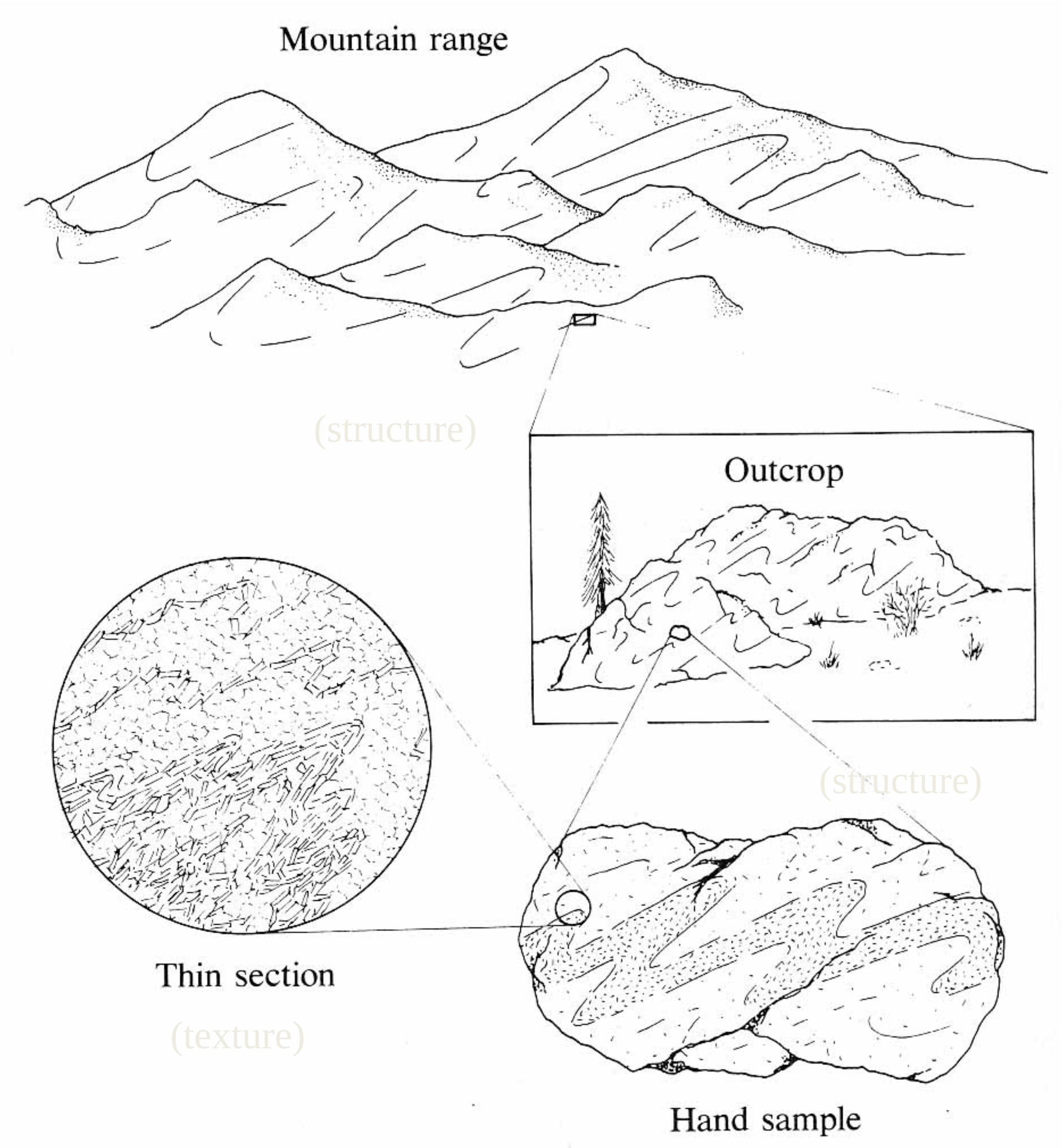
# Chapter 23: Metamorphic Textures




## Structures vs. Textures

## The fractal nature of geology

**Diagram showing that structural and fabric elements are generally consistent in style and orientation at all scales. From Best (1982). *Igneous and Metamorphic Petrology*. W. H. Freeman. San Francisco.**

# Chapter 23: Metamorphic Textures

Textures are small-scale penetrative features

Relict Textures

- Inherited from original rock
- "Blasto-" = relict
- Any degree of preservation
- Pseudomorphs of minerals or pre-metamorphic textures/structures

# Chapter 23: Metamorphic Textures

## Metamorphic Textures

The Processes of Deformation, Recovery, and Recrystallization (listed in order of increasing temperature and/or decreasing strain rate) are:

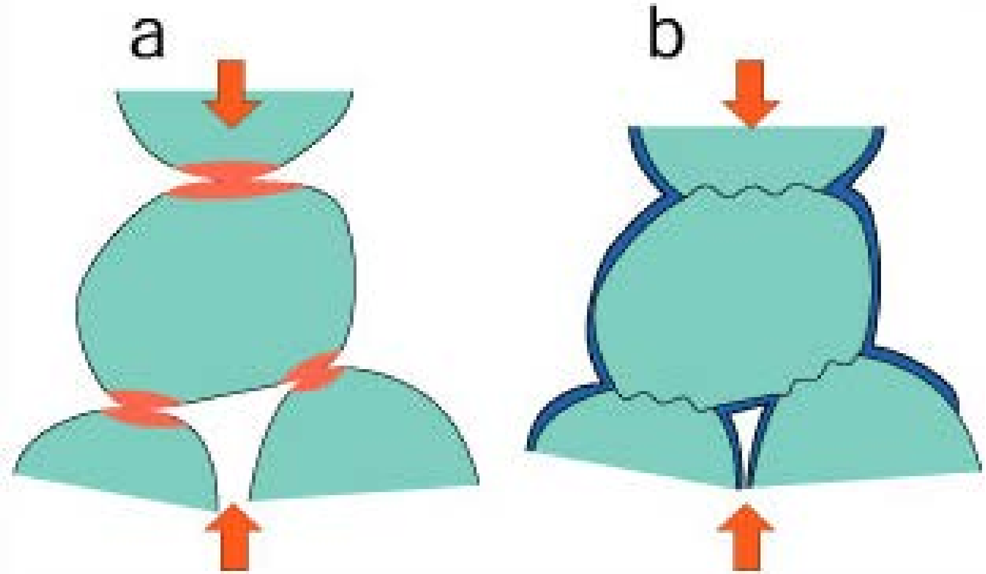
1. **Cataclastic Flow**
    - Mechanical fragmentation and sliding, rotation of fragments
    - Crush, break, bend, grind, kink, def$^{m}$ twins, undulose extinction, shredding of micas, augen, mortar, etc.

# Chapter 23: Metamorphic Textures

## Metamorphic Textures

## The Processes of Deformation, Recovery, and Recrystallization

### 2. Pressure Solution



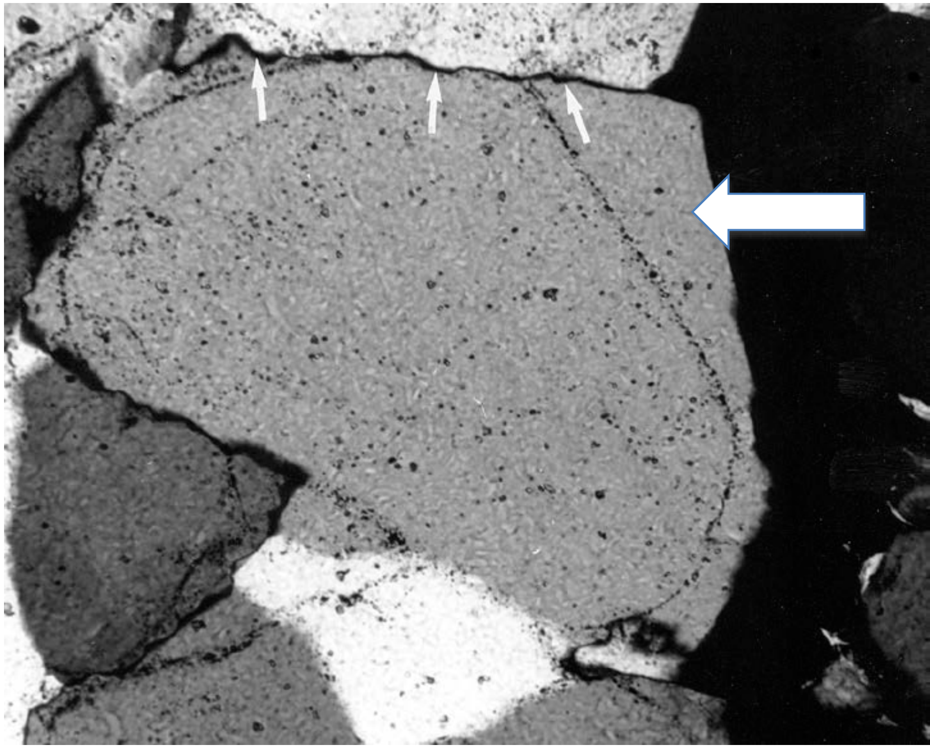



**Figure 23.2 a**. Highest strain in areas near grain contacts (hatch pattern). b. High-strain areas dissolve and material precipitates in adjacent low-strain areas (shaded). The process is accompanied by vertical shortening. c. Pressure solution of a quartz crystal in a deformed quartzite ($\sigma_1$ is vertical). Pressure solution results in a serrated solution surface in high-strain areas (small arrows) and precipitation in low-strain areas (large arrow). ~ 0.5 mm across. The faint line within the grain is a hematite stain along the original clast surface. After Hibbard (1995) *Petrography to Petrogenesis*. Prentice Hall.

# Chapter 23: Metamorphic Textures

## 3. **Plastic Intracrystalline Deformation**

- No loss of cohesion
- Several processes may operate simultaneously
  - Defect migration
  - Slip planes
  - Dislocation glide
  - Deformation twinning

# Chapter 23: Metamorphic Textures

4. **Recovery**
   - Loss of stored strain energy by vacancy migration, dislocation migration and annihilation
   - Polygonization- general term for formation of low-strain subgrains

# Chapter 23: Metamorphic Textures

## 5. Recrystallization

- Grain boundary migration
- Subgrain rotation
- Solid-state diffusion creep at higher T
- Crystal plastic deformation (general term)
  - Grain boundary sliding and area reduction

Coalescence- recovery and recrystallization by which large grains form by the addition of smaller strained grains by grain boundary migration

# Chapter 23: Metamorphic Textures

## Dislocation migration forms two strain-free subgrains

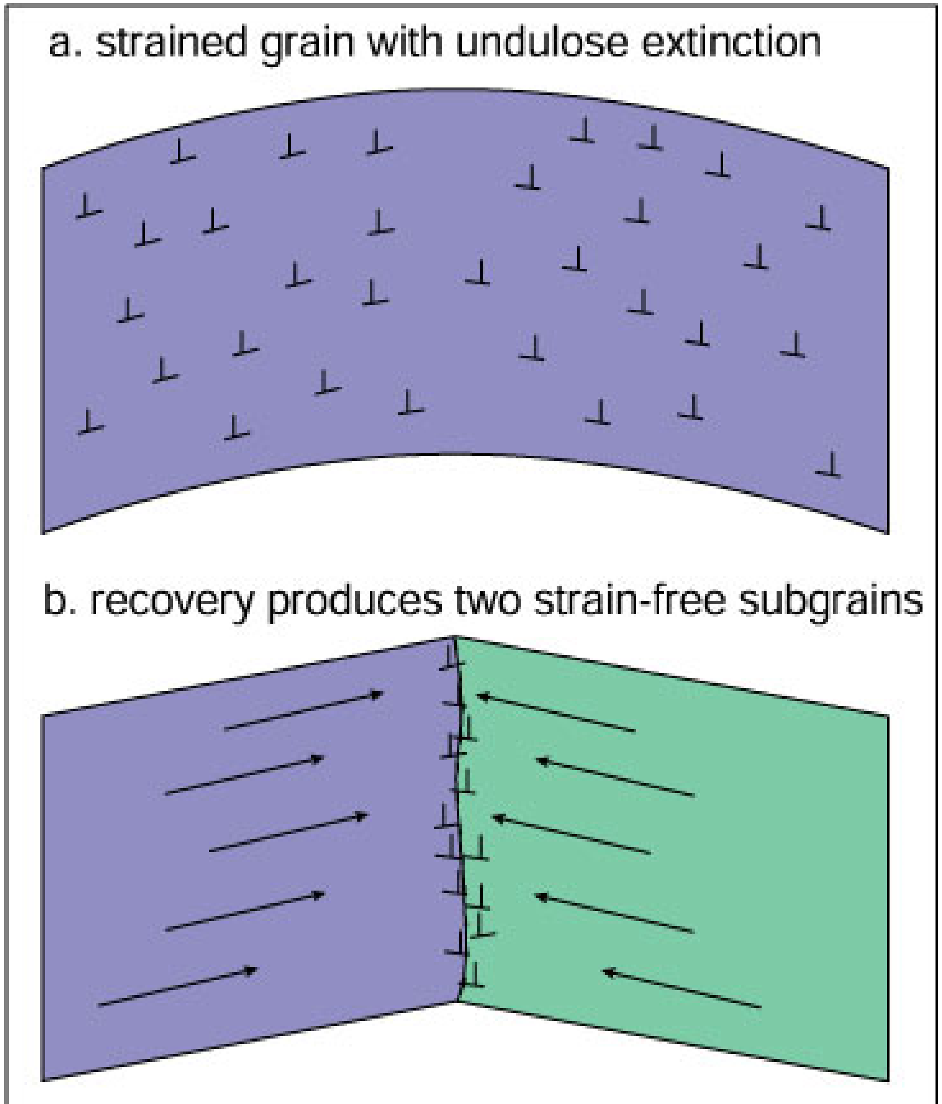



**Figure 23.5.** Illustration of a recovery process in which dislocations migrate to form a subgrain boundary. Winter (2010) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall.

