Chapter 3: Igneous Textures

- **Questions to be considered**?

  - What textures may be produced as magma cools and crystallizes to form igneous rocks?

  – What physical variables control the development of igneous textures, and how they do so?

  – Use knowledge we have and textural information to interpret the developmental history of the rock

Chapter 3: Igneous Textures

The texture of a rock is a result of various *processes* that controlled the rock's genesis and, along with *mineralogy* and *chemical composition*, provides information that we may use to interpret the rock's origin and history

Table 3.1 at end of Chapter 3 provides a glossary of common igneous rock textures

Chapter 3: Igneous Textures

- **3.1. PRIMARY TEXTURES (CRYSTAL/MELT INTERACTIONS)**

- Formation and growth of crystals, either from a melt or in a solid medium, involves 3 principal processes:

  – 1- *Initial nucleation* of the crystal
  – 2- Subsequent *crystal growth*
  – 3- *Diffusion of chemical species* (and heat) through the surrounding medium to and from the surface of a growing crystal

Chapter 3: Igneous Textures

- **Nucleation:**
  - Is a critical step in the development of a crystal.
  - Very tiny initial crystals have a **high ratio of surface area to volume**, and thus, a large proportion of ions at the surface
  - However, surface ions have unbalanced charges because lack the complete surrounding lattice
  - Result is a high surface energy for the ‘initial crystal’ and therefore low stability
  - Hence, clustering of compatible ions in a cooling melt will separate, even though conditions are suitable for crystallization

Chapter 3: Igneous Textures

- **Nucleation (cont'd):**
  - Under such conditions, crystallization is possible, but nucleation isn't
  - Crystallization may take place if a "critically sized embryonic cluster" or "crystal nucleus" must form, with a sufficient internal volume of fully bonded ions to overcome the surface-related instability
  - This typically requires some degree of **undercooling** – *cooling of a melt below the true crystallization temperature of a mineral*, or **supersaturation** – *sufficient number of ions to be stable so as to spontaneously cluster together ("homogeneous nucleation")*.

Chapter 3: Igneous Textures

- **Nucleation (cont'd):**
  - Experimental studies indicate that crystals with simple structures tend to nucleate more easily than those with more complex structures
    - E.g., Oxides (magnetite, ilmenite) generally nucleate more easily (i.e., less undercooling required) than does olivine, followed by pyroxene, plagioclase, and alkali feldspar, with progressively more complex Si-O polymerization
  - May explain why oxides are typically small and numerous, whereas alkali feldspars are large (regardless of degree of undercooling)

Chapter 3: Igneous Textures

- **Crystal Growth:**
  - Involves the addition of ions onto existing crystals or crystal nuclei
  - For simple structures with high symmetry, faces with a high density of lattice points tend to form more prominent faces (the “Law of Bravais”)
  - Different faces also grow at different rates
  - Simplistic generalization, fast-growing faces tend to be those with smaller interplanar lattice spacings (and higher surface energies)

Chapter 3: Igneous Textures

- **Crystal Growth:**
  - In most instances, composition of surrounding melt differs considerably relative to that of the growing crystal
  - Growth of mineral will deplete the adjacent melt in the chemical constituents that are preferentially incorporated into the mineral
  - Hence, for growth to proceed, new material must ***diffuse*** through the melt, cross the depleted zone, and reach the crystal surface
  - Formation of a crystal from a melt produces heat ("the latent heat of crystallization") – this heat must be removed from growing surface, or else temperature may become too high for crystallization to proceed

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

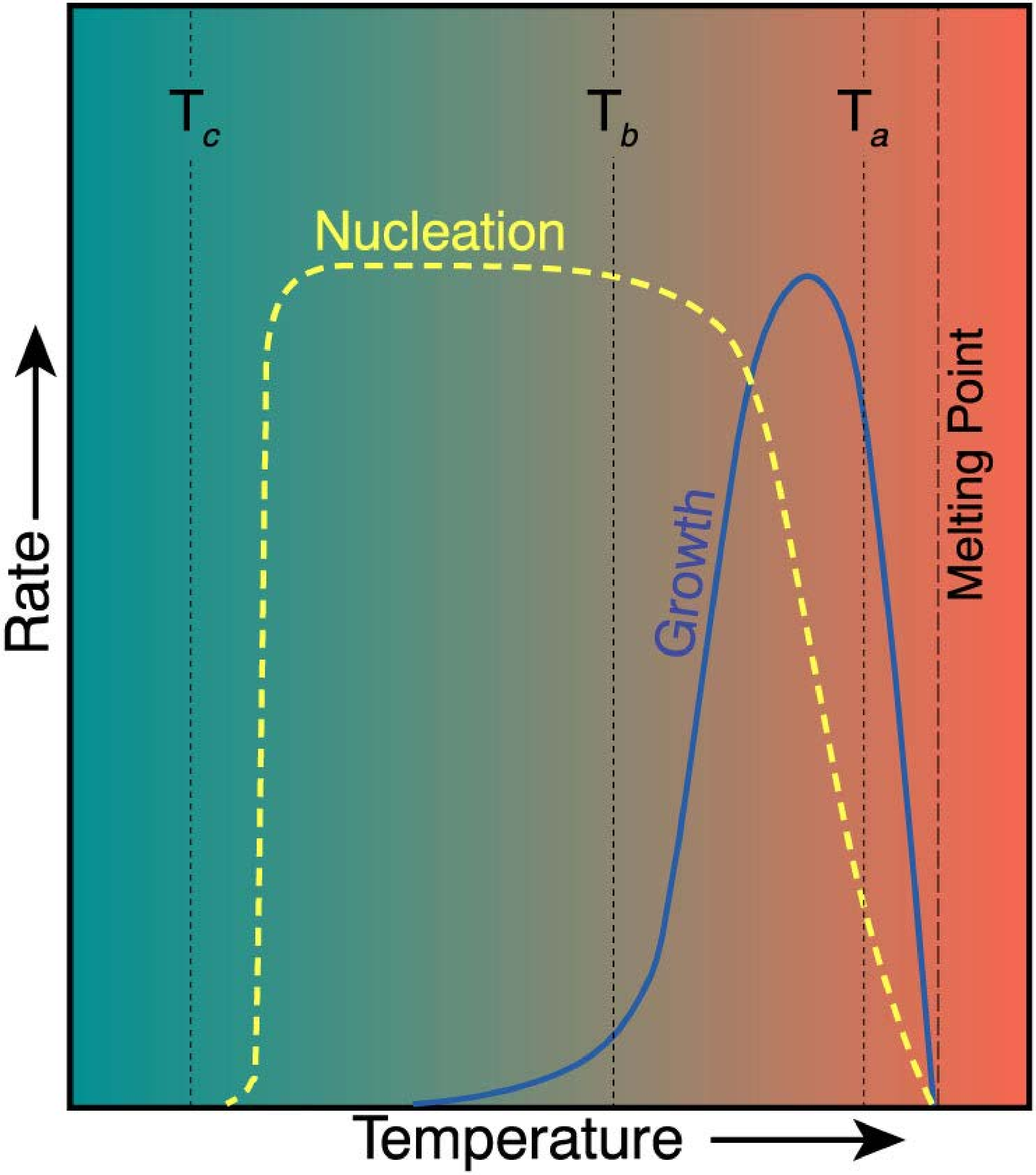
- If cooling rate is slow, equilibrium is maintained or closely approximated

- 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

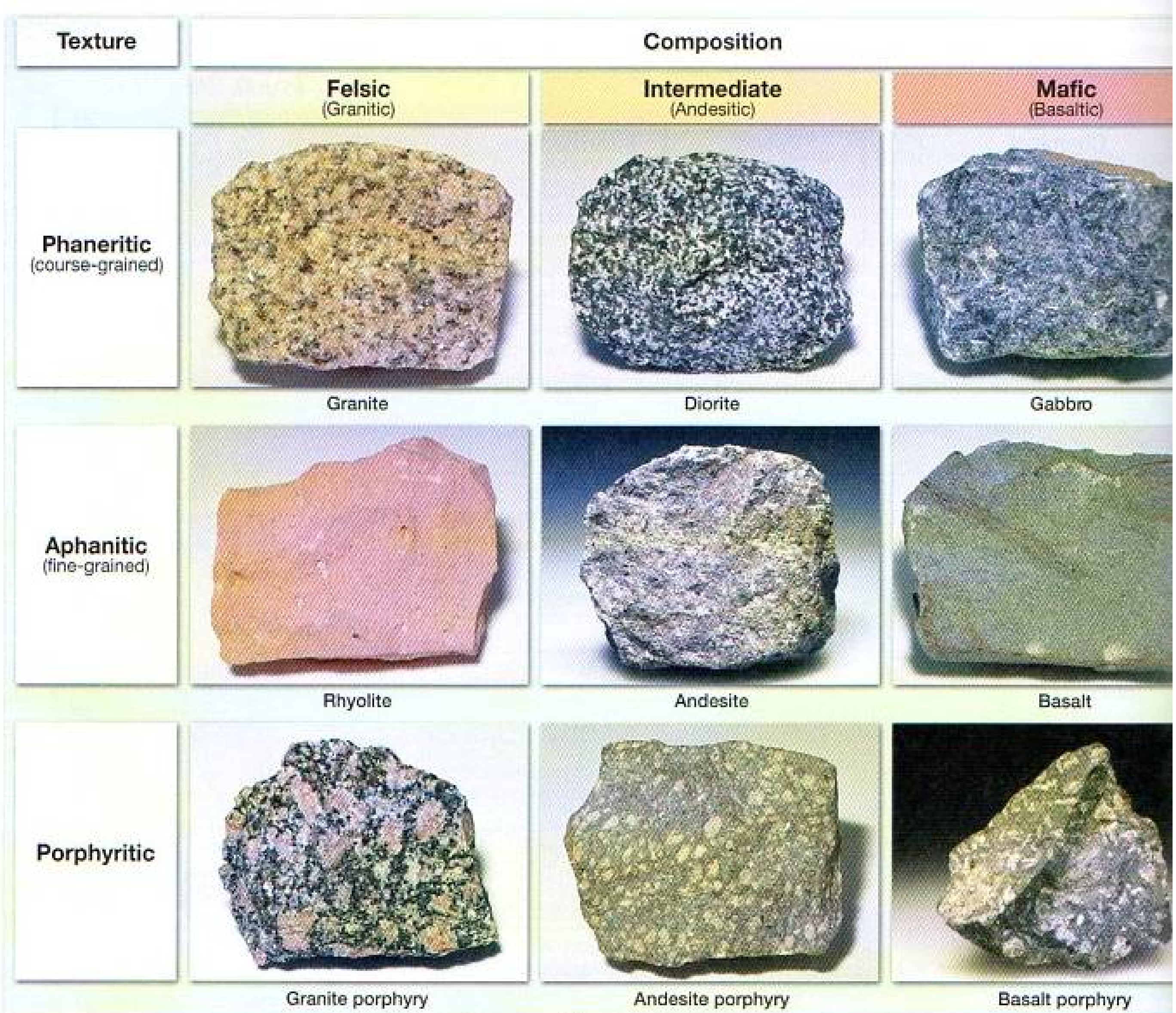
- Growth rate of a crystal depends upon:
  - Surface energy of the faces
  - Diffusion rate
  - If cooling rate is constant, the largest crystals will usually be those with the most plentiful or fastest-diffusing components
  - Diffusion rate of a chemical species is faster at higher temperature, and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

