Stress and Strain

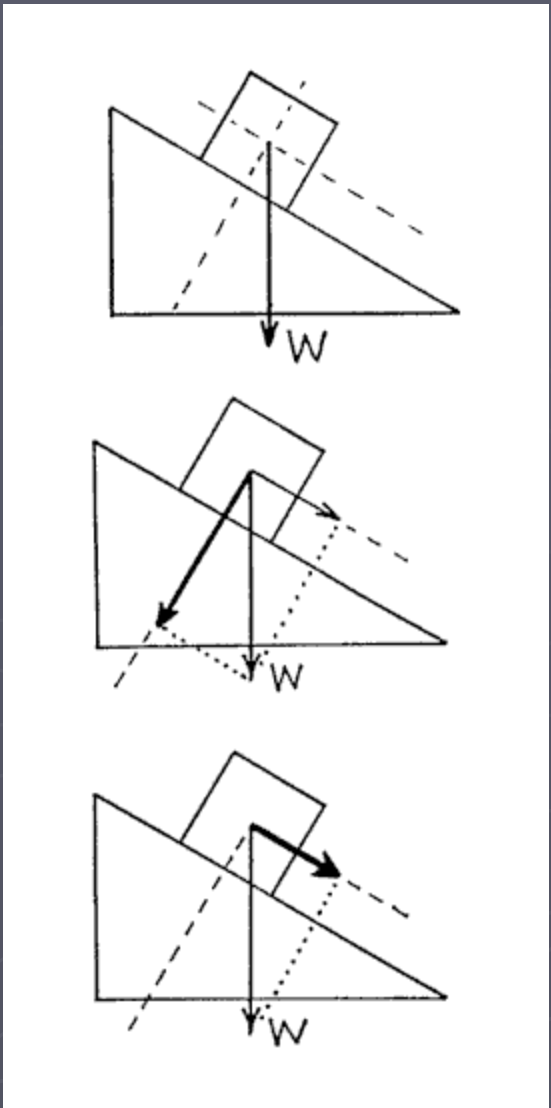
Fractures and Joints

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

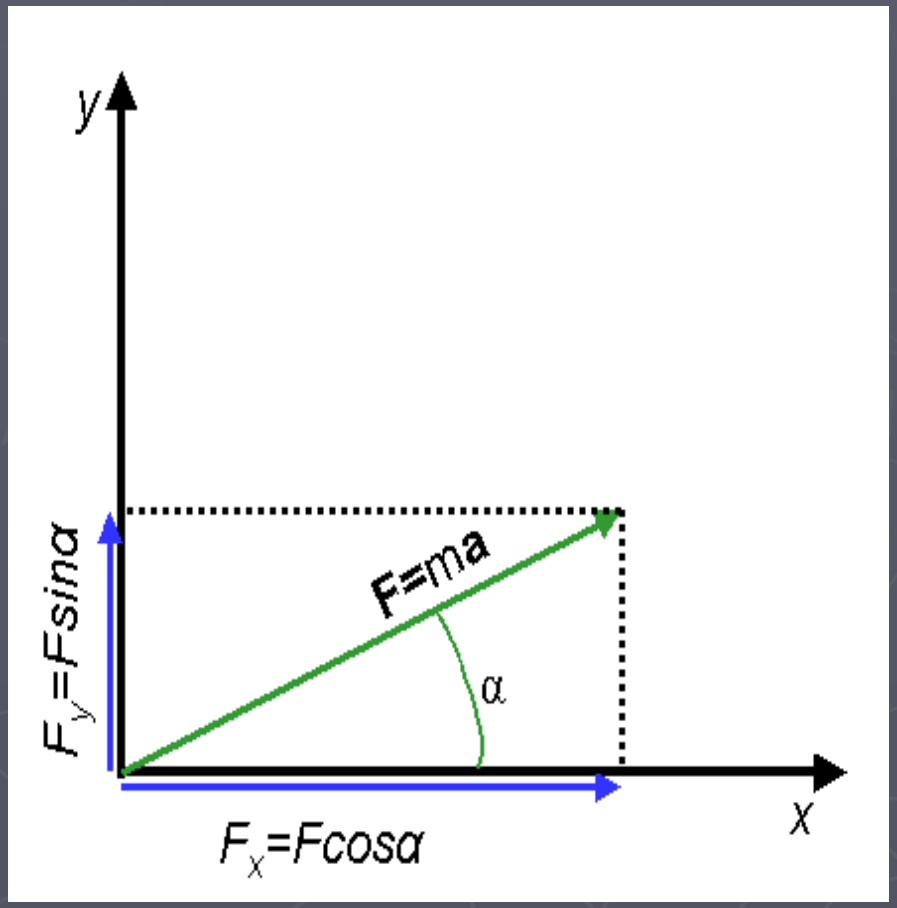
- Force acting on a surface can be divided into two perpendicular components
- The normal force (F_n) acts perpendicular to the surface
- The shear force (F_s) acts parallel to the surface