# Chapter 23: Metamorphic Textures

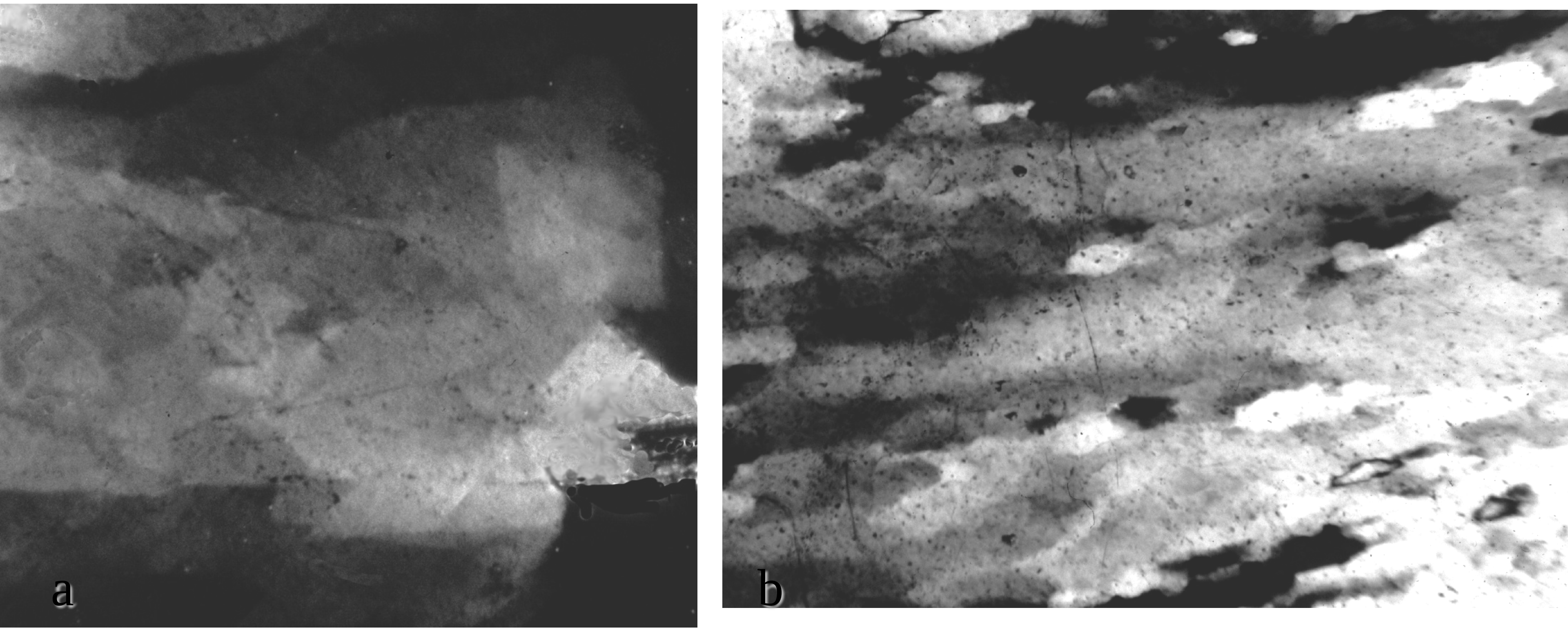



**Figure 23.4 a.** **Undulose extinction and (b) elongate subgrains in quartz due to dislocation formation and migration Winter (2010) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall.**

# Recrystallization by grain boundary migration and sub-grain rotation

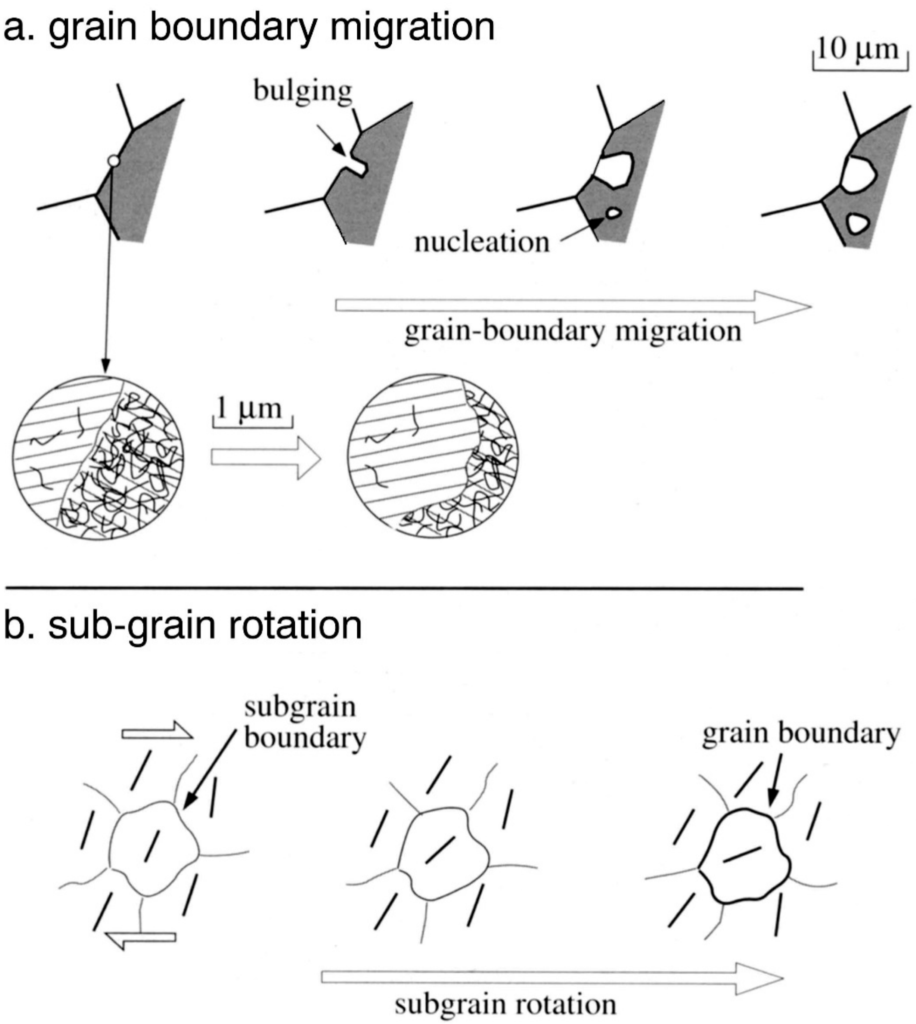



**Figure 23.6.** Recrystallization by (a) grain-boundary migration (including nucleation) and (b) subgrain rotation. From Passchier and Trouw (1996) *Microtectonics*. Springer-Verlag. Berlin.

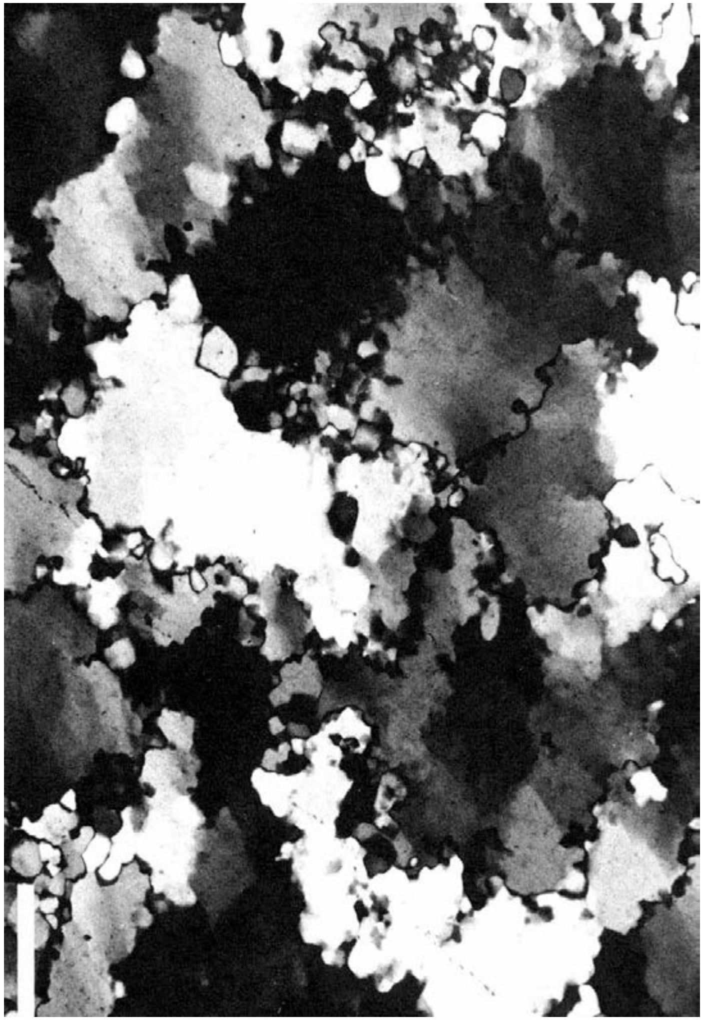
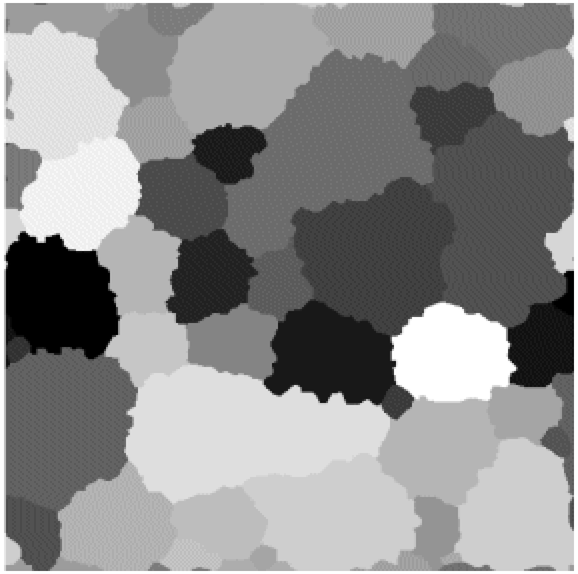


**Figure 23.7a.** Recrystallized quartz with irregular (sutured) boundaries, formed by grain boundary migration. Width 0.2 mm. From Borradaile *et al.* (1982).



# High-Strain Metamorphic Textures (shear zones)

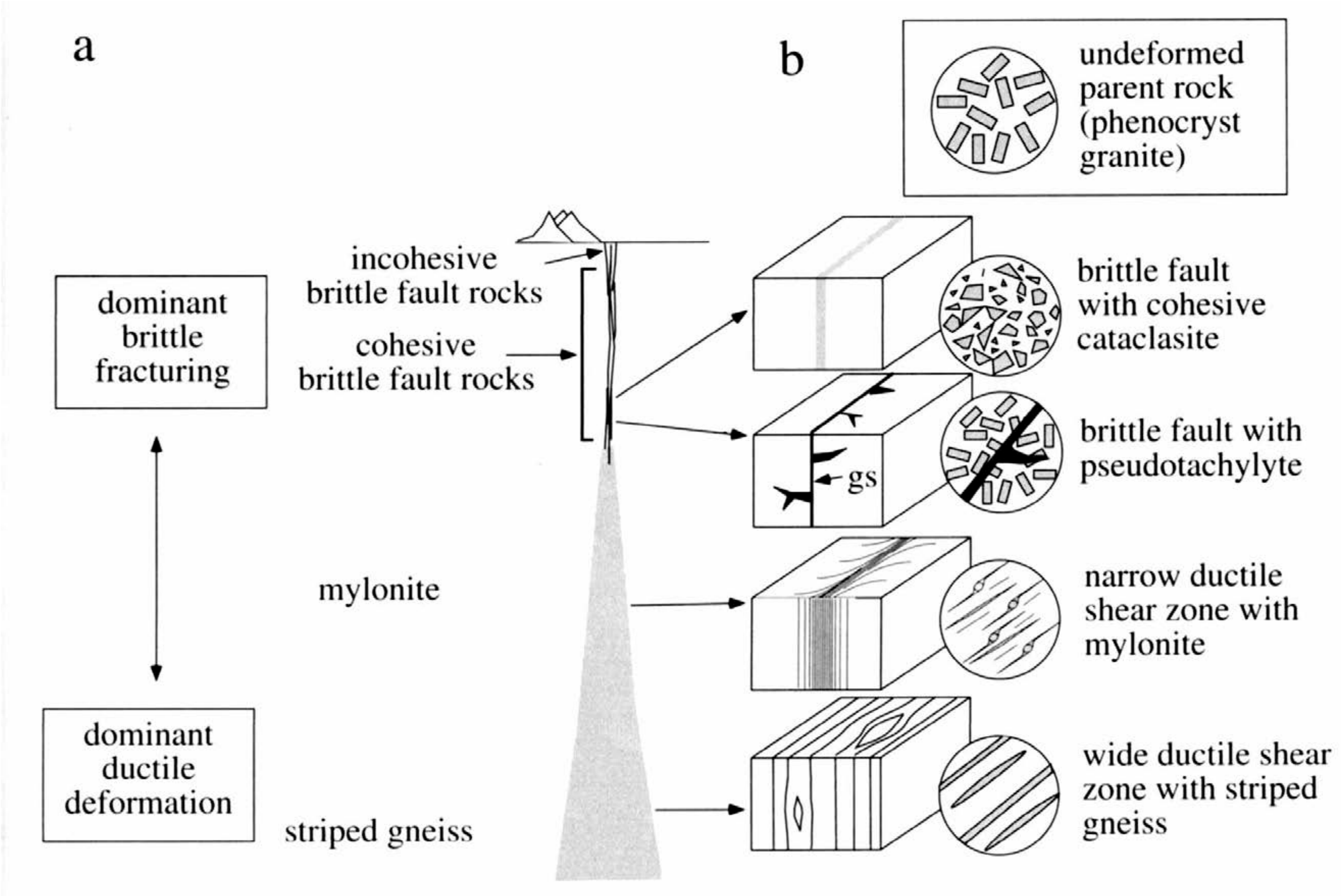



**Figure 22.2.** Schematic cross section through a shear zone, showing the vertical distribution of fault-related rock types, ranging from non-cohesive gouge and breccia near the surface through progressively more cohesive and foliated rocks. Note that the width of the shear zone increases with depth as the shear is distributed over a larger area and becomes more ductile. Circles on the right represent microscopic views or textures. From Passchier and Trouw (1996) *Microtectonics*. Springer-Verlag. Berlin.

# Chapter 23: Metamorphic Textures

## High-Strain Metamorphic Textures

Concentrate on cataclastic processes (shallower levels) relative to ductile behavior (at depth)

- Break, crack, bend, crush, rotate

Cataclastic processes continue at intermediate depths:

- Slip and shredding of phyllosilicates (along 001 plane)
- Undulose extinction is ubiquitous
- Clasts- broken remnants of pre-deformational grains
- Porphyroclast- larger remnant in finer crush matrix
  - Mortar texture (see next slide)
  - Ribbons (see next slide)