Properties of Igneous Rocks

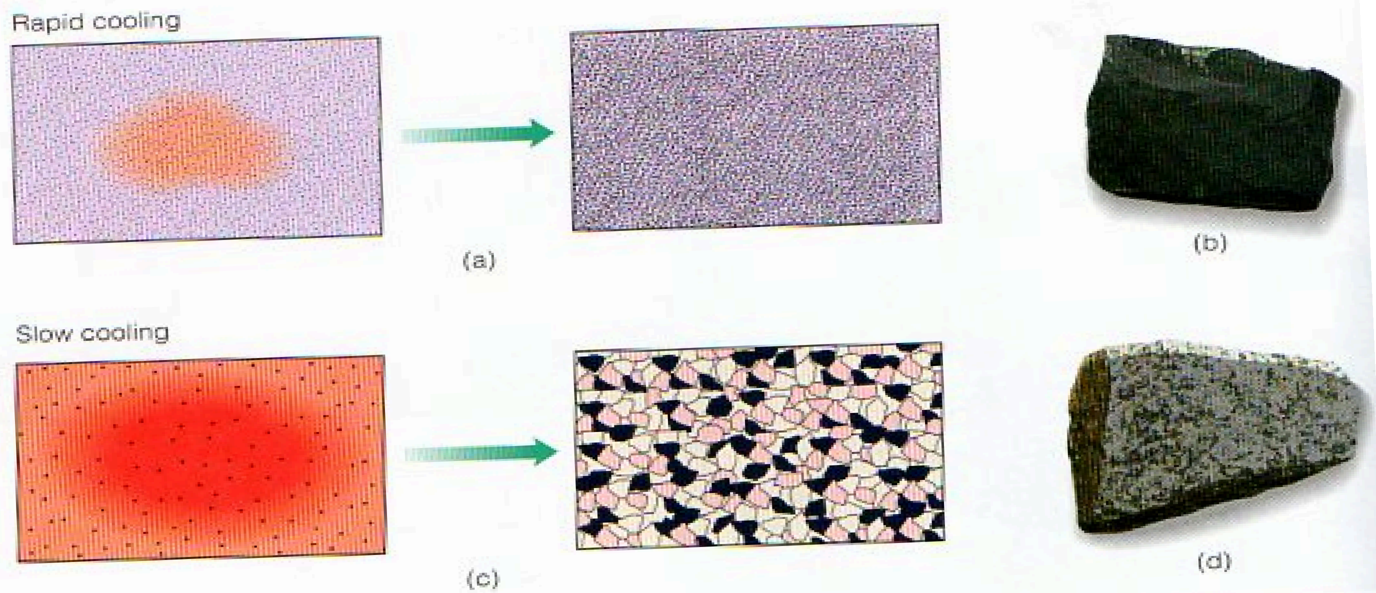
Texture - description of the degree of crystallinity, grain size and shape, and arrangement of the minerals

- **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



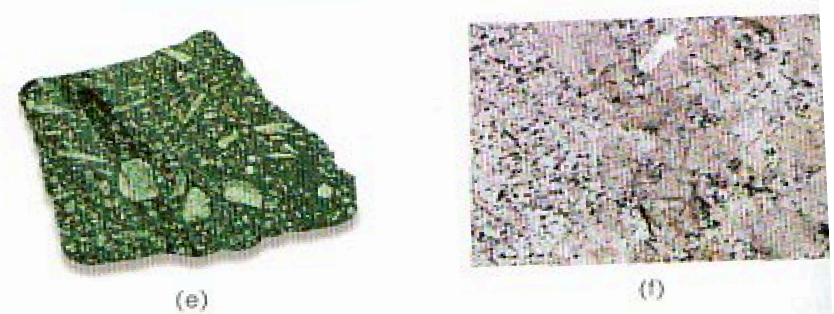
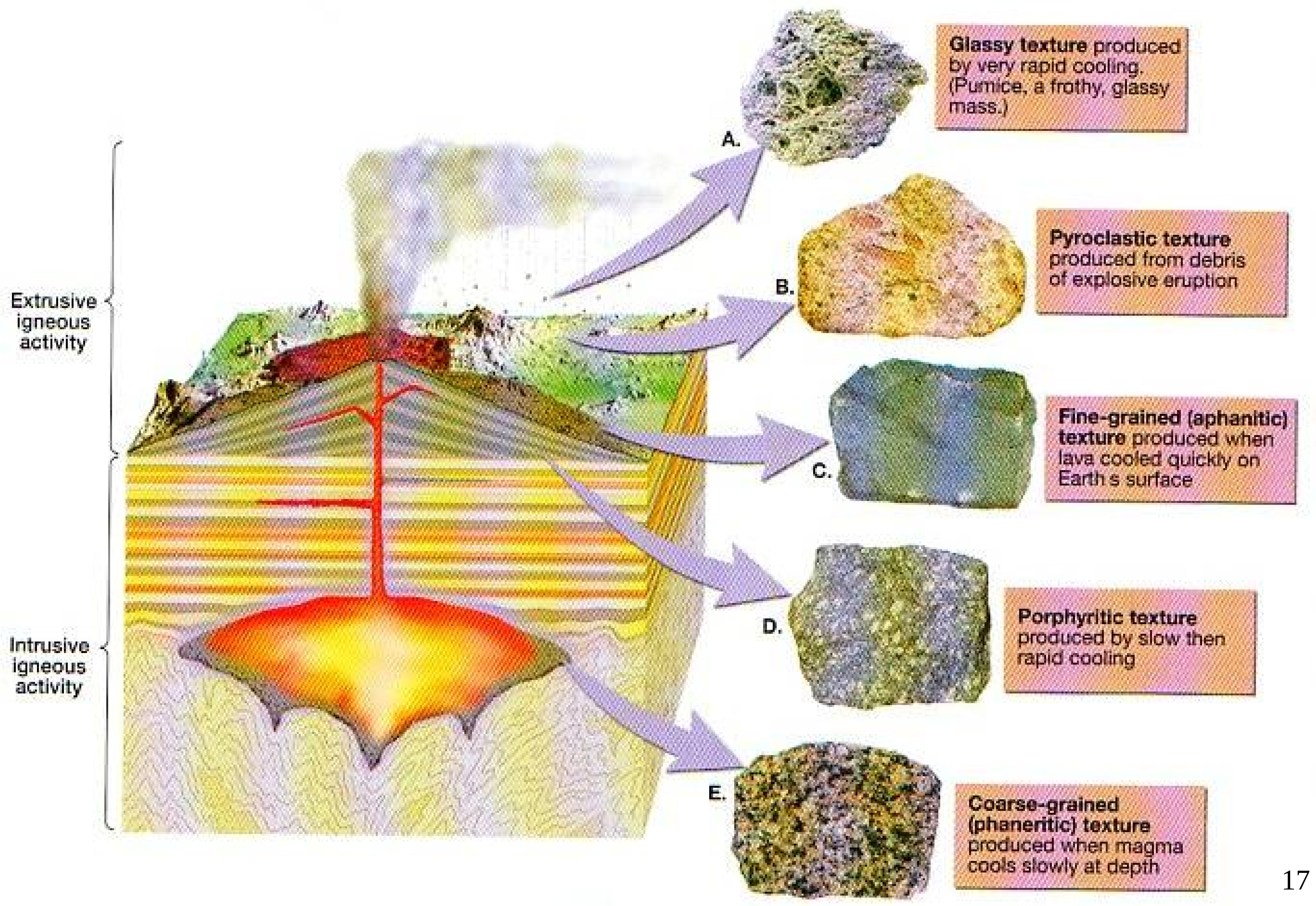


Figure 3.8
Magma cooling rate and its effect on nucleation and growth of mineral crystals. (a) Rapid cooling results in many small minerals and a fine-grained, or aphanitic, texture. (b) Igneous rock with an aphanitic texture. (c) Slow cooling yields a coarse-grained, or phaneritic, texture. (d) Igneous 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

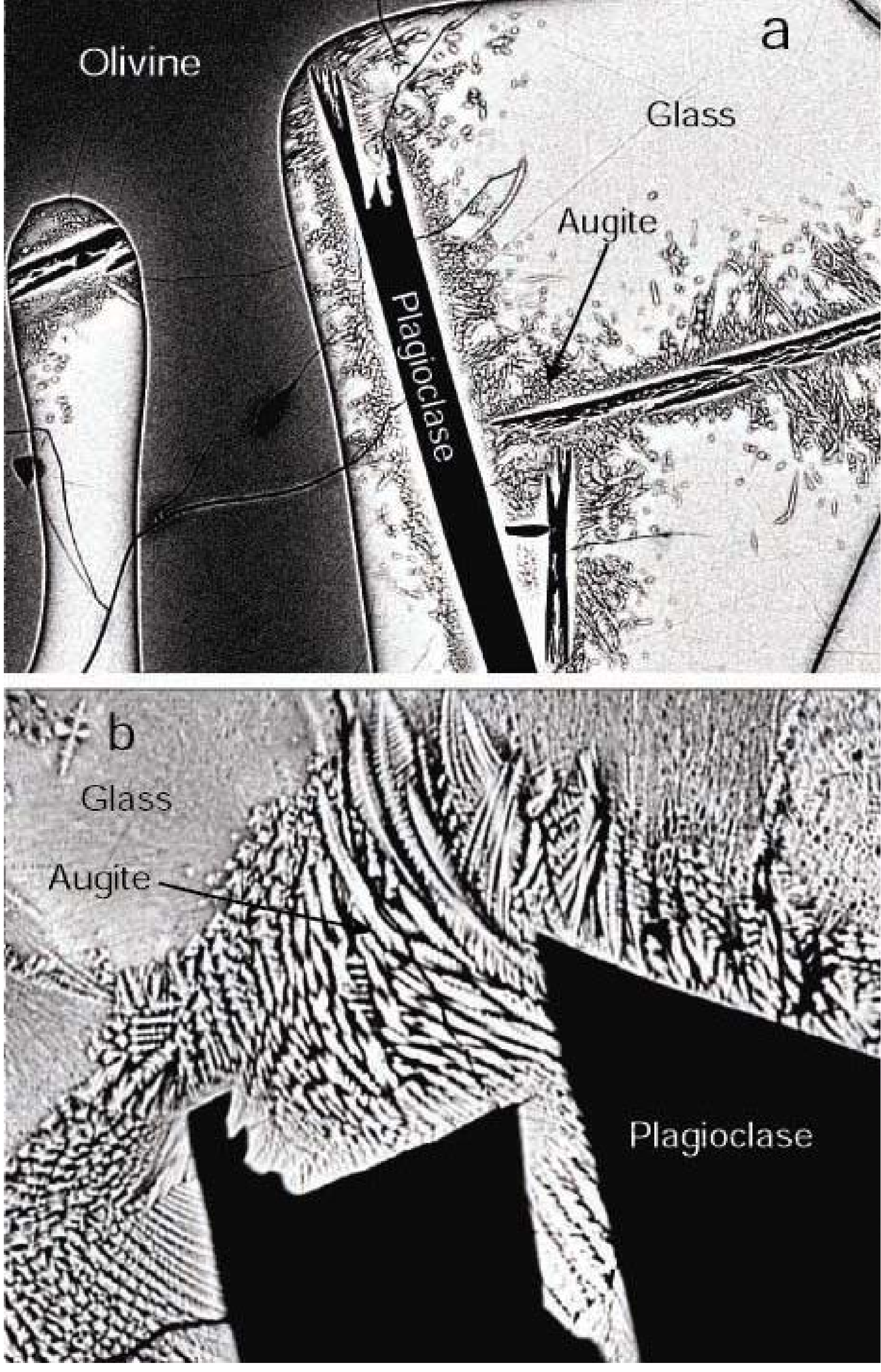


Figure 3.2. Backscattered electron image of quenched "blue glassy pahoehoe," 1996 Kalapana flow, Hawaii. Black minerals are felsic plagioclase and gray ones are mafics. **a.** Large **embayed** olivine phenocryst with smaller plagioclase laths and clusters of feathery augite nucleating on plagioclase. 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.

Chapter 3: Igneous Textures

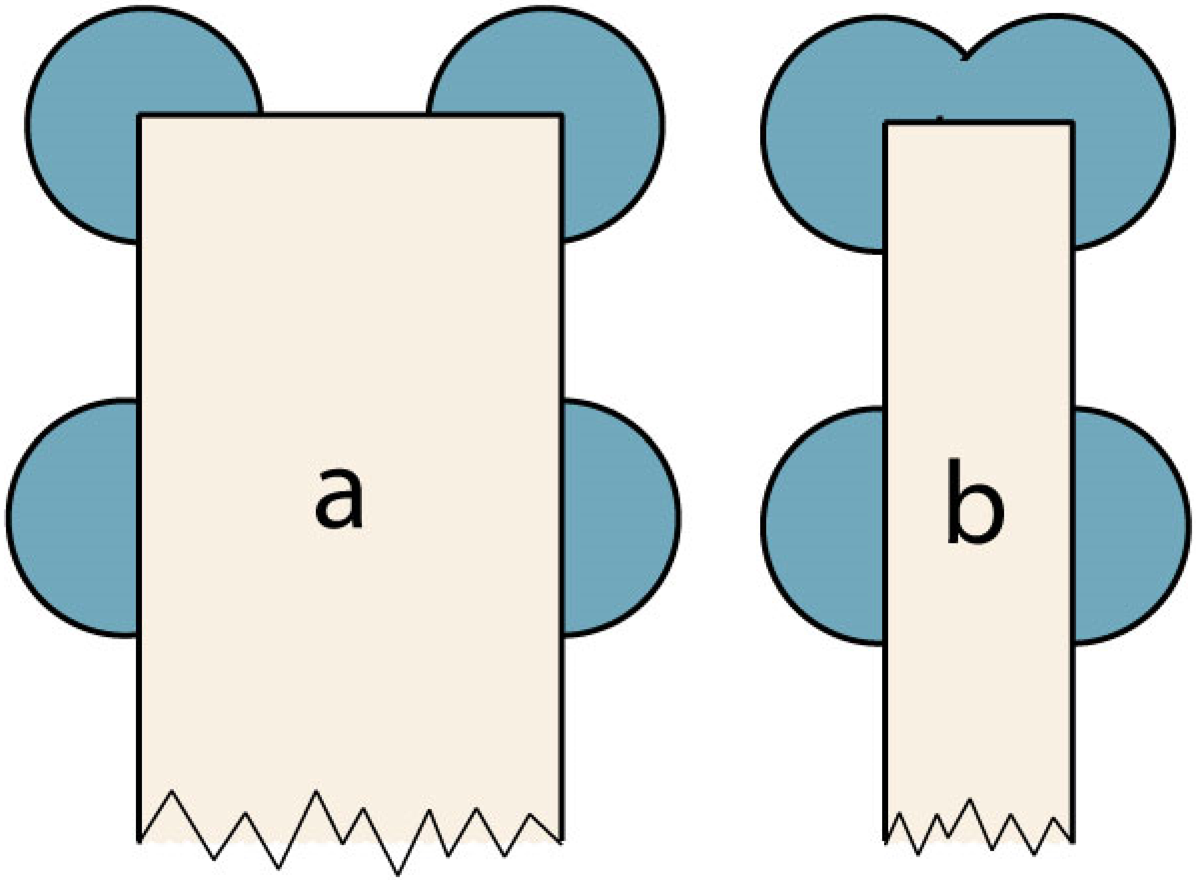
- **Spinifex** texture:
  - Ultramafic lavas, such as Precambrian komatiites, develop spectacularly elongated **olivine** crystals (some up to 1 m long!)
  - Result of rapid growth of olivine (with simple structure) in a very low viscosity magma, **NOT** by slow cooling!

