# Chapter 3: Igneous Textures

- **3.1.1 Rates of nucleation, growth, & diffusion**
  - The **relative rates** of initial *nucleation*, *crystal growth* and *diffusion* will have considerable influence on the ultimate texture of the resulting rock
    - However, whichever rate is the *slowest* will be the overall rate-determining process and exert the most control over crystallization
  - Additional rate to factor-in: **cooling rate**

# Chapter 3: Igneous Textures

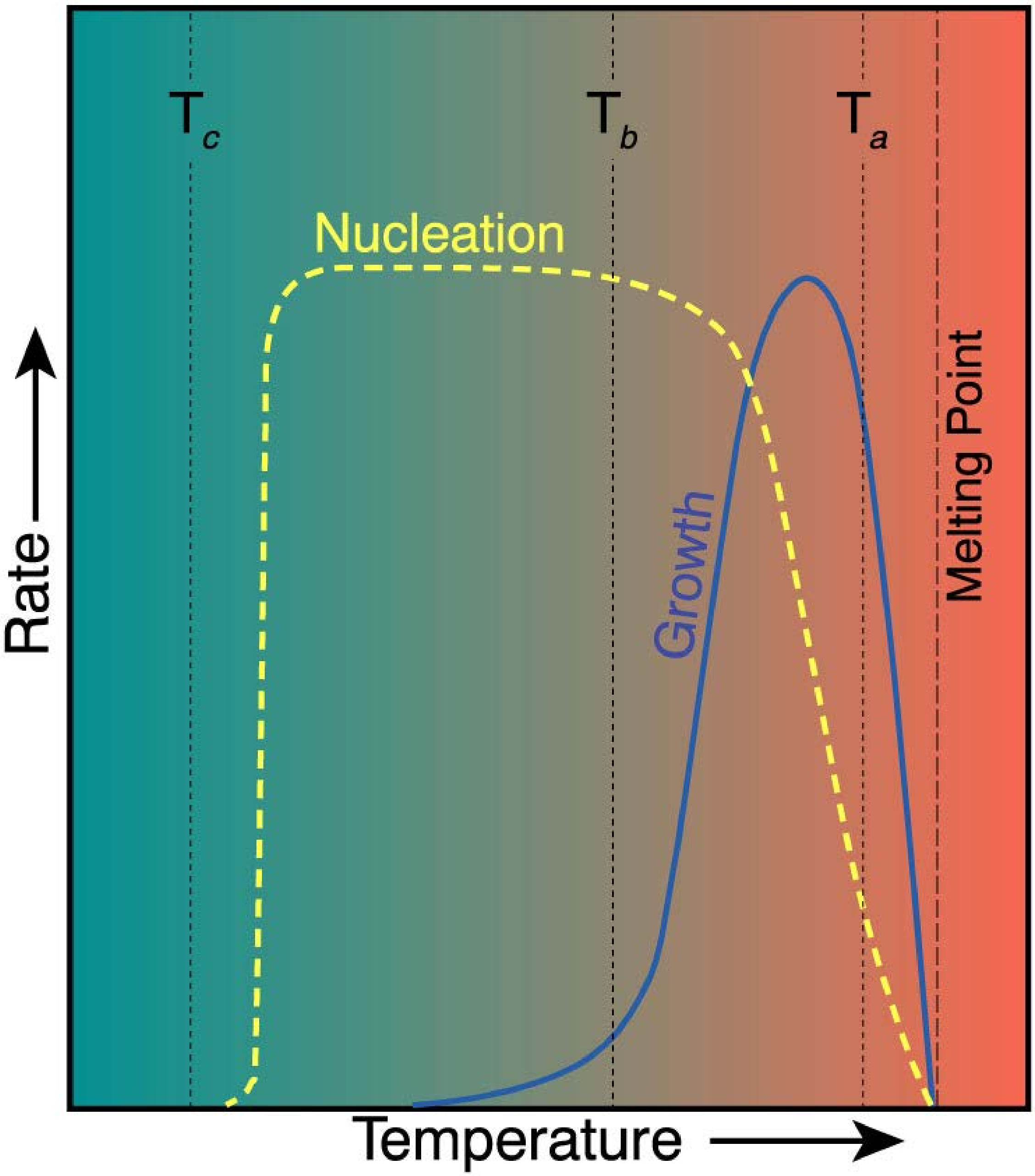
- If cooling rate is slow, equilibrium is maintained or closely approximated

- If cooling rate is too high, significant **undercooling** may take place – reduces nucleation, growth or diffusion

- Initially, undercooling enhances rates of nucleation, crystal growth and diffusion – however, continued undercooling **decreases kinetics** (diffusion, mobility) and **increases viscosity**, thus inhibiting these rates

# Chapter 3: Igneous Textures

Figure 3.1. Idealized rates of crystal nucleation and growth as a function of temperature below the melting point. Slow cooling results in only minor undercooling ($T_a$), so that rapid growth and slow nucleation produce fewer coarse-grained crystals. Rapid cooling permits more undercooling ($T_b$), so that slower growth and rapid nucleation produce many fine-grained crystals. Very rapid cooling involves little if any nucleation or growth ($T_c$) producing a glass.



# Chapter 3: Igneous Textures

- Typically, two-stage cooling results in what type of texture?

- How does two-stage cooling take place?

- **Porphyritic texture**: distinct bimodal distribution in grain size, one considerably larger than the other;
  - i.e., **Phenocrysts** (large crystals) surrounded by a fine-grained **matrix** or **groundmass**

# Chapter 3: Igneous Textures

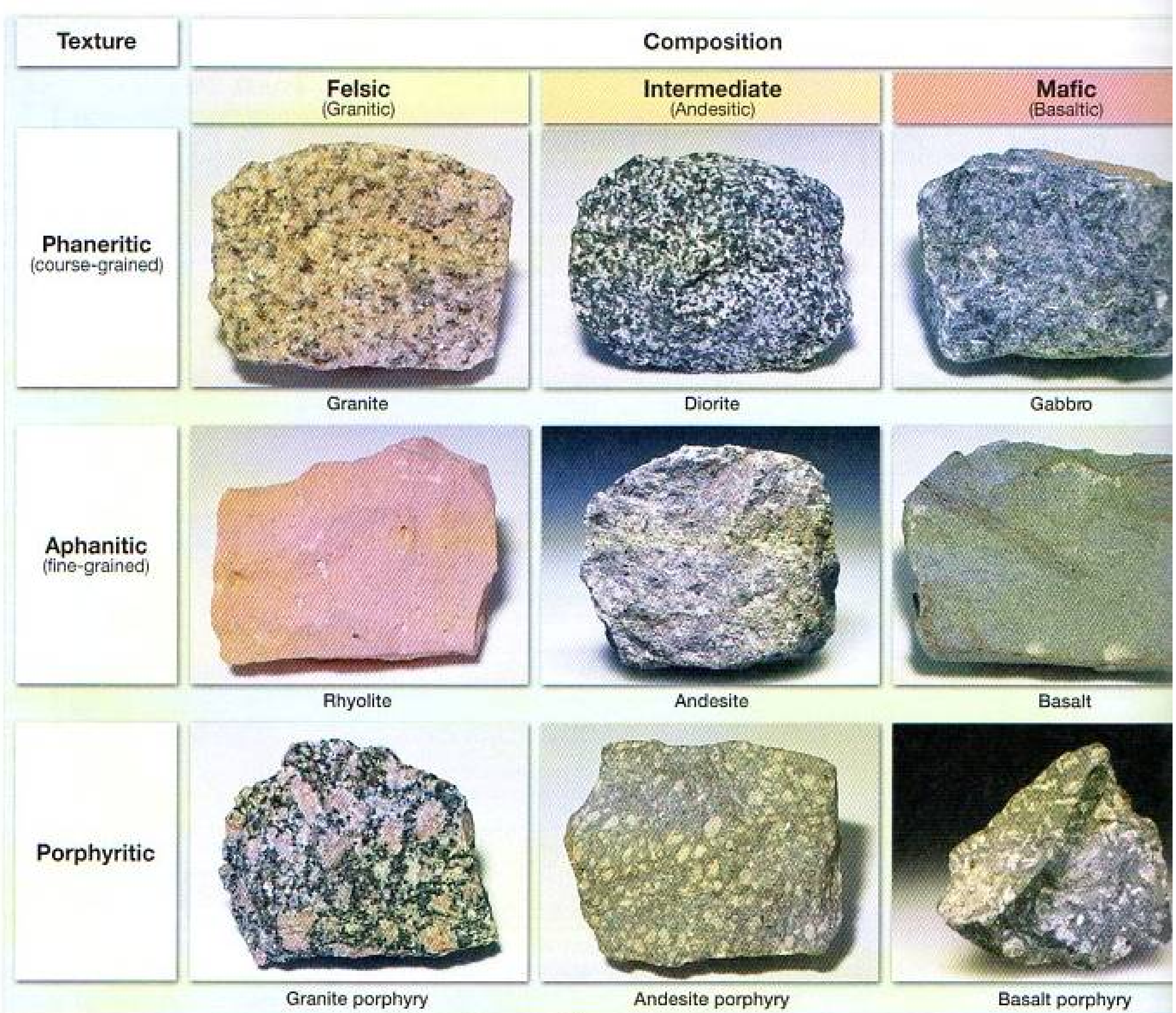
- Growth rate of a crystal depends upon:
  - Surface energy of the faces
  - Diffusion rate
  - If cooling rate is constant, the largest crystals will usually be those with the most plentiful or fastest-diffusing components
  - Diffusion rate of a chemical species is faster at higher temperature, and in lower viscosity
  - Small ions with low charge diffuse better than large polymerized complexes

