Metamorphic Fabric

Chapter 13A

Solid-state Crystal Growth

- Nucleation
  - Crystallization of new phases
- Crystal growth
  - Modification of existing grain boundaries

Nucleation

- Homogeneous nucleation
- Heterogeneous nucleation

Homogeneous Nucleation

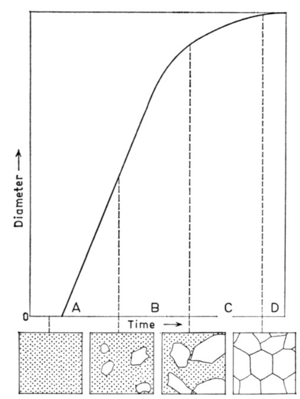
- Formation of new minerals within another mineral
- Free energy of new phase is greater than its surface energy
- Rate of homogeneous nucleation is very slow

Heterogeneous Nucleation

- New minerals form along existing grain boundaries or other discontinuities
- This mechanism is common

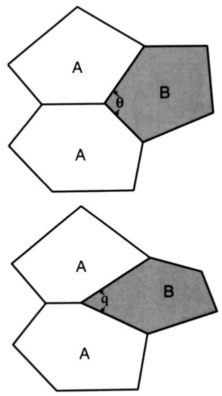
Crystal Growth

- Nucleation
- Independent growth
- Some contacts
- Granoblastic texture



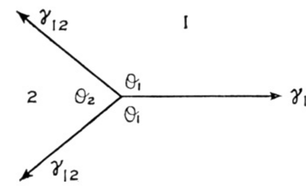
Granoblastic Texture

- Triple points
- Straight grain boundaries
- Interfacial angle controlled by surface energy of crystals in contact



Interfacial Angles

- Dihedral angles (θ)
- Controlled by facial energy
- Sine relationship applies

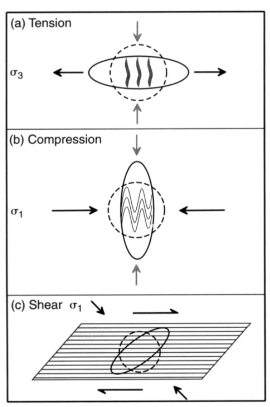


$$\frac{\gamma_{11}}{\sin \theta_2} = \frac{\gamma_{12}}{\sin \theta_1}$$

$$\frac{\gamma_{11}}{\gamma_{12}} = \frac{\sin \theta_2}{\sin \theta_1}$$

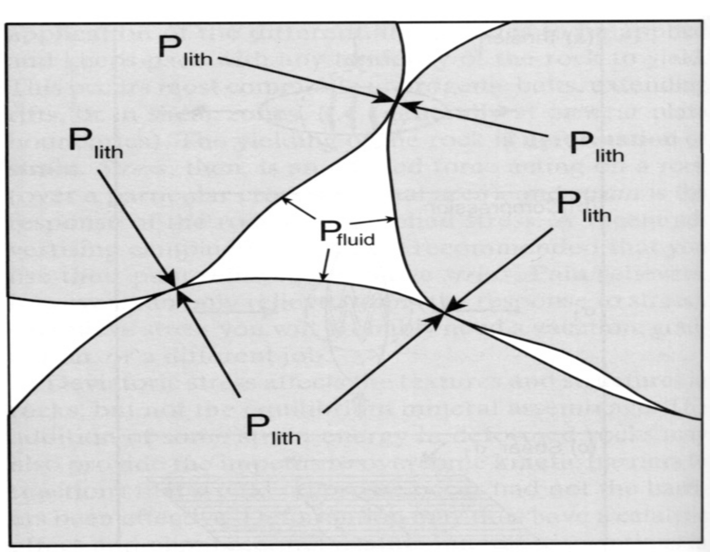
Stress Categories

- Tension
- Compression
- Shear



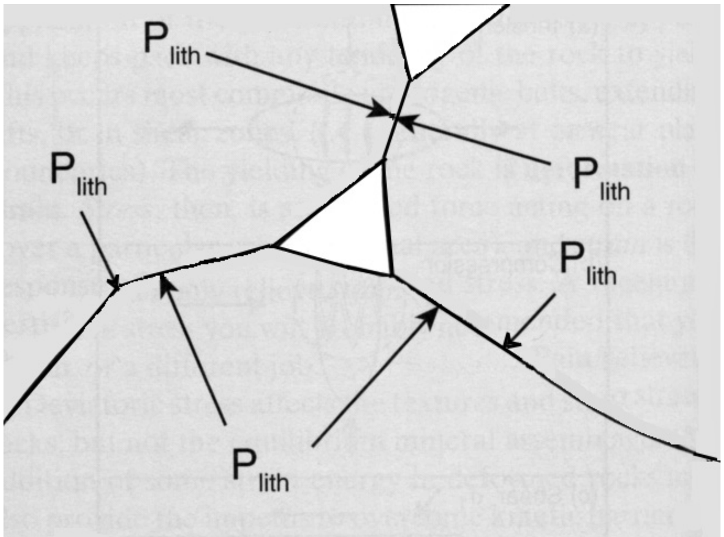
Hydrostatic Pressure

- **Defined as a uniform stress on a point regardless of direction**
- **Hydrostatic pressure increases with depth in the earth**
- **Its value equals ρgz**