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

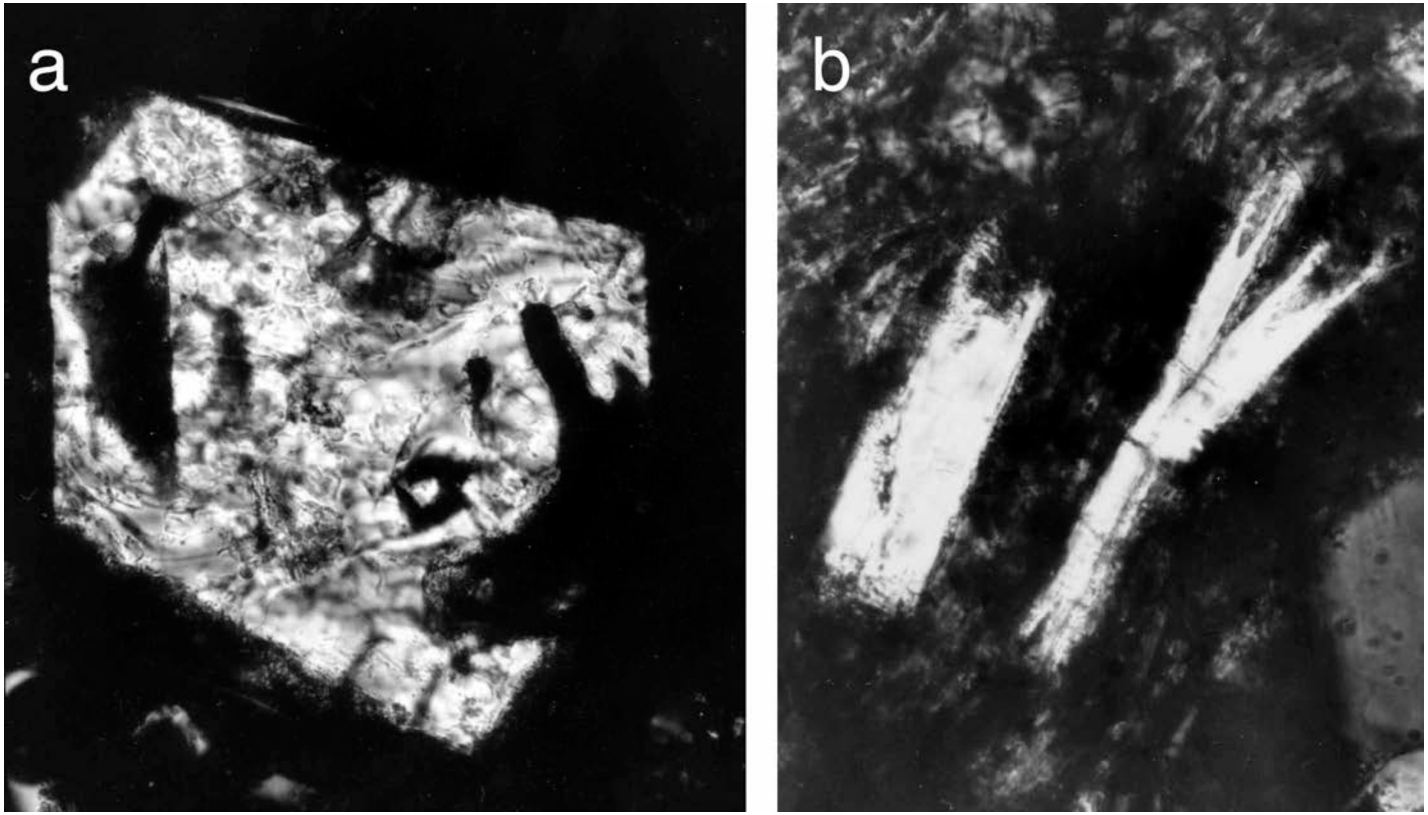


Figure 3.4. a. Skeletal olivine phenocryst with rapid growth at edges enveloping melt at ends. Taupo, N.Z. **b.** "**Swallow-tail**" plagioclase in trachyte, Remarkable Dike, N.Z. Length of both fields ca. 0.2 mm. From Shelley (1993). Igneous and Metamorphic Rocks Under the Microscope. © Chapman and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

Chapter 3: Igneous Textures

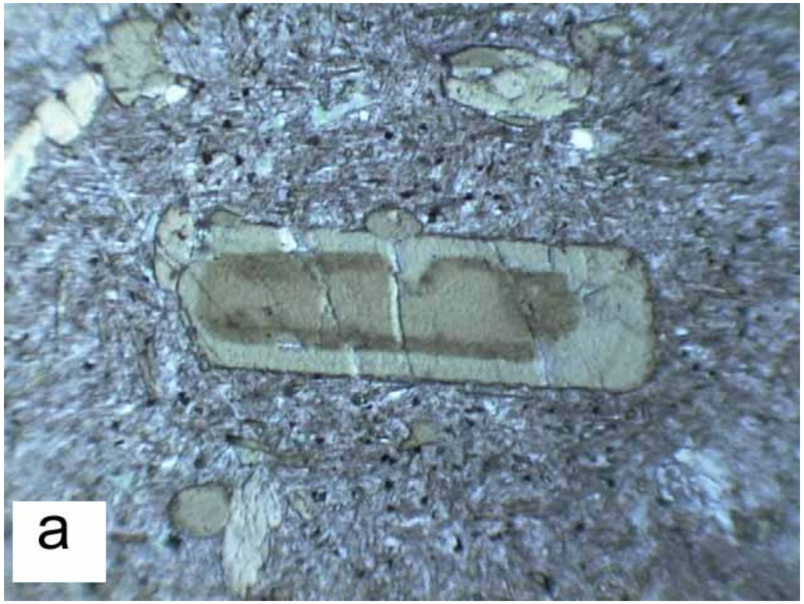
- **Epitaxis** texture:
  - Preferred nucleation of one mineral on a preexisting mineral
  - Similarity of the crystal structures of the mineral substrate and new phase is a prerequisite for epitaxial growth
  - E.g., growth of sillimanite on biotite or muscovite
  - The Si-Al-O structures in both sillimanite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

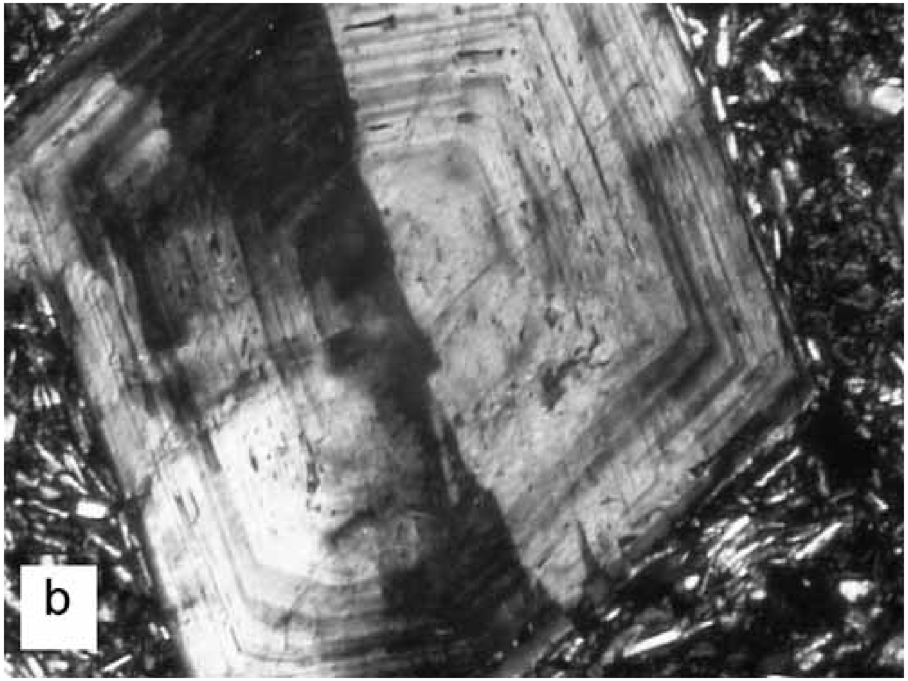
Chapter 3: Igneous Textures

- **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!!

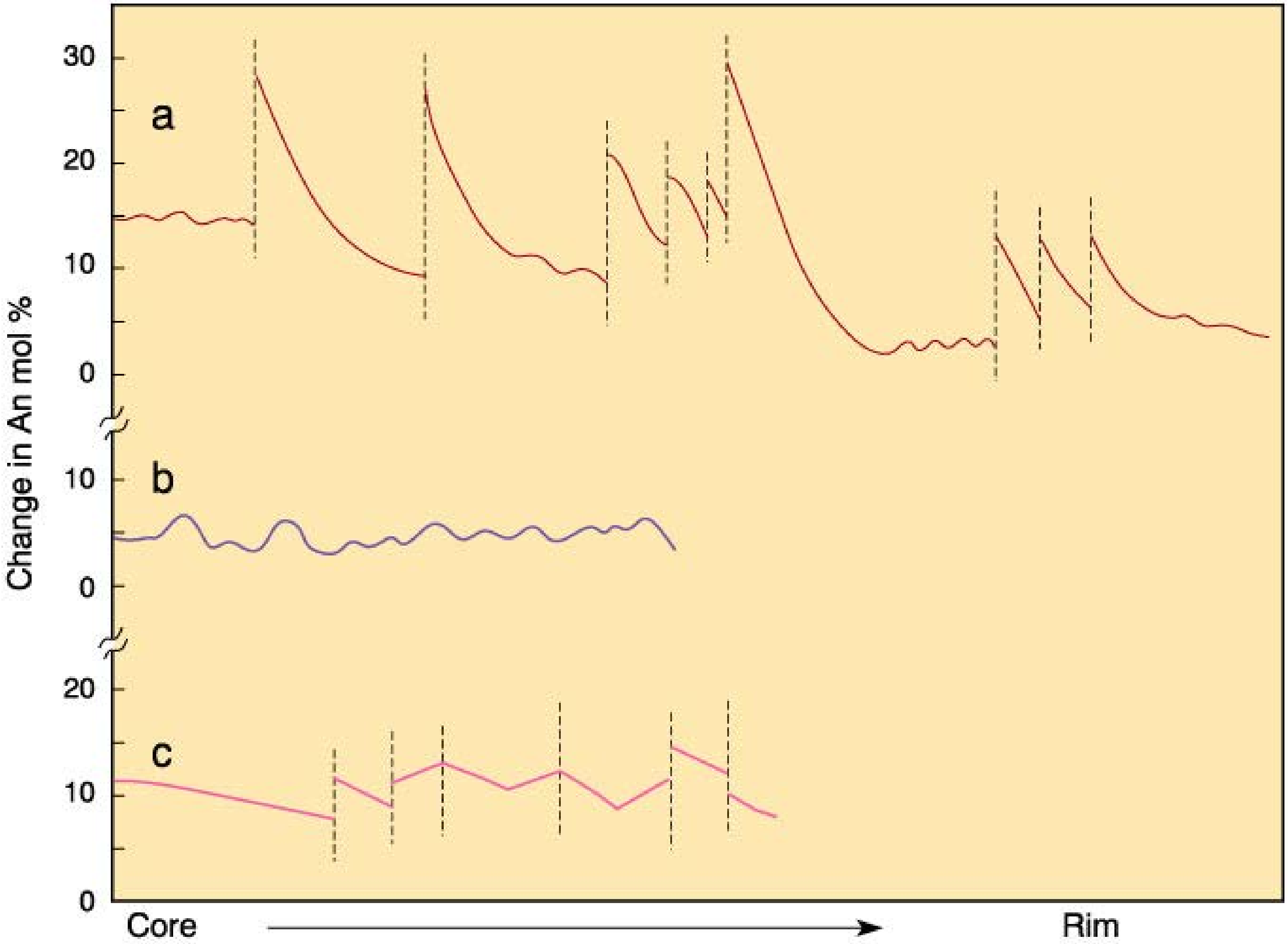


Figure 3.6. Examples of plagioclase zoning profiles determined by microprobe point traverses.