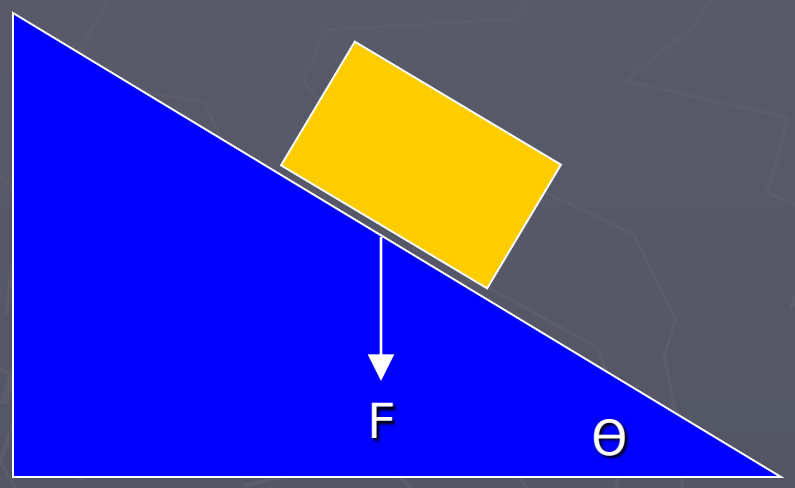
QUANTIFYING COMPONENTS of FORCE

- 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?



- θ=20, F=10,000N
- θ=70, F=10,000N

PRESSURE

- Force applied perpendicularly across a surface (i.e., Force is normal)
- $P=F/A$
- Measured in Pascals (Pa)
- 1Pa is 1N applied over $1m^2$
- 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 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 (σ) is analogous to pressure and traction; it is also measured in Pascals (Pa)

STRESS CONVENTIONS

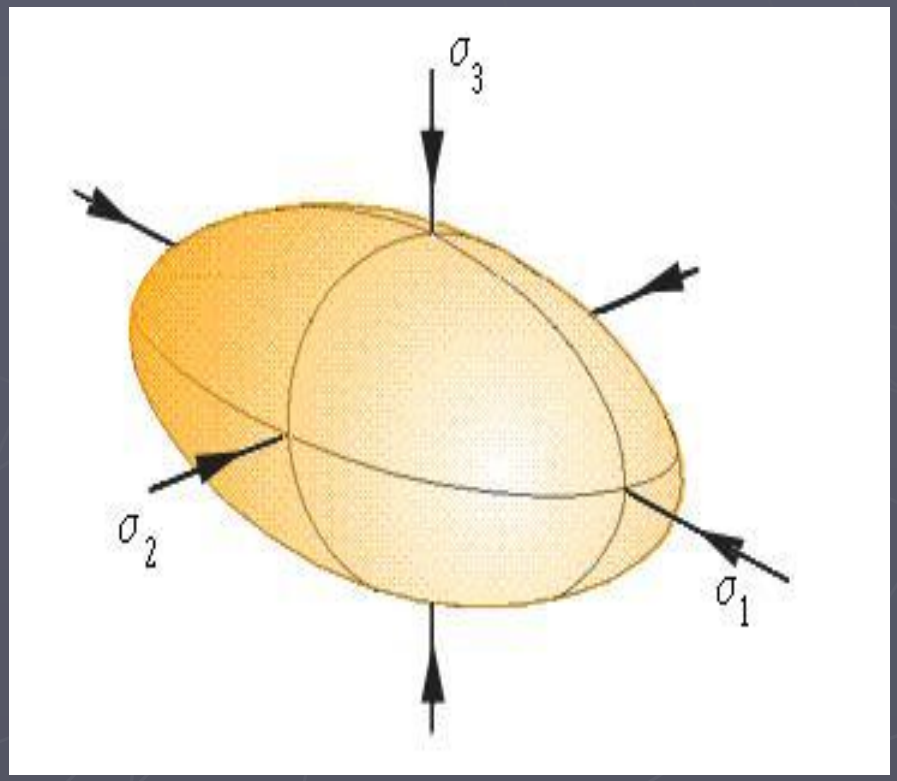
- σ_n is the stress normal to a given surface
  - Positive σ_n is a compressive stress
  - Negative σ_n is an extensional (tensile) stress
- σ_s is the stress parallel to a given surface
  - Positive σ_s causes counterclockwise rotation
    Negative σ_s causes clockwise rotation