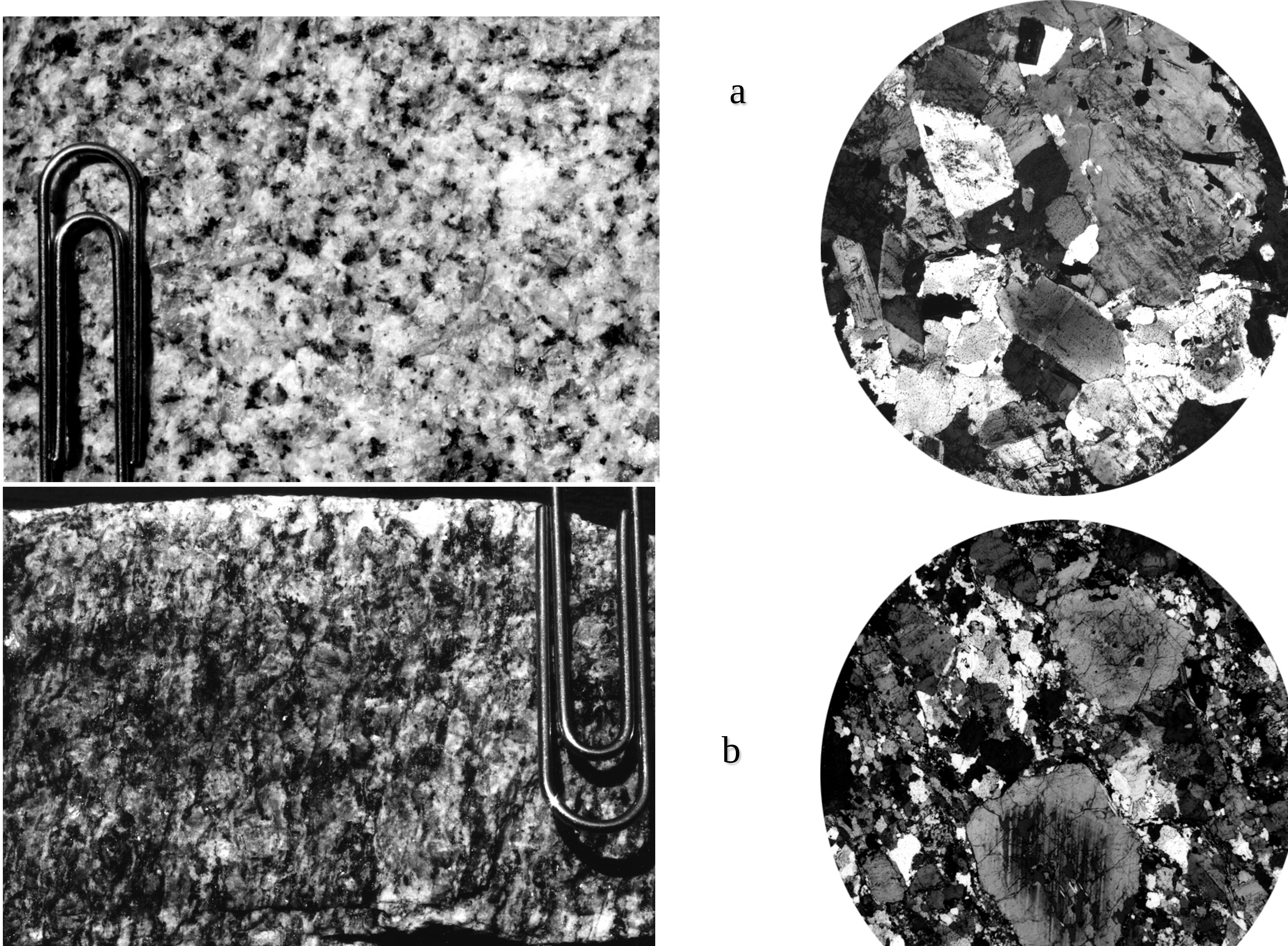
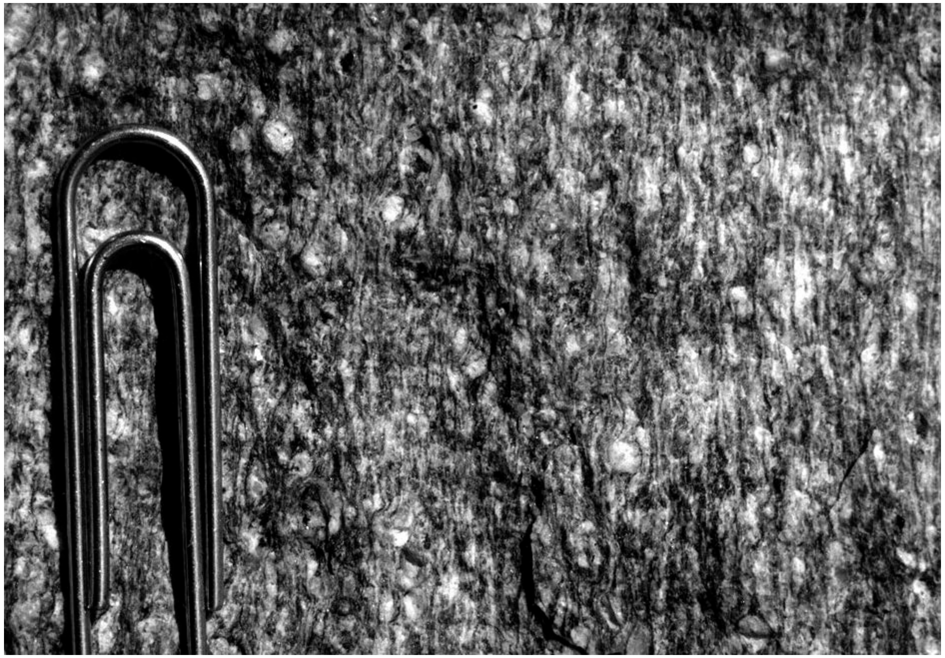



**Figure 23.15.** Progressive mylonitization of a granite. From Shelton (1966). *Geology Illustrated.* Photos courtesy © John Shelton.



c

d

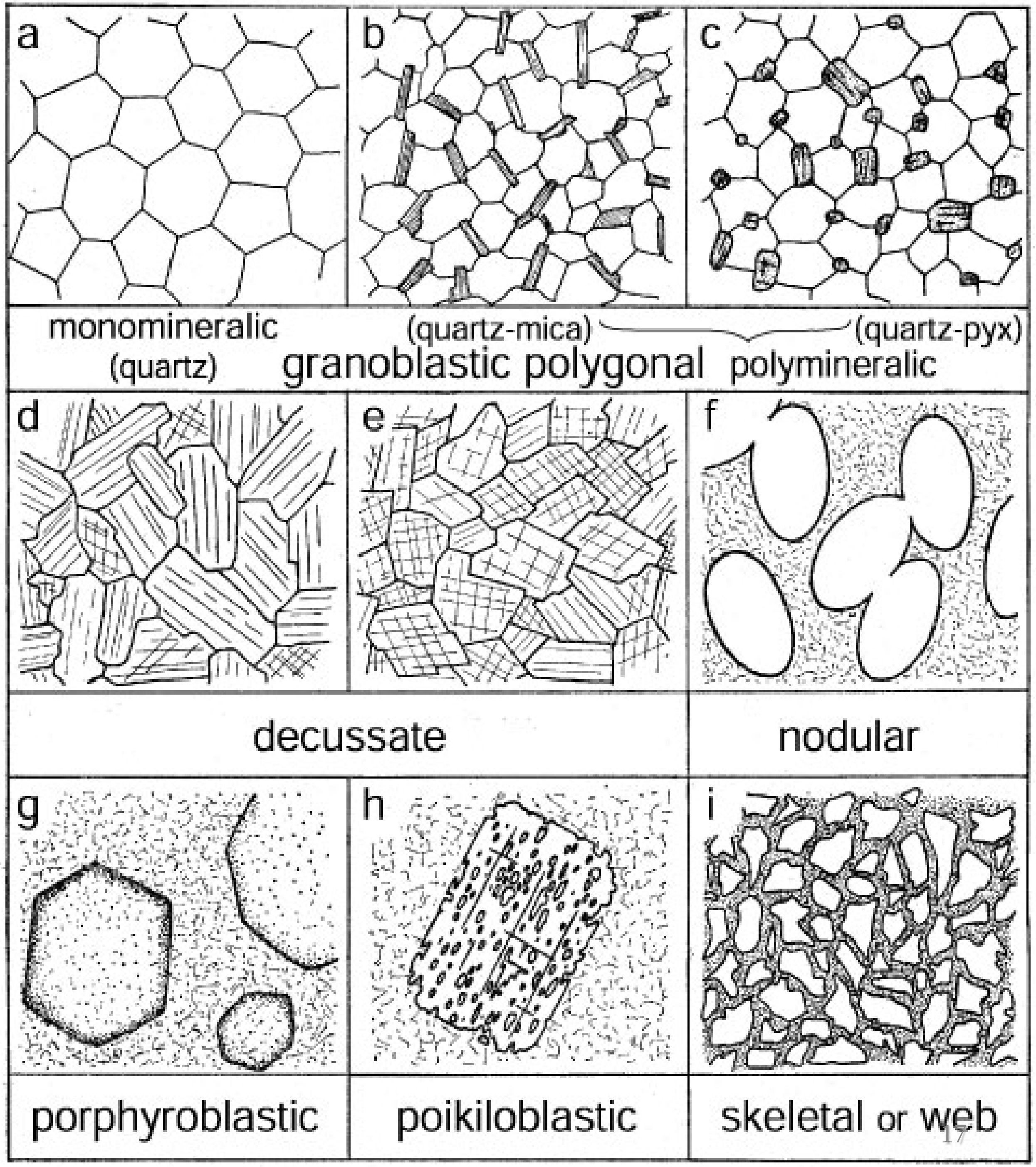
**Figure 23.15.** Progressive mylonitization of a granite. From Shelton (1966). *Geology Illustrated.* Photos courtesy © John Shelton.

# Chapter 23: Metamorphic Textures

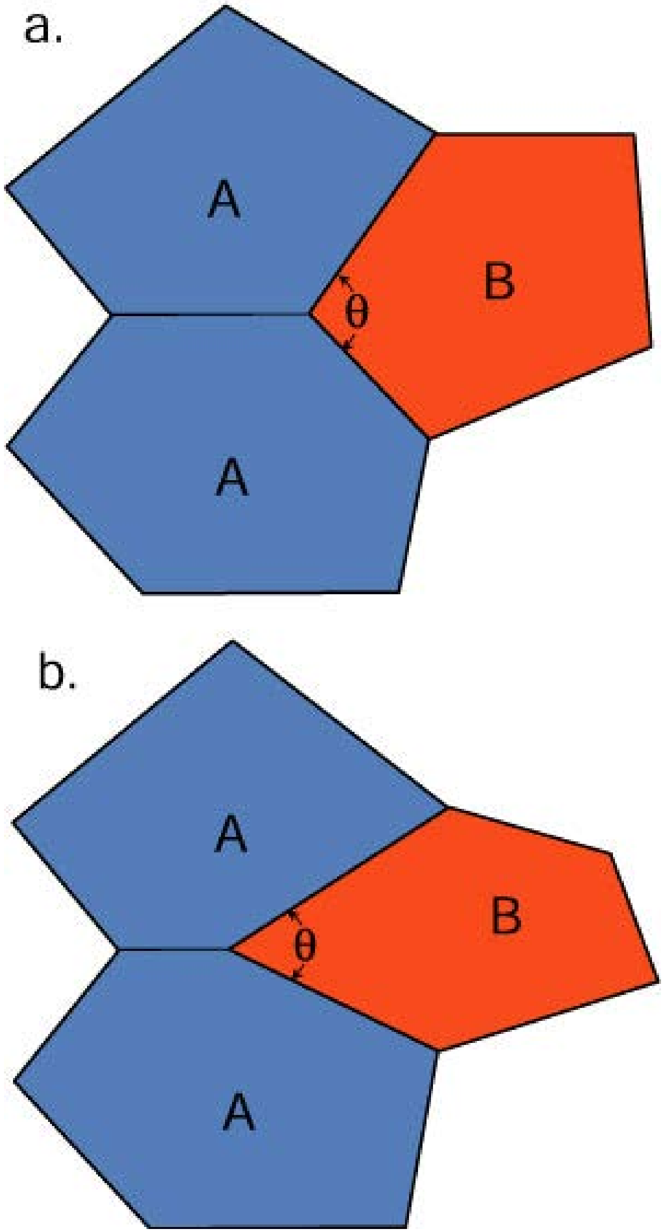
## Textures of Contact Metamorphism

- Typically shallow pluton aureoles (low-P)
- Crystallization/recrystallization is "near-static" = lack of deviatoric stress (i.e., after deformation event)
  - Monomineralic with low Δ surface energy → granoblastic polygonal (triple junctions with ~120° between them)
  - Larger Δ S.E. → decussate
- Isotropic textures (hornfels, granofels)

**Figure 23.9. Typical textures of contact metamorphism. From Spry (1969) *Metamorphic Textures*. Pergamon. Oxford.**



# Fig. 23.10 Grain boundary energy controls triple point angles



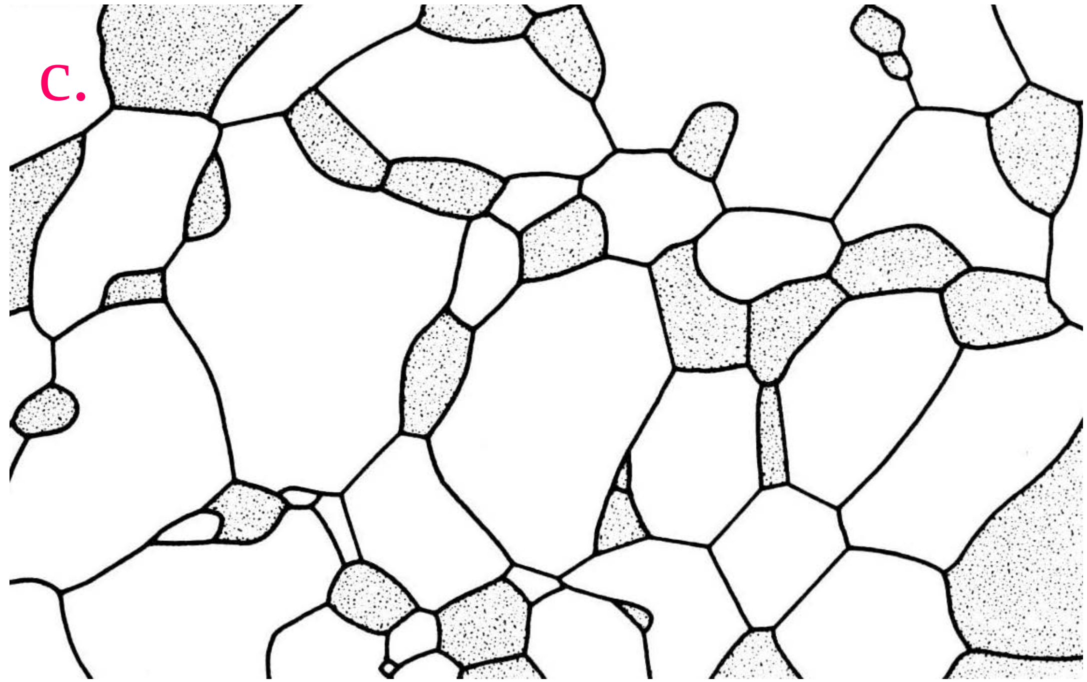




**Figure 23.10. a.** **Dihedral angle between two mineral types. When the A-A grain boundary energy is greater than for A-B, the angle θ will decrease (b) so as to increase the relative area of A-B boundaries. Winter (2010) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall. c. Sketch of a plagioclase (light)-clinopyroxene (dark) hornfels showing lower dihedral angles in clinopyroxene at most cpx-plag-plag boundaries. (c. from Vernon, 1976)** ***Metamorphic Processes: Reactions and Microstructure Development*****. Allen & Unwin, London.**

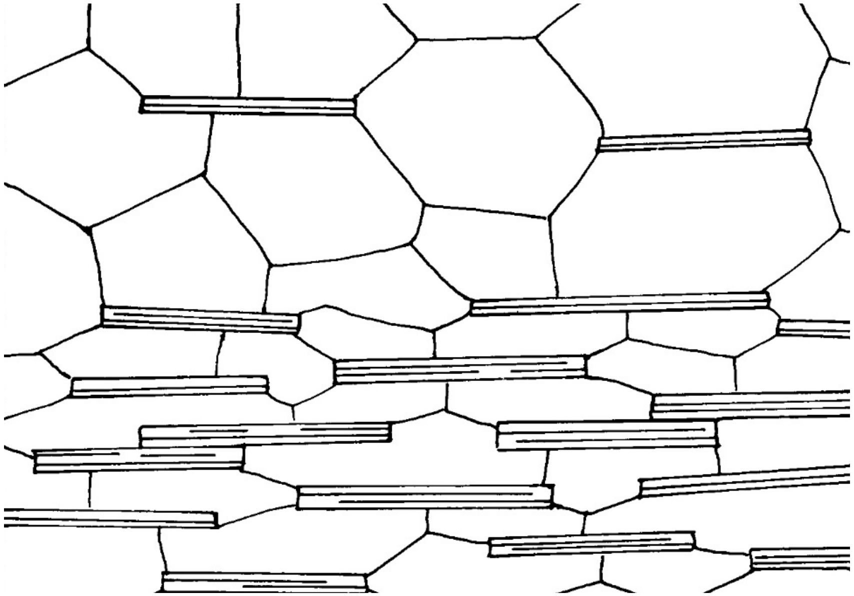
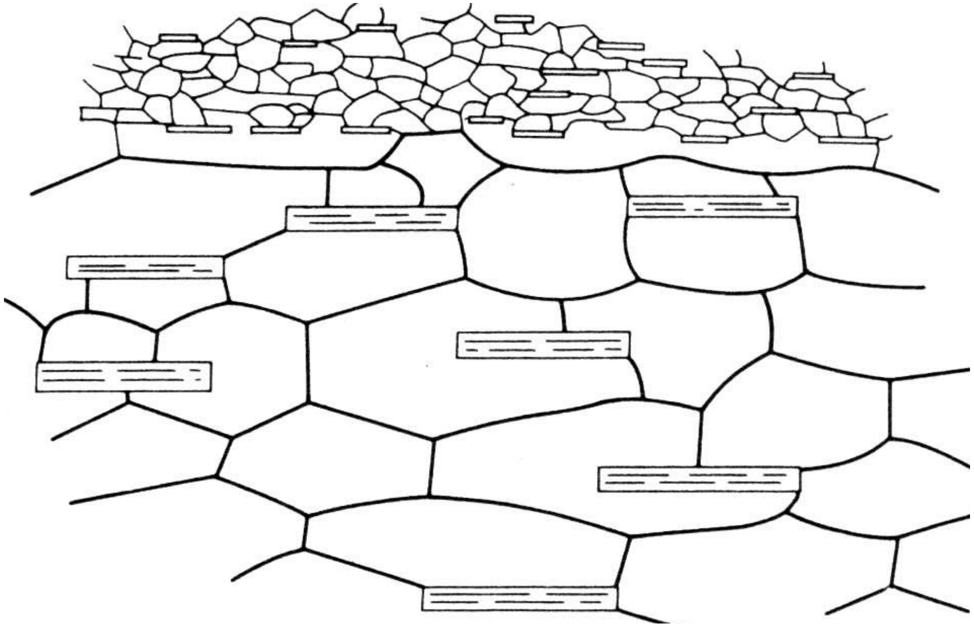