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)

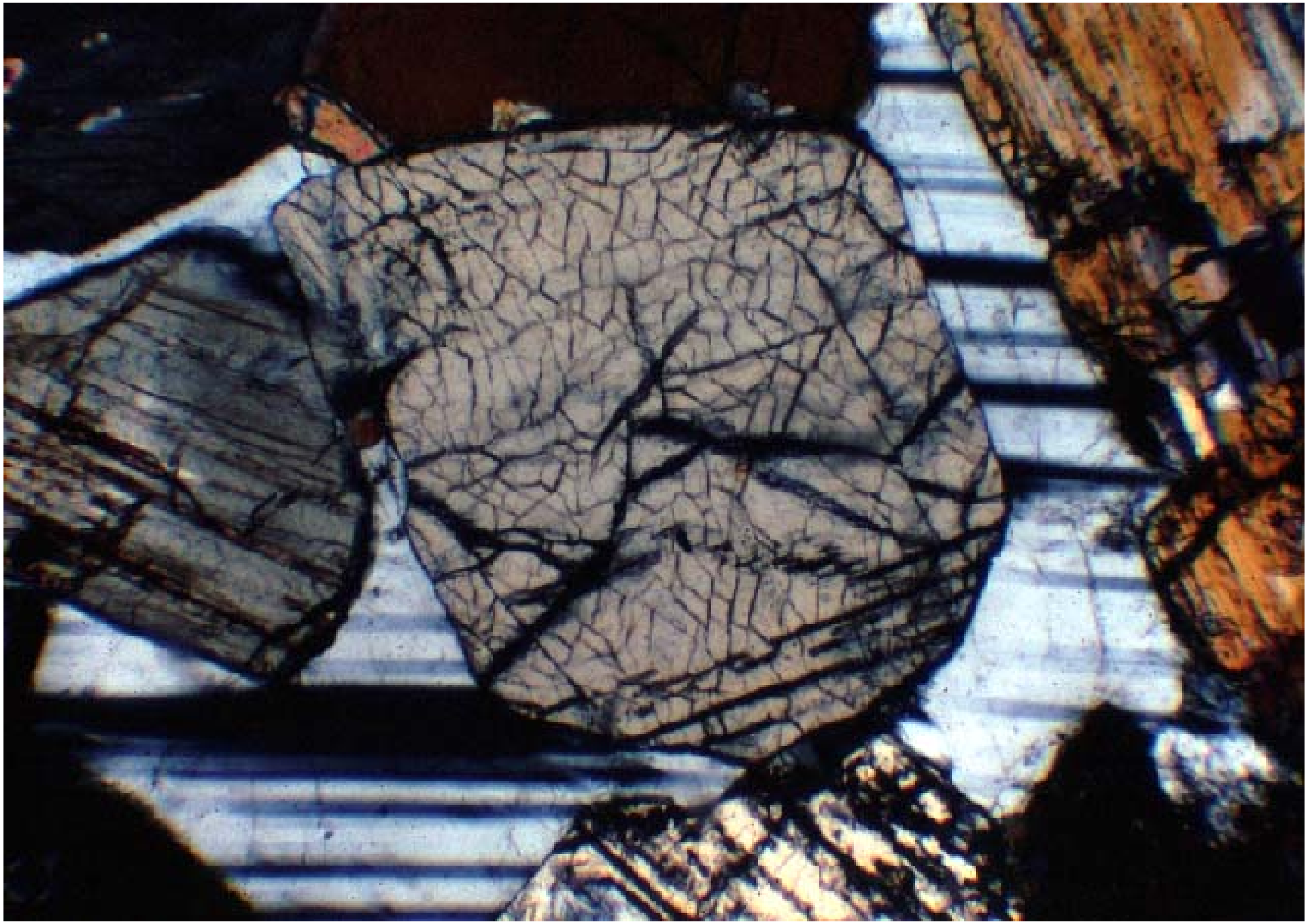


Figure 3.7. Euhedral early pyroxene with late **interstitial** plagioclase (horizontal twins). Stillwater complex, Montana. Field width 5 mm. © John Winter and Prentice Hall.

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.

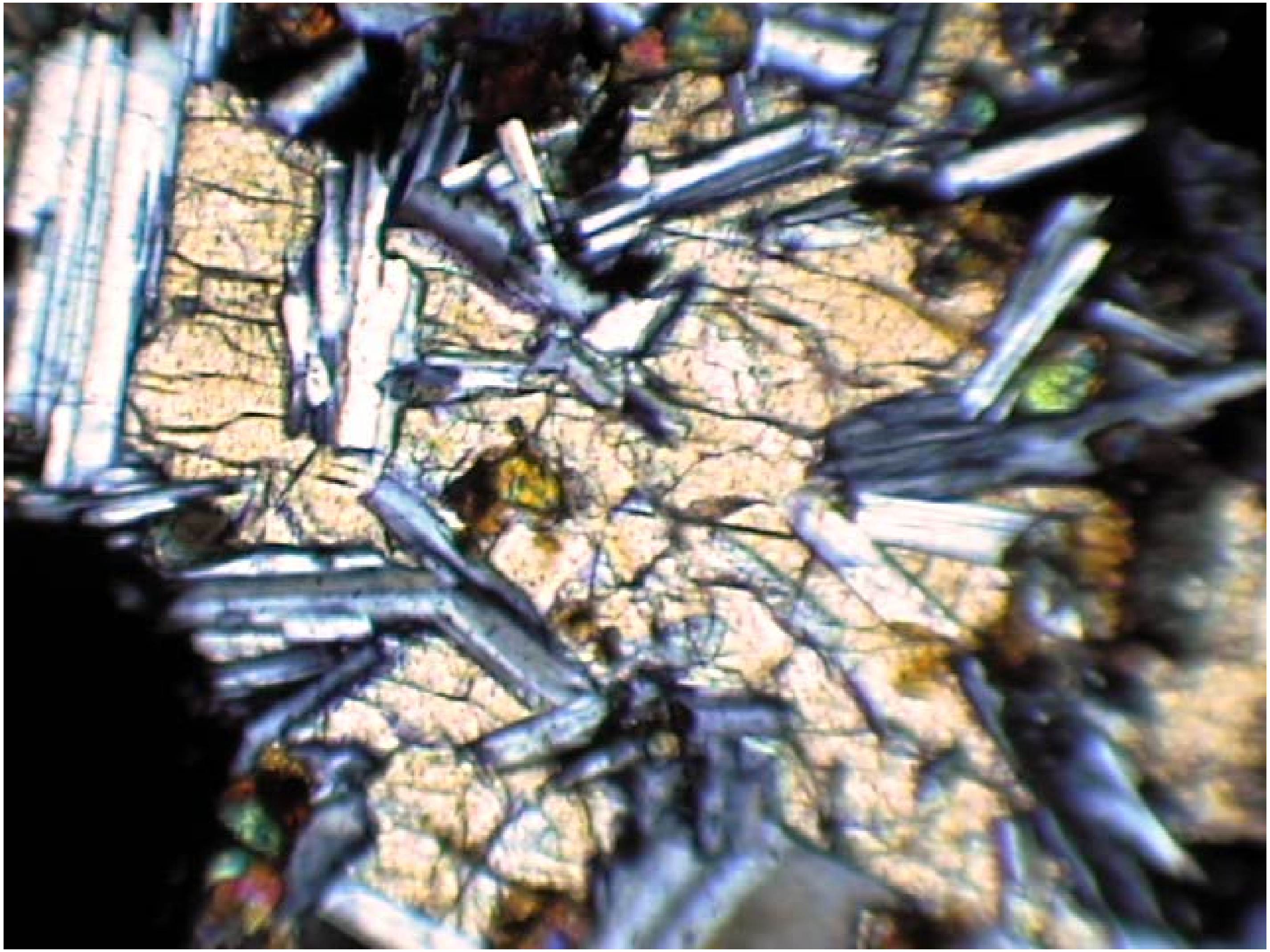


Figure 3.8. Ophitic texture. A single pyroxene envelops several well-developed plagioclase laths. Width 1 mm. Skaergård intrusion, E. Greenland. © John Winter and Prentice Hall.

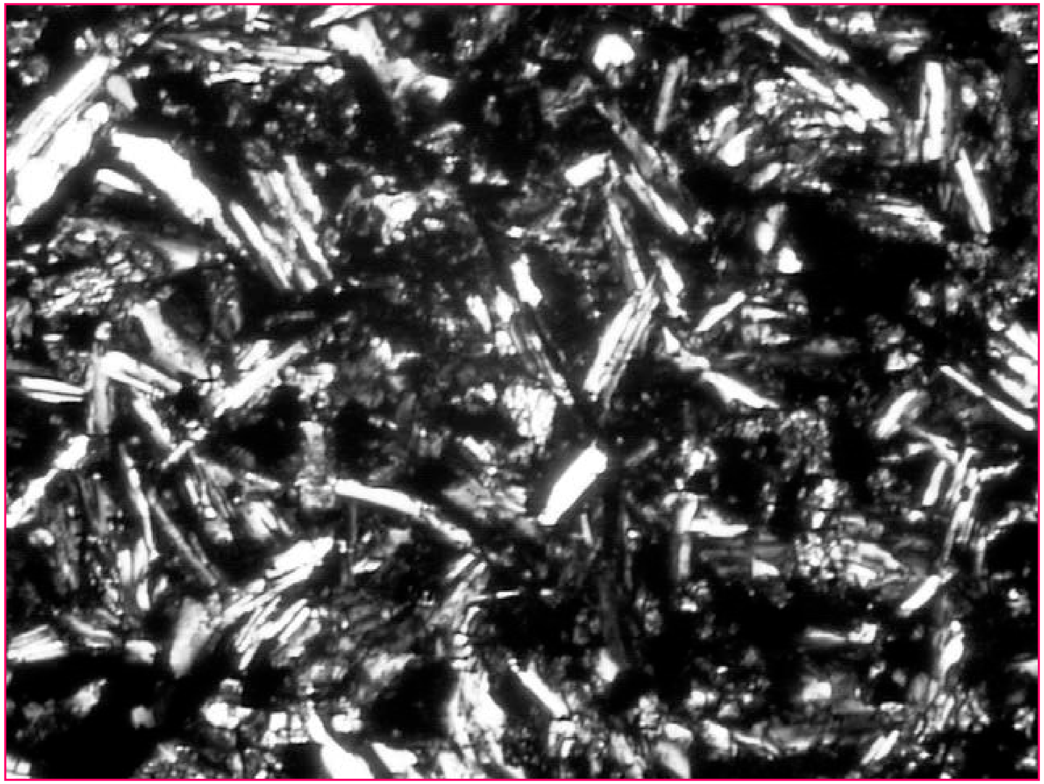


Figure 3.15. Intergranular texture in basalt. Columbia River Basalt Group, Washington. Width 1 mm.

