Metamorphic Structures and Textures

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M.Sc. Semester II

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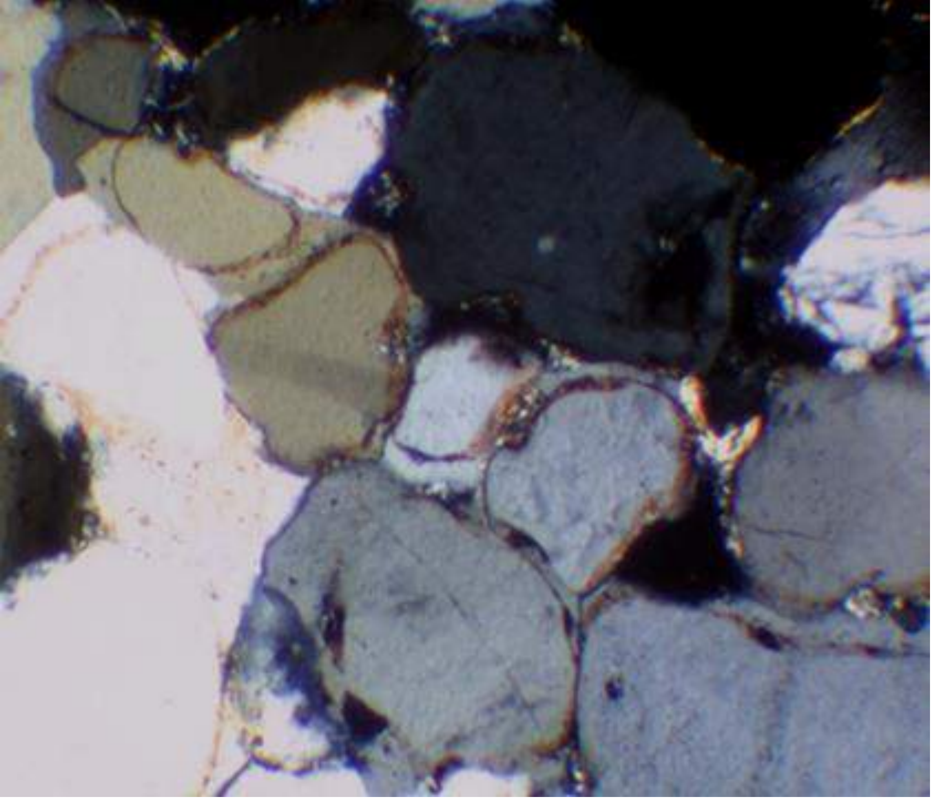
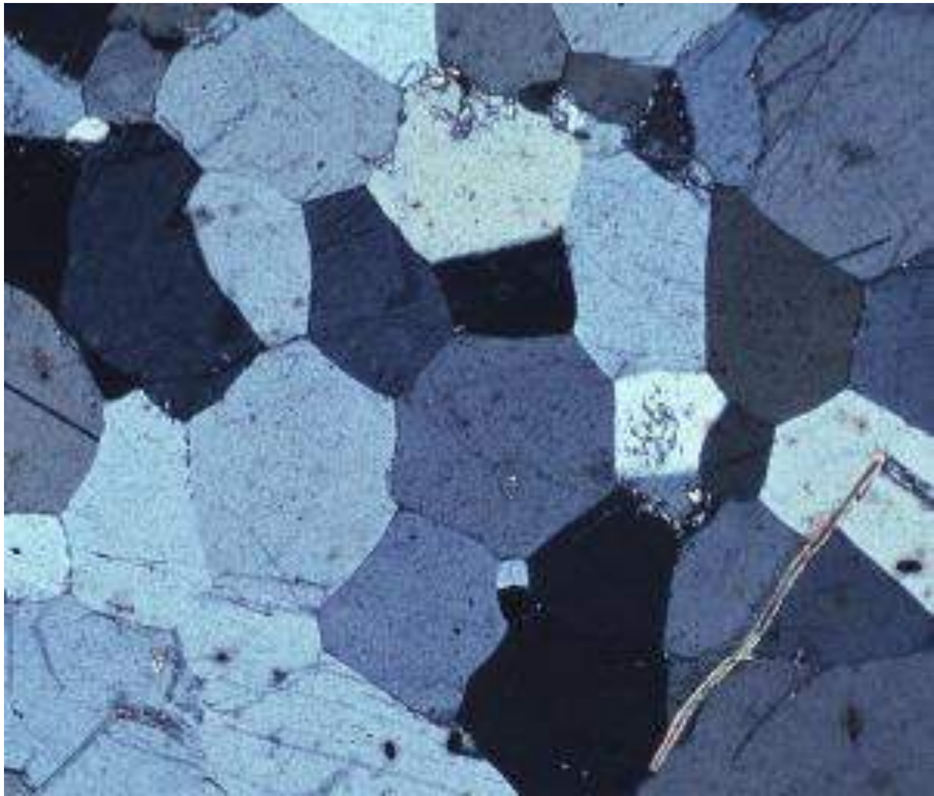
- *Texture* or *fabric* = small-scale features that are *penetrative* (occurs in virtually all of the rock body at the microscopic level).

- *Structure* = larger-scale features; found in hand-sample, outcrop, or regional scale.

- *Microstructure* = advocated term (instead of texture) for microscope-scale features.

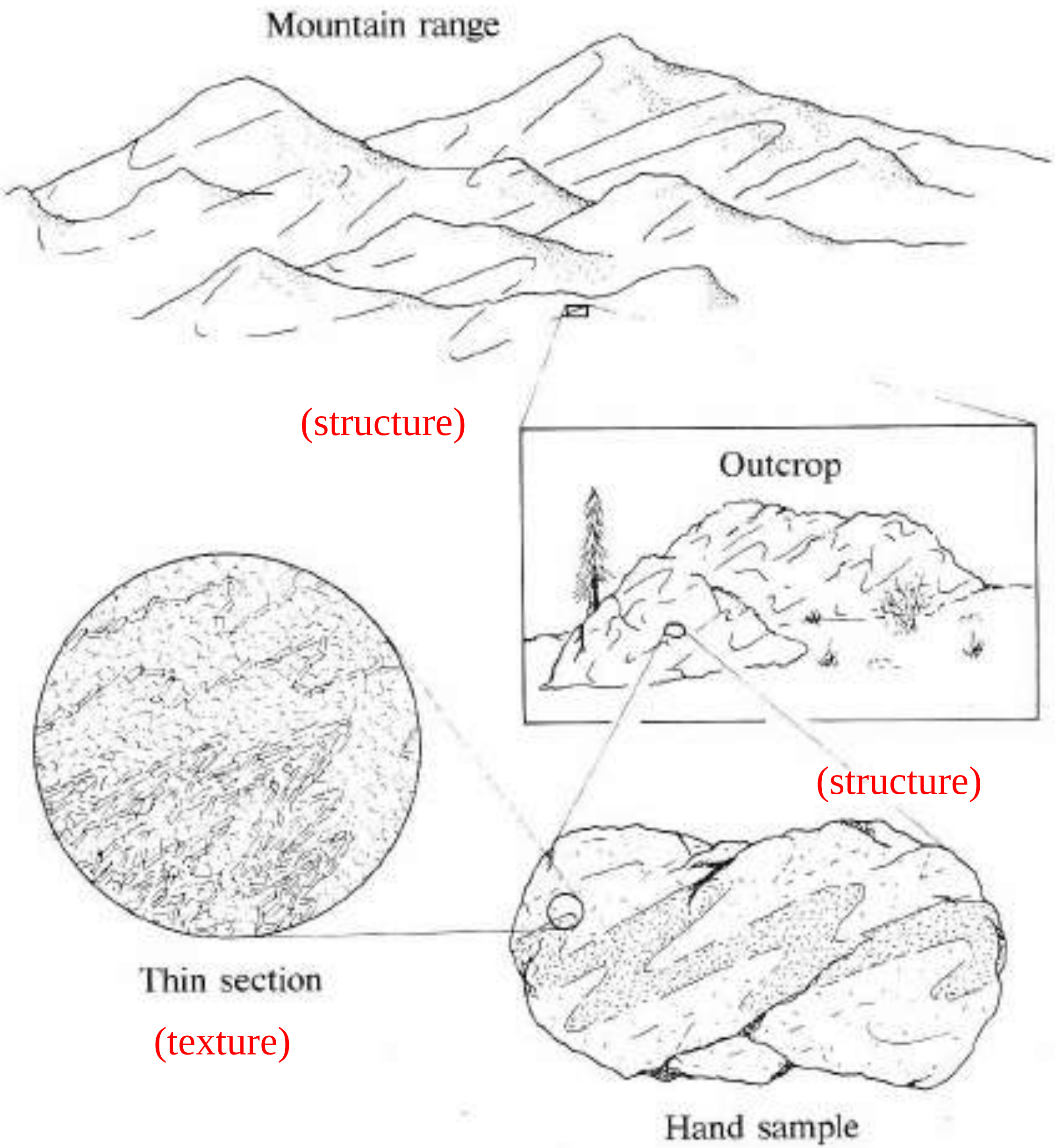


Sandstone
texture



Quartzite
texture

Structures vs. Textures



What we find on the thin section scale is often mirrored by structures found at the hand-sample and larger scale—so looking at thin sections can help us understand the structural history of a region

Texture: Is a term that describes the size, shape and orientation of the grains constituting a rock, as well as the relationship between these grains.

1- Crystal size:

<0.1 mm very fine-grained

0.1-1 mm fine-grained

1-5 mm medium-grained

5-10 mm coarse-grained

> 10 mm very coarse-grained

2-Shape:

Idioblastic: If the mineral grain is euhedral

Subidioblastic: If the grain is subhedral

Xenoblastic: If the grain is anhedral

Foliation

- Pervasive planar structure that results from nearly parallel alignment of sheet-silicate minerals and/ or compositional and mineralogical layering in the rock. Pervasive = feature preserved in mineralogical body)

- Depends on grain size, temperature, pressure and geological environment (depth) at which they are present.

- Develops as a result of differential stress and folding.

On the basis of presence or absence of foliation, metamorphic rocks can be either:

(1) Foliated metamorphic rocks e.g., slate, phyllite, schist, gneiss, etc.

(2) Non-foliated metamorphic rocks e.g, quartzite, marble, hornfels, etc.

Structures of metamorphic rocks (macrotextures):

(i) Slaty cleavage: A pervasive, parallel foliation (layering) of fine-grained platy minerals (chlorite) in a direction perpendicular to the direction of maximum stress. It produces the rocks slate and phyllite.