Pressure Solution

- **Areas under high stress dissolve**
- **Material moves to regions of low stress**
- **Migration facilitated by an intergranular fluid**
- **Driving mechanism is a chemical potential**
- **Evidenced by growth into pressure shadows**



Formation of Porphyroblasts

- Controlled by nucleation phenomena
- Megacrysts have a high surface energy
  - If only a few nuclei may form
  - They may grow to a very large size

Stress

- Stress is measured by F/A
- Units are Newtons/m^2, MPa, bars, etc.
- σ is the symbol for stress
- $\sigma = \lim \Delta F/\Delta A$ as ΔA becomes infinitely small

Directed Stress

- Tectonism produces non-uniform stress
- This causes:
  - Rock deformation
  - Preferred orientation of mineral grains
  - Development of large-scale structures

Strain

- Strain is the response to stress
- ε is the symbol for strain
- $\varepsilon = \lim \Delta l/l_o$ as Δl approaches zero

  Δl is the change in length in a line element

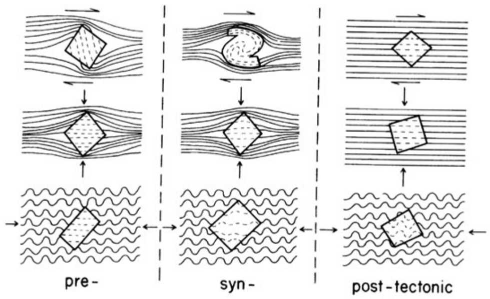
  l_0 is the original length of the same line element

Strain Measurements

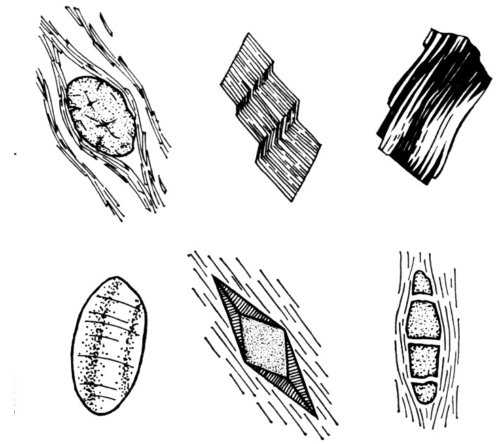
- Units of strain are given as a fraction of the initial dimension
- Length strain
  - $\varepsilon_l = \Delta l/l_o$
- Volume strain
  - $\varepsilon_v = \Delta V/V_o$

Timing of Porphyroblast Growth

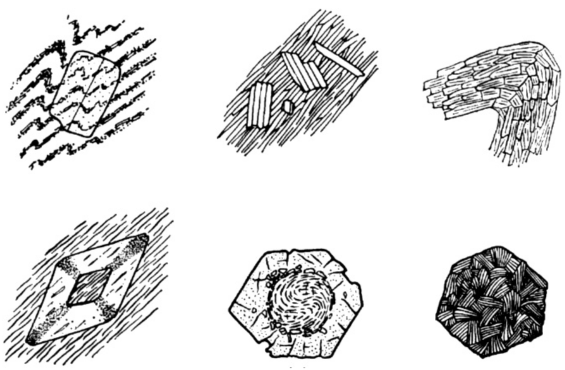
Pre-tectonic, Syn-tectonic, Post-tectonic



Pre-tectonic Textures



Post-tectonic Textures



Types of Rock Behavior

- **Elastic (like a spring)**
  - **All deformation recoverable**
  - **Linear deformation with applied stress**
- **Viscous (honey)**
  - **No deformation recoverable**
  - **No threshold for deformation**

Types of Rock Behavior

- **Plastic (clay)**
  - **Some deformation recoverable**
  - **Yield strength must be overcome**
- **Brittle (halite)**
  - **Yields by fracturing**
  - **Generally elastic behavior prior to rupture**

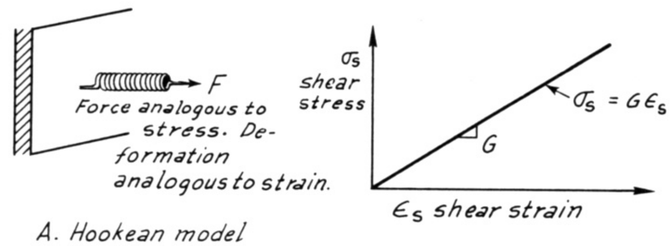
Rheology

- **The study of the flow of materials**
- **Strength describes the condition of materials when they fail**
- **Soft materials begin to yield at their yield strength**
- **Brittle materials will rupture at their fracture strength**