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**

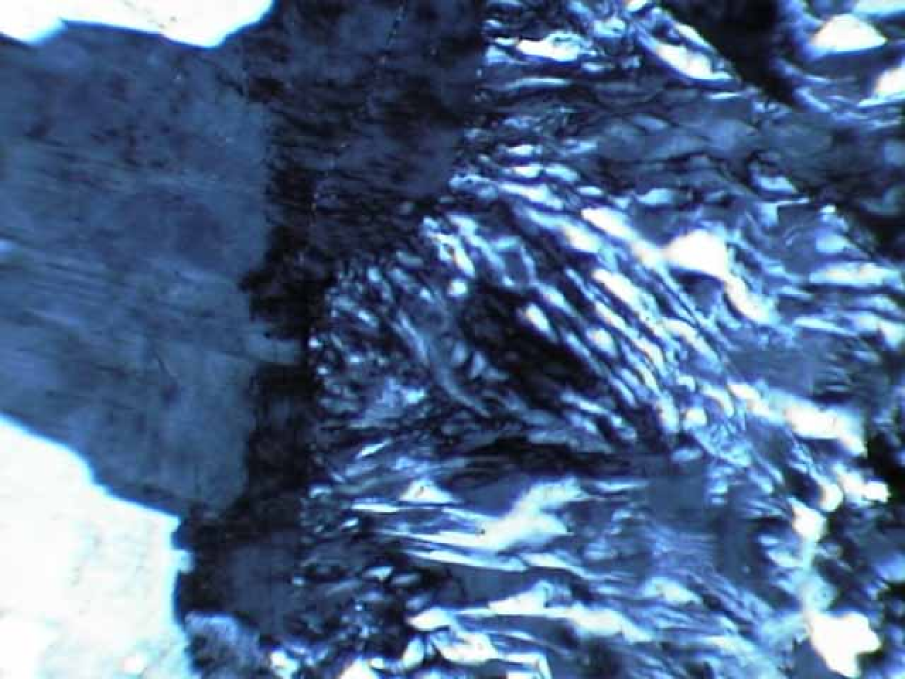


Figure 3.9. a. Granophyric quartz-alkali feldspar intergrowth at the margin of a 1-cm dike. Golden Horn granite, WA. Width 1mm. © John Winter and Prentice Hall

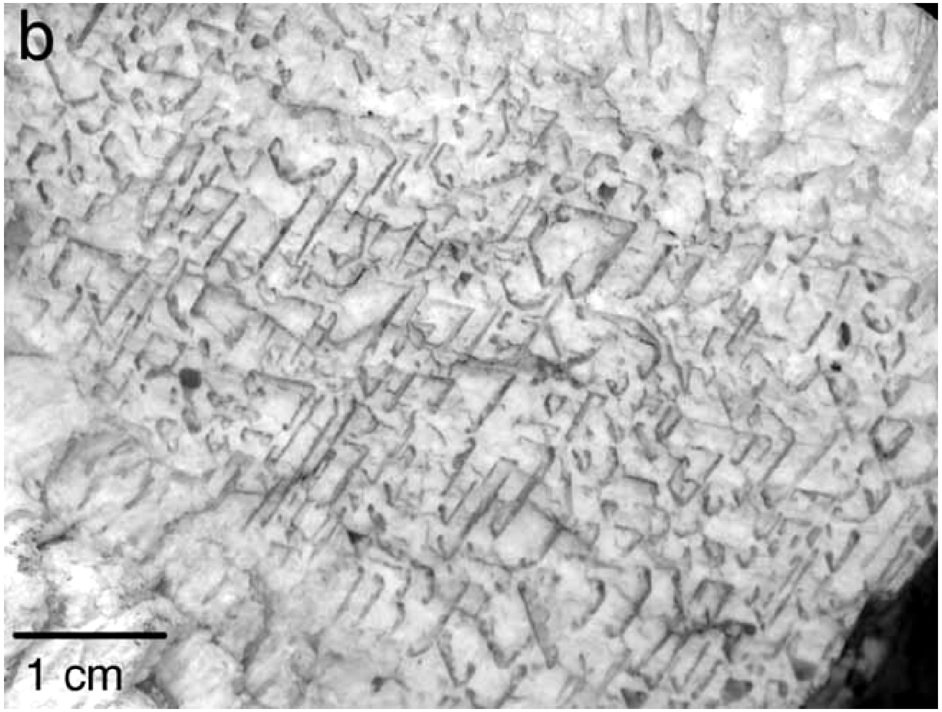
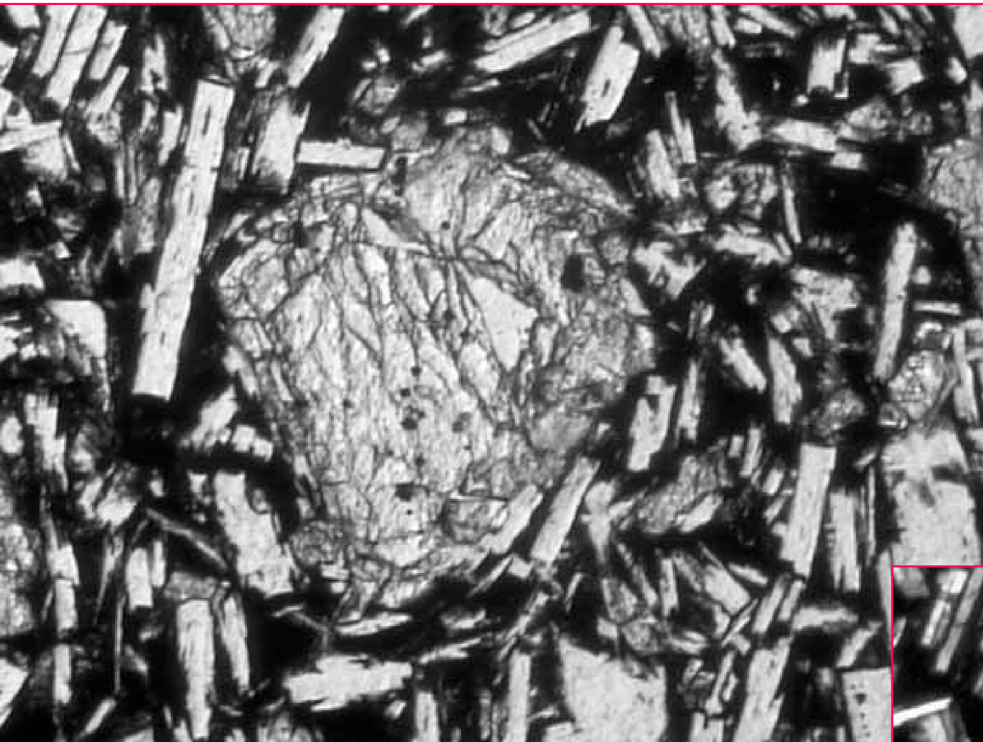


Figure 3.9b. Graphic texture: a single crystal of cuneiform quartz (darker) intergrown with alkali feldspar (lighter). Laramie Range, WY. © John Winter and Prentice Hall.

Chapter 3: Igneous Textures

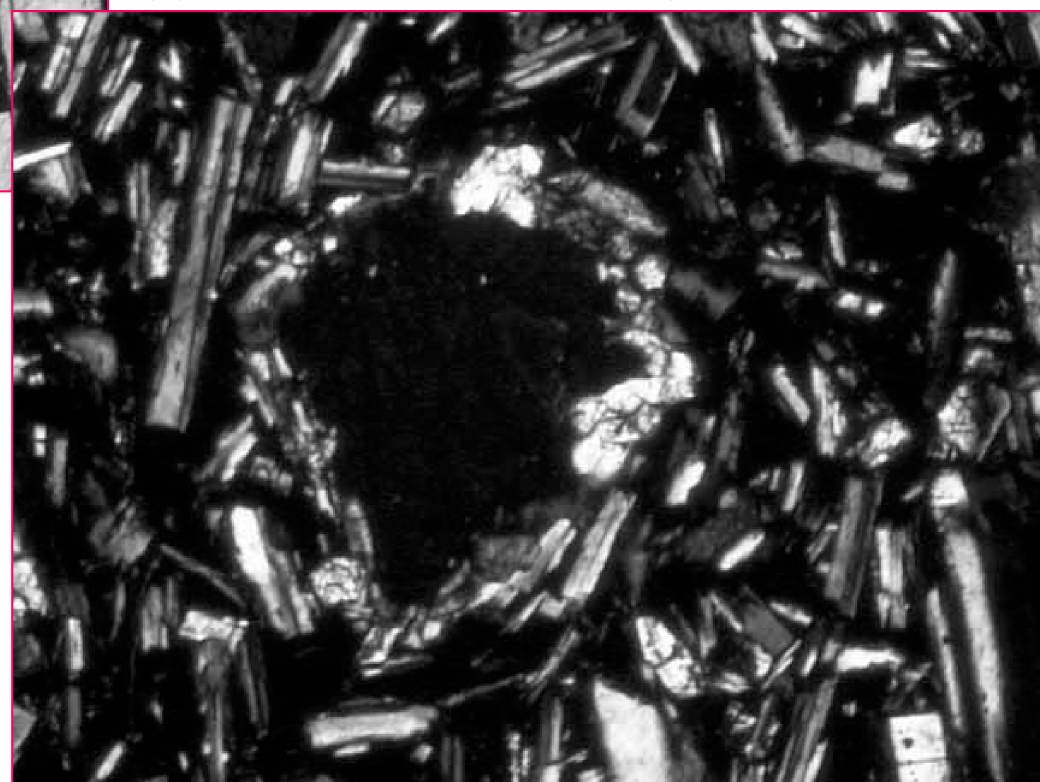
- **Magmatic reaction and resorption**
  - Fig. 3.10 is an example – Olivine ➔ OPX
  - **Resorption** – refusion or dissolution of mineral back into the melt or solution from which it formed
  - Resorbed crystals commonly have rounded corners or are embayed
  - **Sieve texture** (Fig. 3.11a) – evidence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

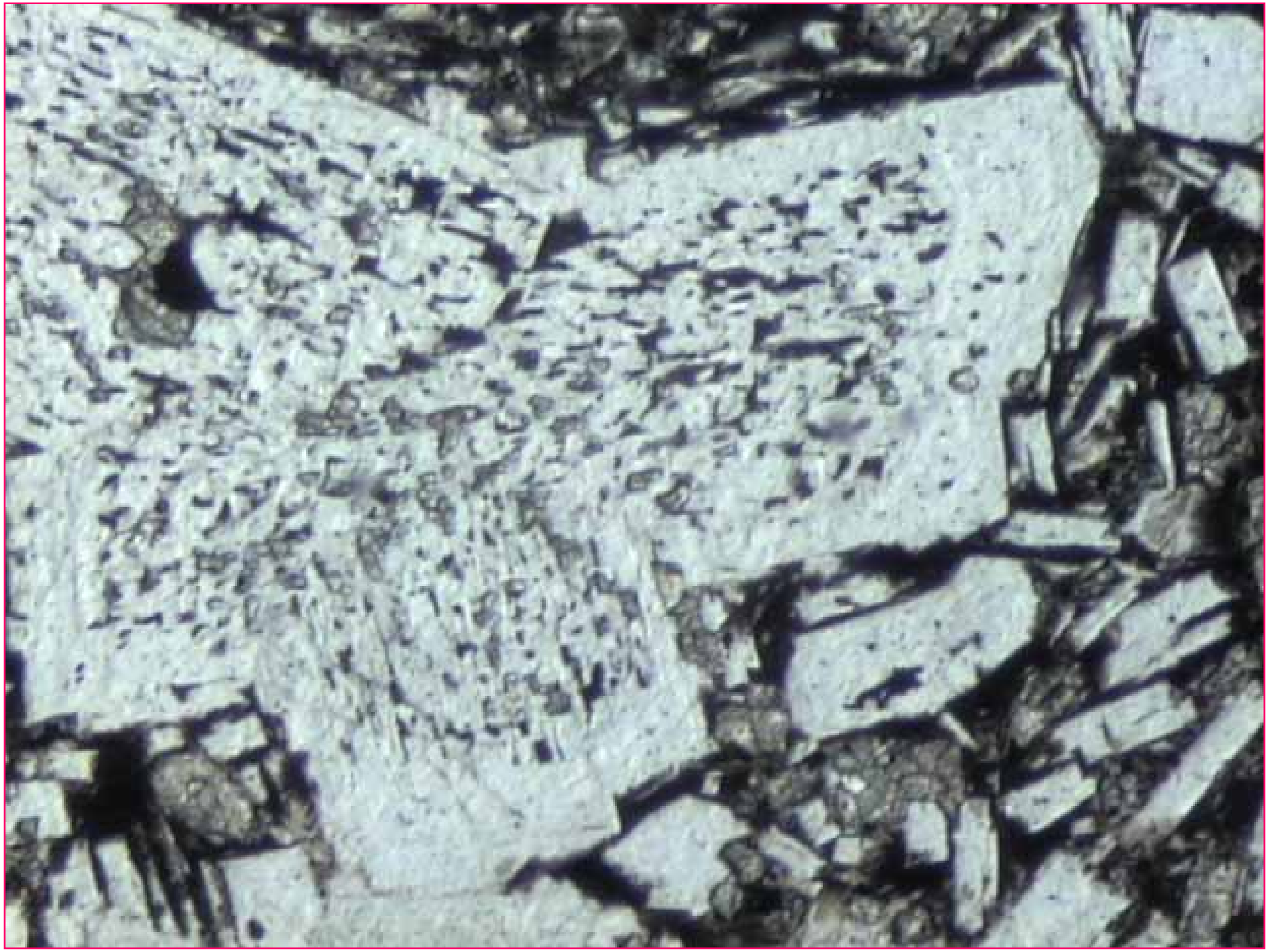


Figure 3.11a. **Sieve** texture in a cumulophyric cluster of plagioclase phenocrysts. Note the later non-sieve rim on the cluster. Andesite, Mt. McLoughlin, OR. Width 1 mm.