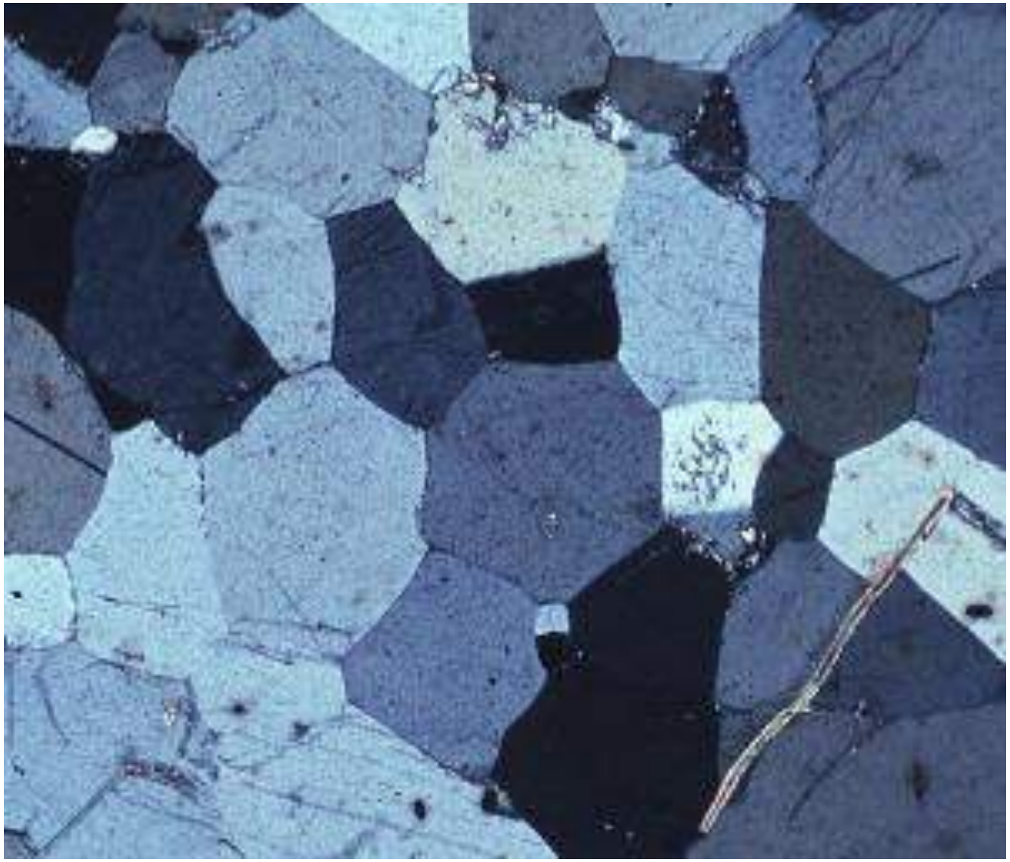
(ii) Schistose: A schist has a lepidoblastic foliation if this foliation is defined by oriented micas, and a nematoblastic foliation if such a foliation is defined by the orientation of prismatic minerals as amphiboles and pyroxenes.

(iii) Gneissic: A complex banded texture made of schistose layers or bands alternating with bands commonly characterized by a granoblastic texture.

(iv) Granoblastic: granular, interlocking equidimensional grains of subequal size; no preferred orientation or cleavage.

(v) Hornfelsic: Fine-grained, granular interlocking grains, possibly of variable shapes and sizes. No preferred orientation.

(vi) Cataclastic:



Granoblastic texture in Quartzite

Cataclastic Structure

- produced under stress and in absence of high temperature, whereby rocks are subjected to shearing and fragmentation.

- Only the durable mineral partly survive the crushing force and the less durable ones are powdered.

- Thus, when resistant minerals and rock fragments stand out in a pseudo porphyritic manner in the finer materials, it is known as 'porphyroclastic structure.' Phenocrysts are called 'porphyroclasts'.

- Argillaceous rocks develop slaty cleavage, harder rocks may be shattered and crushed forming crush breccia and crush conglomerate.

- When the rocks are highly crushed into fine grained rocks, they are known as mylonites. Since these structures are formed due to cataclasis, they are, as a whole, known as cataclastic structure.

The Crystalloblastic Series

- Some metamorphic minerals tend to be more euhedral than others.
- In contrast to igneous rocks, this capacity is no longer a function of which minerals grew earliest (early igneous minerals are surrounded by melt, so growth is unencumbered by contact with other minerals).

The Crystalloblastic Series

- Because all metamorphic minerals grow in contact with others, the tendency for a mineral to be more euhedral must then be a property of the mineral itself.
- Garnet and staurolite, for example, are typically euhedral, whereas quartz and carbonates tend to be anhedral.

The Crystalloblastic Series

Most Euhedral

Titanite, rutile, pyrite, spinel

Garnet, sillimanite, staurolite, tourmaline

Epidote, magnetite, ilmenite

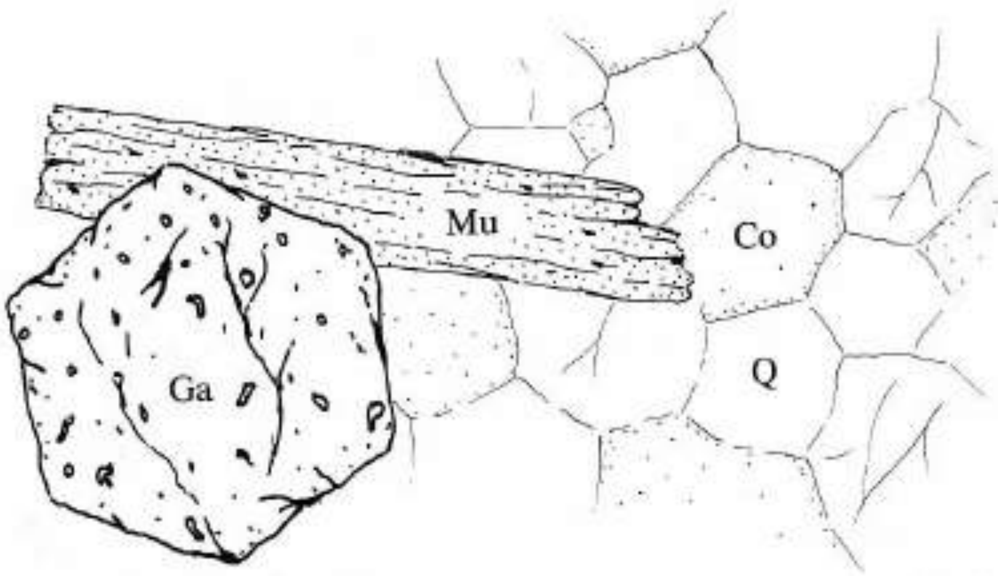
Andalusite, pyroxene, amphibole

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.

Types of metamorphic textures and mineral-mineral relations

Metamorphic textures can be grouped into three main groups:

A- Relict textures (palimpsest textures): are textures inherited from the original rock type, and which have survived metamorphism.

B- Typomorphic textures: textures characteristic of metamorphism.

C- Superimposed textures: textures characteristic of a post-metamorphic event, e.g. alteration, weathering, ... etc.
Other smaller groups as “reaction textures”, “polydeformational textures”, … etc. may also be typomorphic or replacement, but are grouped separately because they have some genetic connotation.

Blasto- and -blastic

- *suffix* -blast or -blastic indicates that a feature is of metamorphic origin.
- *prefix* **blasto-** (meaning that a feature is *not* of metamorphic origin but is inherited from the parent rock)
- ***porphyroblastic*** means a porphyritic-like texture (coarse grains in a finer matrix) that is of metamorphic origin.
- ***blastoporphyritic*** indicates an igneous porphyritic texture that survived metamorphism to the extent that it can still be recognized.
- Sedimentary/ Igneous protolith that have undergone very low grade metamorphism.
- Also, termed as **relict** textures. Broader term. Other examples: ophitic, intergranular, amygdaloidal, spherulitic, pisolitic, oolitic

A- Relict Textures

There are several types of relict textures. Relict textures in metamorphic rocks are indicated by applying the prefix "blasto" to the original textural name. Relict textures are best preserved in low-grade rocks. Examples of such textures include:

- blasto-porphyritic
- blasto-ophitic
- blasto-intergranular
- blasto-amygdaloidal
- blasto-pisolitic
- blasto-oolitic

B- Typomorphic textures

Textures characteristic of thermal/ contact metamorphism:

When thermal metamorphism is not associated with any deformation, the mineral grains are randomly oriented, resulting in either granoblastic or hornfelsic textures. Note that the granoblastic texture can also develop in regionally metamorphosed rocks. The following are some of the types of granoblastic textures:

1- Granoblastic polygonal: where the equidimensional grains may have well developed crystal faces resulting in straight grain boundaries, and where triple junctions are common.

2- Granoblastic interlobate: where the grain boundaries are somewhat irregular.

Textures characteristic of thermal metamorphism:

3- Granoblastic amoeboid: where all the grains have irregular outlines, and all the minerals are anhedral.

4- Granoblastic decussate: where the interlocking randomly oriented crystals are somewhat elongate, prismatic or subidioblastic. Usually applied to rocks with one or two mineral species only. Triple junctions are common.

5- Nodular: results from the growth of oval - shaped porphyroblasts of such minerals as cordierite or scapolite in association with other randomly oriented minerals as Quartz, ..etc.