# Properties of Igneous Rocks

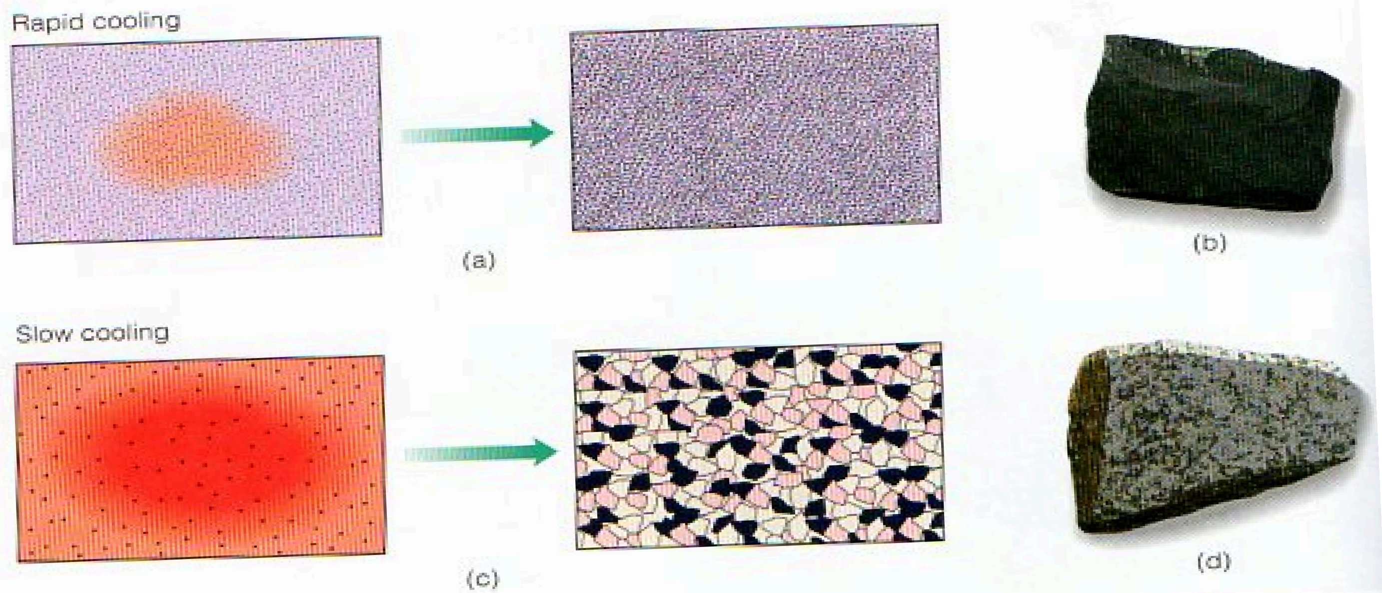
**Texture** - description of the degree of crystallinity, grain size and shape, and arrangement of the minerals

- **Phaneritic** - crystals visible to the naked eye "you can see the bits"
  - Coarse-grained - 3 cm to 5 mm
  - Medium-grained - 1-5 mm
  - Fine-grained - < 1 mm
- **Aphanitic** - crystals so small that they cannot be seen with the naked eye
- **Holocrystalline** - composed entirely of crystals
- **Holohyaline** - composed entirely of glass
- **Hypocrystalline** - composed of crystals and glass
- **Vitrophyric –** phenocrysts set in a glassy groundmass
- **Poikilitic** – phenocrysts contain numerous inclusions of another mineral that they enveloped with growth. Host crystal is called an **Oikocryst**.
- **Vesicles** - holes in the rock formed by escaping gases during solidification

# Properties of Igneous Rocks



# Properties of Igneous Rocks - Cooling Rates & Textures



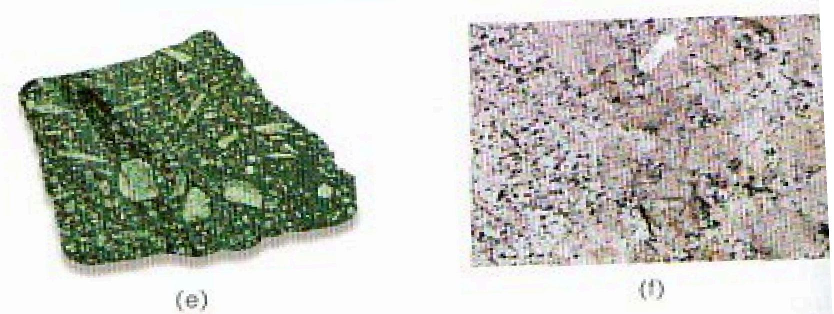
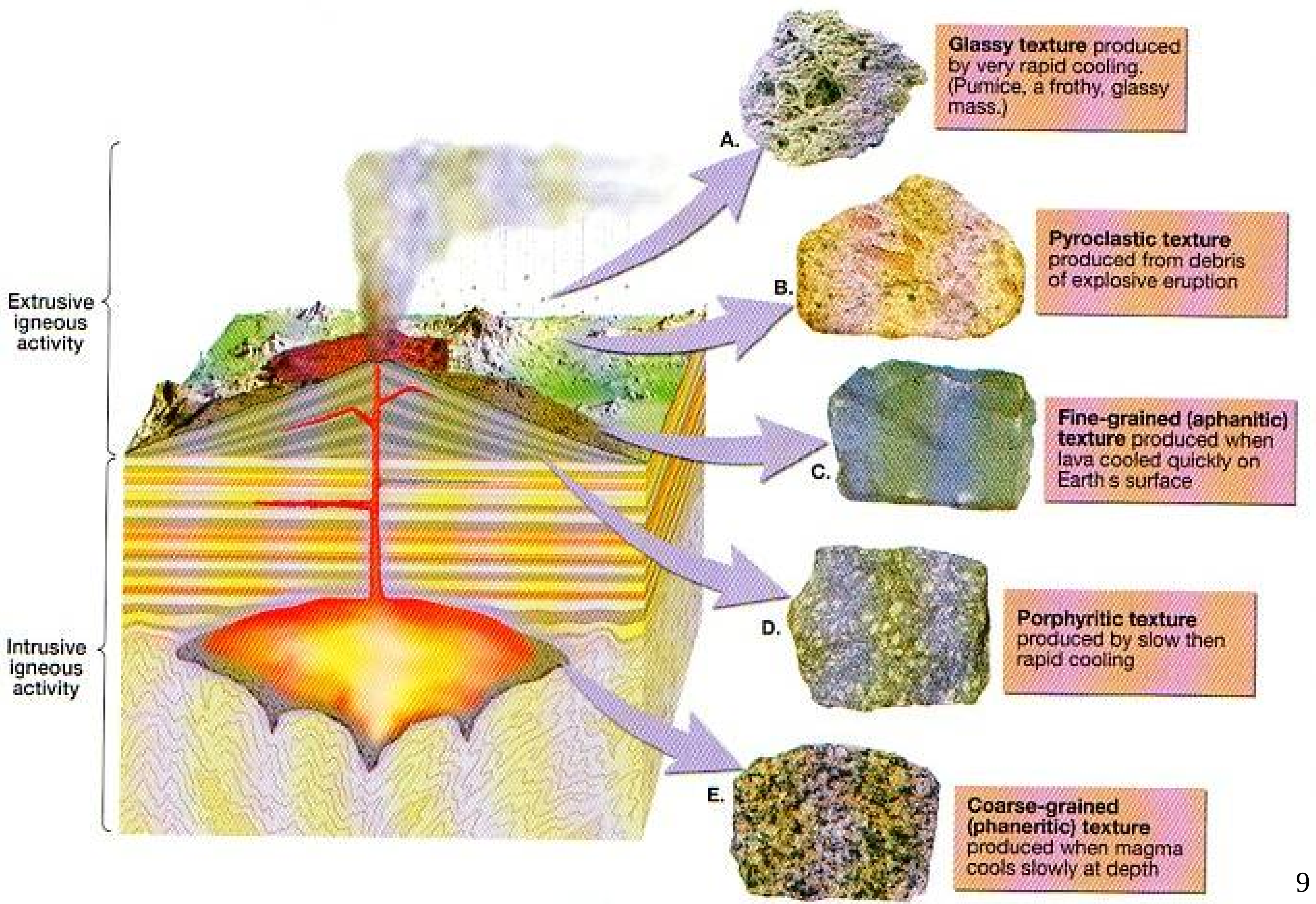




**Figure 3.8**
Magma cooling rate and its effect on nucleation and growth of mineral crystals. (a) Rapid cooling results in many small minerals and a fine-grained, or aphanitic, texture. (b) Igneous rock with an aphanitic texture. (c) Slow cooling yields a coarse-grained, or phaneritic, texture. (d) Igneous rock with a phaneritic texture. The rocks in (e) and (f), both of which are porphyritic, had a more complex cooling history. The texture in (e) is appropriately called aphanitic porphyritic, whereas the one in (f) is phaneritic porphyritic.