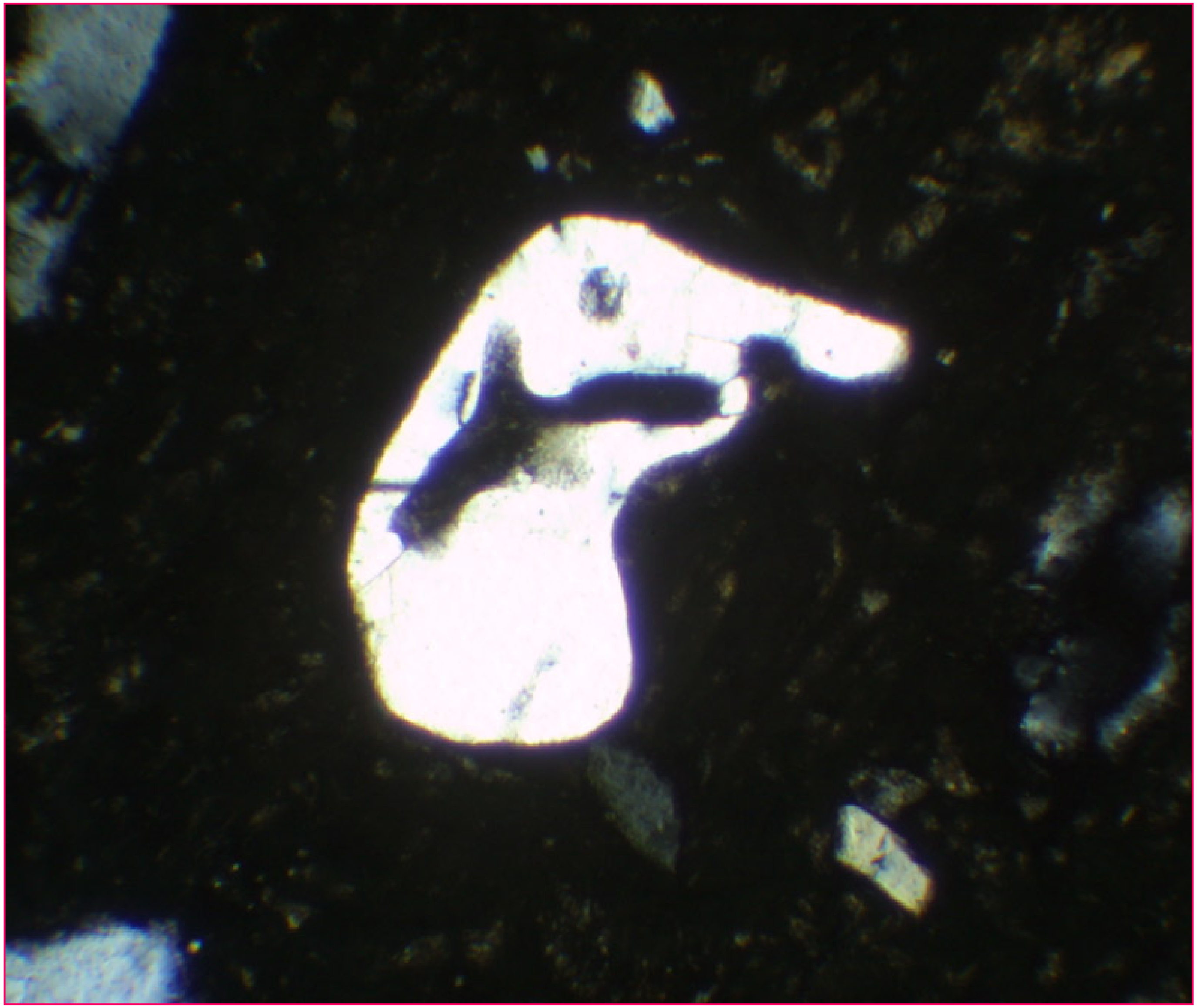


Figure 3.11b. Partially **resorbed** and **embayed** quartz phenocryst in rhyolite. Width 1 mm. © John Winter and Prentice Hall.

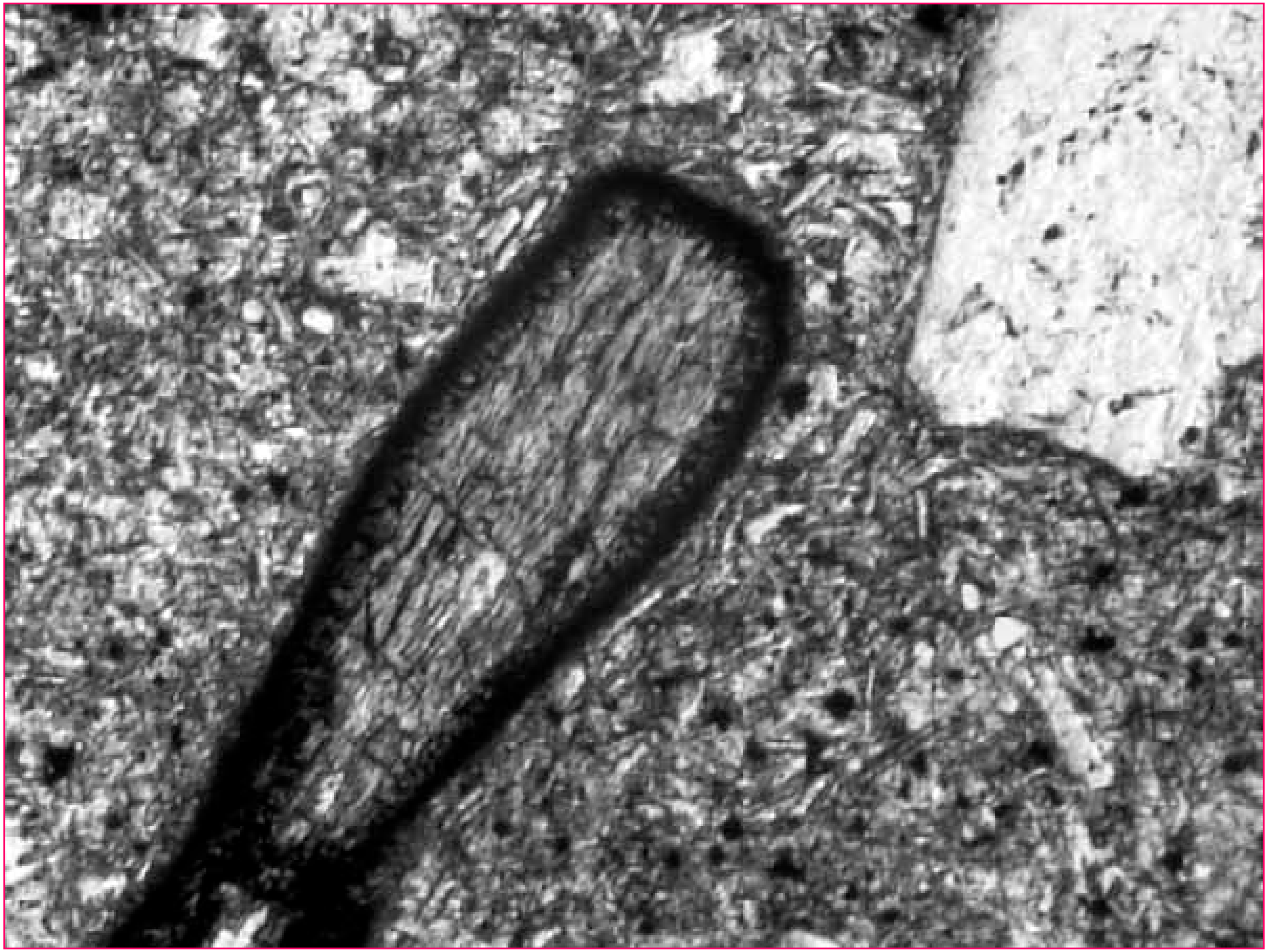


Figure 3.11c. **Hornblende** phenocryst **dehydrating** to **Fe-oxides plus pyroxene** due to pressure release upon eruption, andesite. Crater Lake, OR. Width 1 mm.

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.

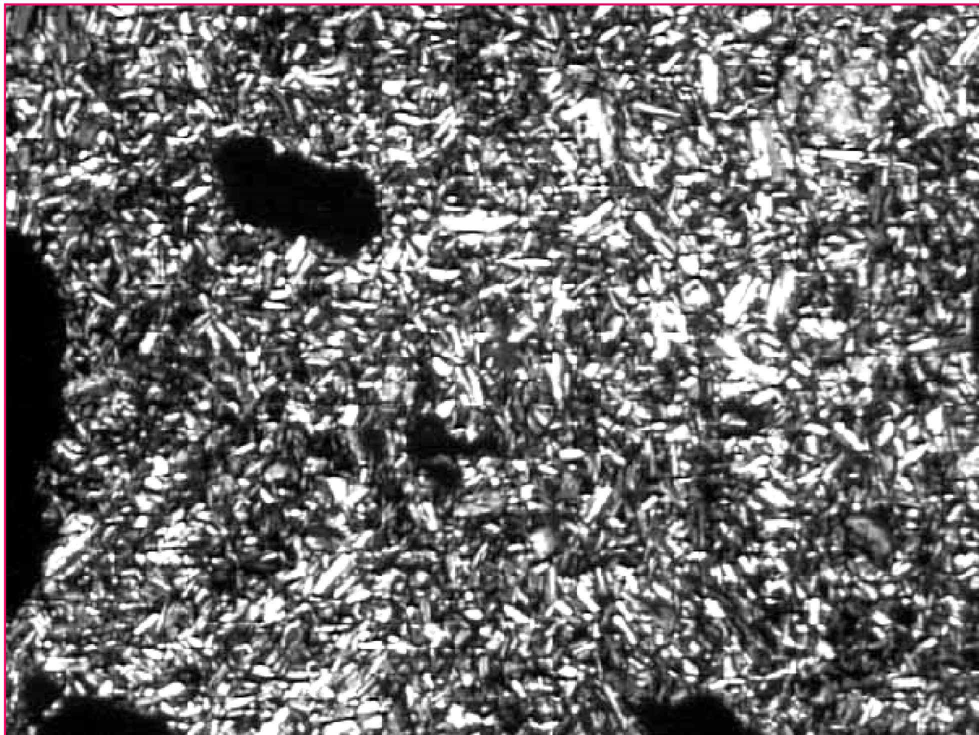


Figure 3.12b. Felty or **pilotaxitic** texture in which the microphenocrysts are randomly oriented. Basaltic andesite, Mt. McLaughlin, OR. Width 7 mm. © John Winter and Prentice Hall.

Figure 3.13. Flow banding in andesite. Mt. Rainier, WA.