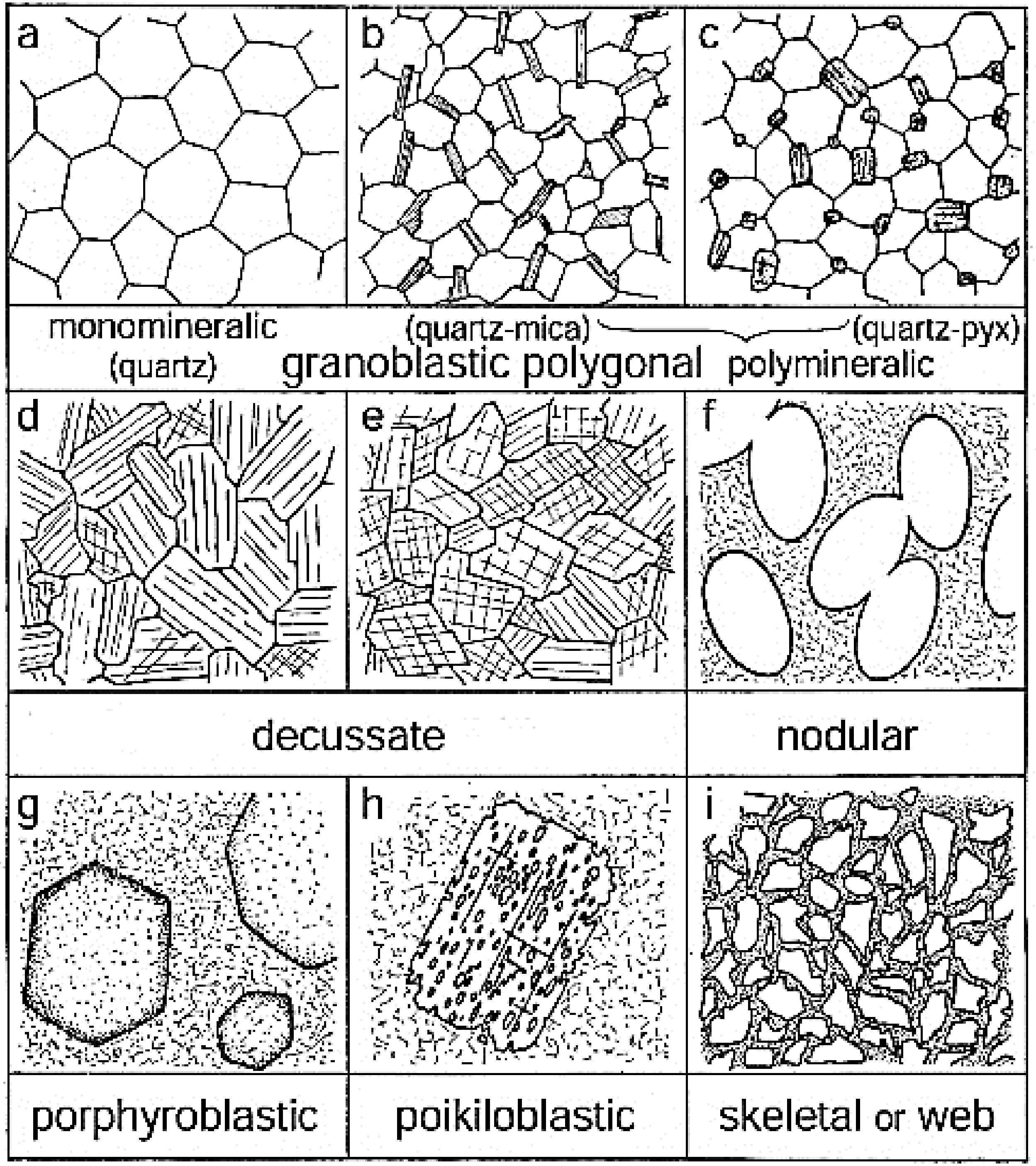
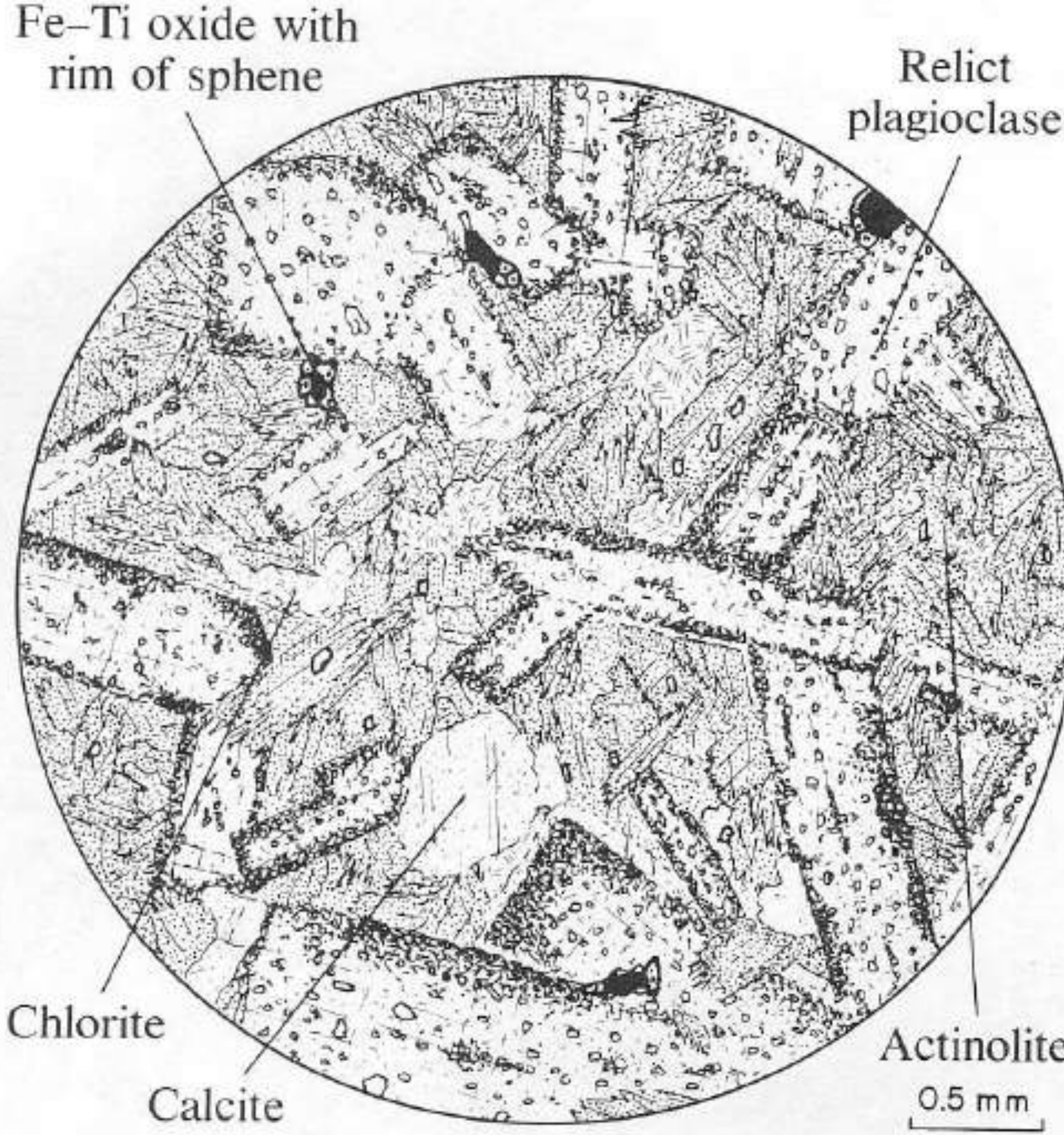


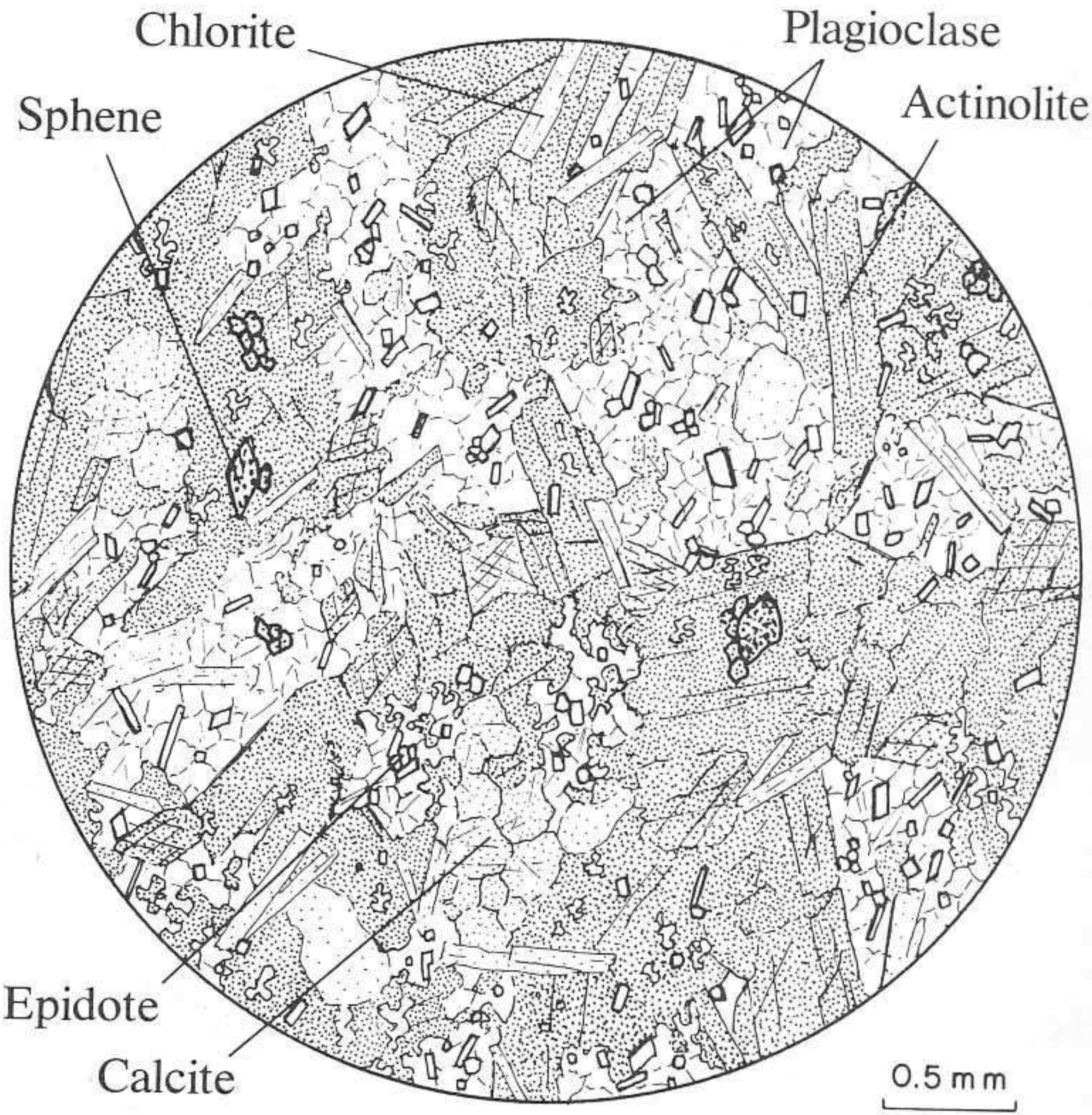
Figure. **Typical textures of thermal metamorphism.**

Textures of Contact Metamorphism

- Typically shallow pluton aureoles (low-P)
- Crystallization/recrystallization is near-static
  - Monomineralic with low Δ surface energy → granoblastic polygonal
  - Larger Δ S.E. → decussate
- Isotropic textures (hornfels, granofels)
- Relict textures are common



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



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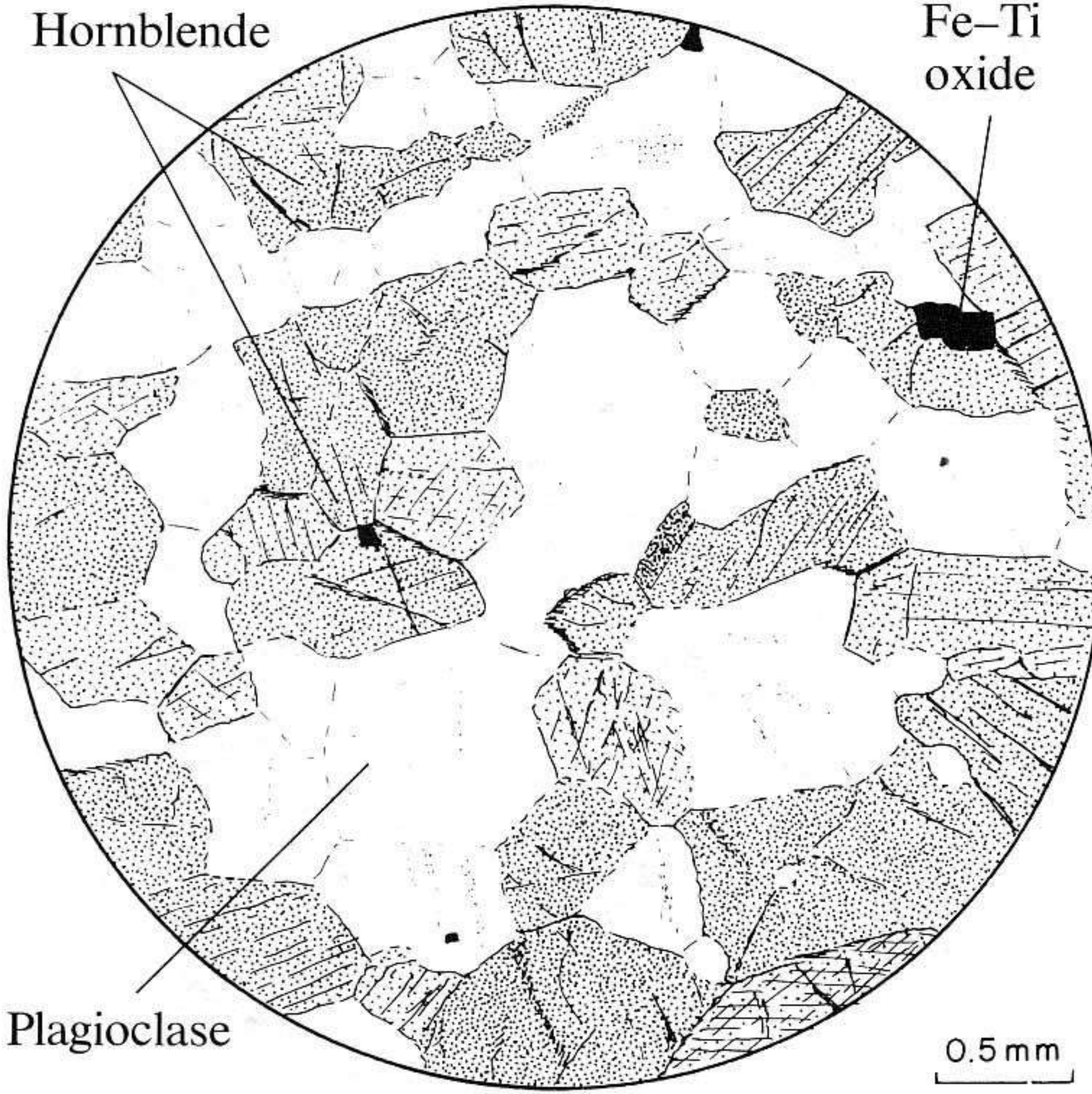