**Figure 23.11.** **Drawings of quartz-mica schists. a. Closer spacing of micas in the lower half causes quartz grains to passively elongate in order for quartz-quartz boundaries to meet mica (001) faces at 90º. From Shelley (1993). b. Layered rock in which the growth of quartz has been retarded by grain boundary "pinning" by finer micas in the upper layer. From Vernon, 1976) *Metamorphic Processes: Reactions and Microstructure Development*. Allen & Unwin, London.**



# The Crystalloblastic Series

*Most Euhedral*

Titanite, rutile, pyrite, spinel

**Garnet**, sillimanite, staurolite, tourmaline

Epidote, magnetite, ilmenite

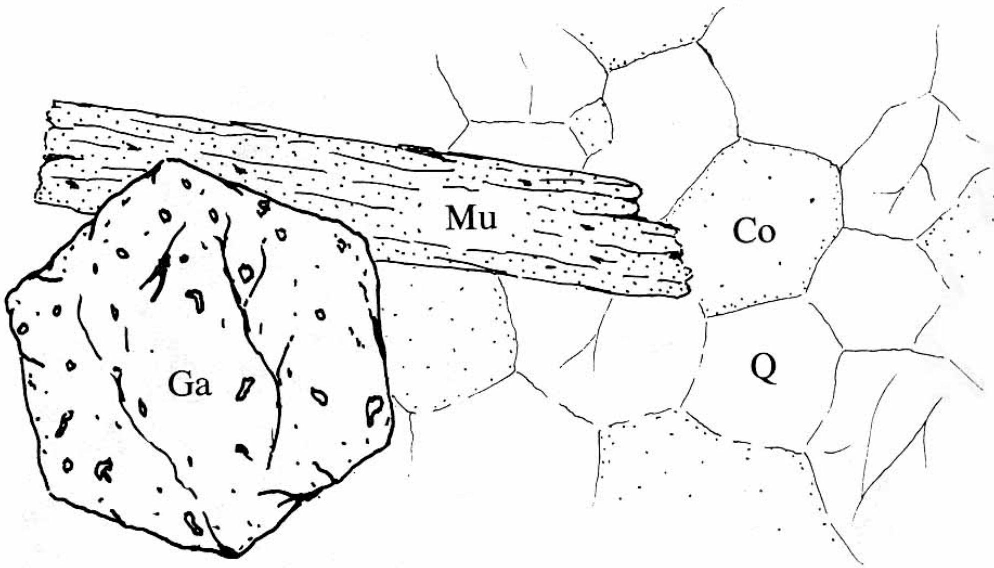
Andalusite, pyroxene, amphibole

**Mica**, chlorite, dolomite, kyanite

Calcite, vesuvianite, scapolite

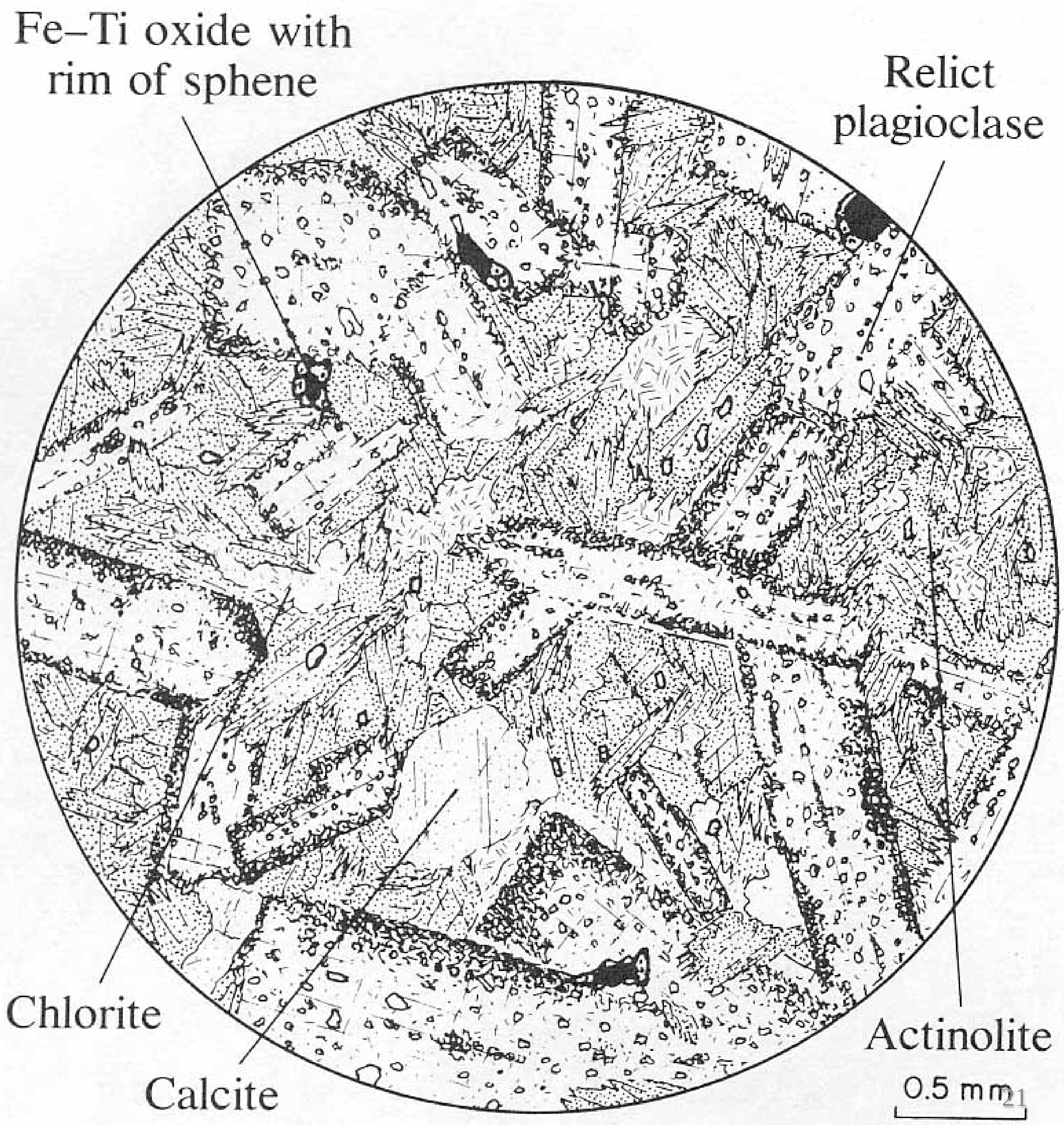
Feldspar, **quartz**, **cordierite**

*Least Euhedral*

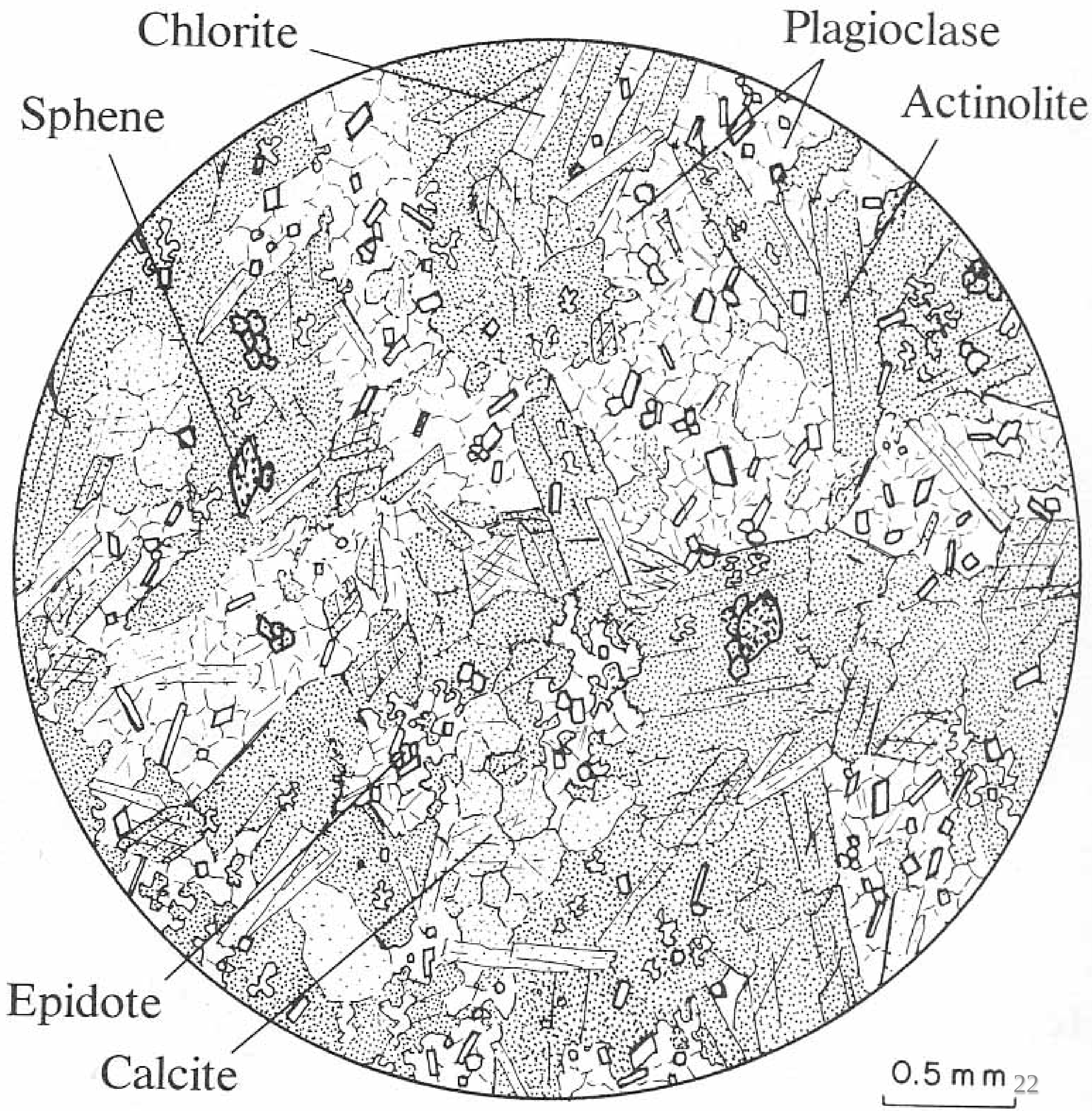


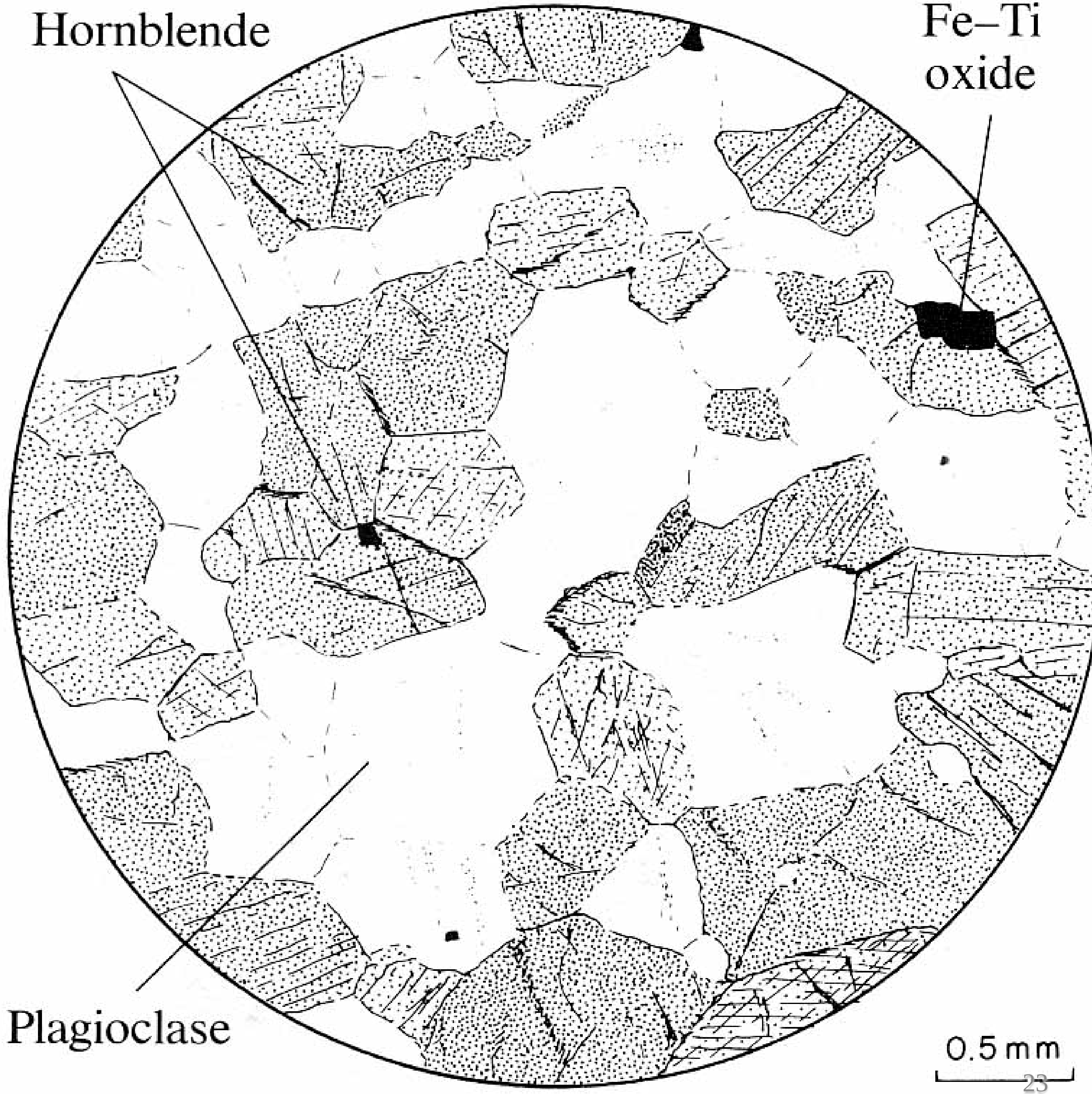

**Differences in development of crystal form among some metamorphic minerals. From Best (1982). *Igneous and Metamorphic Petrology*. W. H. Freeman. San Francisco.**