Chapter 3: Cumulate Textures

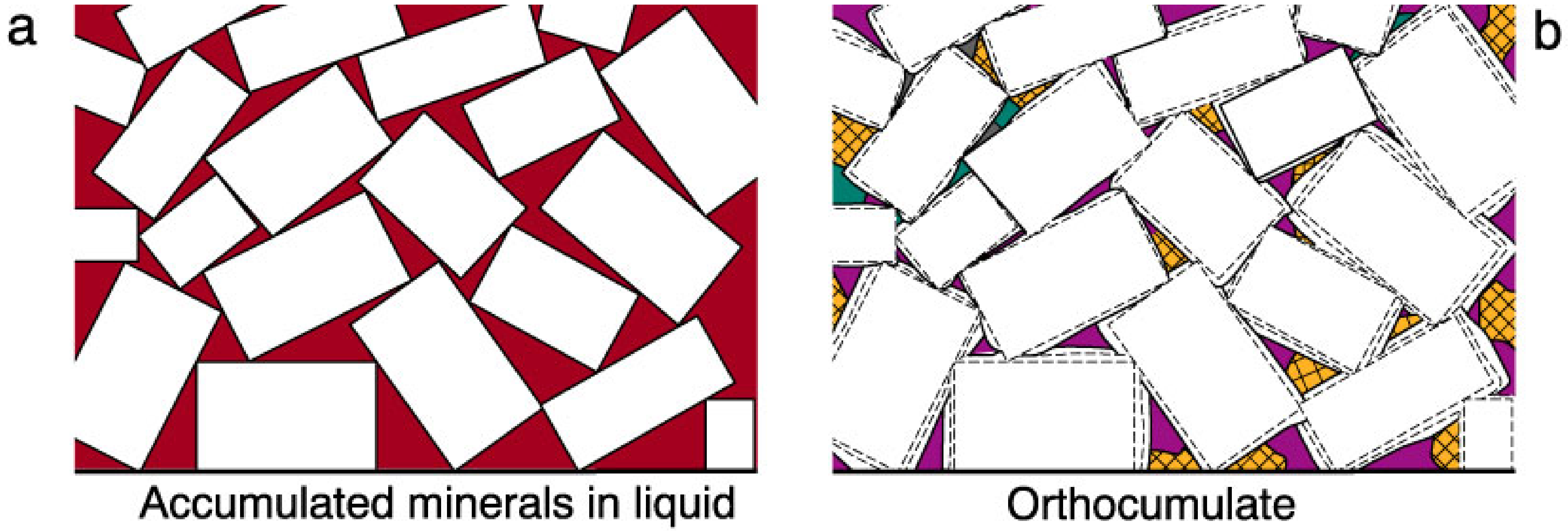


Figure 3.14. Development of **cumulate textures**. **a.** Crystals accumulate by crystal settling or simply form in place near the margins of the magma chamber. In this case plagioclase crystals (white) accumulate in mutual contact, and an intercumulus liquid (red) fills the interstices. **b.** Orthocumulate: intercumulus liquid crystallizes to form additional plagioclase rims plus other phases in the interstitial volume (colored). There is little or no exchange between the intercumulus liquid and the main chamber. After Wager and Brown (1967), *Layered Igneous Rocks*. © Freeman. San Francisco.

Chapter 3: Cumulate Textures

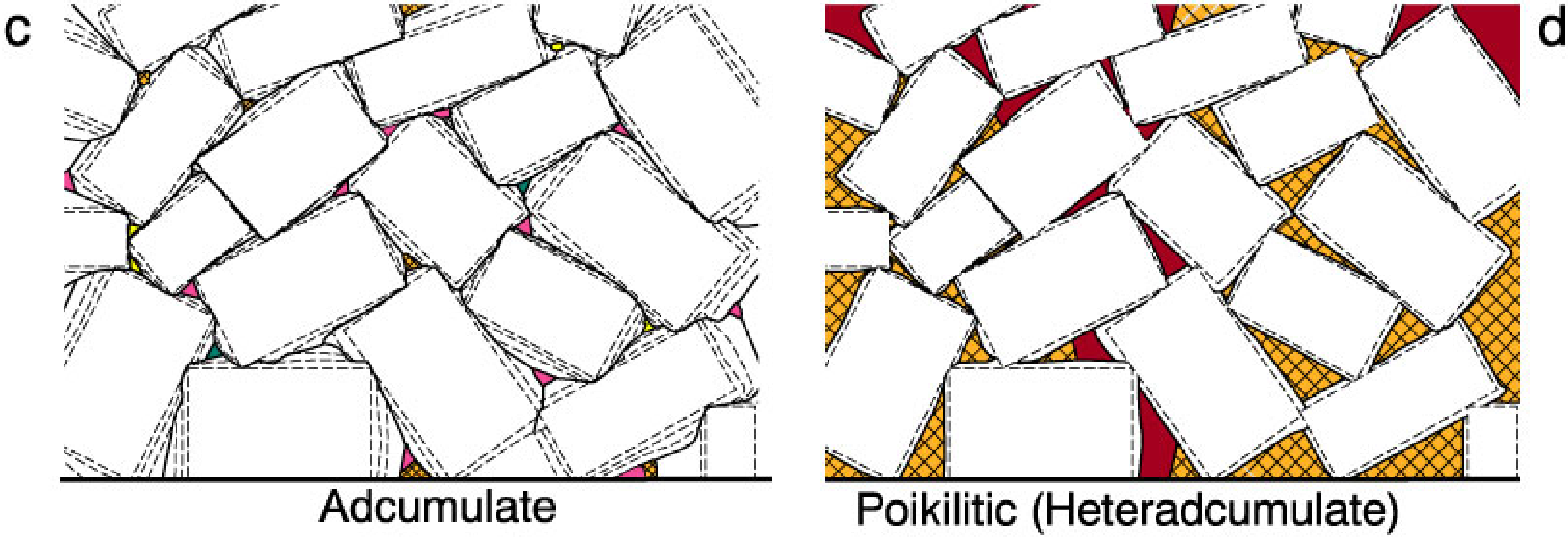
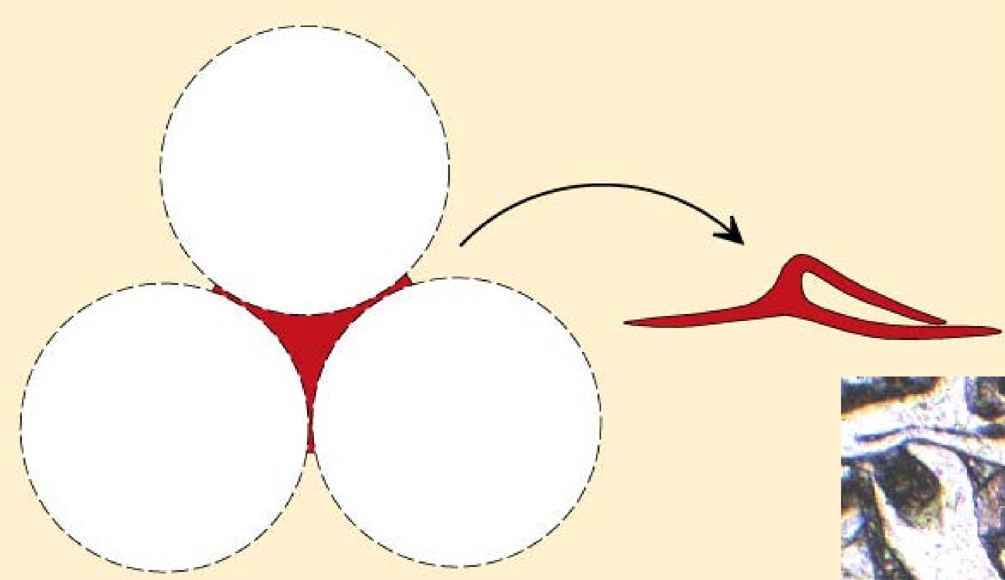


Figure 3.14. Development of **cumulate textures**. **c. Adcumulates**: open-system exchange between the intercumulus liquid and the main chamber (plus compaction of the cumulate pile) allows components that would otherwise create additional intercumulus minerals to escape, and plagioclase fills most of the available space. **d. Heteradcumulate**: intercumulus liquid crystallizes to additional plagioclase rims, plus other large minerals (hatched and shaded) that nucleate poorly and poikilitically envelop the plagioclases. . After Wager and Brown (1967), *Layered Igneous Rocks*. © Freeman. San Francisco.

Pyroclastic Textures



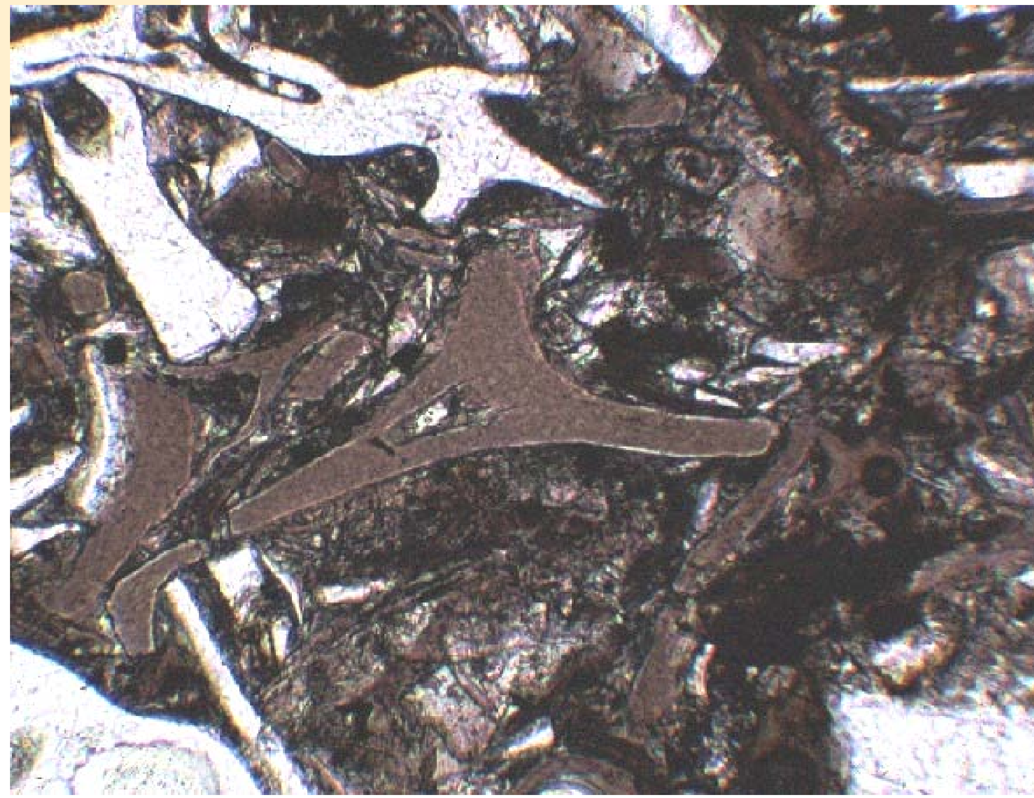


Figure 3.16a. The interstitial liquid (red) between bubbles in pumice (left) become 3-pointed-star-shaped glass shards in ash containing pulverized pumice. If they are sufficiently warm (when pulverized or after accumulation of the ash) the shards may deform and fold to contorted shapes, as seen on the right and **b.** in the photomicrograph of the Rattlesnake ignimbrite, SE Oregon. Width 1 mm. © John Winter.

Figure 3.18. a. Carlsbad twin in orthoclase. Wispy perthitic exsolution is also evident. Granite, St. Cloud MN. Field widths ~1 mm. © John Winter and Prentice Hall.

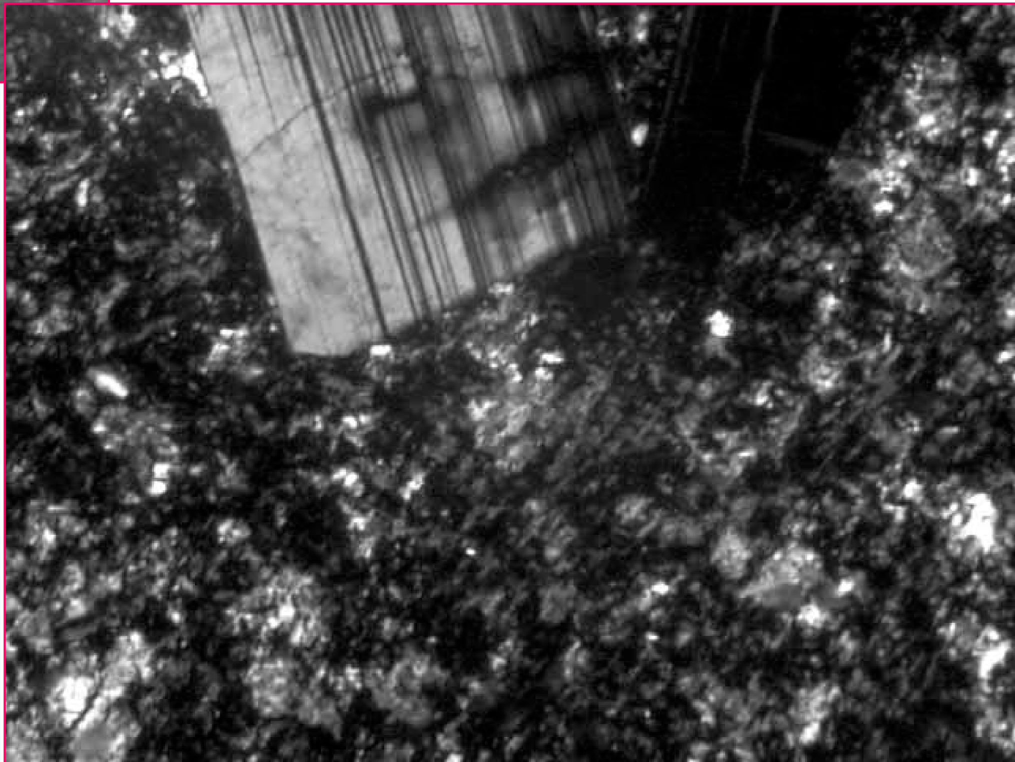


Figure 3.18. b. Very straight multiple **albite twins** in plagioclase, set in felsitic groundmass. Rhyolite, Chaffee, CO. Field widths ~1 mm. © John Winter and Prentice Hall.