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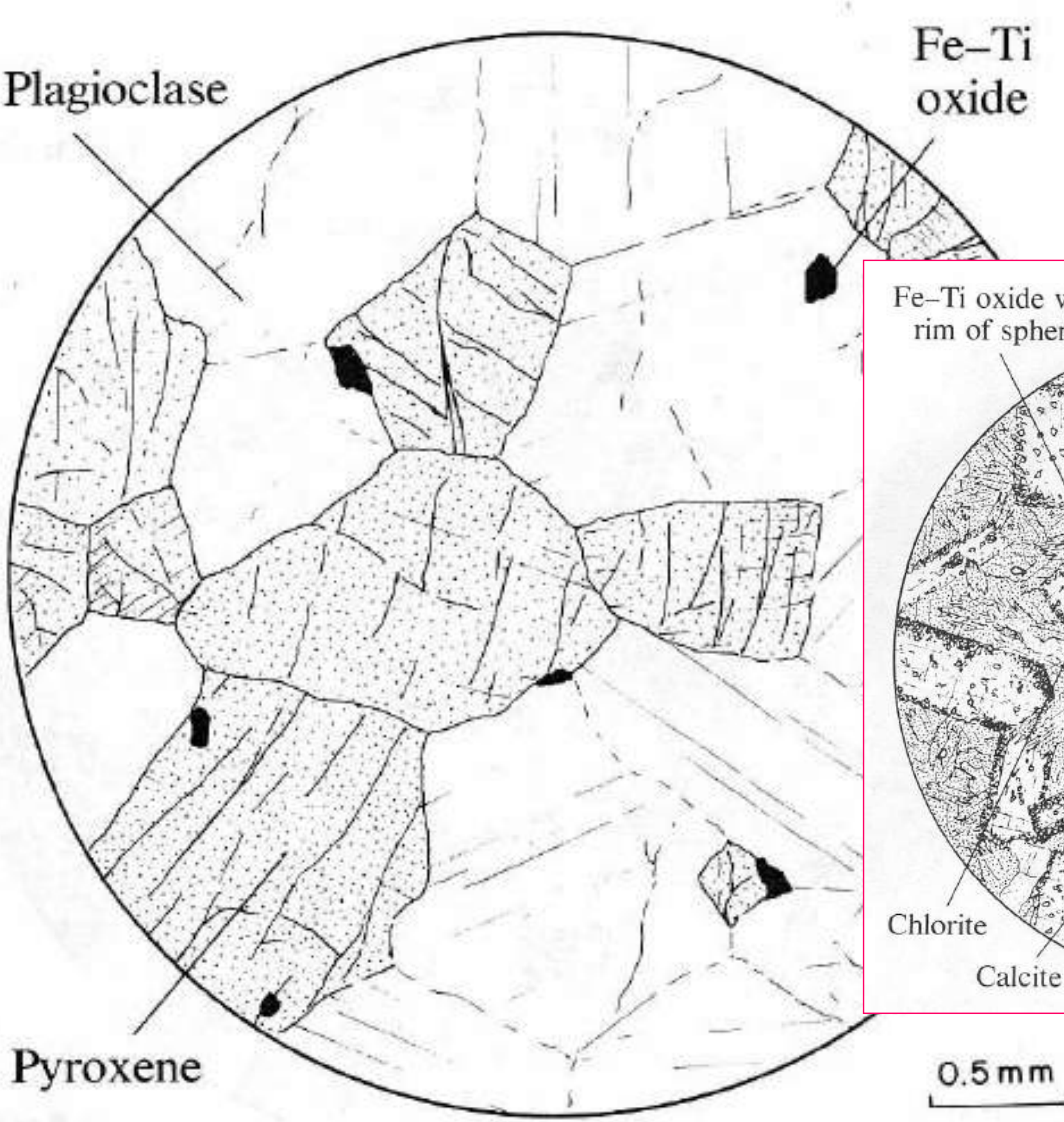
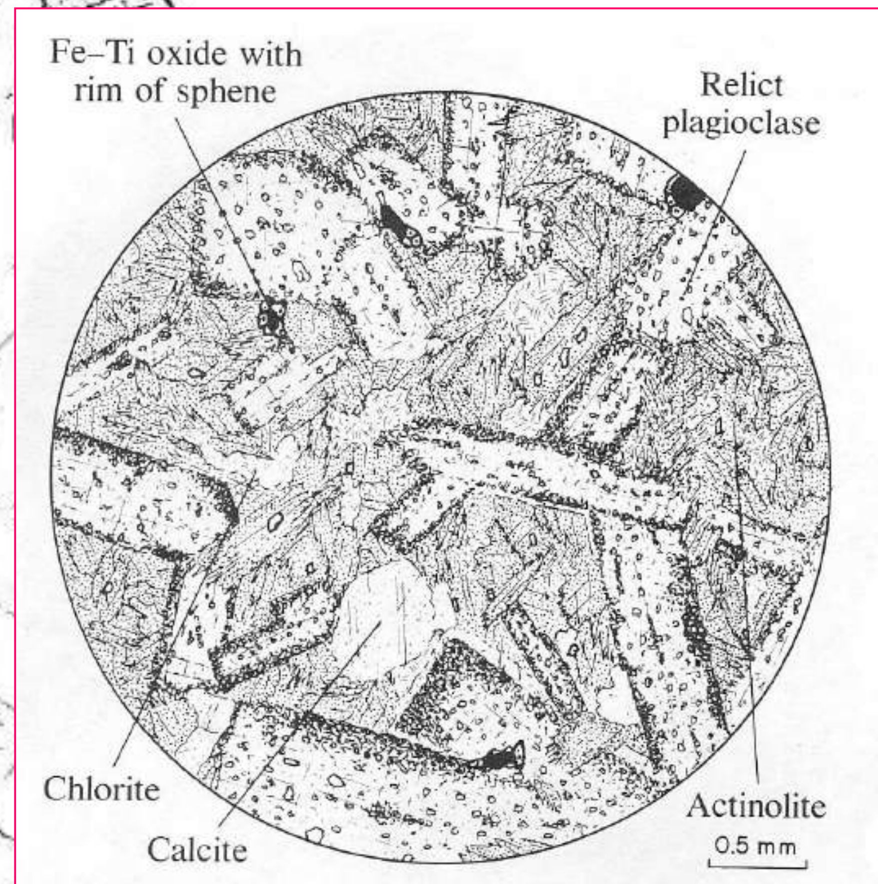
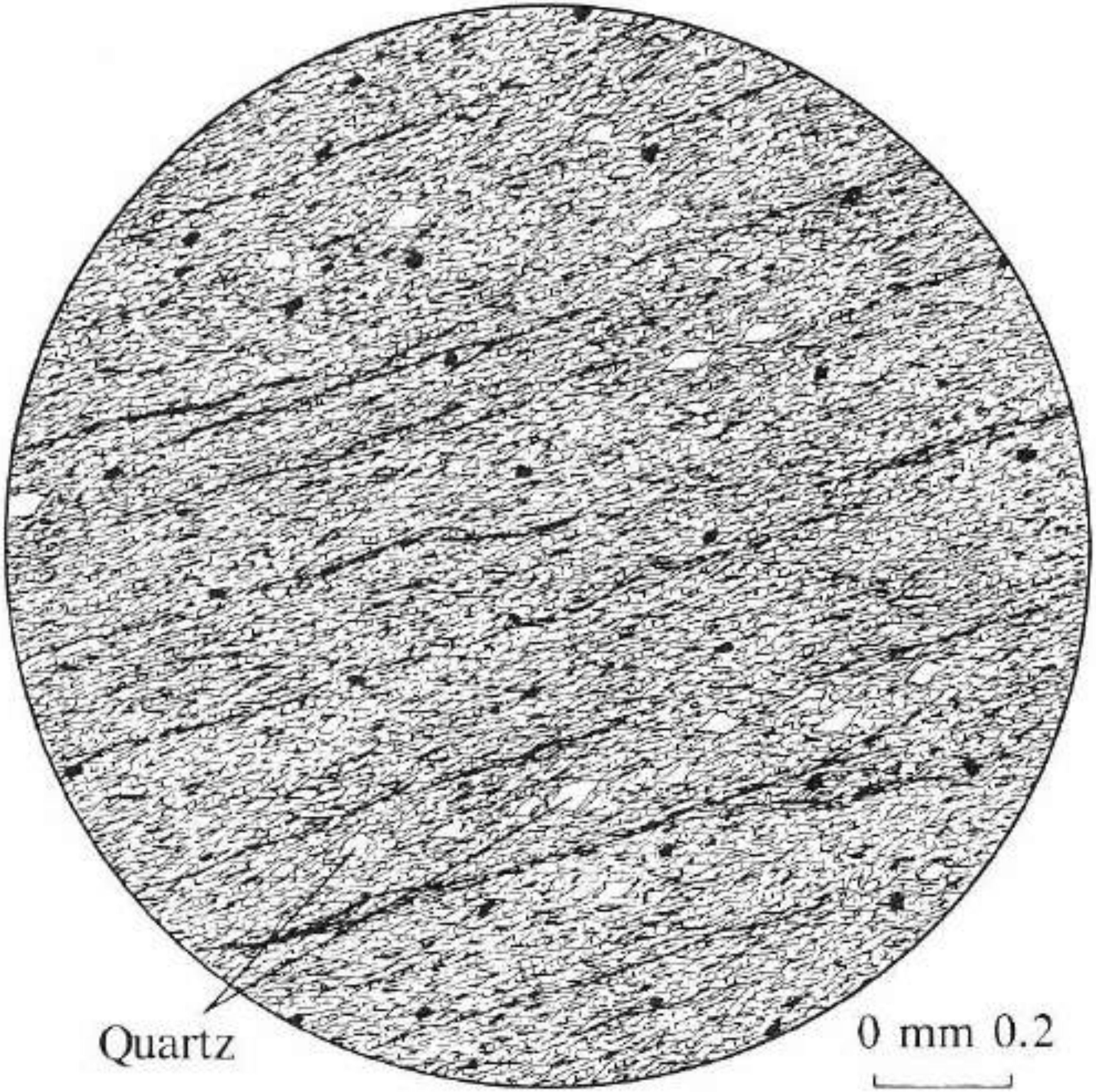




Progressive thermal metamorphism of slate. From Best (1982). *Igneous and Metamorphic Petrology*. W. H. Freeman. San Francisco.