Cauchy's Theorum

- 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 σ_1, σ_2, and σ_3
- By definition $\sigma_1 \geq \sigma_2 \geq \sigma_3$

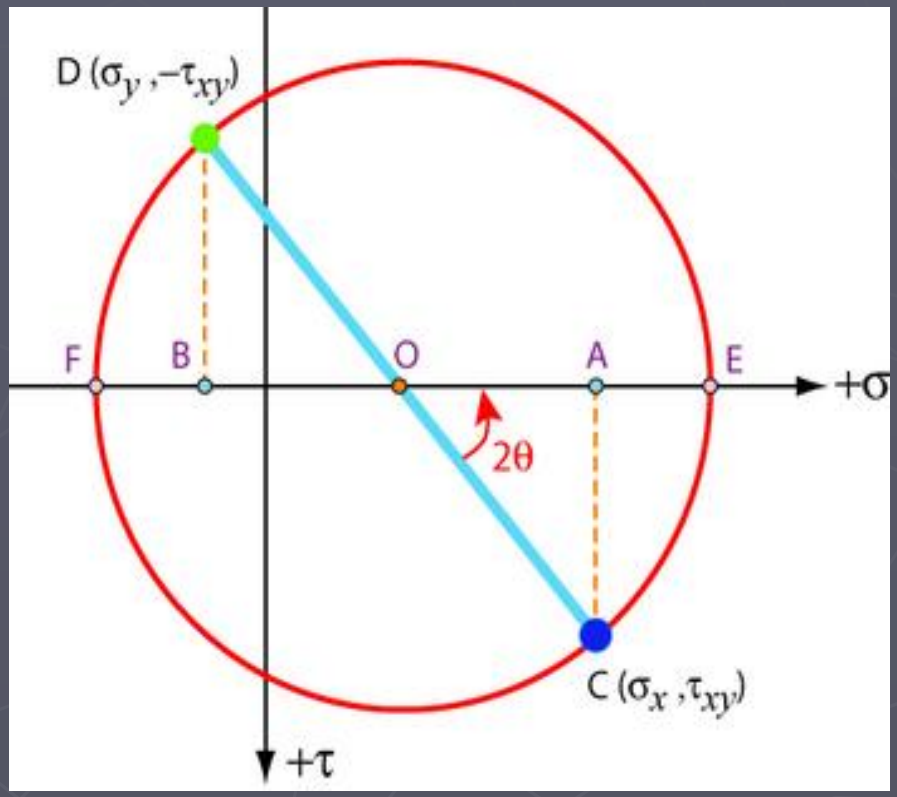
STRESS ELLIPSOID

- 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



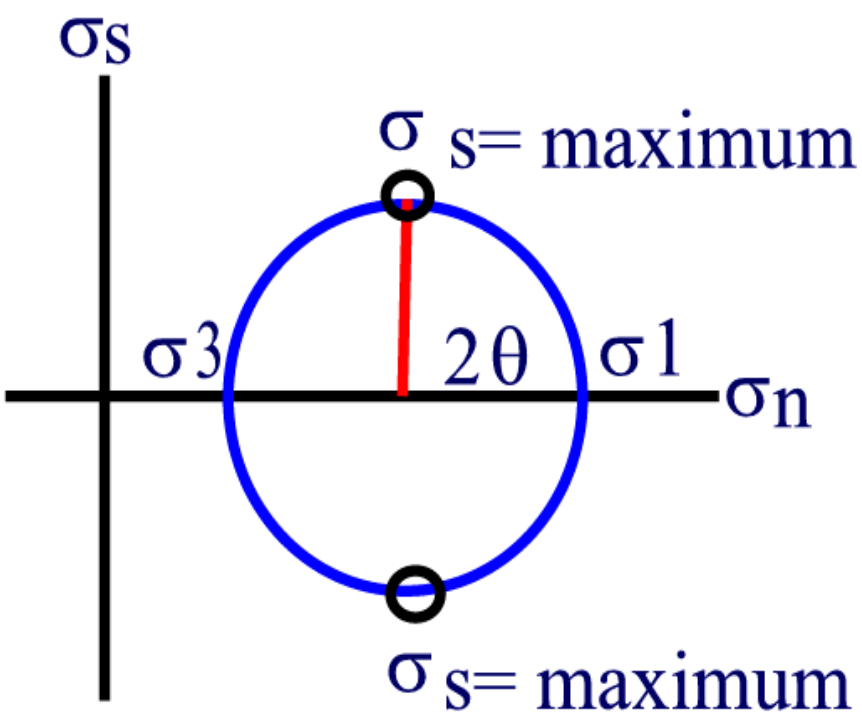
MOHR CIRCLE

- For any plane not perpendicular to the principal stress axes, there will be both a σ_n and a σ_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



MOHR CIRCLE

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

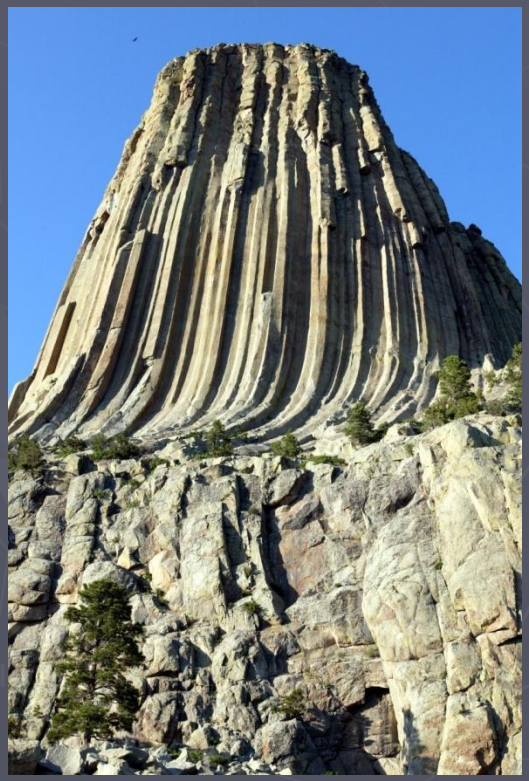