Figure 3.18. (c-d) Tartan twins in microcline. Field widths ~1 mm. © John Winter and Prentice Hall.

Figure 3.19. Polysynthetic **deformation twins** in plagioclase. Note how they concentrate in areas of deformation, such as at the maximum curvature of the bent cleavages, and taper away toward undeformed areas. Gabbro, Wollaston, Ontario. Width 1 mm.

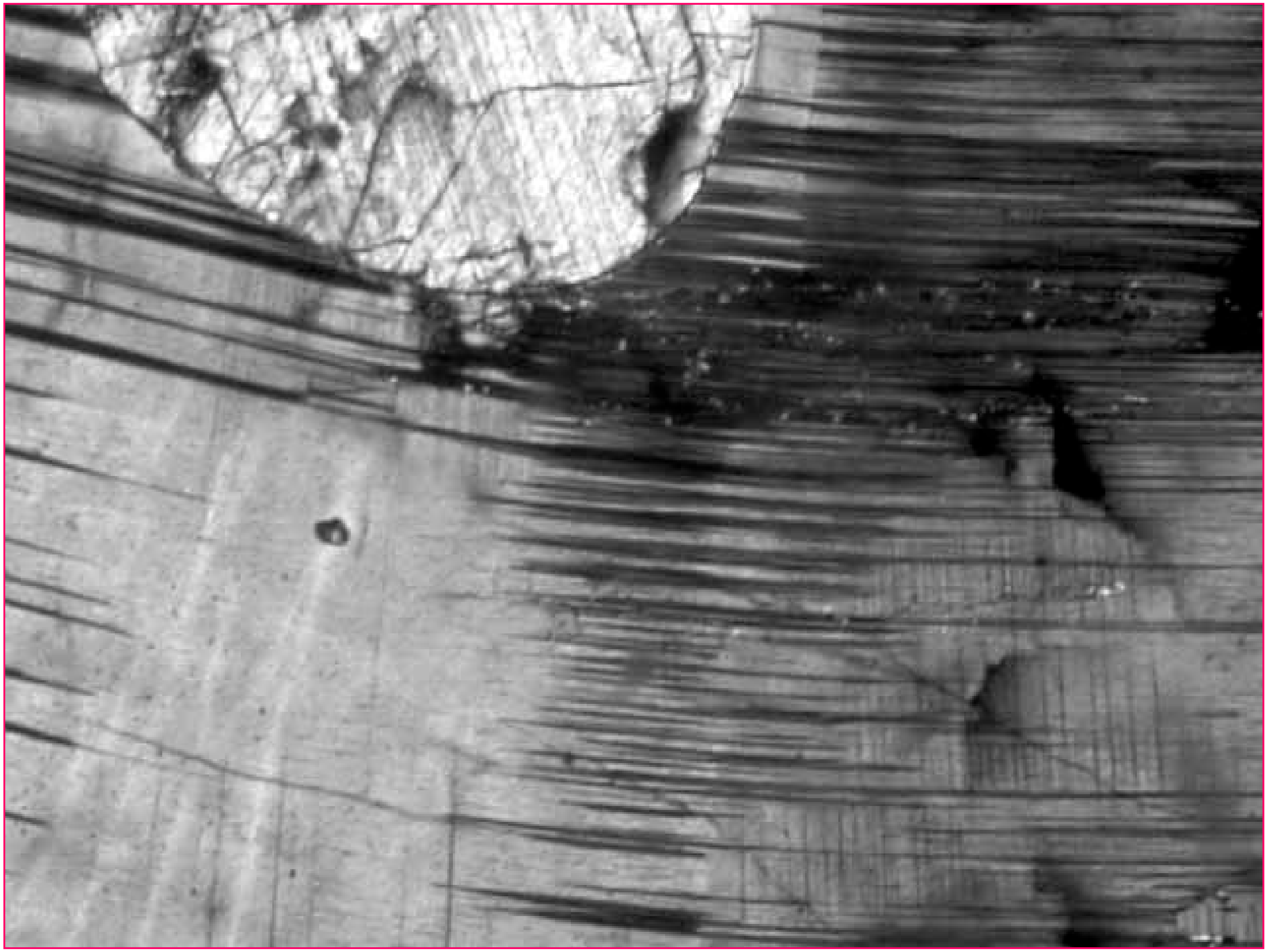
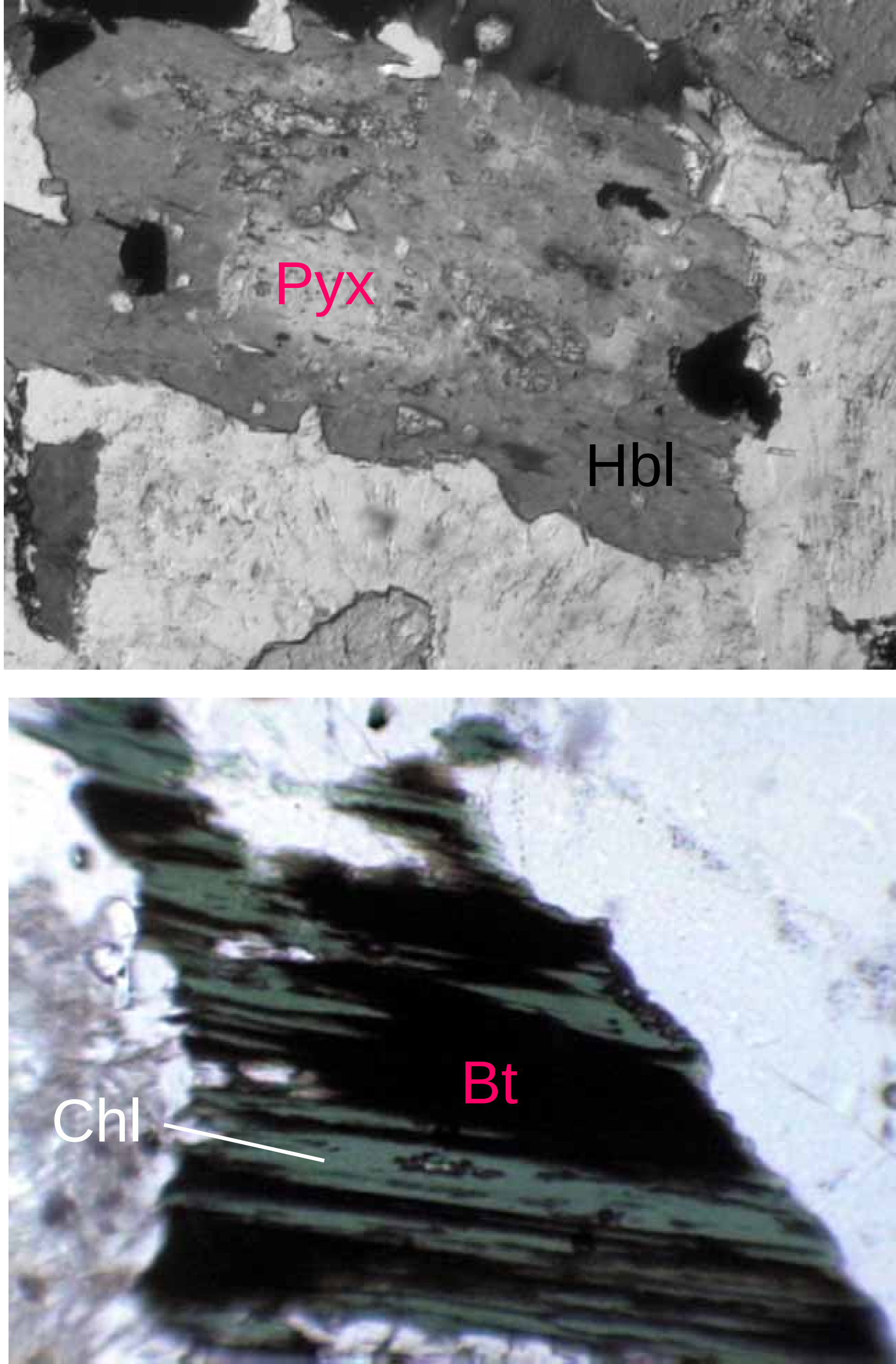


Figure 3.20. a. Pyroxene largely **replaced** by hornblende. Some pyroxene remains as light areas (Pyx) in the hornblende core. Width 1 mm. **b.** Chlorite (green) replaces biotite (dark brown) at the rim and along cleavages. Tonalite. San Diego, CA. Width 0.3 mm. © John Winter and Prentice Hall.



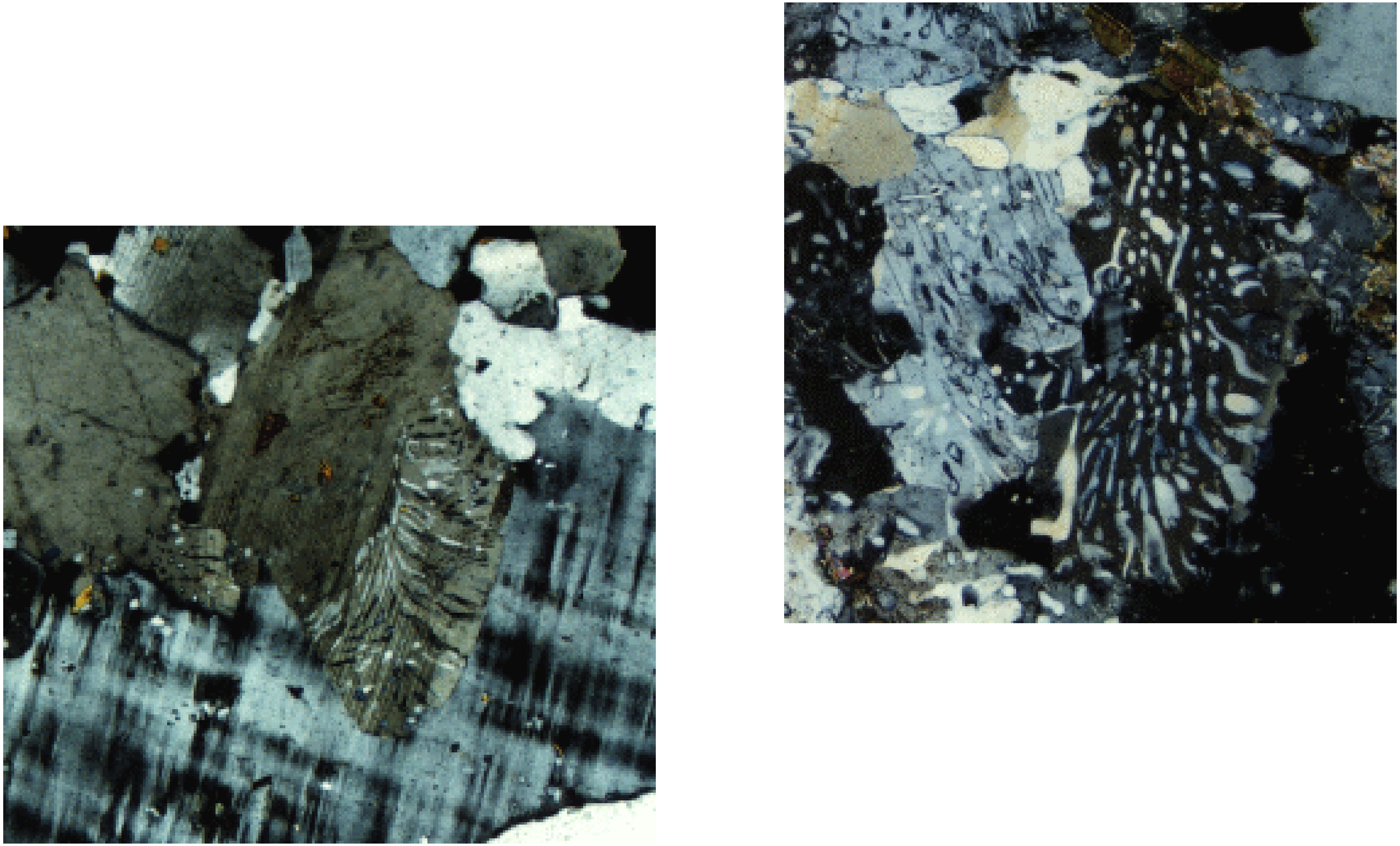


Figure 3.21. **Myrmekite** formed in plagioclase at the boundary with K-feldspar. Photographs courtesy © L. Collins. http://www.csun.edu/~vcgeo005