# Igneous Rock Textures –
# Relation to Environment of Cooling & Solidification

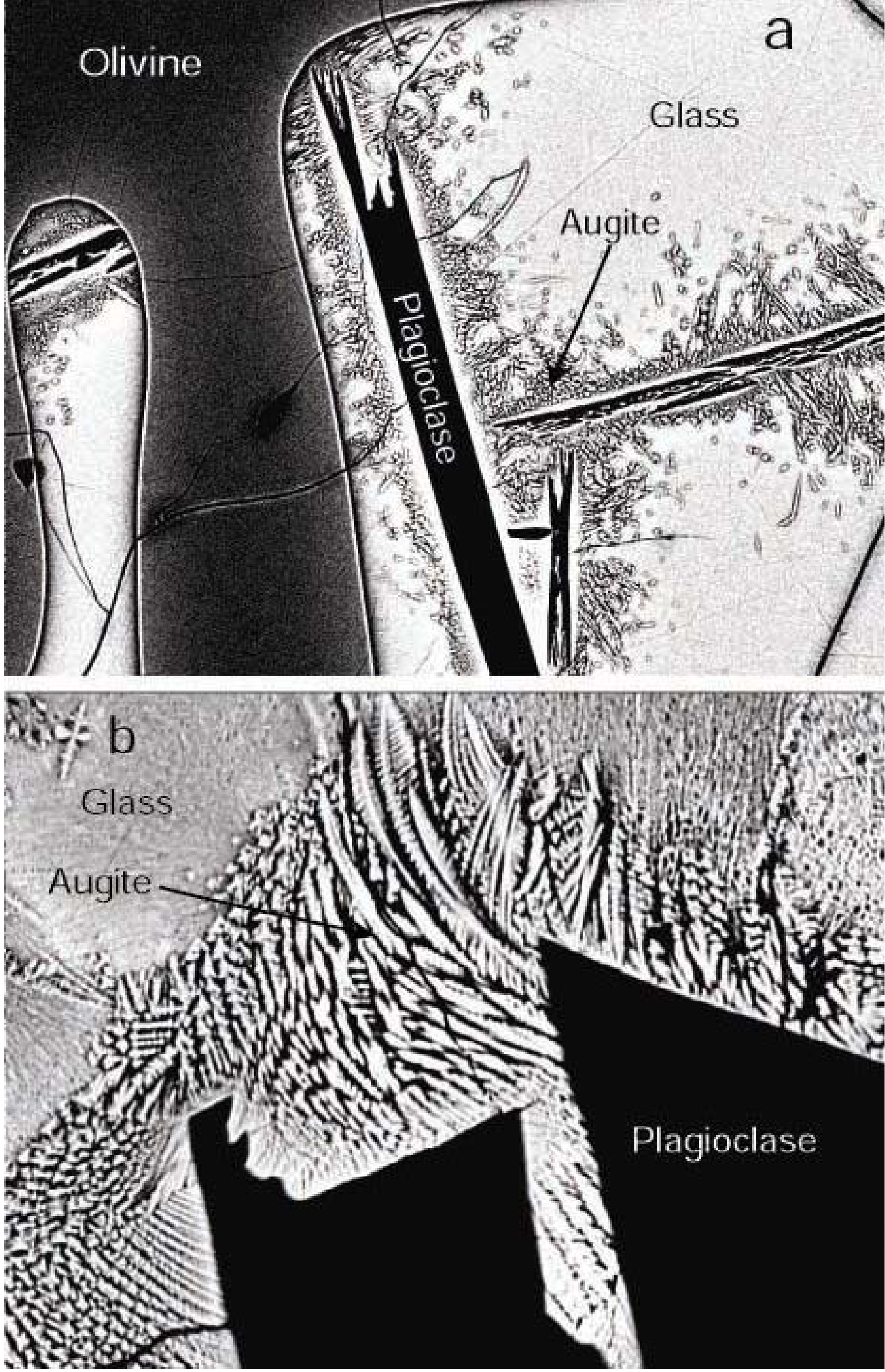


# Chapter 3: Igneous Textures

- **Dendritic** texture (Fig. 3.2)
  - Radiating form, or tree-like branching
  - Rate of diffusion is slower than the rate of growth (e.g., quickly cooled, or “quenched” lavas)
  - Depleted liquid builds up at crystal-liquid interface
  - Crystals reach out in tendrils beyond depleted zone to tap a supply of appropriate elements or cooler melt
  - Eliminate heat build up?
  - Result of both processes?

# Igneous Textures

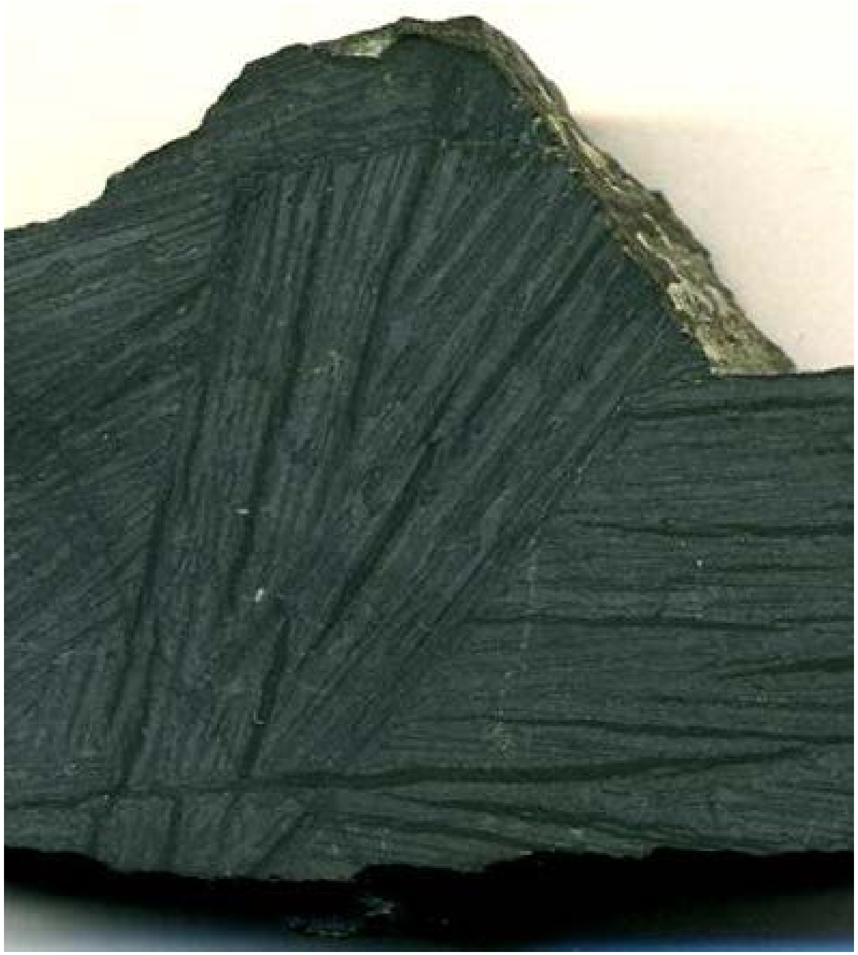
**Figure 3.2**. Backscattered electron image of quenched "blue glassy pahoehoe," 1996 Kalapana flow, Hawaii. Black minerals are felsic plagioclase and gray ones are mafics. **a.** Large **embayed** olivine phenocryst with smaller plagioclase laths and clusters of feathery augite nucleating on plagioclase. Magnification ca. 400X. **b**. ca. 2000X magnification of feathery quenched augite crystals nucleating on plagioclase (black) and growing in a dendritic form outward. Augite nucleates on plagioclase rather than pre-existing augite phenocrysts, perhaps due to local enrichment in mafic components as plagioclase depletes the adjacent liquid in Ca, Al, and Si. © John Winter and Prentice Hall.



# Chapter 3: Igneous Textures

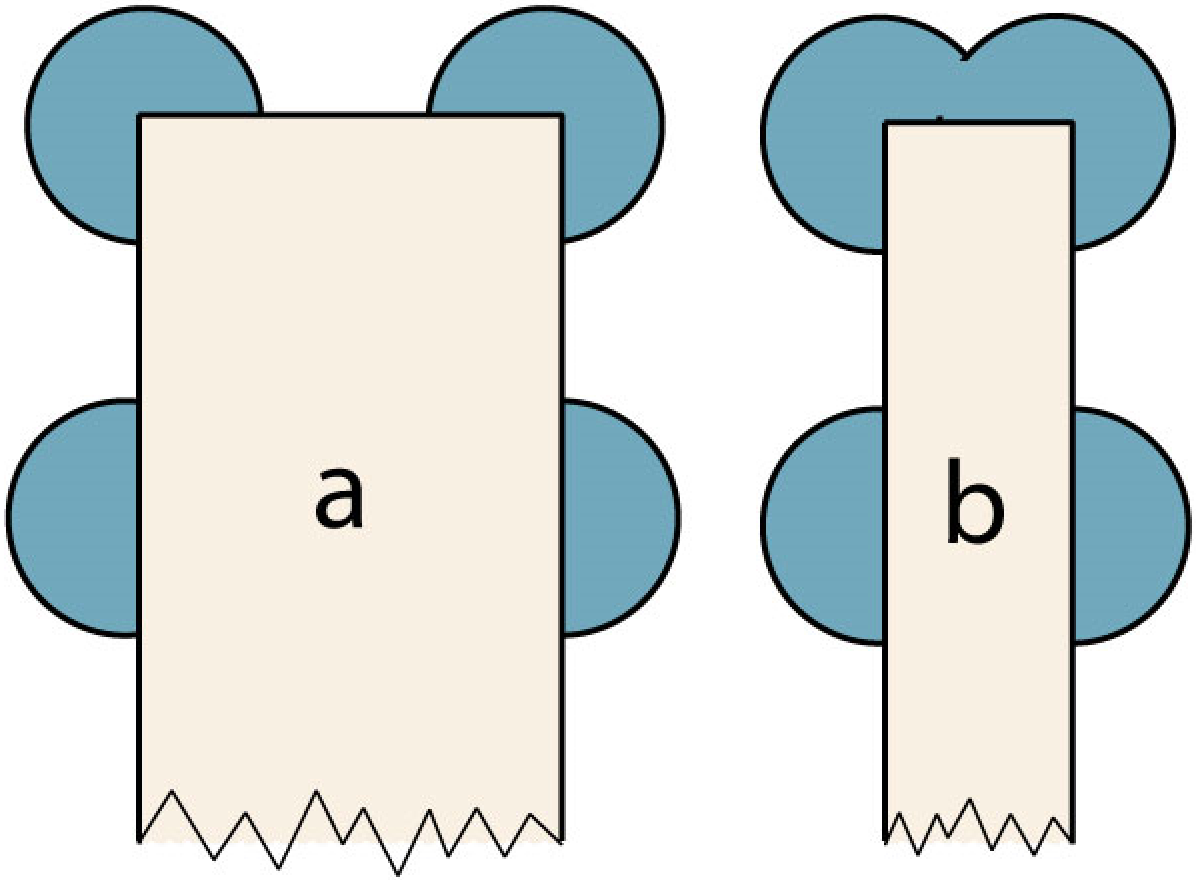
- **Spinifex** texture:
  - Ultramafic lavas, such as Precambrian komatiites, develop spectacularly elongated **olivine** crystals (some up to 1 m long!)
  - Result of rapid growth of olivine (with simple structure) in a very low viscosity magma, **NOT** by slow cooling!

# **Spinifex** texture



# Igneous Textures –
# Skeletal & "swallow-tail" textures

**Figure 3.3. a.** Volume of liquid (green) available to an edge or corner of a crystal is greater than for a side. **b.** Volume of liquid available to the narrow end of a slender crystal is even greater. After Shelley (1993). Igneous and Metamorphic Rocks Under the Microscope. © Chapman and Hall. London.