**Progressive thermal metamorphism of a diabase (coarse basalt).** **From Best (1982).** ***Igneous and Metamorphic Petrology*. W. H. Freeman. San Francisco.**

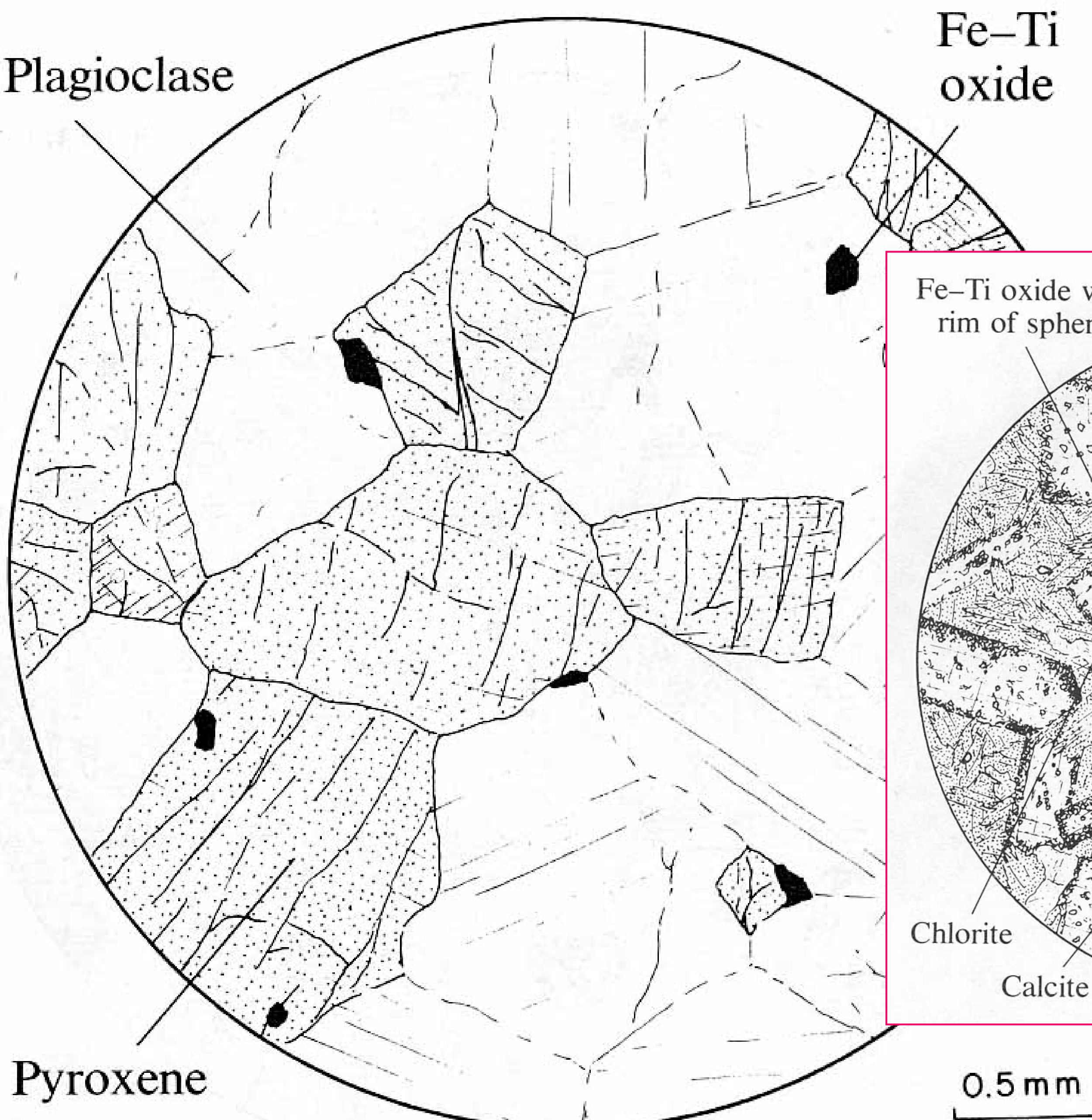


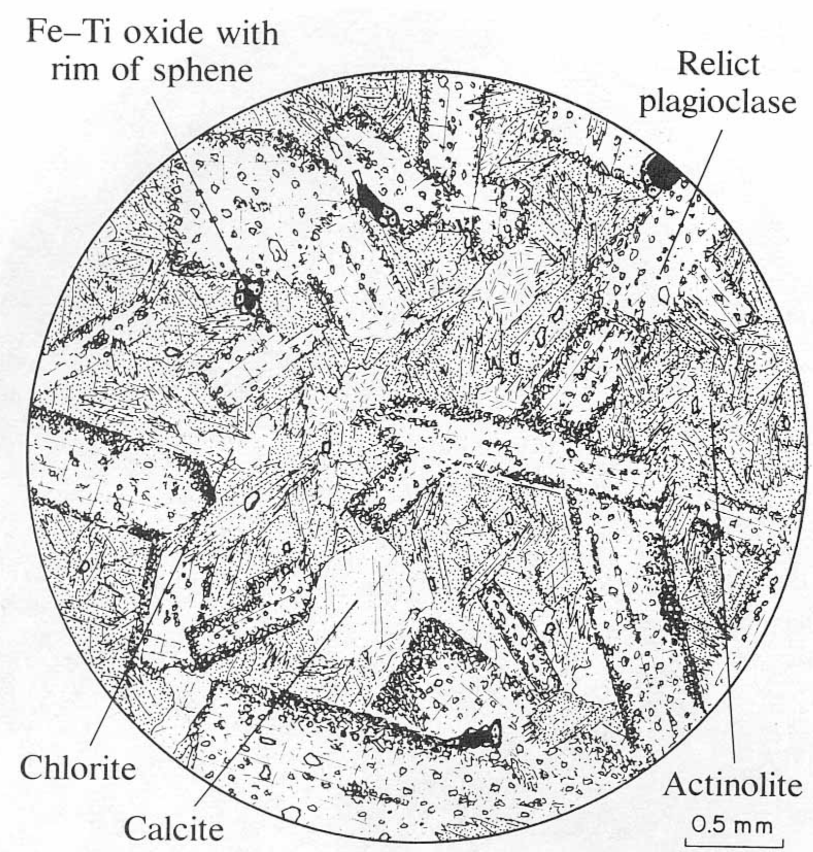
Progressive thermal metamorphism of a diabase (coarse basalt). From Best (1982). *Igneous and Metamorphic Petrology*. W. H. Freeman. San Francisco.





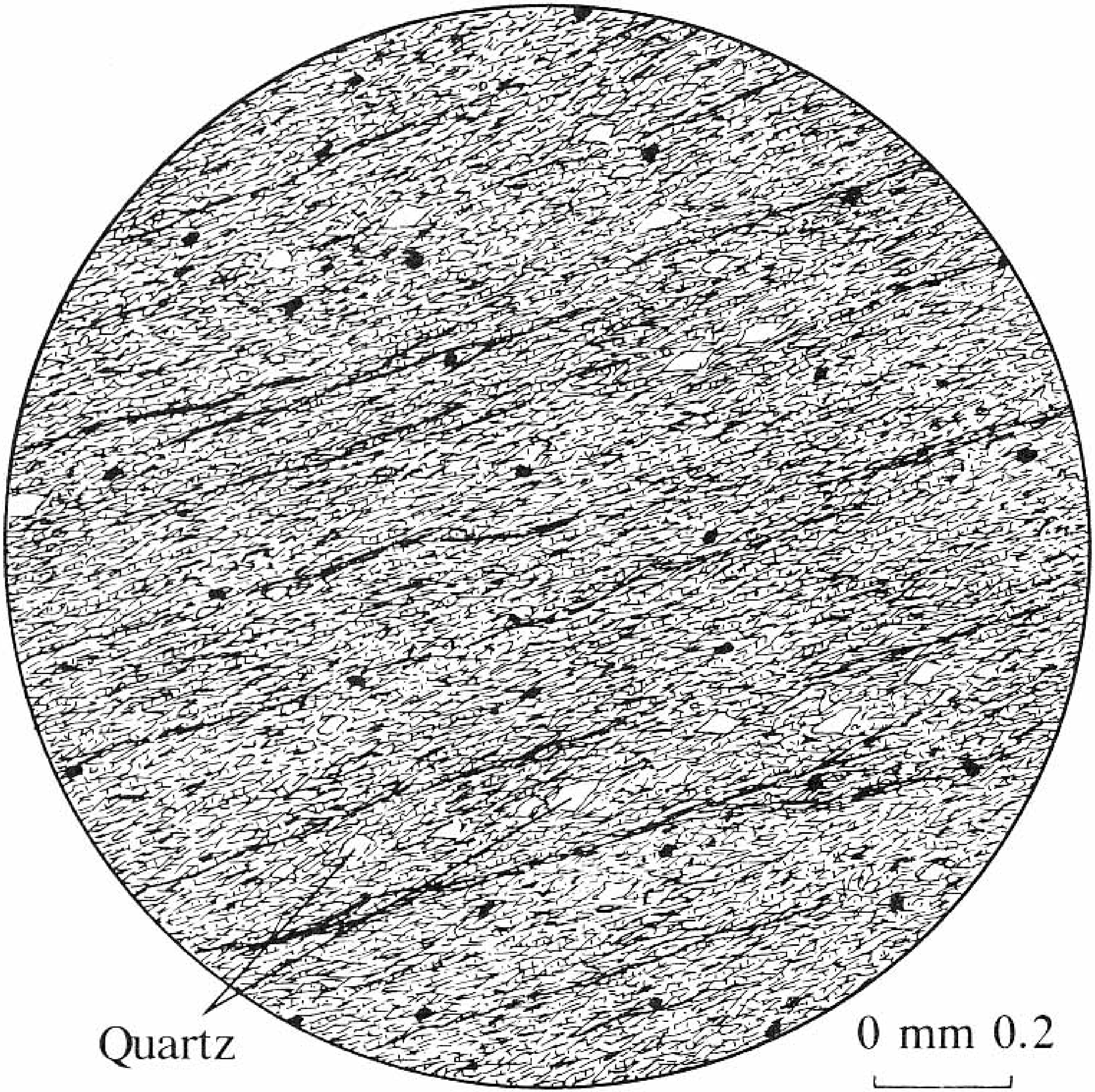

**Progressive thermal metamorphism of a diabase (coarse basalt). From Best (1982).** ***Igneous and Metamorphic Petrology*****. W. H. Freeman. San Francisco.**



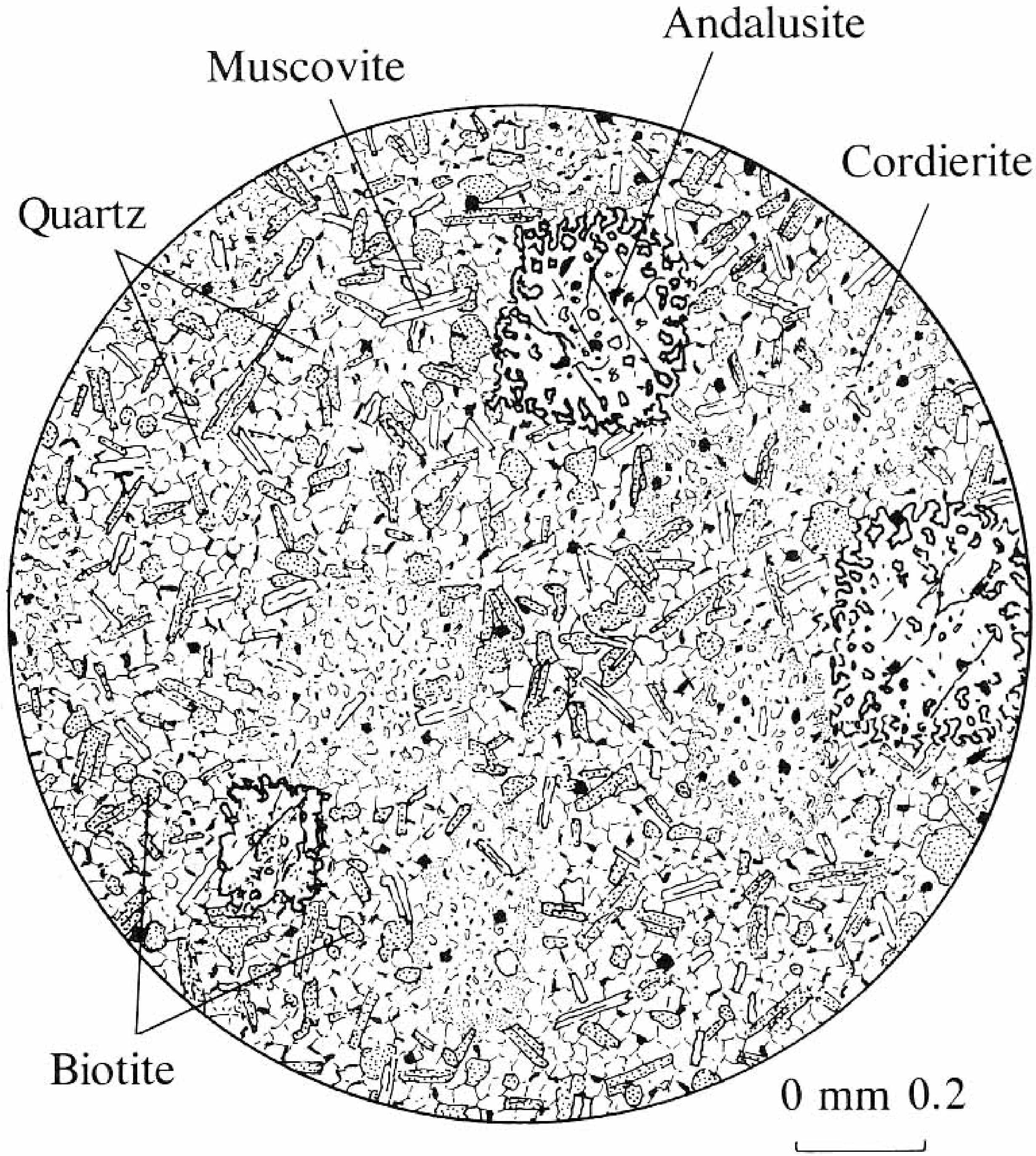




**Progressive thermal metamorphism of a diabase (coarse basalt). From Best (1982). *Igneous and Metamorphic Petrology*. W. H. Freeman. San Francisco.**