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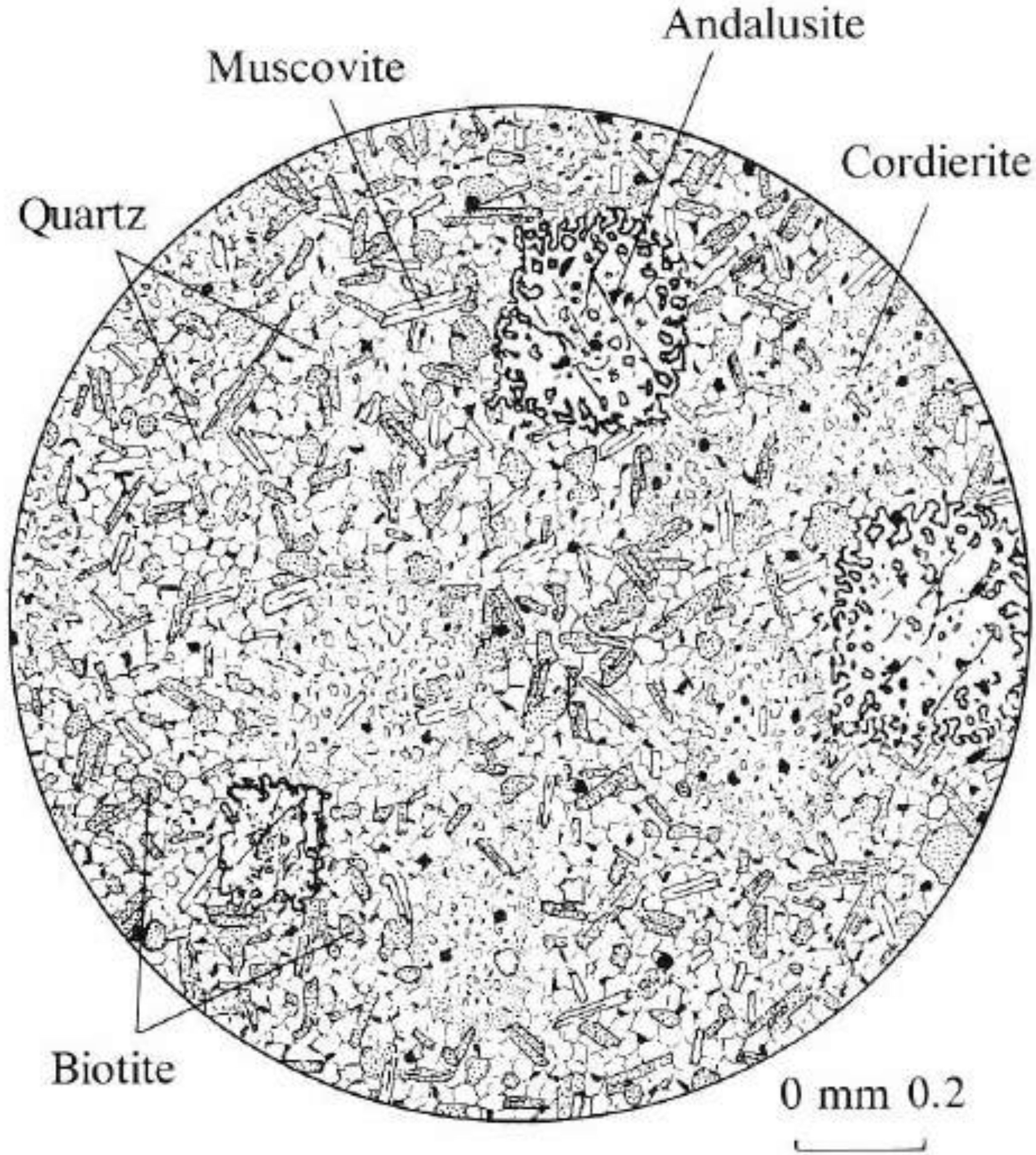

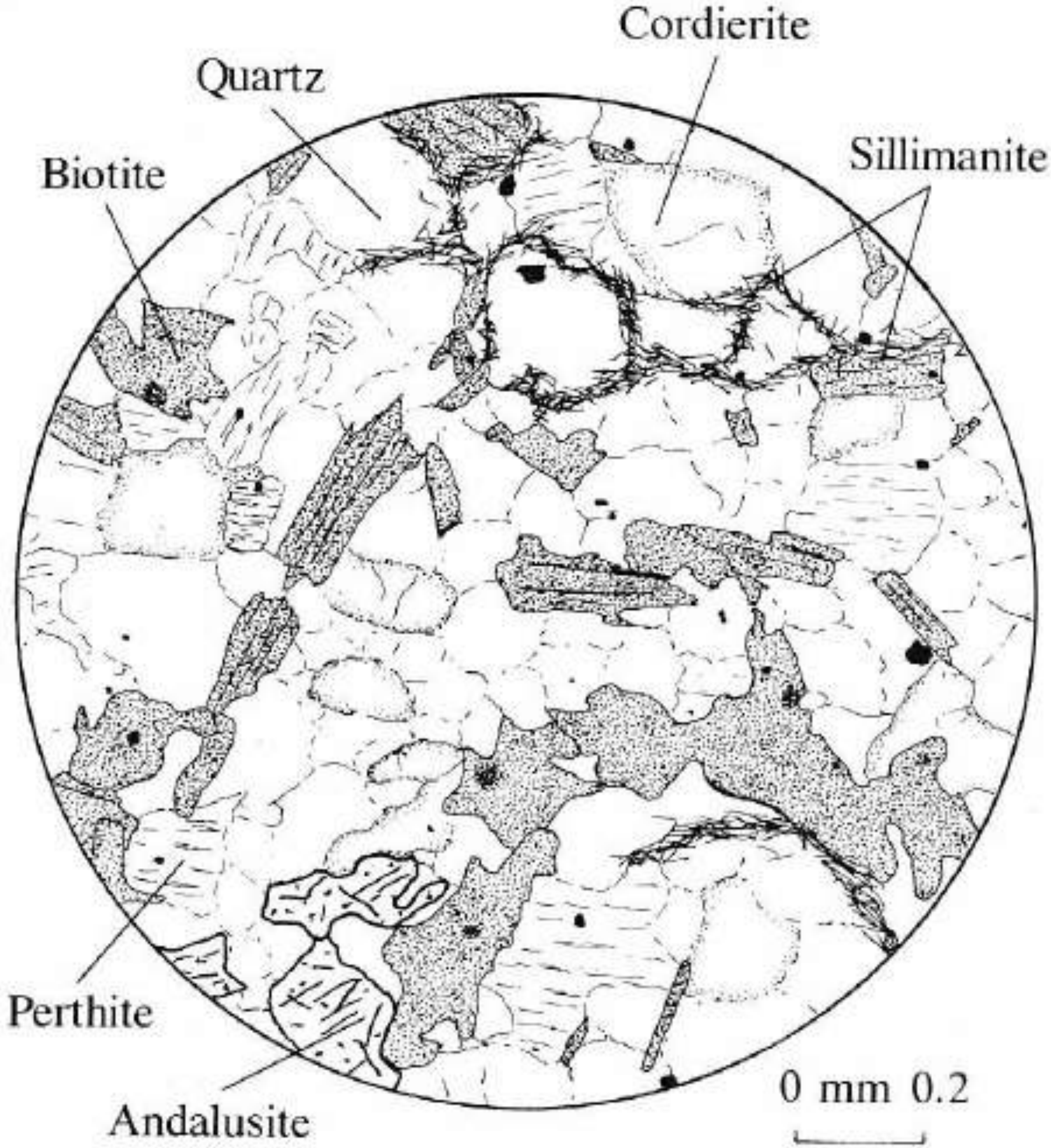

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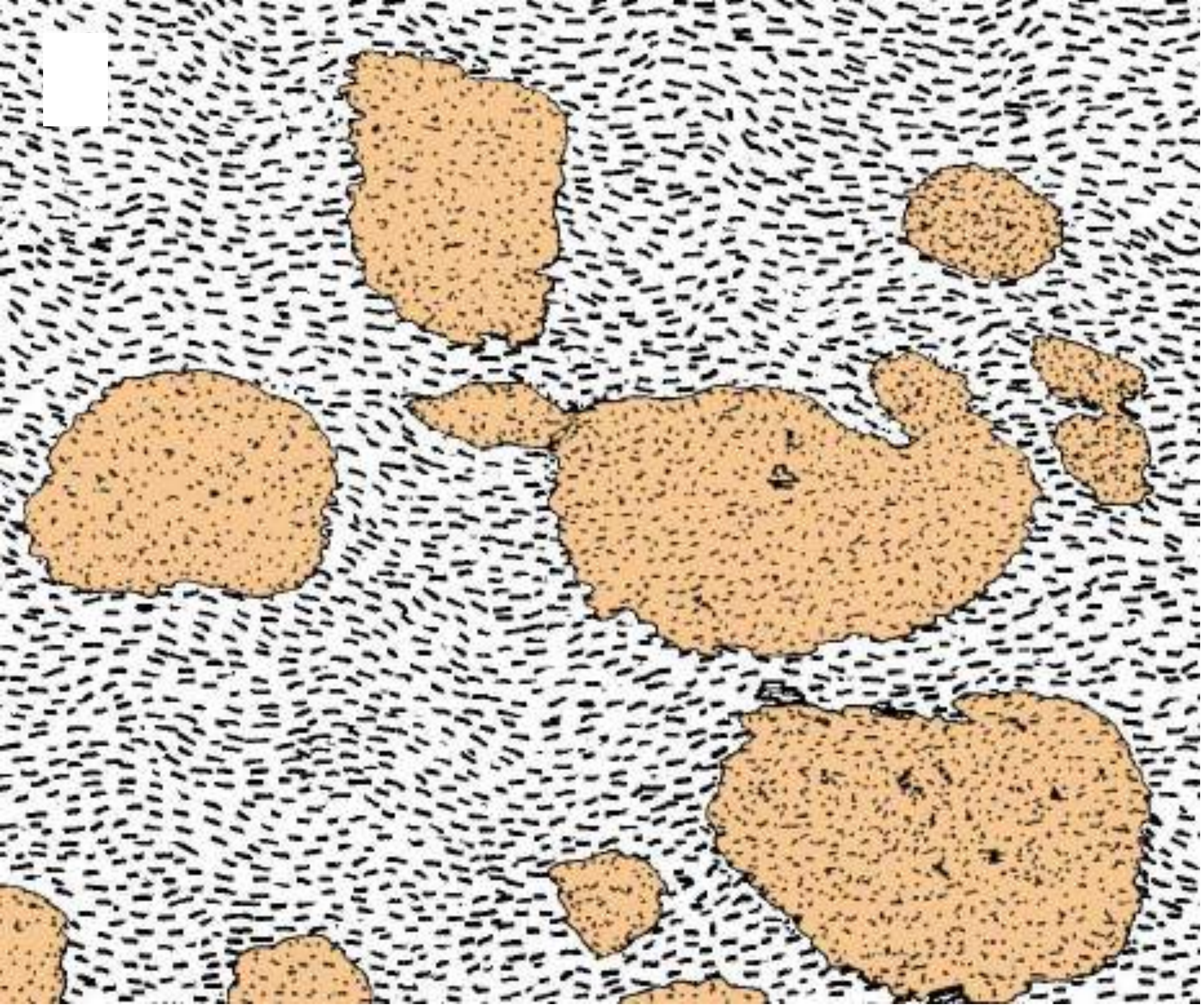