- Joint sets can develop in any orientation: vertical, horizontal, oblique
- A joint system in multiple orientations can allow for extension in 3 dimensions

3D joint system

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

COLUMNAR JOINTS

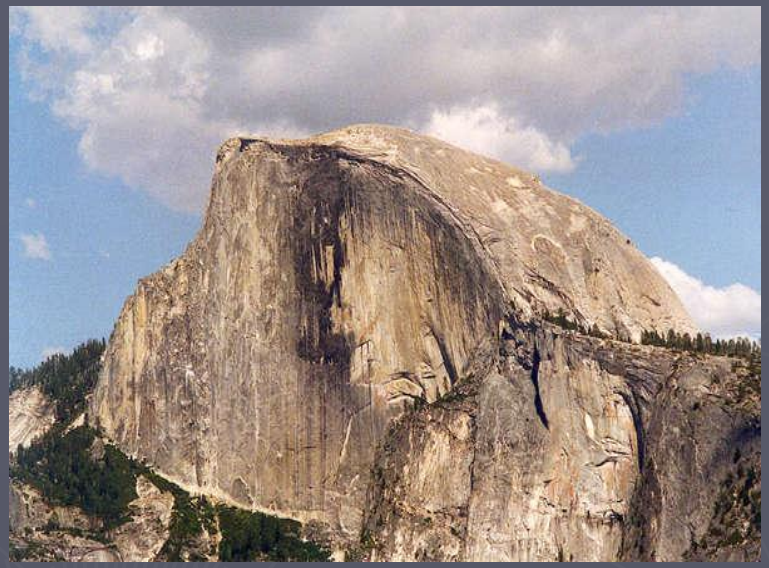
- Columnar joints are parallel, prismatic columns that occur in volcanic flows and shallow-level intrusions
- Form due to the tensile stress that develops in a cooling sheet-like igneous body due to contraction
- Joints initiate at the contacts and propagate inward