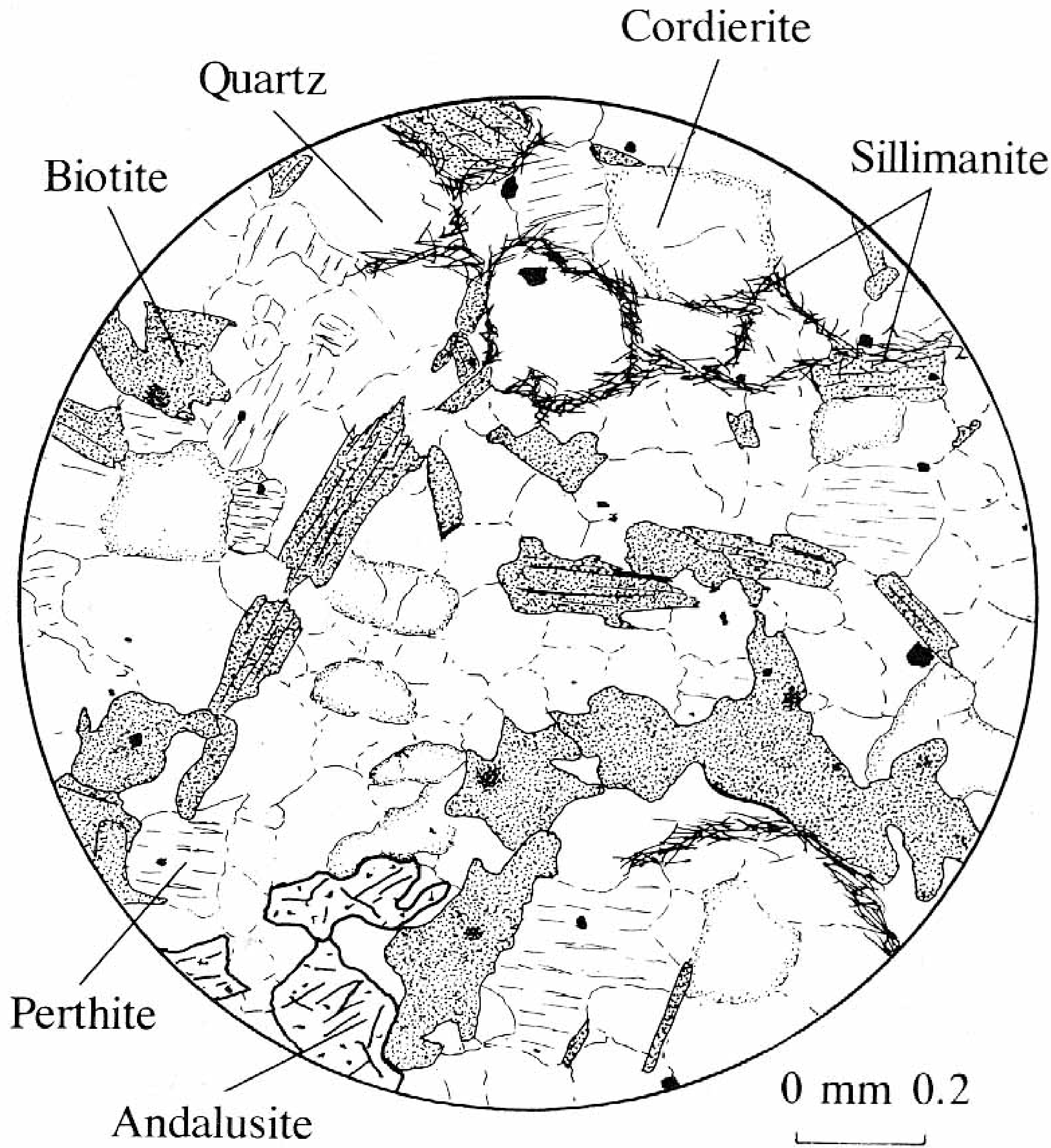
**Progressive thermal metamorphism of slate. From Best (1982). *Igneous and Metamorphic Petrology*. W. H. Freeman. San Francisco.**



Progressive thermal metamorphism of slate. From Best (1982). *Igneous and Metamorphic Petrology*. W. H. Freeman. San Francisco.

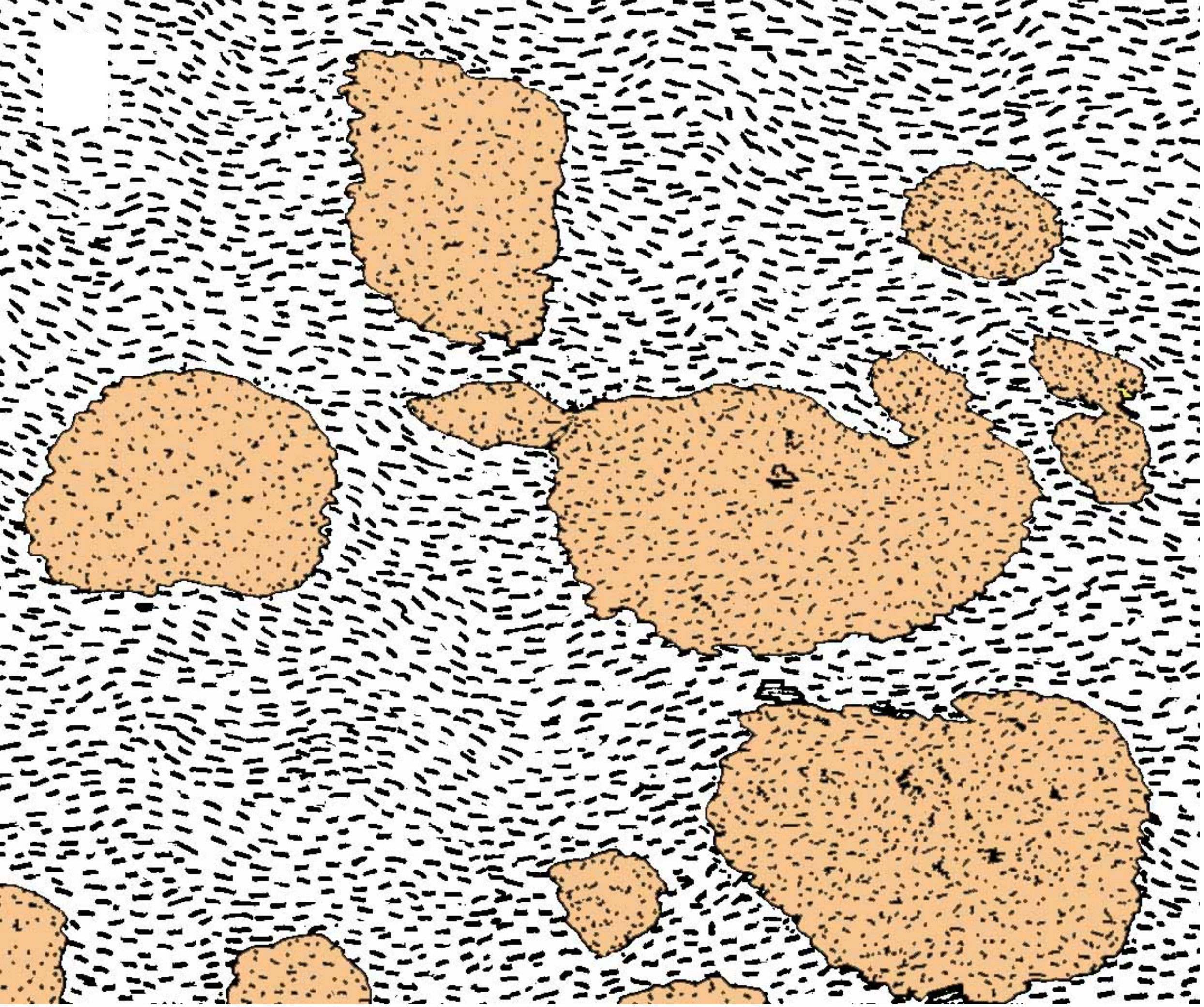


**Progressive thermal metamorphism of slate. From Best (1982).** ***Igneous and Metamorphic Petrology*****. W. H. Freeman. San Francisco.**



# Metamorphic Textures

- Contact overprint on earlier regional events are common
  - Thermal maximum later than deformational
- Nodular overprints
- Spotted slates and phyllites



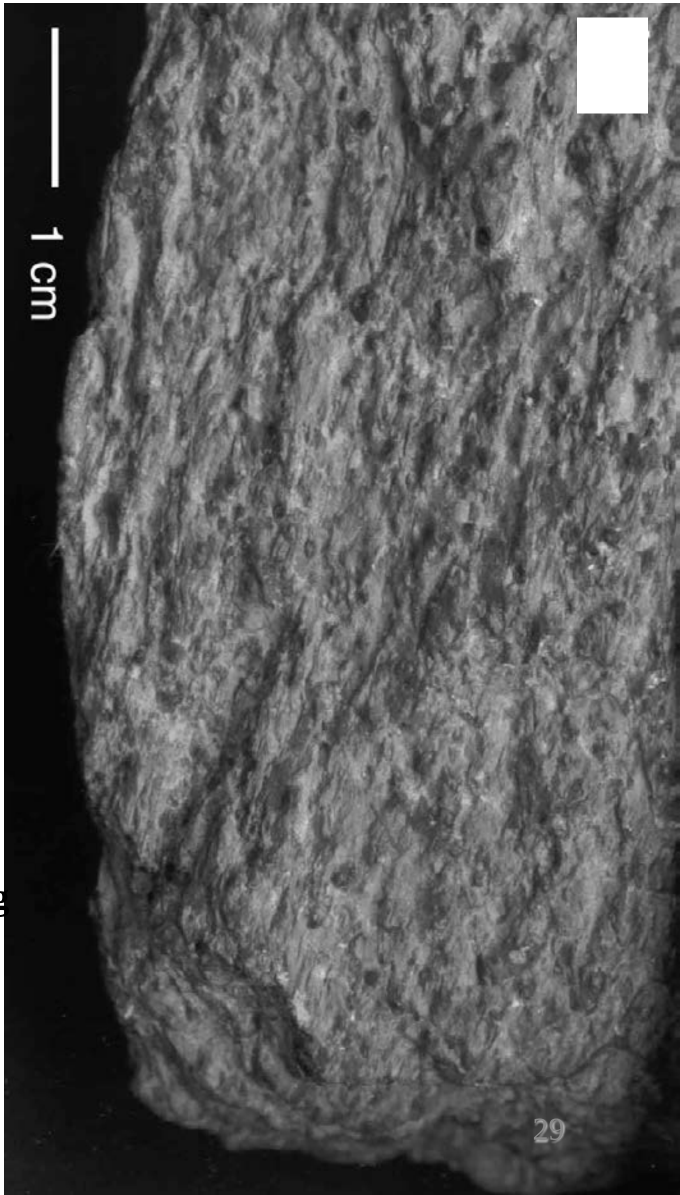
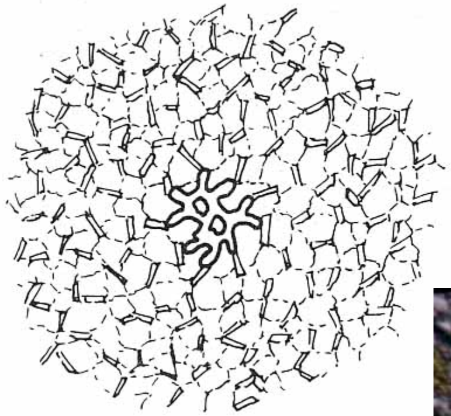
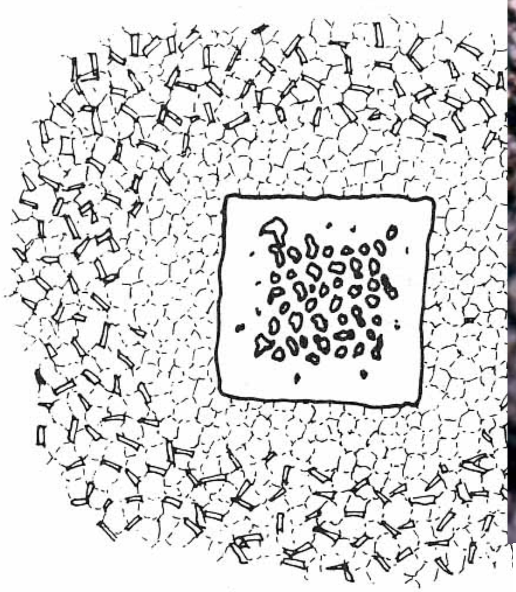



**Figure 23.14. Overprint of contact metamorphism on regional. a. Nodular texture of cordierite porphyroblasts developed during a thermal overprinting of previous regional metamorphism (note the foliation in the opaques). Approx. 1.5 x 2 mm. From Bard (1986) *Microtextures of Igneous and Metamorphic Rocks*. Reidel. Dordrecht. b. Spotted phyllite in which small porphyroblasts of cordierite develop in a preexisting phyllite. Winter (2010) *An Introduction to Igneous and Metamorphic Petrology*. Prentice Hall.**

# Depletion haloes



Progressive development of a depletion halo about a growing porphyroblast. From Best (1982). *Igneous and Metamorphic Petrology*. W. H. Freeman. San Francisco.



Depletion halo around garnet porphyroblast. Boehls Butte area, Idaho

# Metamorphic Textures

## Textures of Regional Metamorphism

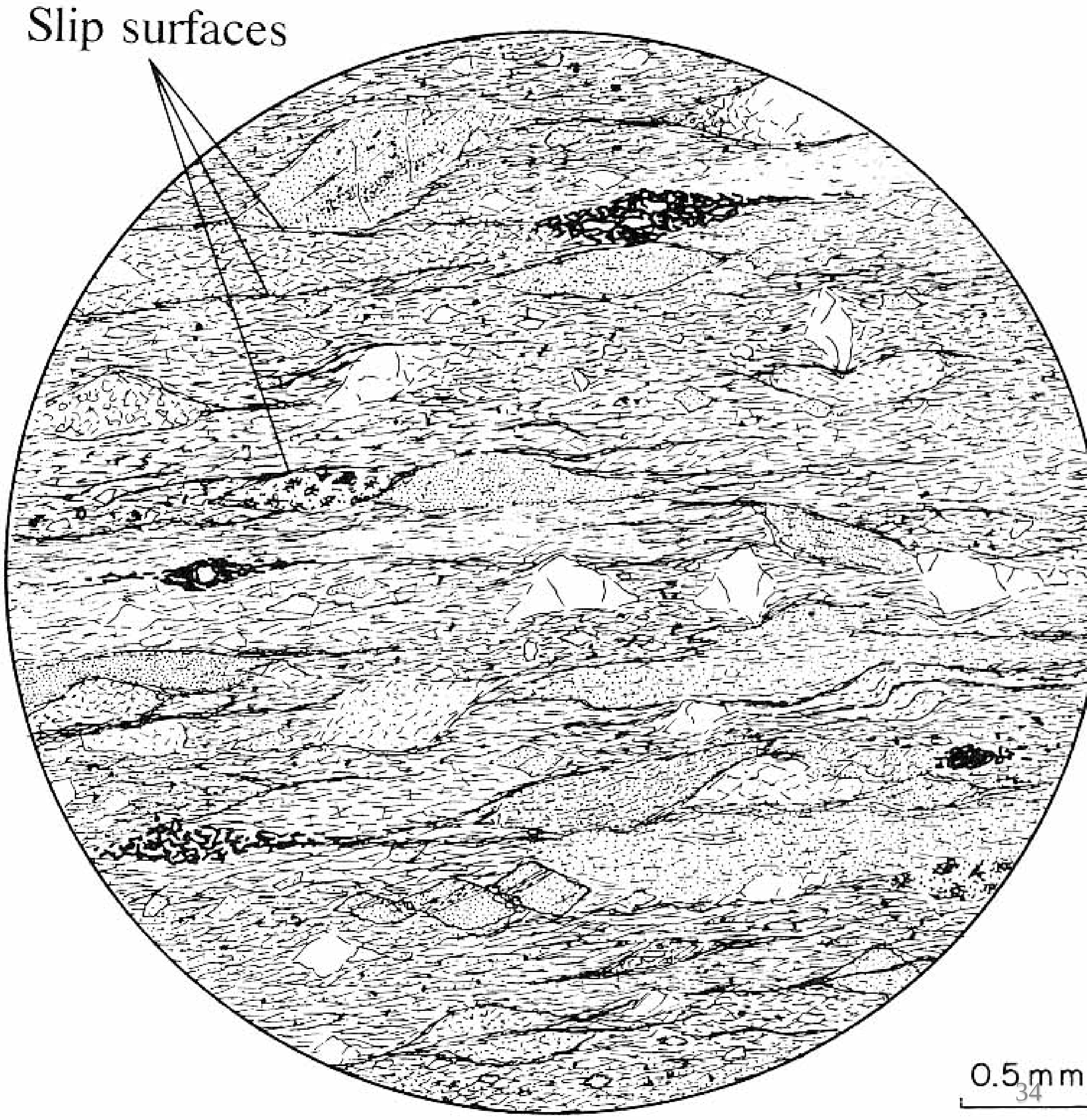
- Dynamothermal (crystallization under dynamic conditions)
- Orogeny- long-term mountain-building
  - May comprise several Tectonic Events
    - May have several Deformational Phases
- May have an accompanying Metamorphic Cycles with one or more Reaction Events