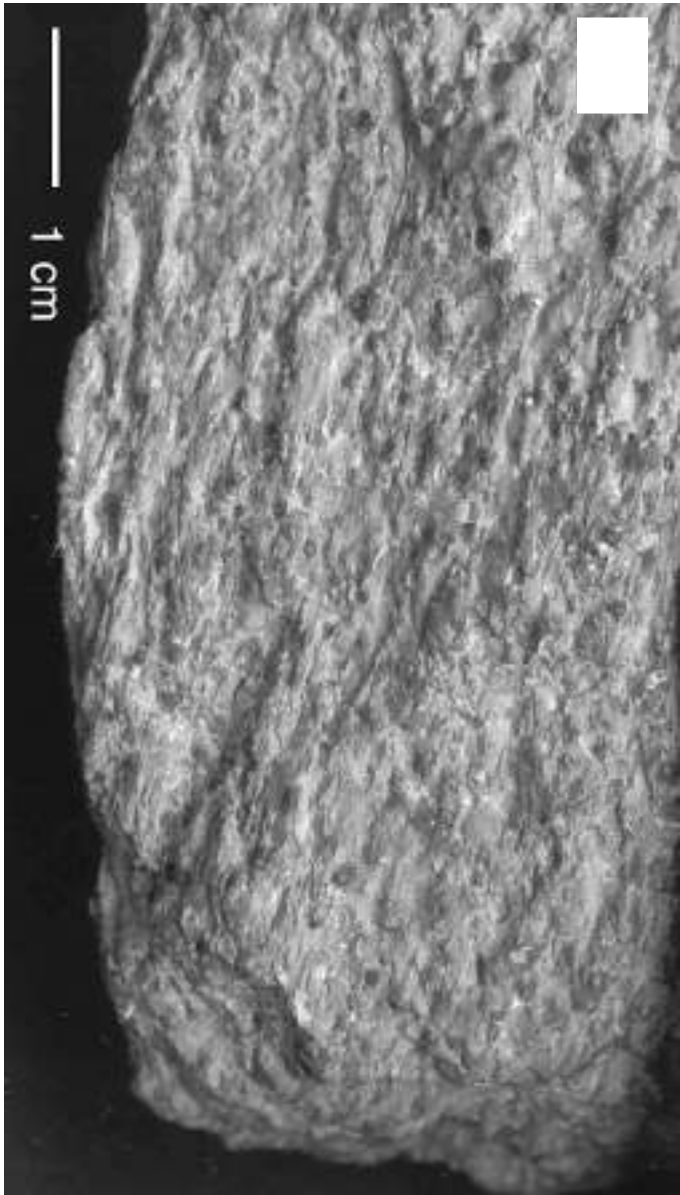


Figure. **Overprint of contact metamorphism on regional. a. Nodular texture of cordierite porphyroblasts developed during a thermal overprinting of previous regional metamorphism (note the foliation in the opaques). Approx. 1.5 x 2 mm. From Bard (1986) *Microtextures of Igneous and Metamorphic Rocks*.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

Metamorphic Textures

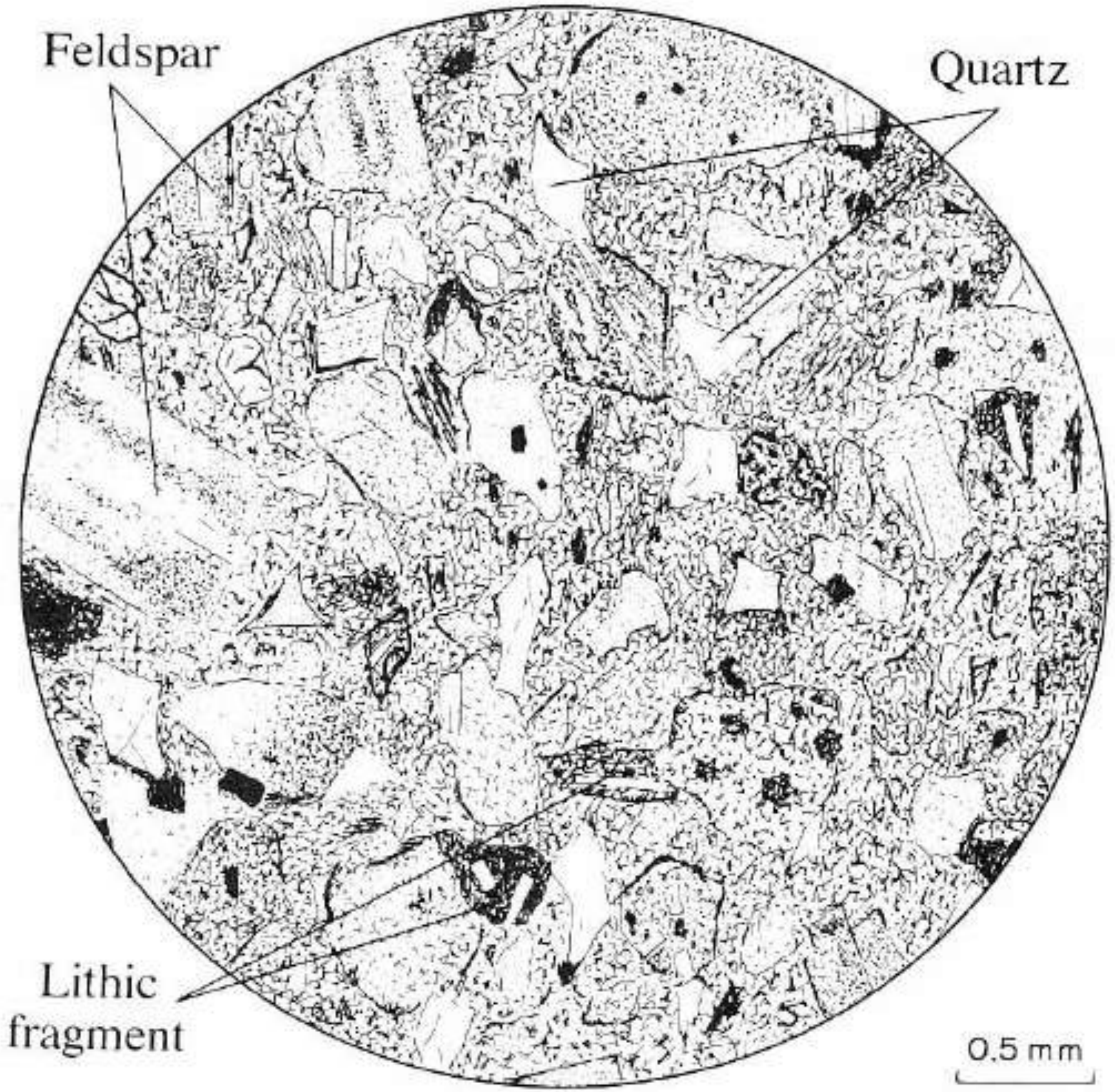
Textures of Regional Metamorphism

- 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

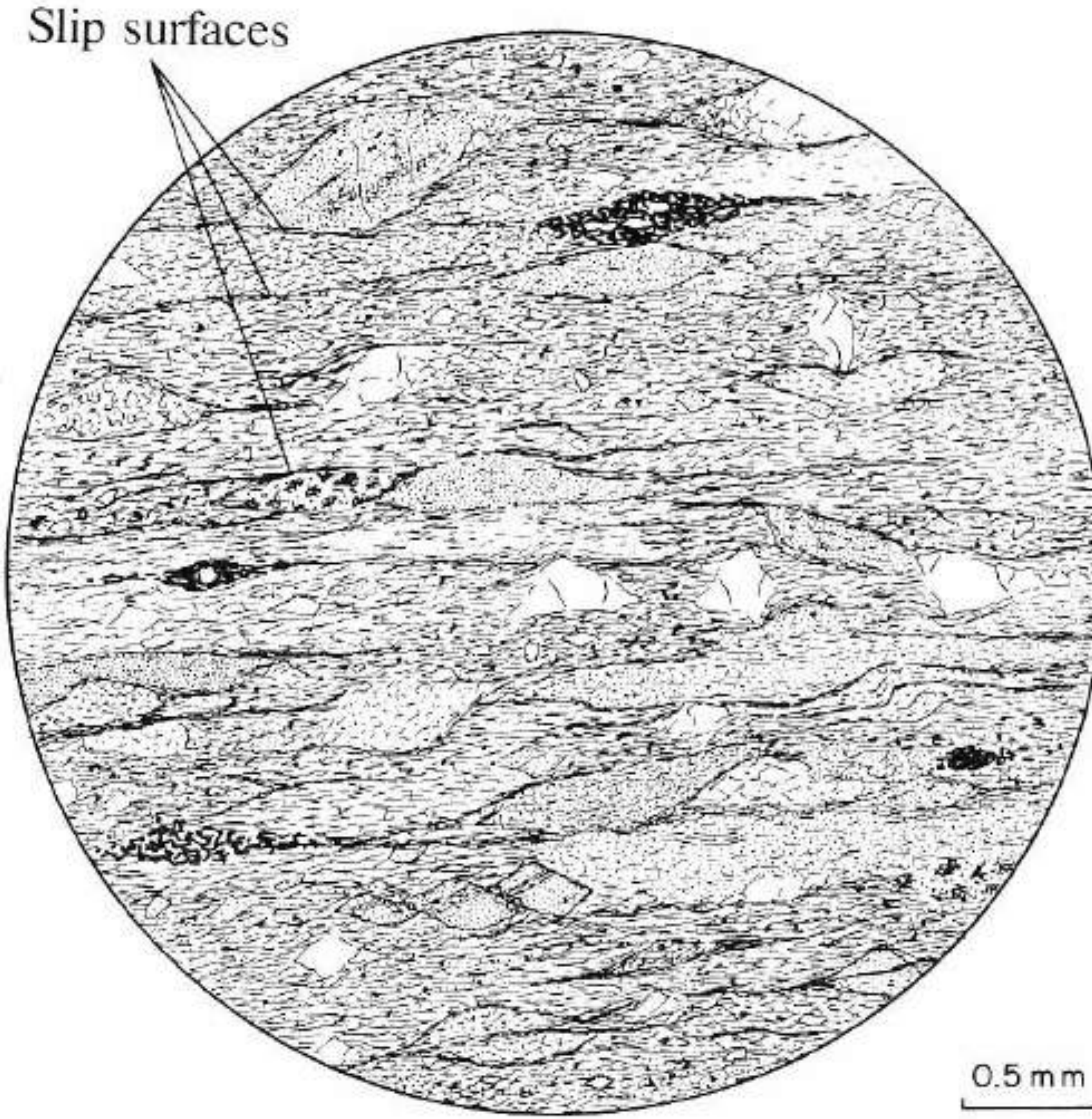
Metamorphic Textures

Textures of Regional Metamorphism

- Tectonite- a deformed rock with a texture that records the deformation
- Fabric- the complete spatial and geometric configuration of textural elements
  - Foliation- planar textural element
  - Lineation- linear textural element
  - Lattice Preferred Orientation (LPO)
  - Dimensional Preferred Orientation (DPO)



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



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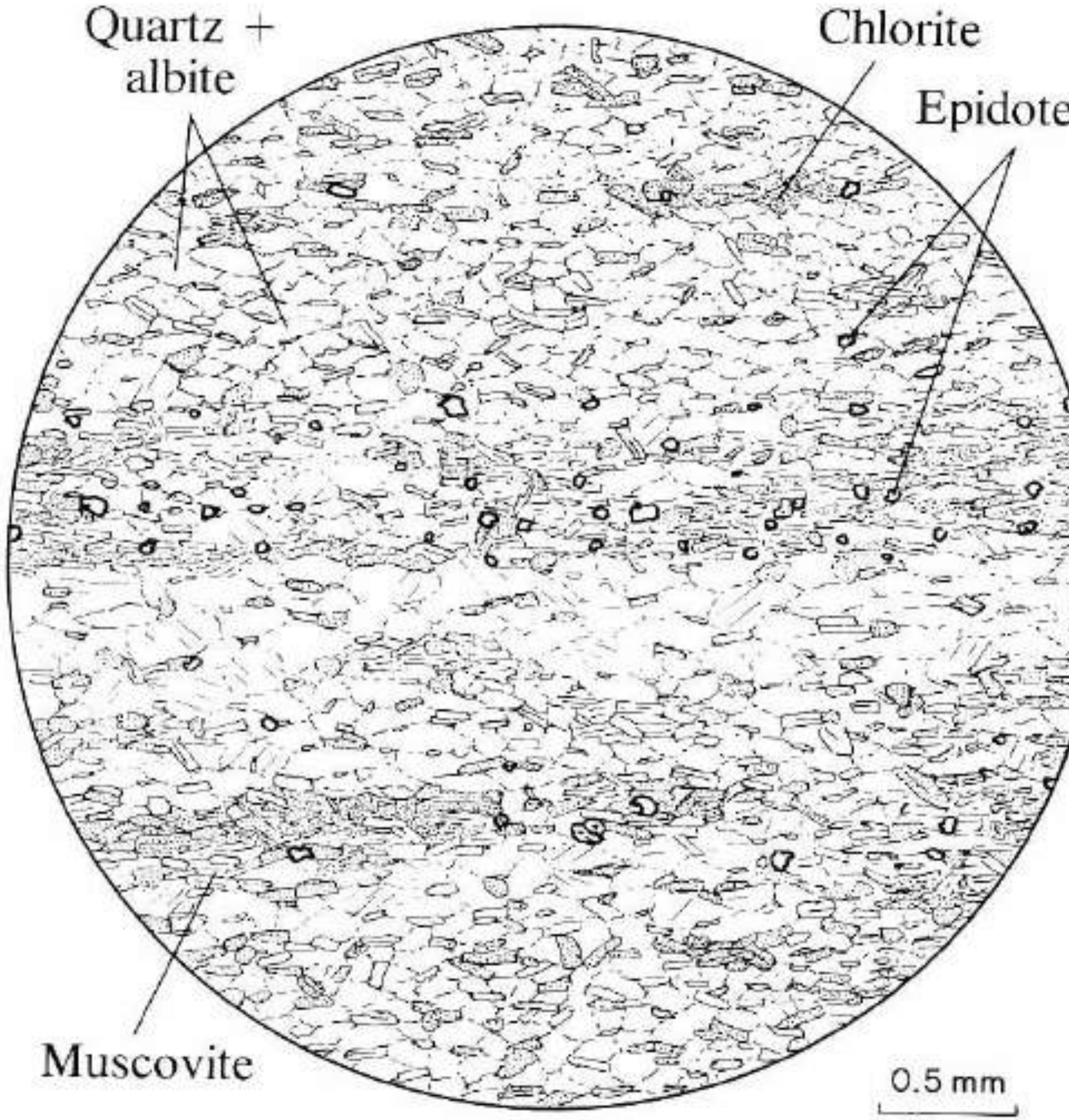