# Igneous Textures

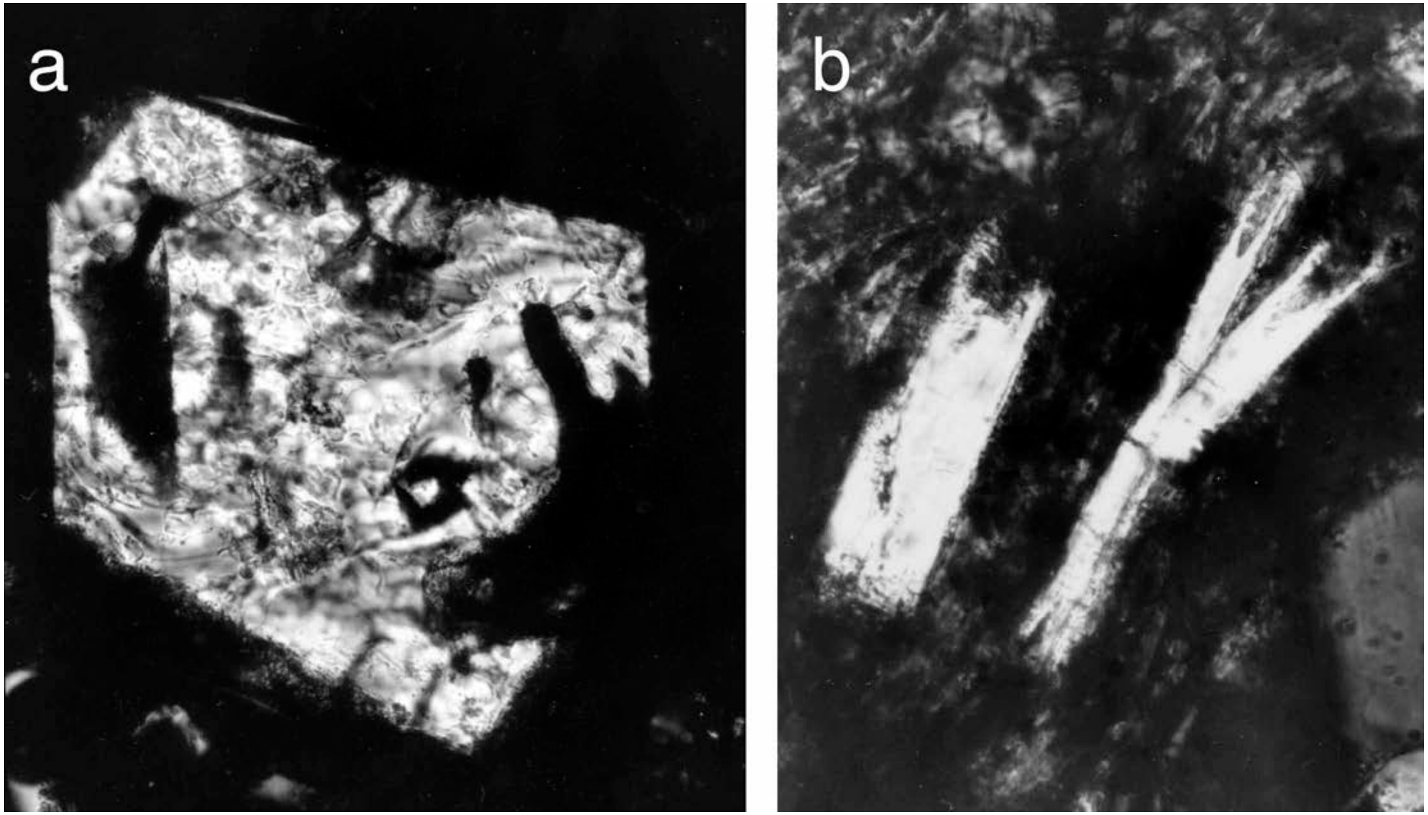



**Figure 3.4. a. Skeletal** olivine phenocryst with rapid growth at edges enveloping melt at ends. Taupo, N.Z. **b.** "**Swallow-tail**" plagioclase in trachyte, Remarkable Dike, N.Z. Length of both fields ca. 0.2 mm. From Shelley (1993). Igneous and Metamorphic Rocks Under the Microscope. © Chapman and Hall. London.

# Chapter 3: Igneous Textures

- **Epitaxis** texture:
  - Preferred nucleation of one mineral on a preexisting mineral
  - Similarity of the crystal structures of the mineral substrate and new phase is a prerequisite for epitaxial growth
  - E.g., growth of sillimanite on biotite or muscovite
  - The Si-Al-O structures in both sillimanite and mica are similar in geometry and bond lengths

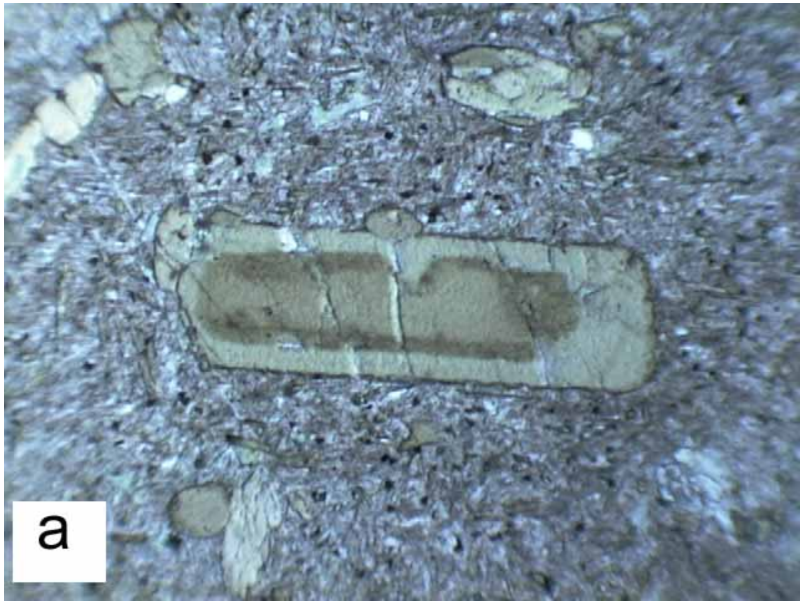
# Chapter 3: Igneous Textures

- **Rapakivi** texture:
  - Plagioclase overgrowths on orthoclase (K-feldspar)
  - Occurs in some granites

- **Spherulitic** texture:
  - In silicic volcanic rocks in which needles of quartz and alkali feldspar grow radially from a common center

- **Variolitic** texture:
  - Radiating plagioclase laths in some basalts are probably the result of nucleation of later crystals on the first nuclei to form during devitrification of glass.

# Igneous Textures – **Compositional zoning**



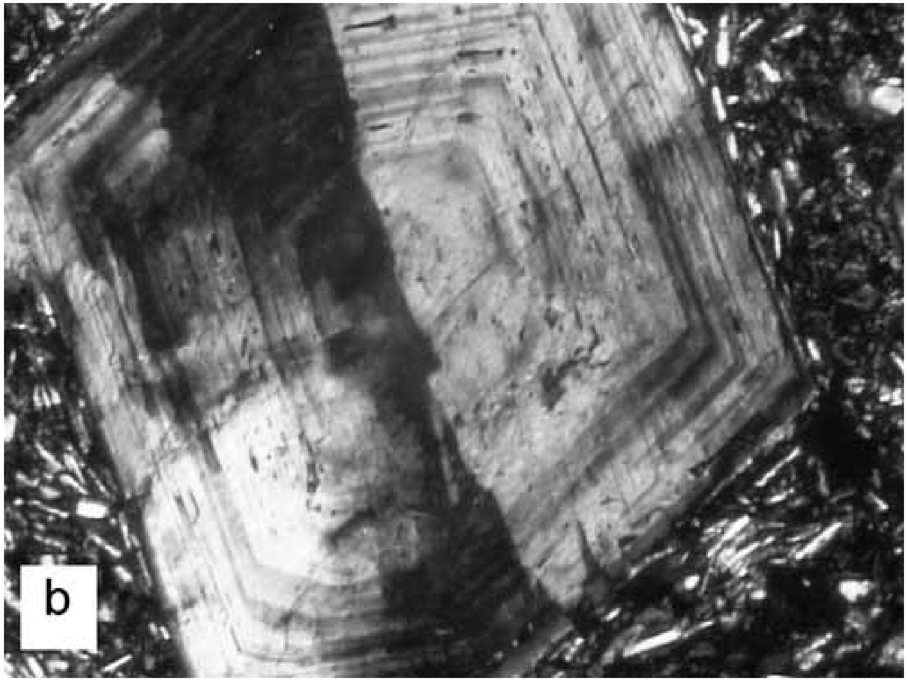




**Figure 3.5. a. Compositionally zoned** hornblende phenocryst with pronounced color variation visible in plane-polarized light. Field width 1 mm. **b.** Zoned (**oscillatory**) plagioclase twinned on the carlsbad law. Andesite, Crater Lake, OR. Field width 0.3 mm. © John Winter and Prentice Hall.