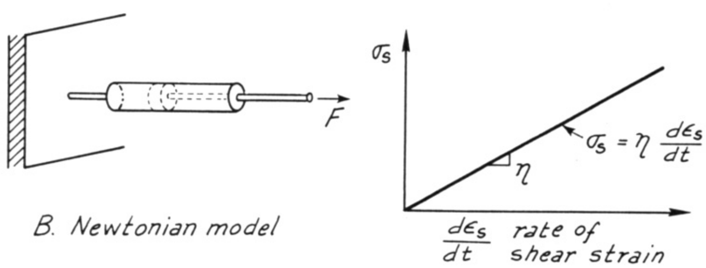
Linear Rheological Models

- **Hookean model** **elastic**
- **Newtonian model** **viscous**
- **Saint Venant model** **plastic**

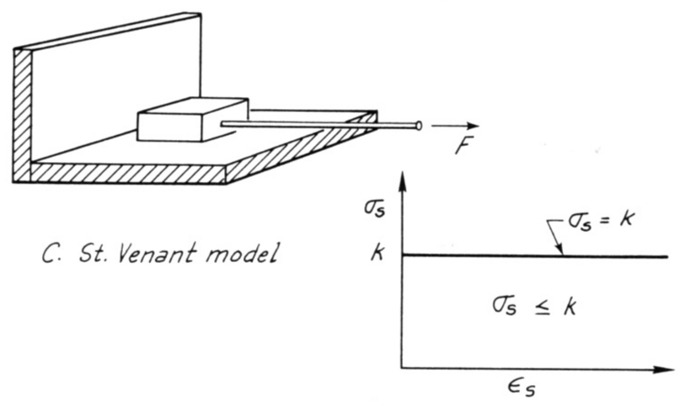
Elastic Model



Viscous Model



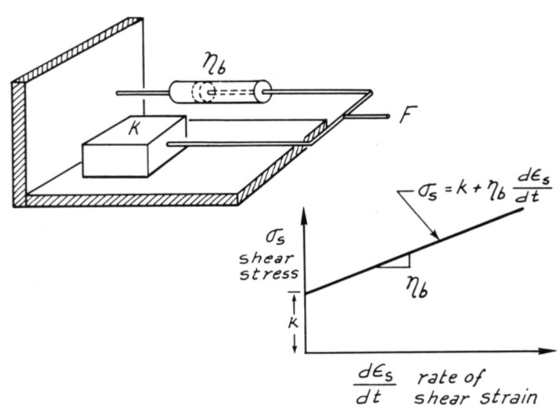
Sliding Block Model



Complex Rheological Models

- **Bingham model**
- **Has both a yield strength (k_b)and a viscosity (η_b)**
- **Common behavior of natural materials**

Plastic Model

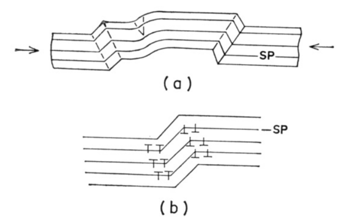


Metamorphic Tectonites

- Undulatory extinction
  - Wavy extinction in quartz
  - Bent twin planes in crystals
- Deformation bands
- Deformation lamellae

Low Temperatures & High Strain Rates

- Undulatory extinction
- Kink bands
- Deformation lamellae



High Temperatures & Slow Strain Rates

- Recovery and recrystallization occur
- Sutured grain boundaries
- Small new grains form

Diffusive Flow

- Thermally activated
- Stress induced
- Diffusive recrystallization
- Sometimes called pressure solution

Role of Fluids in Deformation

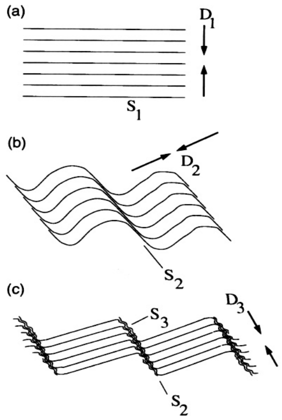
- Hydraulic weakening of non-hydrous silicates
- Prograde dehydration reduces ductility
- High pore P_{H20} may cause rock to be brittle

Anisotropic Fabric

- Results from syntectonic flow under stress
- Causes include:
  - Applied nonhydrostatic stress
  - Magnitude of strain
  - Strain rate
  - T & P

Fabric Geometry

- Very complicated
- Non-homogeneous rock bodies
- Linked chain of events
- Unambiguous answers



Grain Orientation

- Foliation commonly parallel to axial plane of folds
  – Noted by orientation of platy minerals
- Lineation commonly parallels hinge line
  – Given by alignment of elongate minerals

Orientation Mechanism

- Not easy to determine
- Nucleation and growth?
- Rotation of grains?
- Pressure solution?

Segregation Layering

- Alternating bands of different minerals
  – Relict beds?
  – Mechanical transportation processes?
- Easier to determine in lower grade rocks
- Uncertain origin in higher grade rocks