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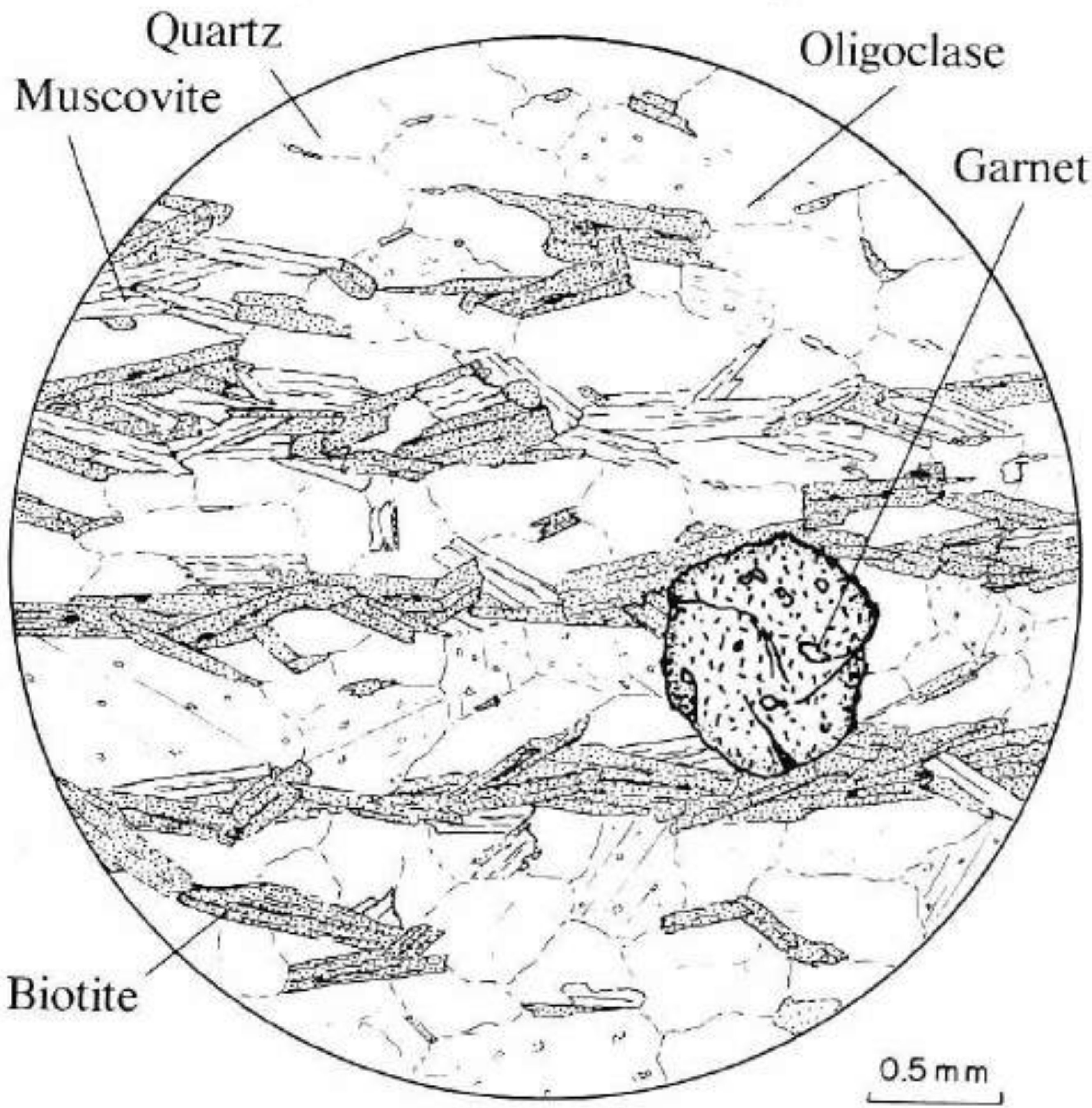


Progressive syntectonic metamorphism of a volcanic graywacke, New Zealand. From Best (1982). ***Igneous and Metamorphic Petrology*****. W. H. Freeman. San Francisco.**

Textures of dynamic metamorphism:

1- Porphyroclastic: A texture produced by the crushing or fragmentation of large grains, resulting in two distinct grain size distributions of the same mineral: coarser grained porphyroclasts and finer grained fragments.

2- Mortar: similar to porphyroclastic but in which the smaller fragments are further crushed to finer and finer sizes (close to becoming powders), while some porphyroclasts still persist.

3- Protomylonitic: A more advanced stage of cataclasis, where some minerals begin to deform in a ductile manner, giving rise to an incipient foliation or preferred orientation.

Textures of dynamic metamorphism:

4- Orthomylonitic (mylonitic): Where the rocks develop a well - defined foliation. In quartz rich rocks, an orthomylonitic fabric is often indicated by quartz crystals elongated like ribbons or flames (ribbon quartz).

5- Polygonized/ recrystallized/ annealed (ultramylonitic): The most advanced stages of cataclastic metamorphism result in the recrystallization of the highly strained crystals into smaller ones developing a granoblastic polygonal texture. At the same time, a foliation defined by micaceous or prismatic minerals persists.

Crystallization textures:

1. Porphyroblastic: Where coarse-grained metamorphic minerals (porphyroblasts) occur in a matrix of finer grained crystals.

2. Poikiloblastic: Where coarse-grained metamorphic minerals contain numerous inclusions of finer-grained crystals of other minerals. It is of different types:

   a- Fish-net or skeletal texture: rapid crystallization
   b- Sieve texture

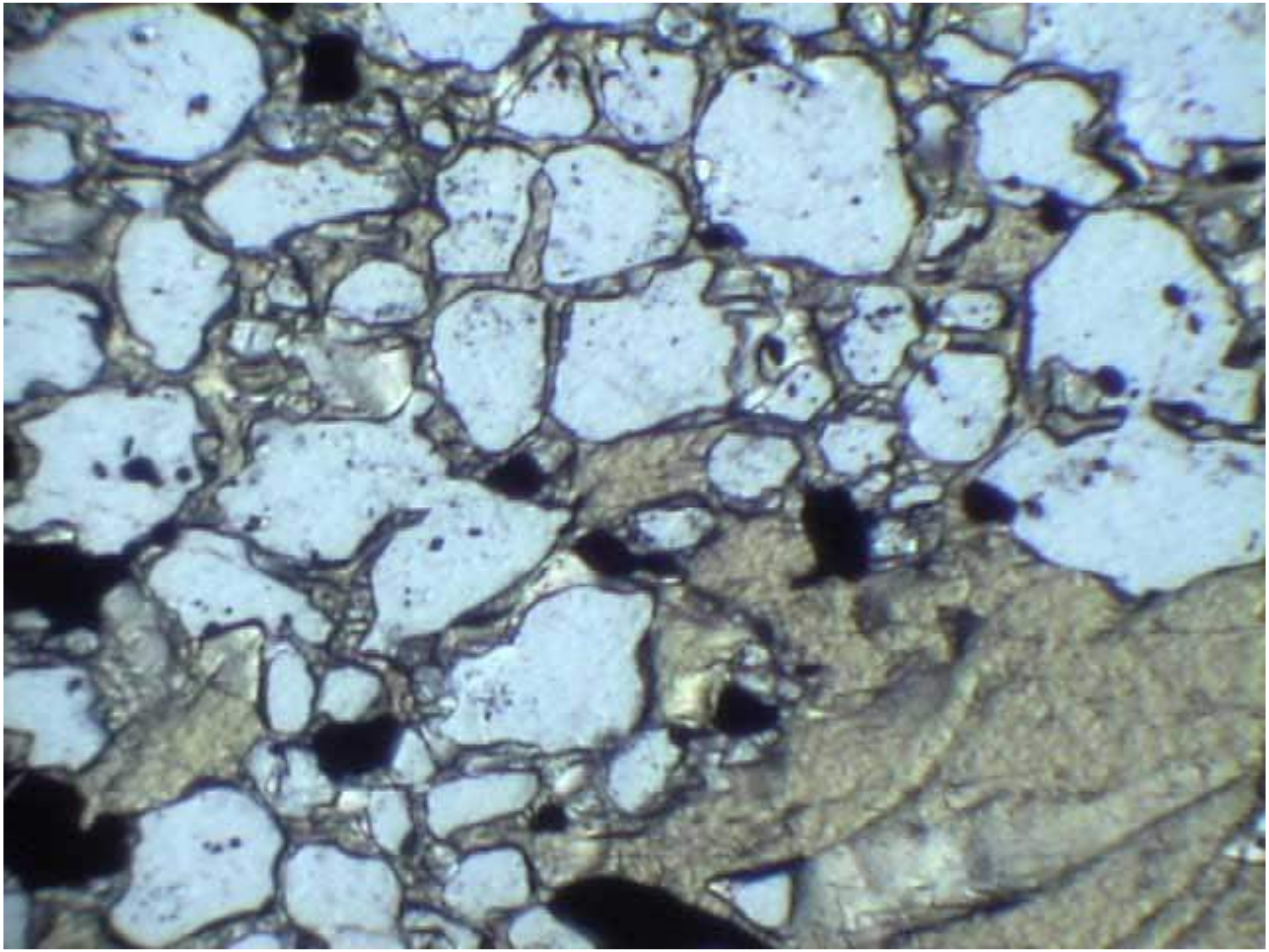


Figure. **Skeletal or web texture of staurolite in a quartzite. The gray intergranular material, and the mass in the lower left, are all part of a single large staurolite crystal. Pateca, New Mexico. Width of view ~ 5 mm. Winter (2010) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall.**

Crystallization textures:

c- Rotational texture: where the inclusions are oriented at an angle that suggests that the poikiloblast may have rotated during its growth, thus indicating syndeformational or syntectonic growth. An alternative interpretation of such texture is the rotation of the foliation during the growth of the poikiloblast, which still makes the growth syndeformational.

d- Snowball: Similar to rotational texture, but where the inclusions define a spiral shaped trail, which may have developed from the "rolling over" of the poikiloblasts.