**Indicative of <u>non-equilibrium crystallization</u> conditions!!**

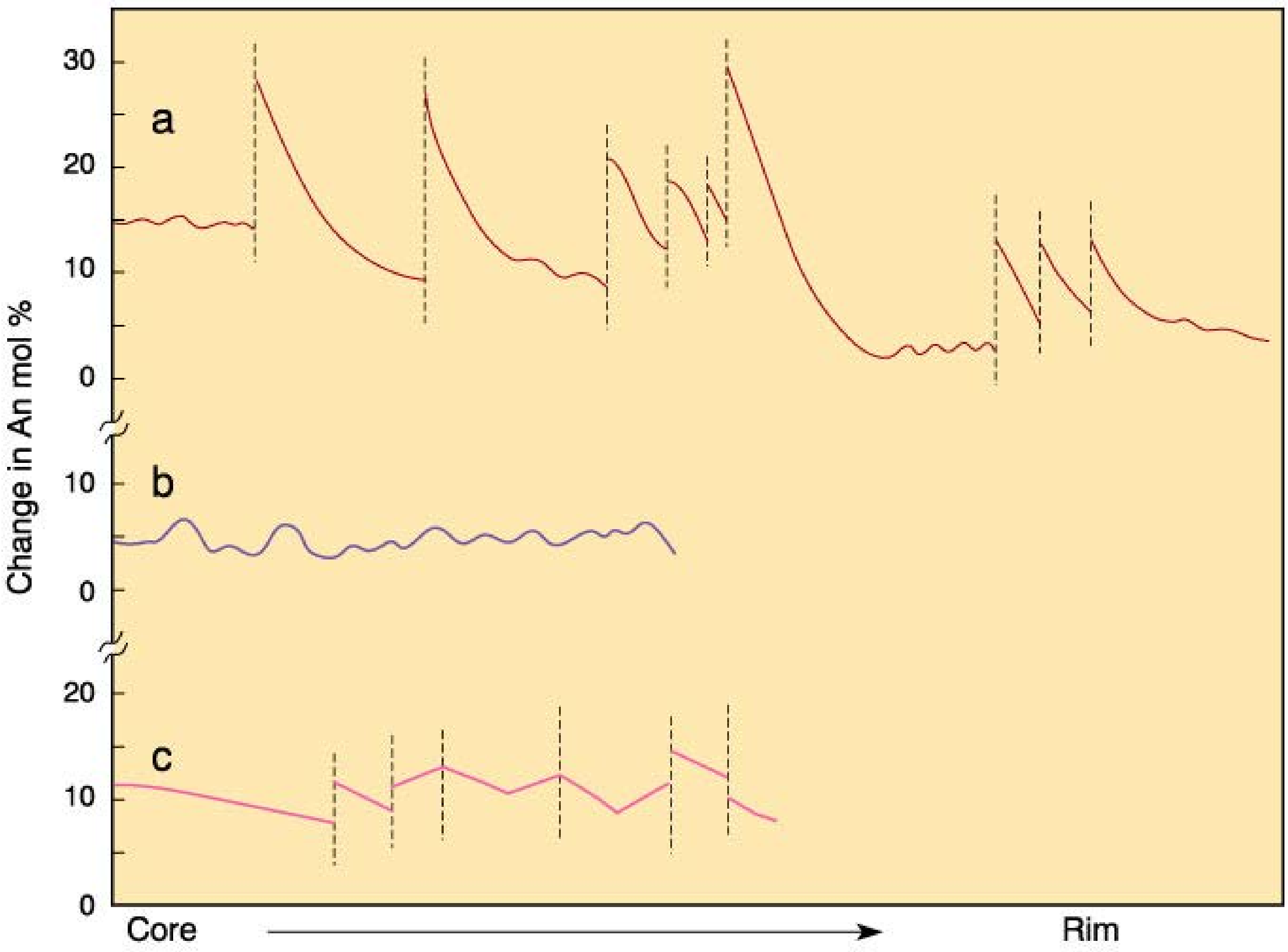



**Figure 3.6.** Examples of plagioclase zoning profiles determined by microprobe point traverses.

**a.** Repeated sharp **reversals** attributed to magma mixing, followed by **normal** cooling increments.

**b.** Smaller and irregular oscillations caused by local disequilibrium crystallization.

**c.** Complex oscillations due to combinations of magma mixing and local disequilibrium.

From Shelley (1993). Igneous and Metamorphic Rocks Under the Microscope. © Chapman and Hall. London.

# Chapter 3: Igneous Textures

- **3.1.4 Crystallization sequence**:
  - As a general rule, early-forming minerals in melts are not significantly undercooled and are surrounded completely by melt and develop ***euhedral*** crystals
  - As more crystals form and fill the magma chamber and come into contact with one another, this then impedes the development of crystal faces and ***subhedral*** and ***anhedral*** crystals form
  - Latest formed crystals may be interstitial, filling spaces between the earlier ones (Fig. 3.7 –next slide)

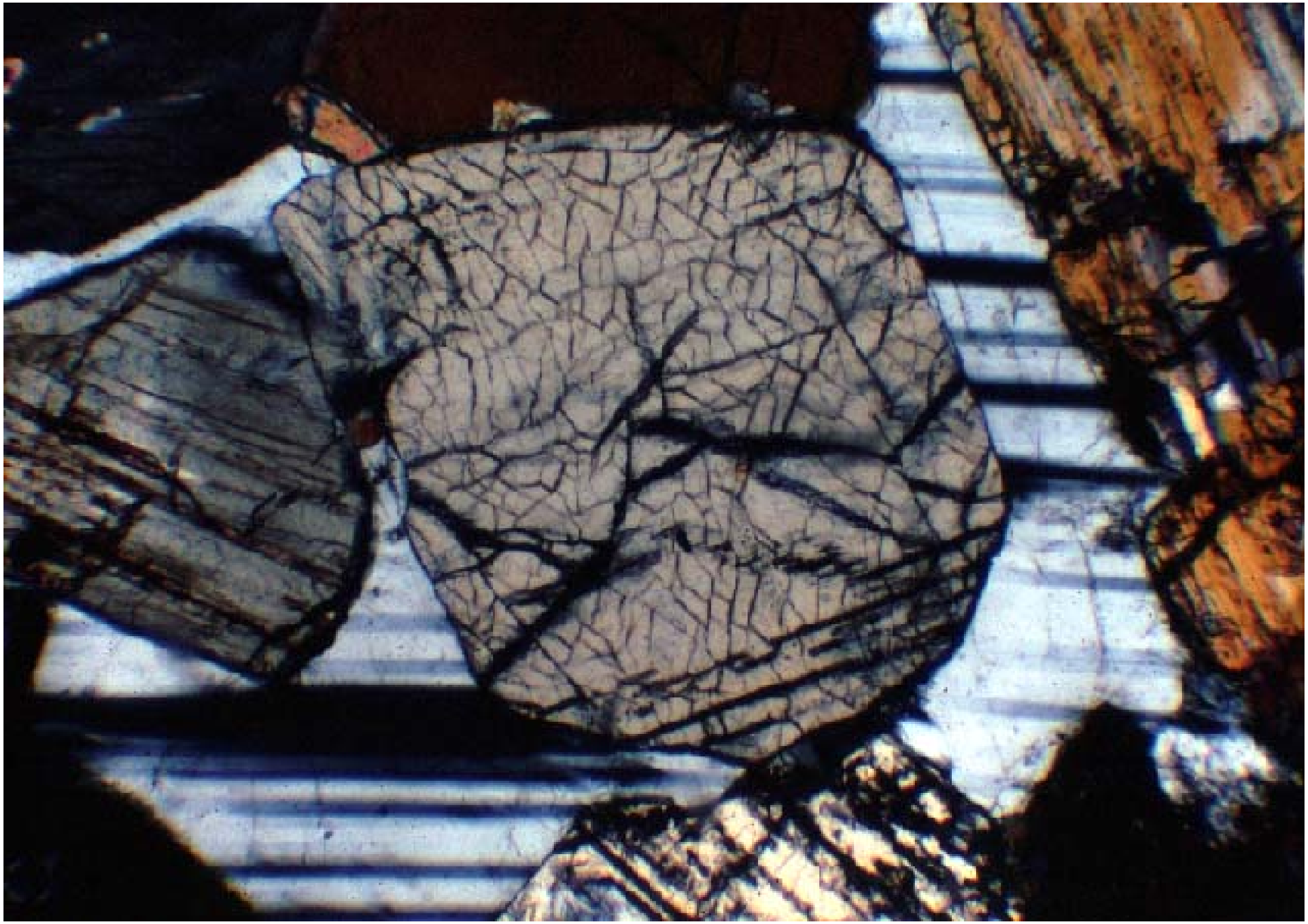


**Figure 3.7.** Euhedral early pyroxene with late **interstitial** plagioclase (horizontal twins). Stillwater complex, Montana. Field width 5 mm. 

# Chapter 3: Igneous Textures

- **Ophitic** texture (Fig. 3.8 – next slide)
  - Refers to envelopment of plagioclase laths by larger clinopyroxenes and is commonly interpreted to indicate that clinopyroxenes formed later.