# Metamorphic Textures

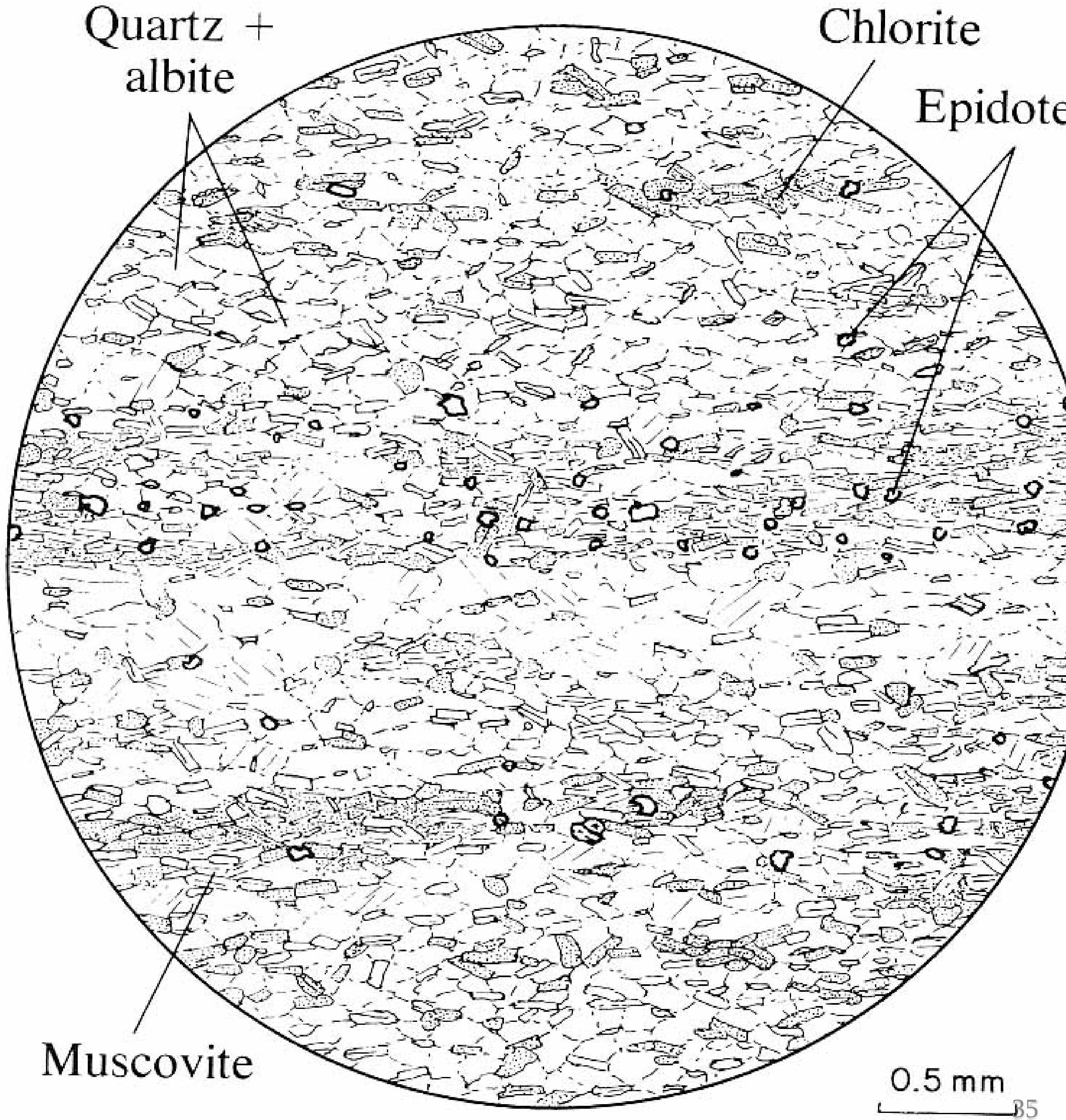
## Textures of Regional Metamorphism

- Tectonite- a deformed rock with a texture that records the deformation, e.g., preferred mineral orientation
- Fabric- the complete <u>spatial</u> and <u>geometric</u> configuration of textural elements
  - Foliation- planar textural element
  - Lineation- linear textural element

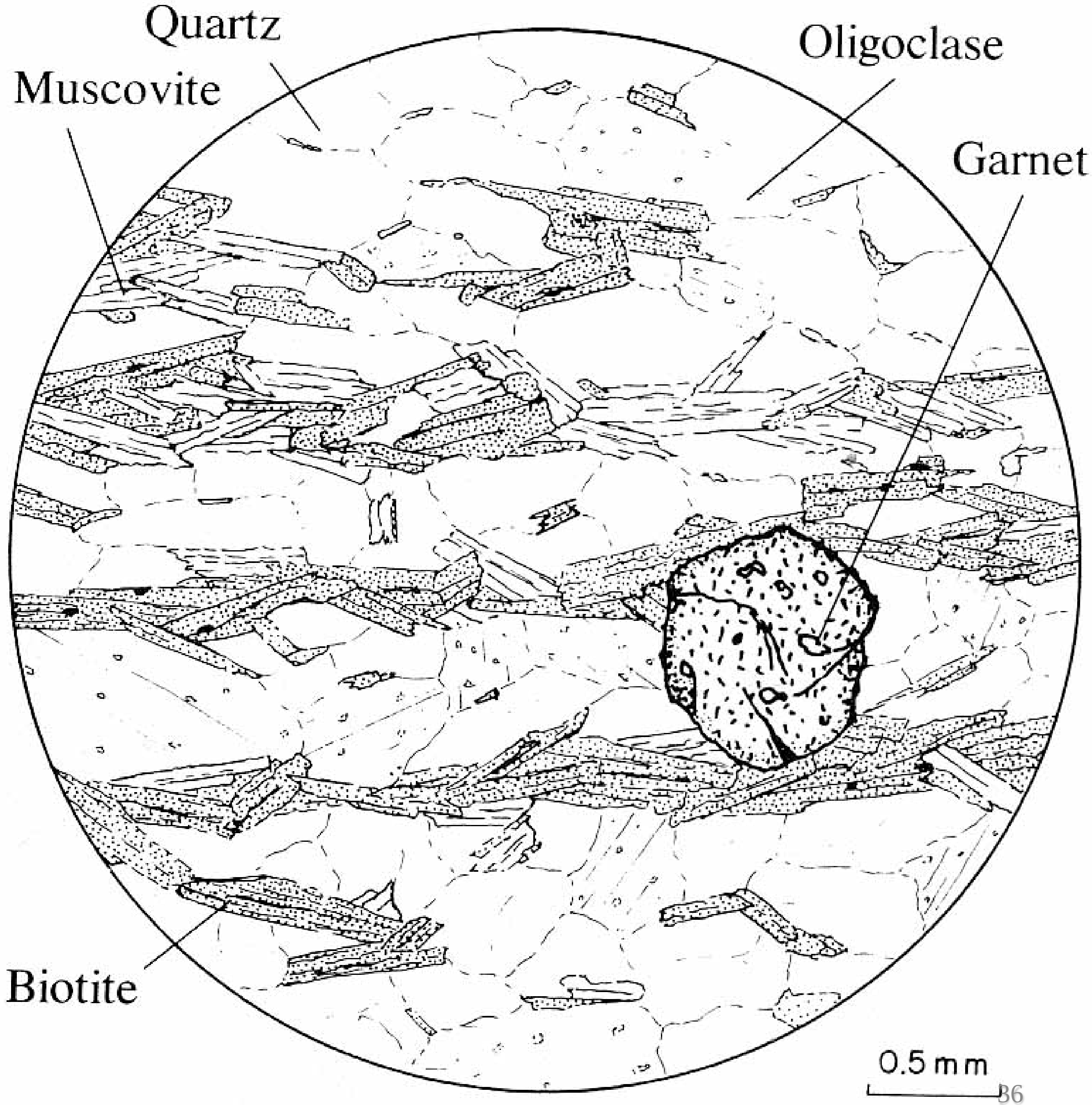
**Progressive syntectonic metamorphism of a volcanic graywacke,** **New Zealand. From Best (1982).** ***Igneous and Metamorphic Petrology*****. W. H. Freeman. San Francisco.**




**Progressive syntectonic metamorphism of a volcanic graywacke, New Zealand. From Best (1982). *Igneous and Metamorphic Petrology*. W. H. Freeman. San Francisco.**




**Progressive syntectonic metamorphism of a volcanic graywacke, New Zealand. From Best (1982). *Igneous and Metamorphic Petrology*. W. H. Freeman. San Francisco.**




**Progressive syntectonic metamorphism of a volcanic graywacke, New Zealand. From Best (1982).** ***Igneous and Metamorphic Petrology*****. W. H. Freeman. San Francisco.**

# Fig 23.21 Types of foliations

**a.** Compositional layering

**b.** Preferred orientation of platy minerals

**c.** Shape of deformed grains

**d.** Grain size variation

**e.** Preferred orientation of platy minerals in a matrix without preferred orientation

**f.** Preferred orientation of lenticular mineral aggregates

**g.** Preferred orientation of fractures

**h.** Combinations of the above

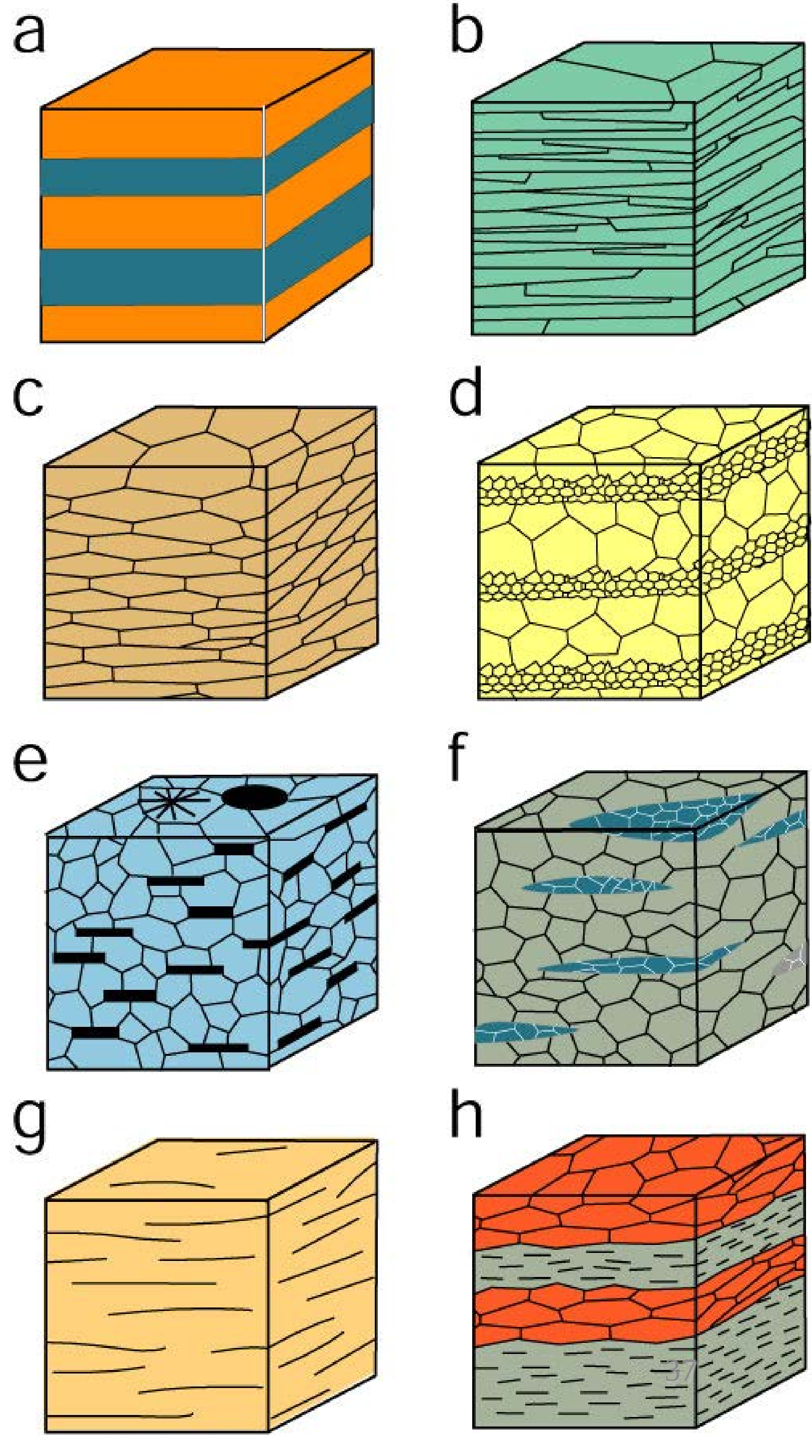



**Figure 23.21.** Types of fabric elements that may define a foliation. From Turner and Weiss (1963) and Passchier and Trouw (1996).