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/~rmr/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

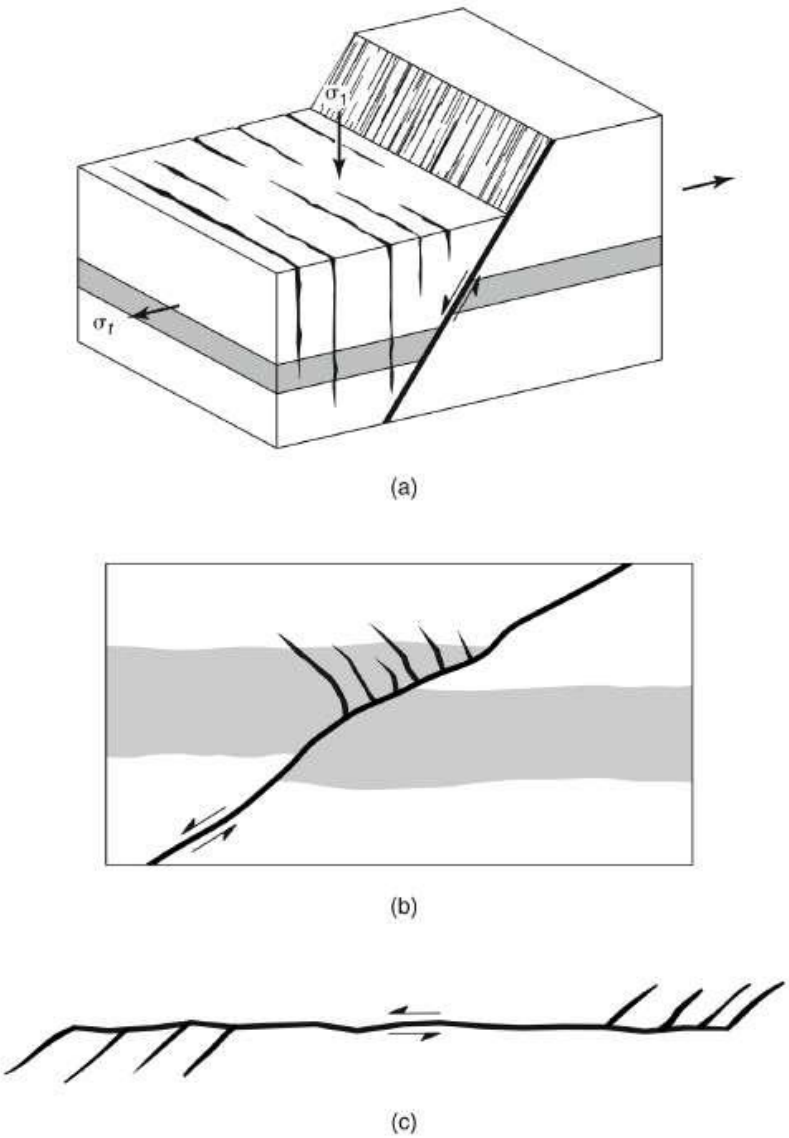
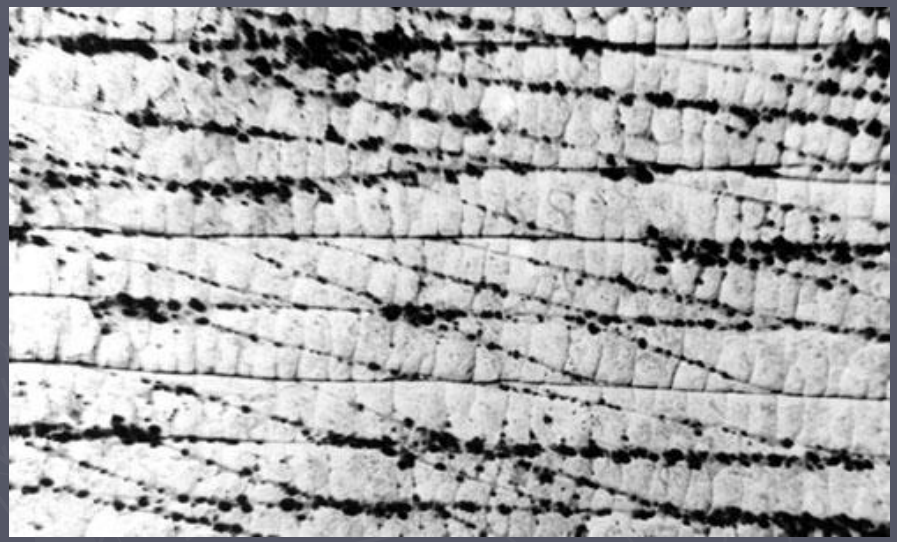