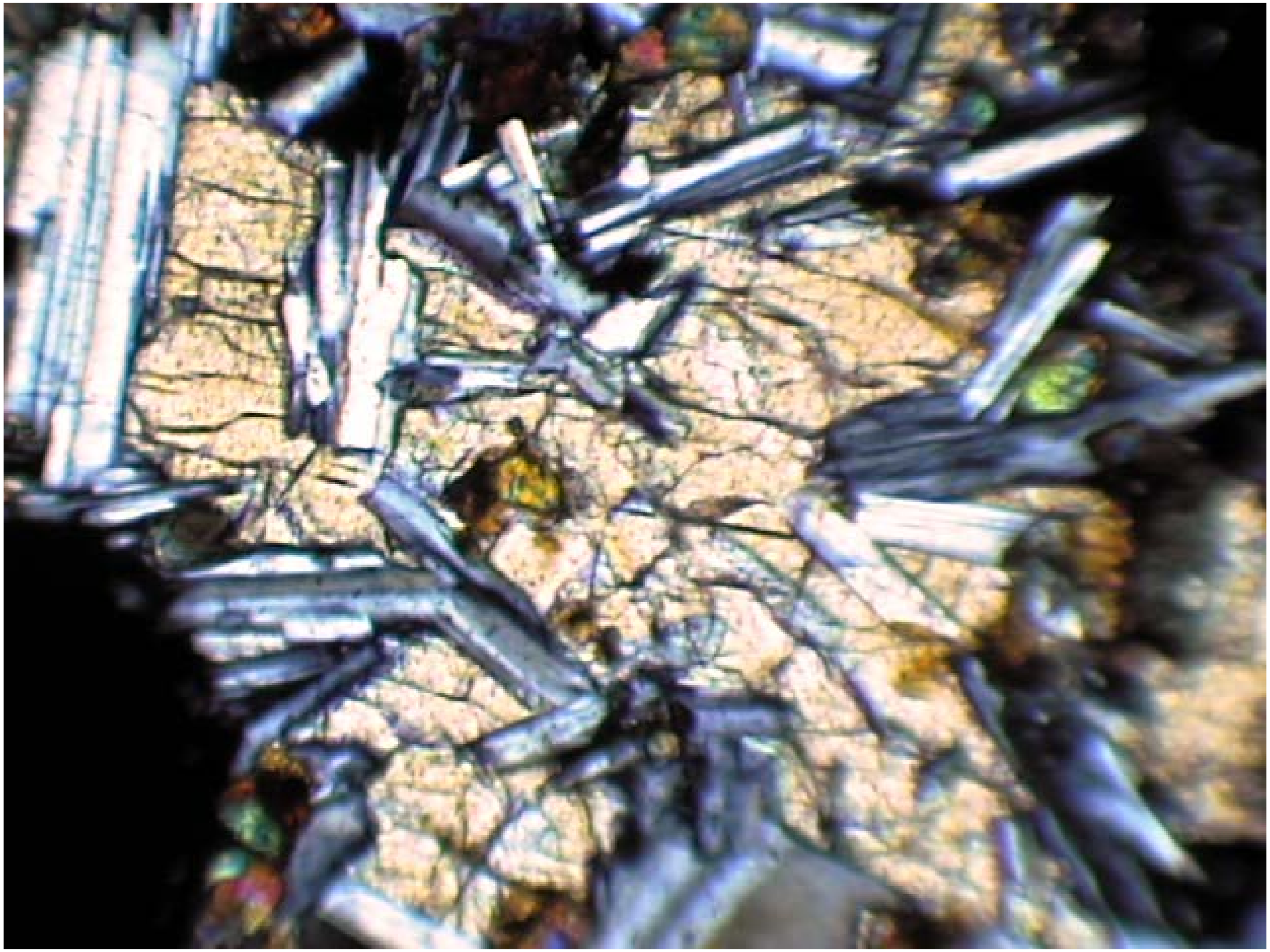
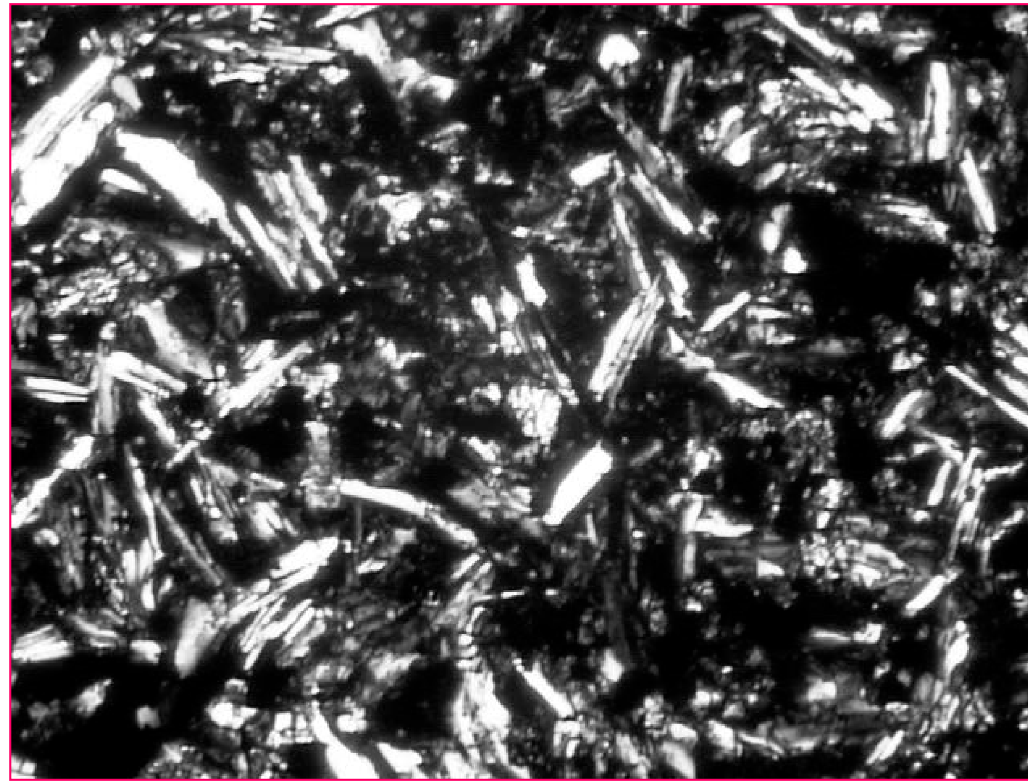


**Figure 3.8.** **Ophitic** texture. A single pyroxene envelops several well-developed plagioclase laths. Width 1 mm. Skaergård intrusion, E. Greenland. © John Winter and Prentice Hall.

**Figure 3.15. Intergranular** texture in basalt. Columbia River Basalt Group, Washington. Width 1 mm. 



# Chapter 3: Igneous Textures

- **Granophyre & Graphic** textures (Fig. 3.9 – next slide)
  - Simultaneous crystallization of **feldspar** and **quartz**
  - The intergrowth forms epitaxially on preexisting phenocrysts or dikelet walls
  - Branching quartz rods set in a single crystal of feldspar
  - The quartz rods all go extinct at the same time, indicating that they are all part of the same larger crystal
  - A coarser variation of granophyric texture is referred to as **graphic**

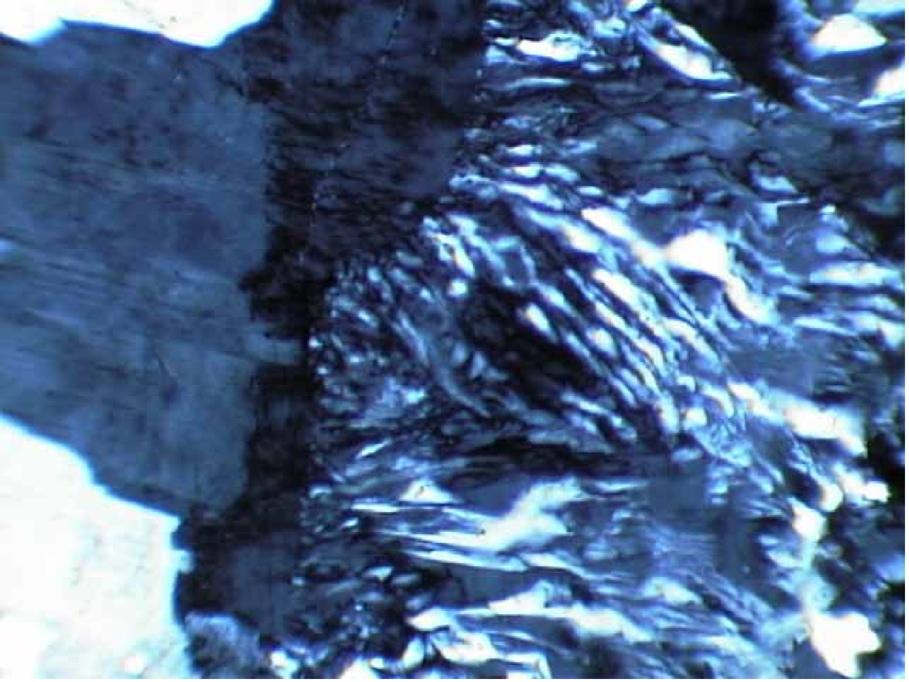


**Figure 3.9. a. Granophyric** quartz-alkali feldspar intergrowth at the margin of a 1-cm dike. Golden Horn granite, WA. Width 1mm. © John Winter and Prentice Hall.

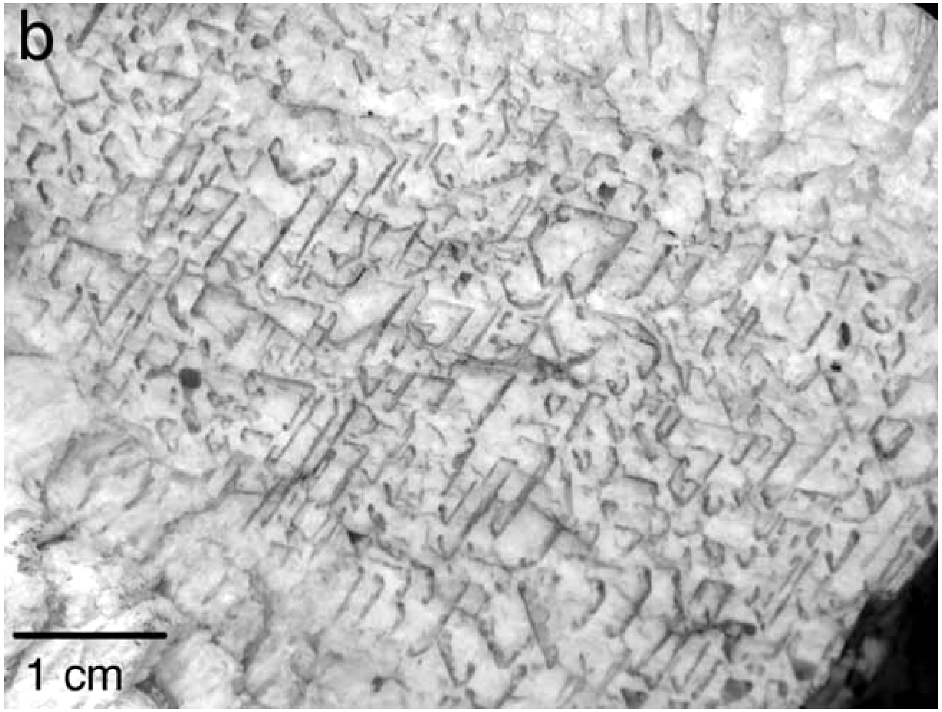
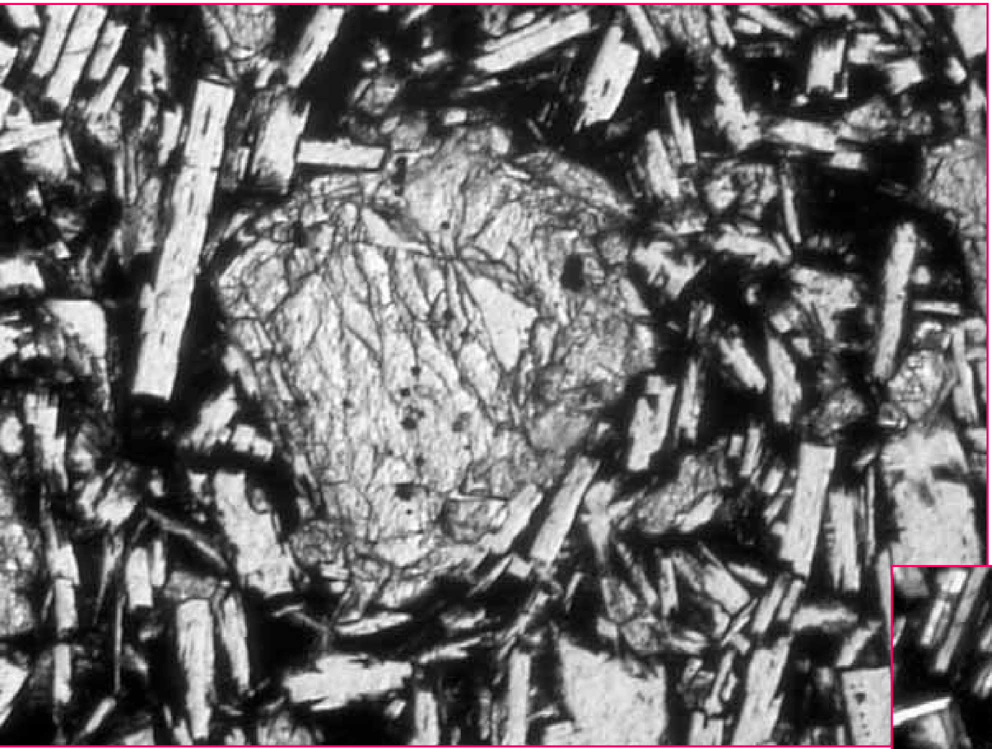