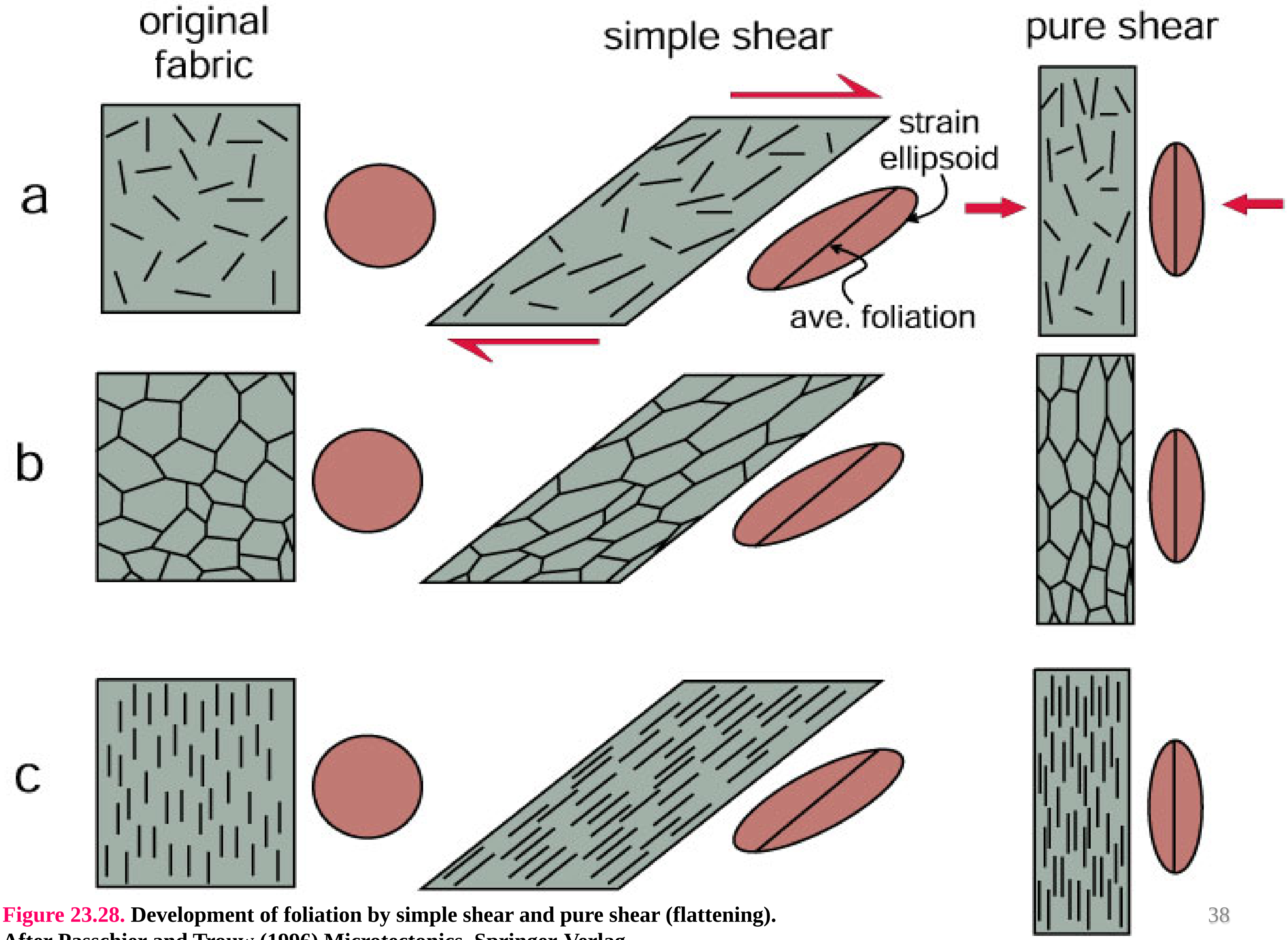
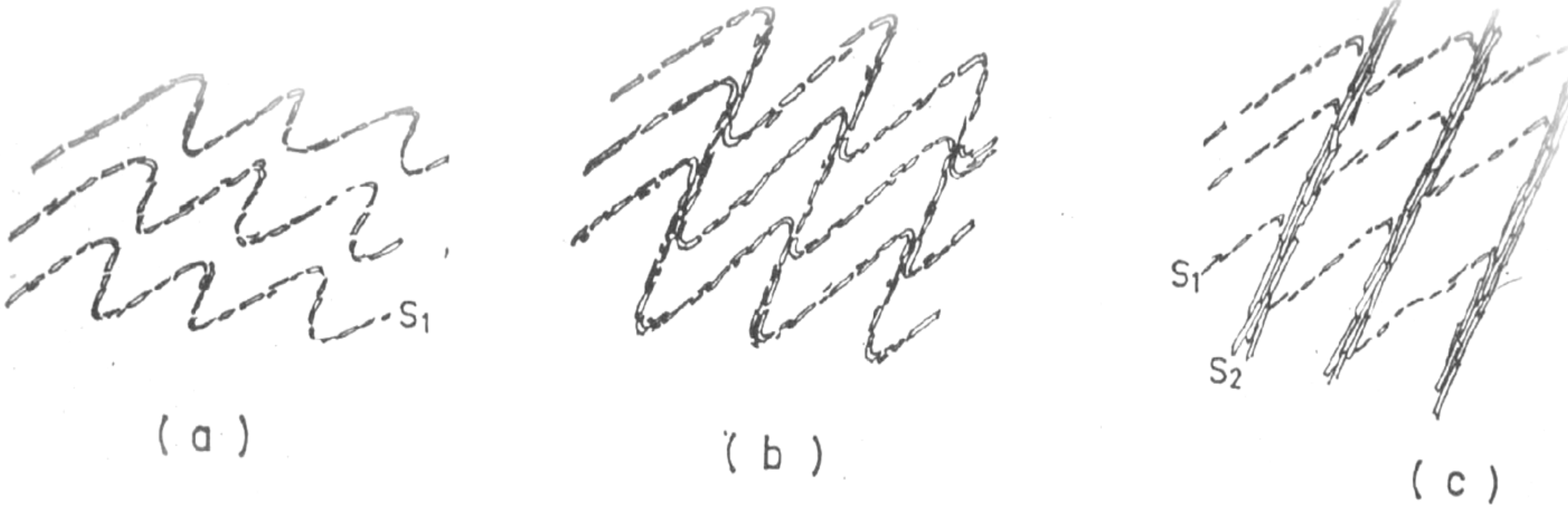


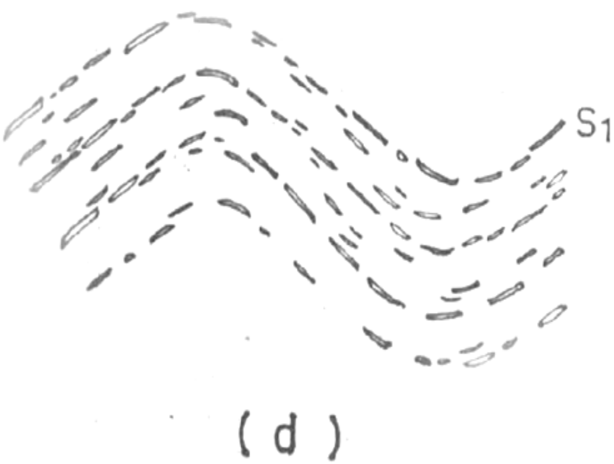

**Figure 23.28.** Development of foliation by simple shear and pure shear (flattening). After Passchier and Trouw (1996) Microtectonics. Springer-Verlag.

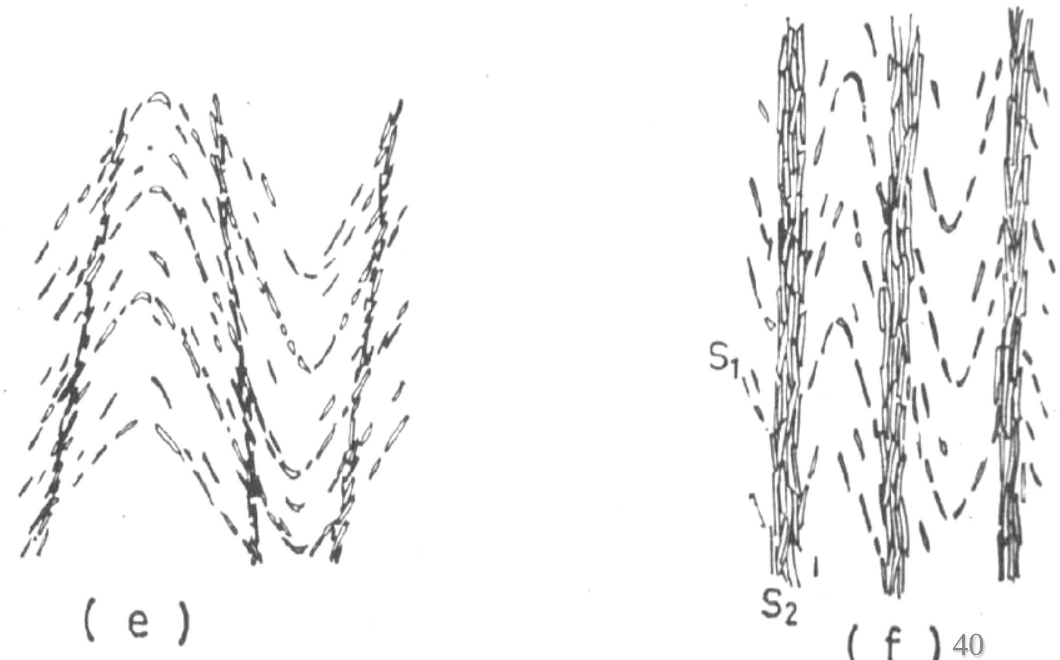
# Types of foliations

- **Crenulation Cleavage-**
  - Actually consists of 2 cleavages
  - The first may be a *slaty cleavage* or *schistosity* that becomes *microfolded*
  - Fold axial planes typically form at high angle to the $\sigma_1$ of the second compressional phase




Progressive development (a → c) of a crenulation cleavage for both asymmetric (top) and symmetric (bottom) situations.  From Spry (1969) *Metamorphic Textures*. Pergamon. Oxford.



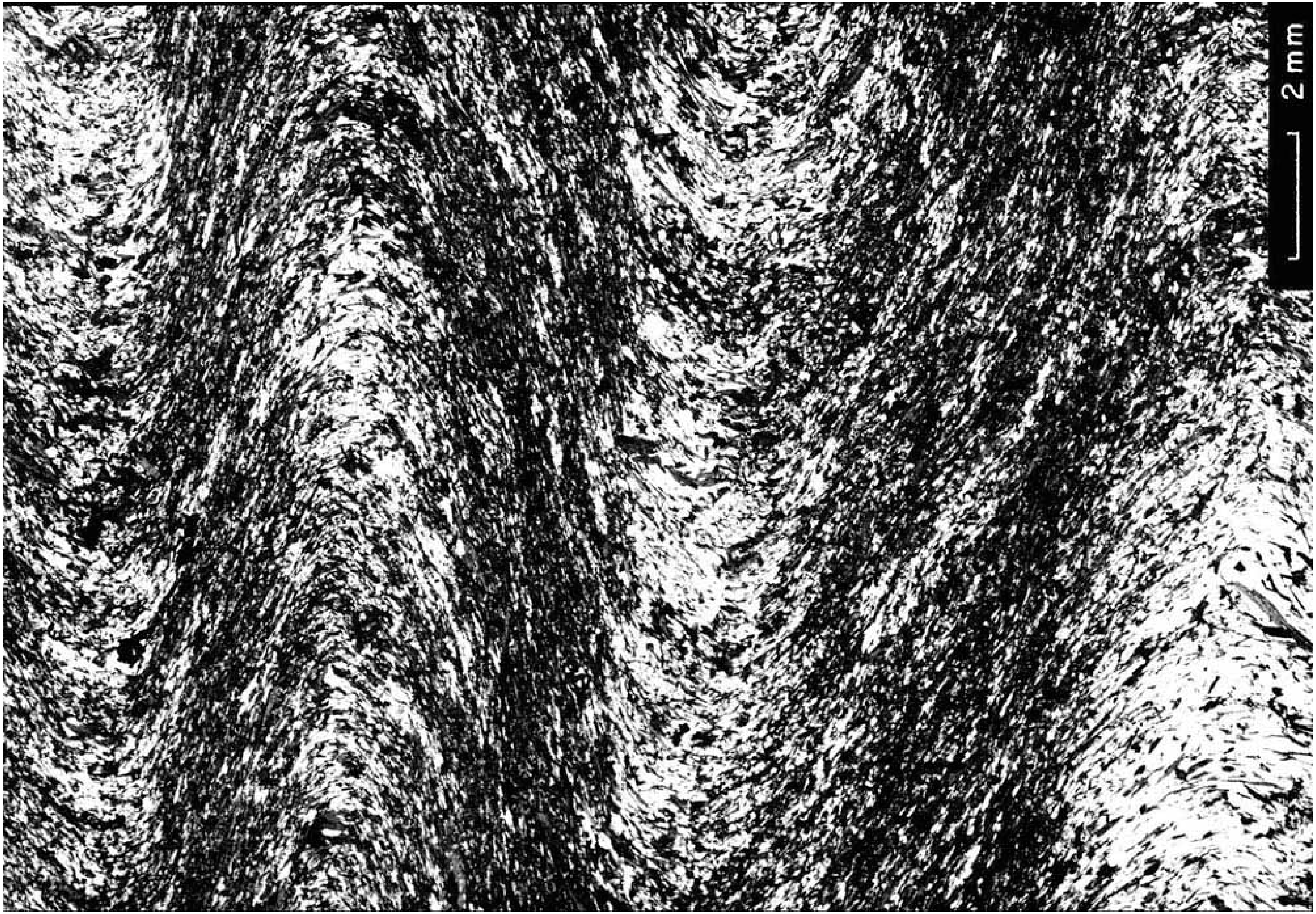



**Figure 23.24a.** **Symmetrical crenulation cleavages** **in amphibole-quartz-rich schist. Note concentration of quartz in hinge areas. From Borradaile *et al*. (1982) *Atlas of Deformational and Metamorphic Rock Fabrics*. Springer-Verlag.**

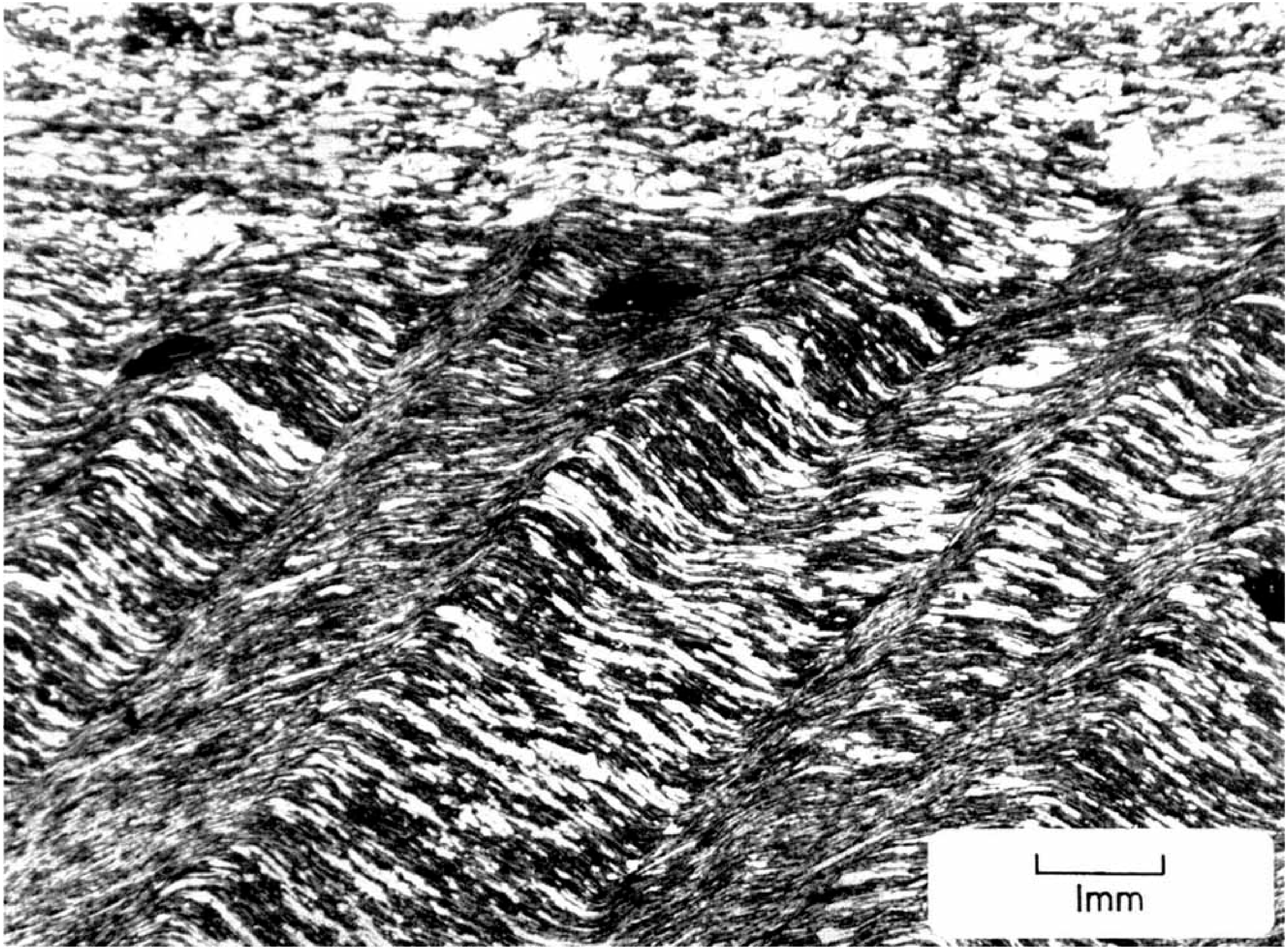



**Figure 23.24b. Asymmetric crenulation cleavages in mica-quartz-rich schist. Note horizontal compositional layering (relict bedding) and preferential dissolution of quartz from one limb of the folds. From Borradaile *et al*. (1982) *Atlas of Deformational and Metamorphic Rock Fabrics*. Springer-Verlag.**