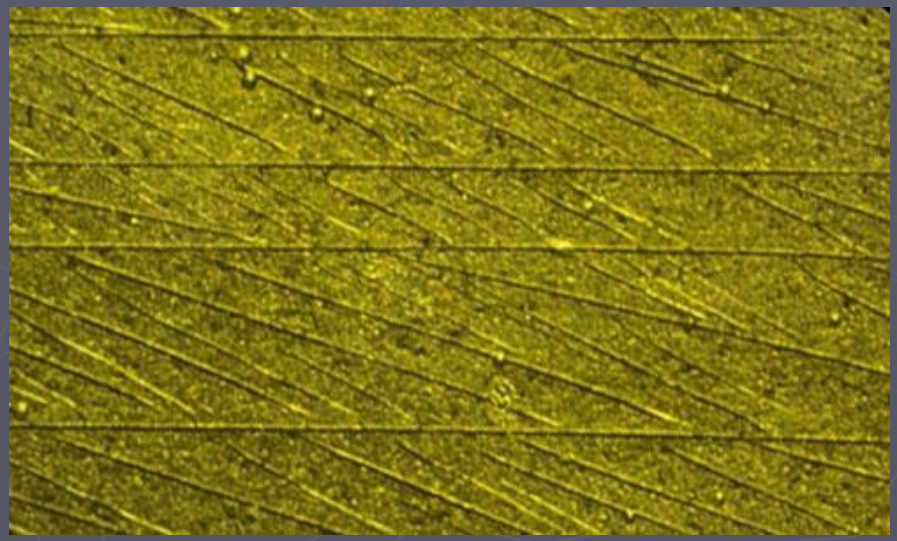
FIGURE 7.17 (a) Formation of joints in the hanging-wall block of a region in which normal faulting is taking place. (b) Formation of joints above an irregularity in a (reverse) fault surface. (c) Pinnate joints along a fault.

Joints can develop in regions of active faulting

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

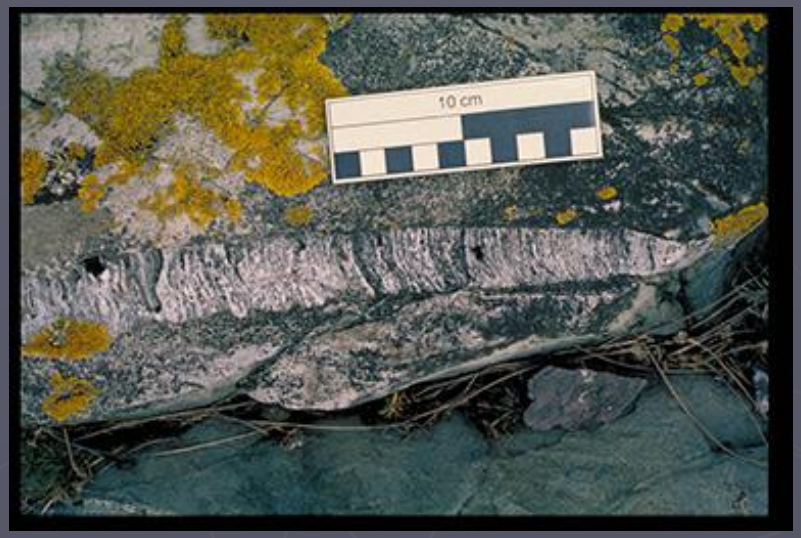


Joint pattern in varnish on folded surface

http://www.dstu.univ-montp2.fr/geofracnet/techniques.html

VEINS

- If a fracture opens then minerals may precipitate in the empty space to form a vein
  - Length parallel to σ1
  - Width parallel to σ3



- Extensional Veins tend to be continuous and straight

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

Interpret…