**Figure 3.9b. Graphic** texture: a single crystal of cuneiform quartz (darker) intergrown with alkali feldspar (lighter). Laramie Range, WY. © John Winter and Prentice Hall.

# Chapter 3: Igneous Textures

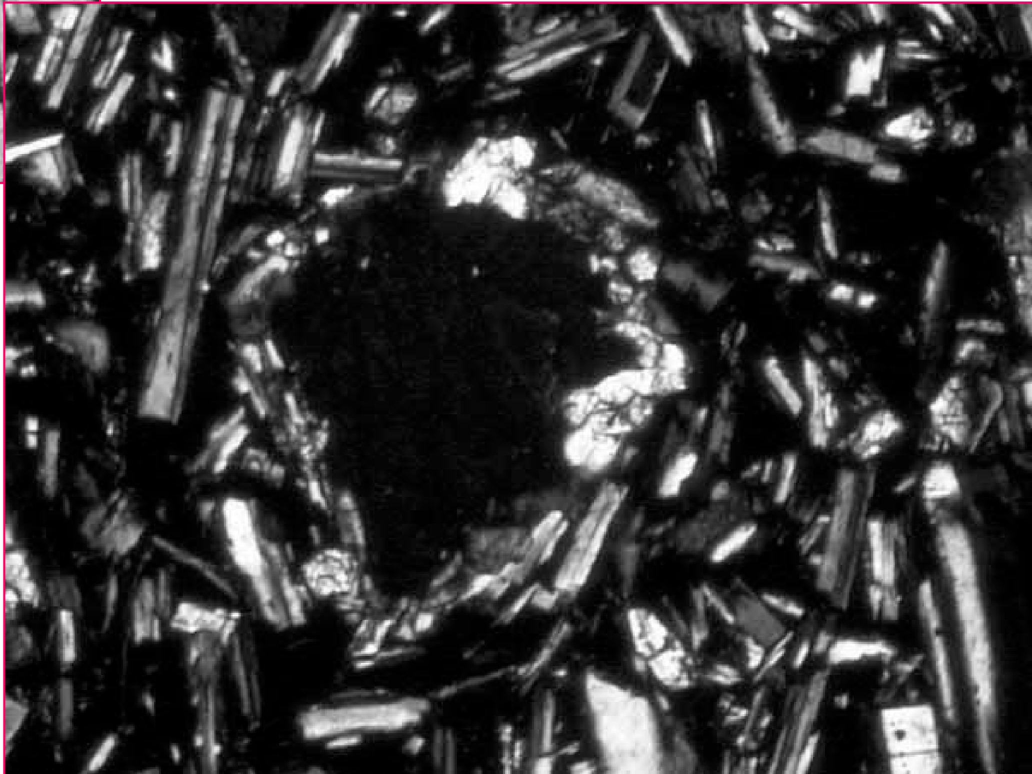
- **Magmatic reaction and resorption**
  - Fig. 3.10 is an example – Olivine ➔ OPX
  - **Resorption** – refusion or dissolution of mineral back into the melt or solution from which it formed
  - Resorbed crystals commonly have rounded corners or are embayed
  - **Sieve texture** (Fig. 3.11a) – evidence for advanced resorption, or rapid growth enveloping melt due to undercooling

**Figure 3.10.** Olivine mantled by orthopyroxene



(**a**) plane-polarized light

(**b**) crossed nicols: olivine is extinct and the pyroxenes stand out clearly.



Basaltic andesite, Mt. McLaughlin, Oregon.

Width ~ 5 mm.

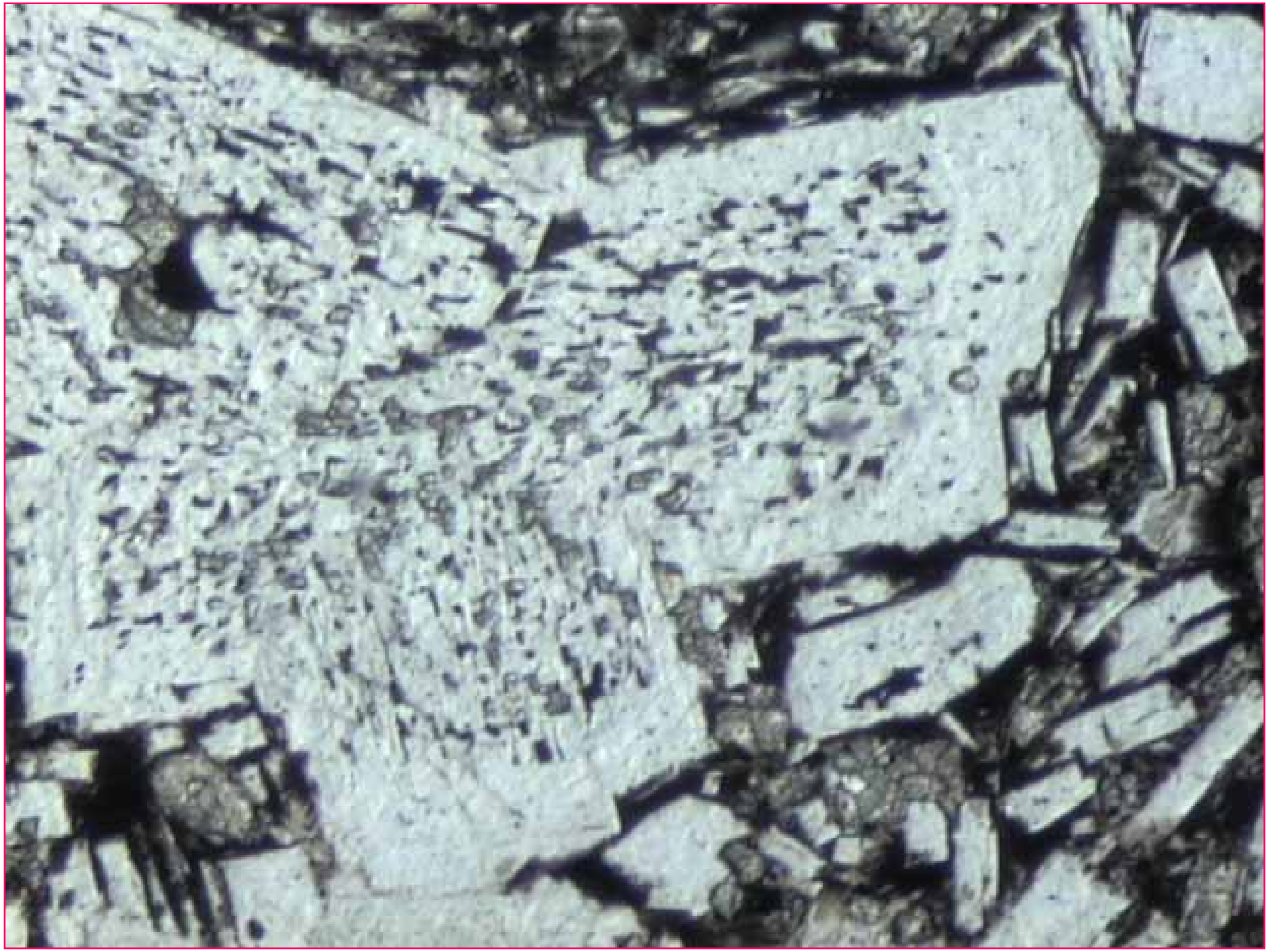


**Figure 3.11a**. **Sieve** texture in a cumulophyric cluster of plagioclase phenocrysts. Note the later non-sieve rim on the cluster. Andesite, Mt. McLoughlin, OR. Width 1 mm. © John Winter and Prentice Hall.

