object that causes a body to accelerate

► \( F = ma \)

► Measured in Newtons (N)

► 1N is the force required to accelerate 1kg by 1m/s\(^2\)

► Force is a vector: magnitude and direction
NORMAL and SHEAR FORCE

- Force acting on a surface can be divided into two perpendicular components

- The normal force \( (F_n) \) acts perpendicular to the surface

- The shear force \( (F_s) \) acts parallel to the surface
QUANTIFYING COMPONENTS of FORCE

► Basic trigonometry allows us to calculate the magnitude of the normal and shear components of a force

► Trig Mnemonic
   SOH-CAH-TOA
What are $F_n$ and $F_s$ in these Cases?

- $\Theta=20^\circ$, $F=10,000\text{N}$
- $\Theta=70^\circ$, $F=10,000\text{N}$
PRESSURE

- Force applied perpendicularly across a surface (i.e., Force is normal)

- \[ P = \frac{F}{A} \]

- Measured in Pascals (Pa)

- 1Pa is 1N applied over 1m²

- Pressure in geology: pore pressure, lithostatic pressure
TRACTION

- Force applied across a surface at a specific point regardless of orientation

- $\Sigma = F/A$

- Measured in Pascals (Pa)

- 1Pa is 1N applied over 1m$^2$

- Traction can be broken into normal and shear components
STRESS

► Traction is defined for a single plane that passes through a given point

► STRESS is the sum of forces acting across the infinite number of planes that pass through a point

► Thus stress is a concept that applies to 3D objects and not merely planes, and so is a central concept to structural geology

► Stress ($\sigma$) is analogous to pressure and traction; it is also measured in Pascals (Pa)
STRESS CONVENTIONS

- $\sigma_n$ is the stress normal to a given surface
  - Positive $\sigma_n$ is a compressive stress
  - Negative $\sigma_n$ is an extensional (tensile) stress

- $\sigma_s$ is the stress parallel to a given surface
  - Positive $\sigma_s$ causes counterclockwise rotation
  - Negative $\sigma_s$ causes clockwise rotation
Cauchy’s Theorem

- The stress state at a point has three orthogonal normal tractions

- All other tractions (infinite) have a component of shear stress

- These three normal tractions are called the principal stresses and are designated as $\sigma_1$, $\sigma_2$, and $\sigma_3$

- By definition $\sigma_1 \geq \sigma_2 \geq \sigma_3$
The state of stress at a point can be expressed graphically as an ellipsoid where the axes of the ellipsoid correspond to the principle stresses.
For any plane not perpendicular to the principal stress axes, there will be both a \( \sigma_n \) and a \( \sigma_s \).

The Mohr Circle is a convenient graphical means of determining the state of stress of any plane relative to the principle stress axes without calculations.
Maximum Shear stress occurs when $\theta = 45$ degrees and $2\theta = 90$ degrees.
WORK

- Force acting on an object to cause displacement

- \( W = Fd \)

- Measured in Joules (J)

- 1J is 1N of force causing the displacement of an object by 1m

- Geological example of work: Fault movement
**STRAIN**

- Force acting on an object to cause deformation

- Geological example of strain: Folding, compression, expansion

- What kind of strain would result from...
  - $\sigma_1 > \sigma_2 > \sigma_3$
  - $\sigma_1 = \sigma_2 = \sigma_3$
DEFINITIONS

► **FRACTURE**: A surface along which the rock has broken

► **JOINT**: A fracture along which there has been negligible motion, both extension (normal) and shear
JOINT SETS

Many joints with similar orientation generally occur together, and are called a joint set.

Each joint has negligible extension, but the sum of the total extension across a joint set can be considerable.

Joint Set in the Entrada Sandstone, Arches National Park

www.geology.wisc.edu/~maher/air/air05.htm
JOINT SYSTEM

- Different joint sets commonly occur together, and such occurrences are called **joint systems**
- Joint systems allow for extension in multiple directions

Joint system in the Entrada Sandstone, Arches National Park

www.geology.wisc.edu/~maher/air/air05.htm
JOINT SYSTEM

► Joint sets can develop in any orientation: vertical, horizontal, oblique

► A joint system in multiple orientations can allow for extension in 3 dimensions

www.ngdir.ir/.../structural%20geology_Joints.htm
COLUMNAR JOINTS

- Columnar joints are parallel, prismatic columns that occur in volcanic flows and shallow-level intrusions.
- Form due to the tensile stress that develops in a cooling sheet-like igneous body due to contraction.
- Joints initiate at the contacts and propagate inward.

Devil’s Tower National Monument, WY
www.pirateplanet.com/Rushmore_Devils_Tower.html

Devil’s Postpile National Monument, CA
www.env.duke.edu/eos/geo41/st.htm
EXFOLIATION JOINTS

► Exfoliation joints are curved joints parallel to the ground surface, and are common in granite plutons.

► Granite plutons cool parallel to their margins, and so contract parallel to their contacts.

► Also, plutonic rocks cool at depth under great pressure, they essentially de-pressurizes once the overburden is removed.

Half Dome, Yosemite National Park, CA
www.raingod.com/.../YosemiteHalfDome.html

Enchanted Rock State Park, TX
uts.cc.utexas.edu/~rnr/E-rock/exfol.html
INTERPRETATION OF JOINTS

- Joints develop where extensional stresses exist
- Joints are oriented perpendicular to extensional stress axes
  - One joint set:
    - One extensional principle axis of stress
    - Associated with regional faulting and/or folding
  - Two perpendicular joint sets:
    - Two extensional principle axes of stress
    - Regional extension in two directions
  - Three perpendicular joint sets:
    - Three extensional principle axes of stress
    - Regional Uplift
Joints can develop in regions of active faulting

**Figure 7.17**  
(a) Formation of joints in the hanging-wall block of a region in which normal faulting is taking place.  
(b) Formation of joints above an irregularity in a (reverse) fault surface.  
(c) Pinnate joints along a fault.
Complex joints can form in the crests of folds where the rock is changing its orientation relative to the stress field.

Joint pattern in Entrada Sandstone, UT
Joint pattern in varnish on folded surface

http://www.dstu.univ-montp2.fr/geofracnet/techniques.html
If a fracture opens then minerals may precipitate in the empty space to form a vein:
- Length parallel to $\sigma_1$
- Width parallel to $\sigma_3$

Extensional Veins tend to be continuous and straight.

Shear (Gash) Veins tend to be short, en echelon, and curved.
Interpret...