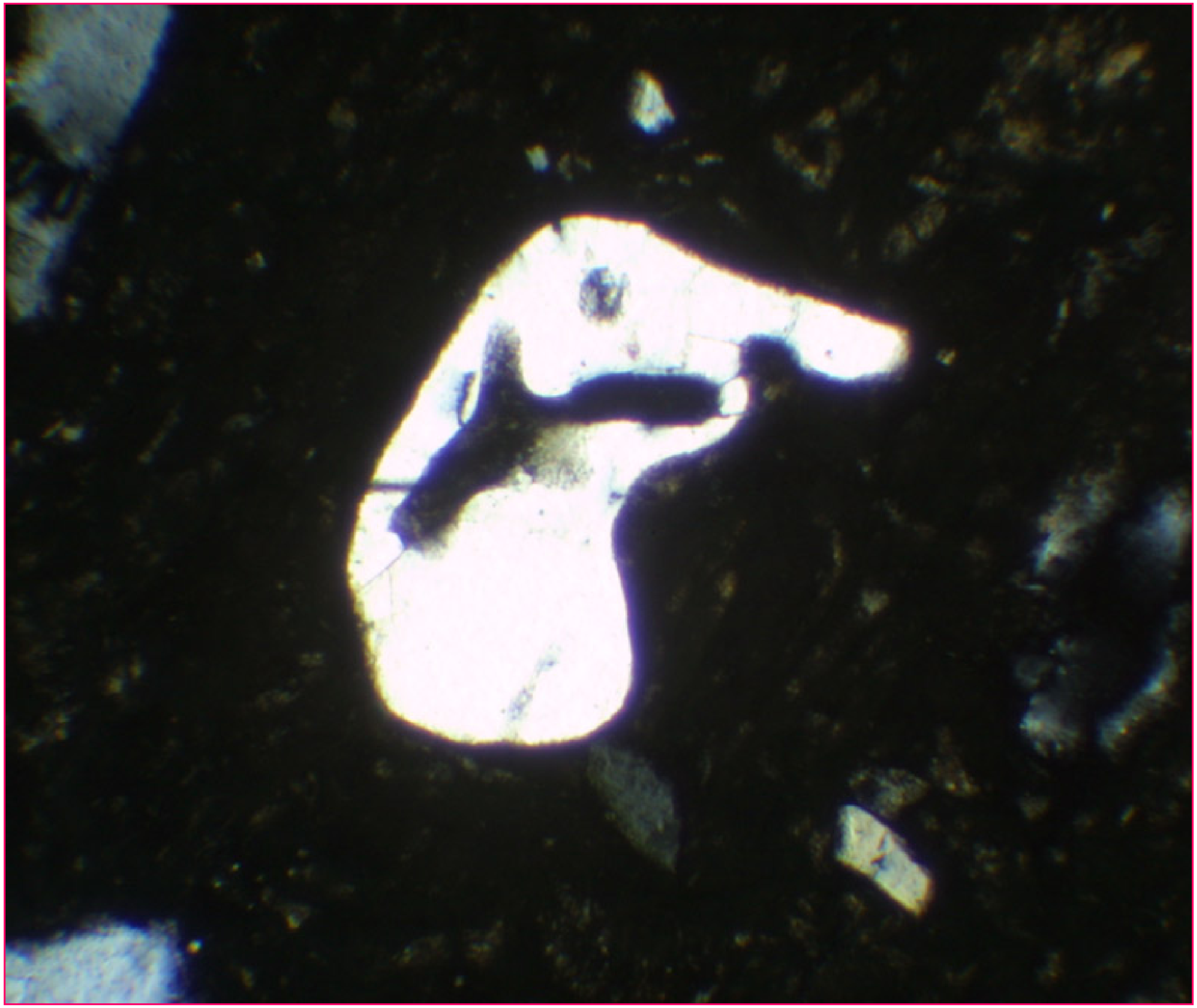


**Figure 3.11b.** Partially **resorbed** and **embayed** quartz phenocryst in rhyolite. Width 1 mm. © John Winter and Prentice Hall.

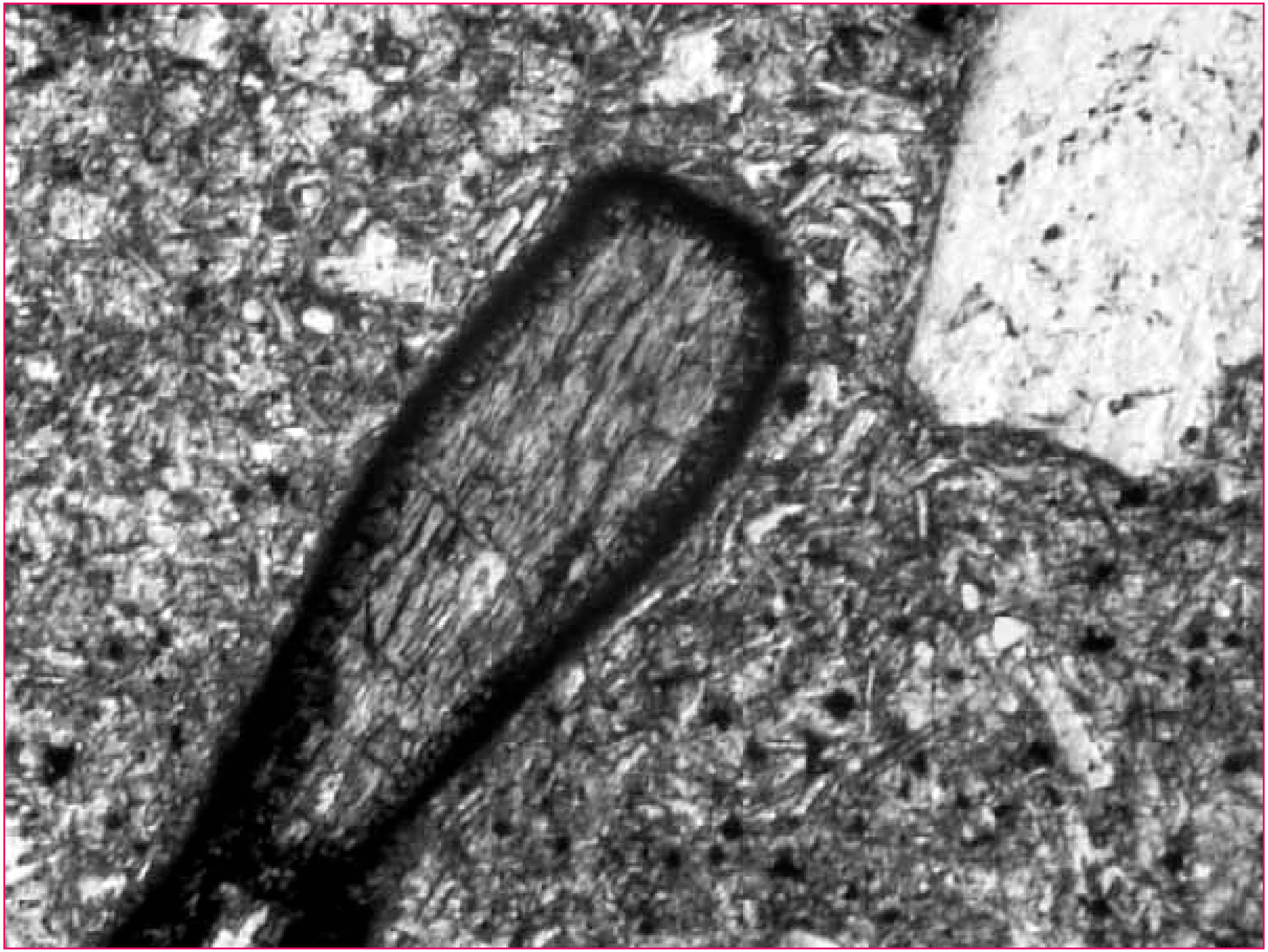


**Figure 3.11c.** **Hornblende** phenocryst **dehydrating** to **Fe-oxides plus pyroxene** due to pressure release upon eruption, andesite. Crater Lake, OR. Width 1 mm. © John Winter and Prentice Hall.

# Chapter 3: Igneous Textures

- **Differential movement of crystals and melt**

**Figure 3.12a. Trachytic** texture in which microphenocrysts of plagioclase are aligned due to flow. Note flow around phenocryst (P). Trachyte, Germany. Width 1 mm. From MacKenzie *et al*. (1982). © John Winter and Prentice Hall.

**Figure 3.12b. Felty** or **pilotaxitic** texture in which the microphenocrysts are randomly oriented. Basaltic andesite, Mt. McLaughlin, OR. Width 7 mm. © John Winter and Prentice Hall.

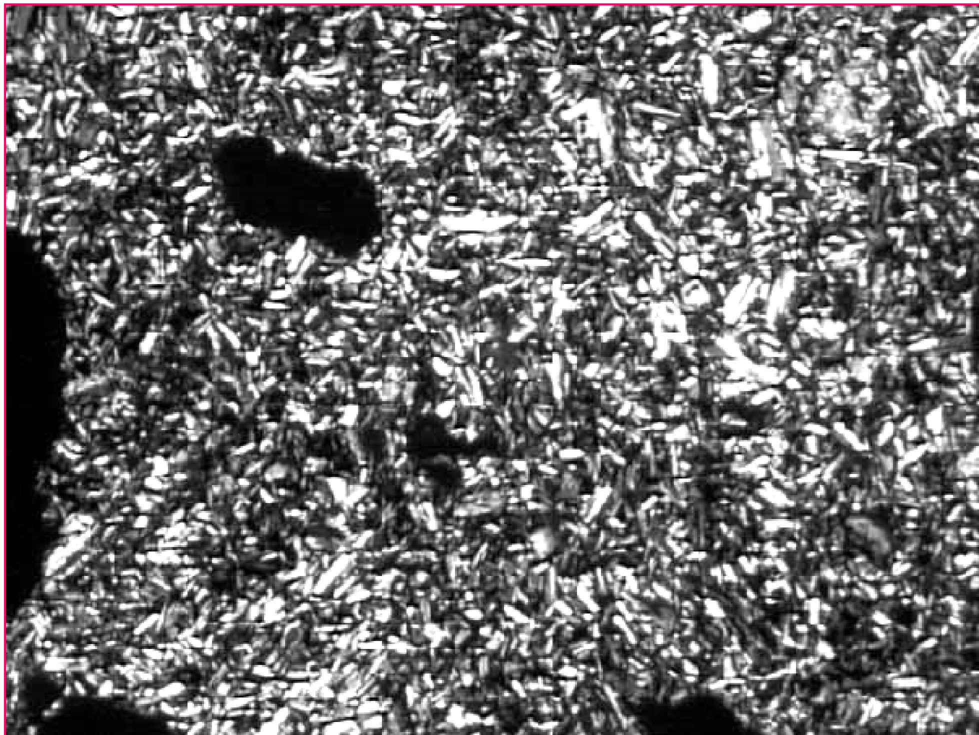


**Figure 3.13.** **Flow banding** in andesite. Mt. Rainier, WA. © John Winter and Prentice Hall.