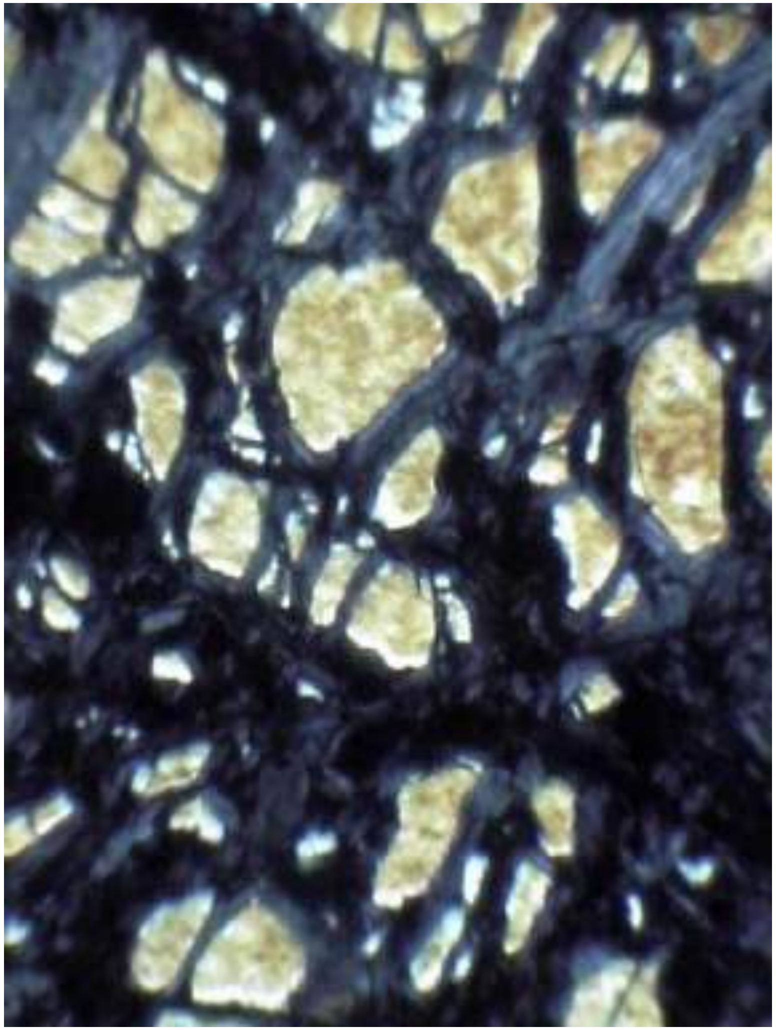
e- Helicitic: Where the poikiloblasts overgrow the pre-existing foliation. This texture therefore indicates post-tectonic crystallization of the poikiloblasts.

C- Replacement textures (superimposed in part!)

1. Mesh texture: develops in serpentinites, where the needle shaped serpentine minerals occur in aggregates interwoven like a mesh.

2. Hour-glass texture: Also in serpentinites, where the serpentine minerals replace the granular olivine crystals giving rise to hour-glass like appearances.

a



b

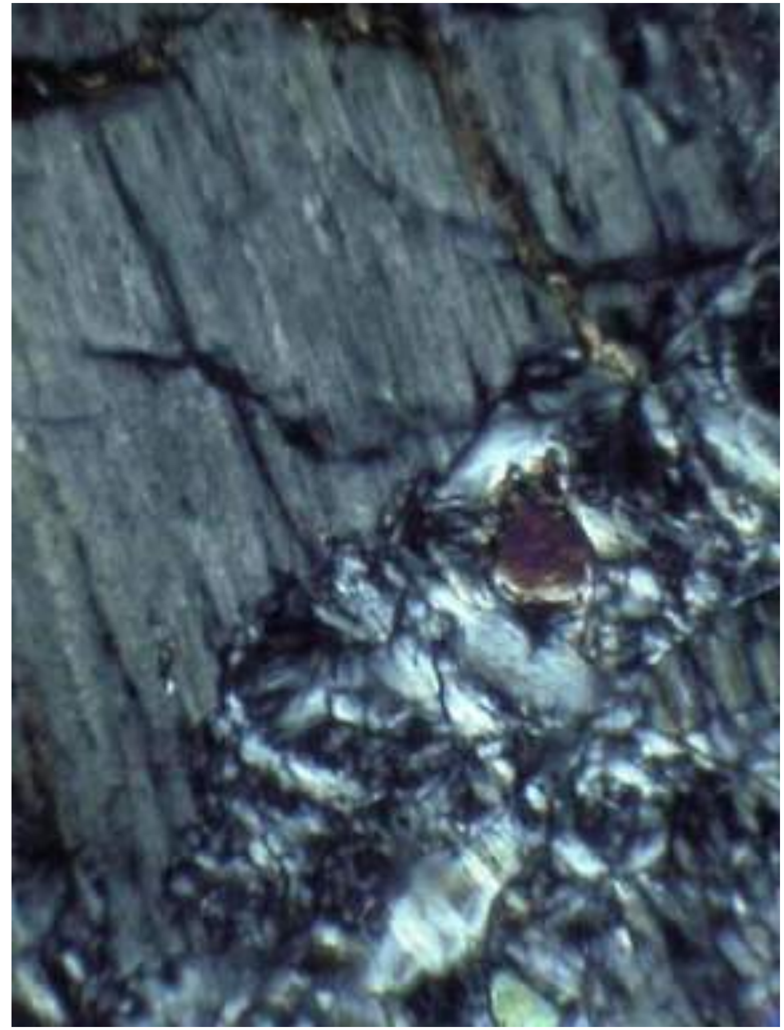


Figure. a. Mesh texture in which serpentine (dark) replaces a single olivine crystal (light) along irregular cracks. Field of view ca. 0.1 mm.

Figure. b. Serpentine pseudomorphs orthopyroxene to form bastite in the upper portion of photograph, giving way to mesh olivine below. Field of view ca. 0.1 mm.

C- Replacement textures (superimposed in part!)

3. Bastite texture: A third texture that occurs in serpentinites, where Opx crystals were completely replaced by aggregates of serpentine minerals retaining the prismatic shape of the original Opx.

4. Pseudomorphic replacement textures:

(i) single-crystal
(ii) multi-crystal
(iii) multi-phase, multi-crystal

D- Reaction textures

1. Epitaxial overgrowth: Epitaxial overgrowth is characterized by optical continuity between the mineral and its overgrowth. Both the mineral and the overgrowth must belong to the same structural group, and may possibly be the same mineral. This type of overgrowth is controlled fully by the the matrix mineral.

2. Topotactic replacement: One mineral overgrows another of a similar structure (e.g. Actinolite rims on glaucophane). Orientation of overgrowing mineral is controlled by that of the overgrown one.

D- Reaction textures

3. Kelyphitic texture (also a replacement texture): A kelyphitic texture is a replacement of one mineral along its rim by an intergrowth of two or more minerals, in a way that the new minerals almost completely surround the mineral being replaced. The term is most commonly used when the replacing minerals form during retrogression. Examples include kelyphitic rims of chlorite + Fe-oxides after garnet.

4. Reaction-rim texture: when one mineral replaces another along its rims, suggesting a reaction between both phases. The contacts between both phases are irregular.

D- Reaction textures

5. Corona texture: several concentric layers of one or more minerals completely encircling an older phase. The layers (which range from one to five in number) represent a sequence of reactions that have taken place (none to completion) to replace the mineral in the core or center of the corona. Coronas form during both prograde or retrograde metamorphism. Monomineralic coronas are also known as moats.

6. Atoll texture: where the core of a mineral is dissolved or replaced leaving behind a surviving rim. Such textures usually form due to an original compositional zoning within the mineral with the replaced core.

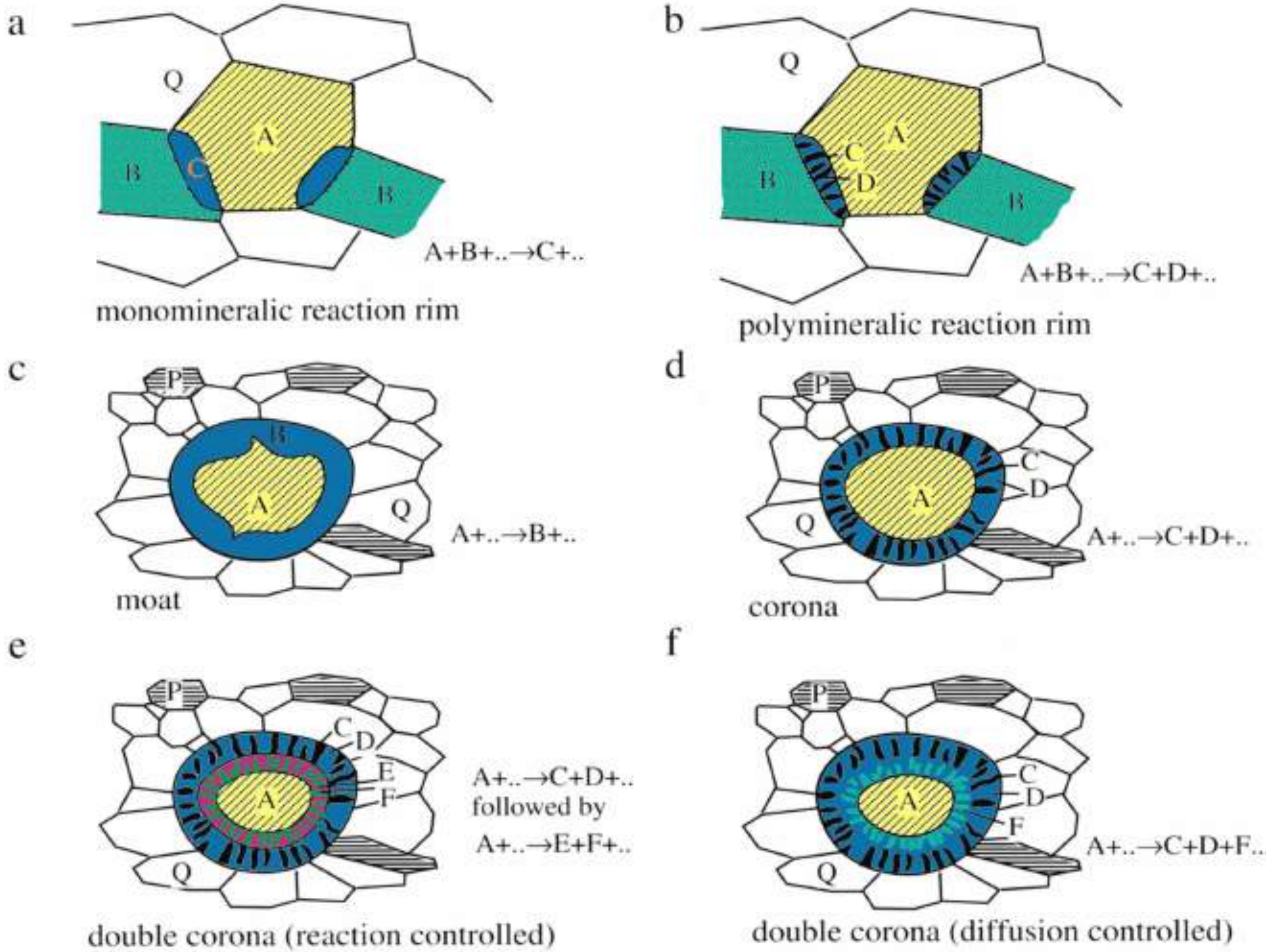


Figure. Reaction rims and coronas. From Passchier and Trouw (1996) Microtectonics. Springer-Verlag.

Fig. Coronites in outcrop. Cores of orthopyroxene (brown) with successive rims of clinopyroxene (dark green) and garnet (red) in an anorthositic matrix. Austrheim, Norway.

E- Intergrowth texture

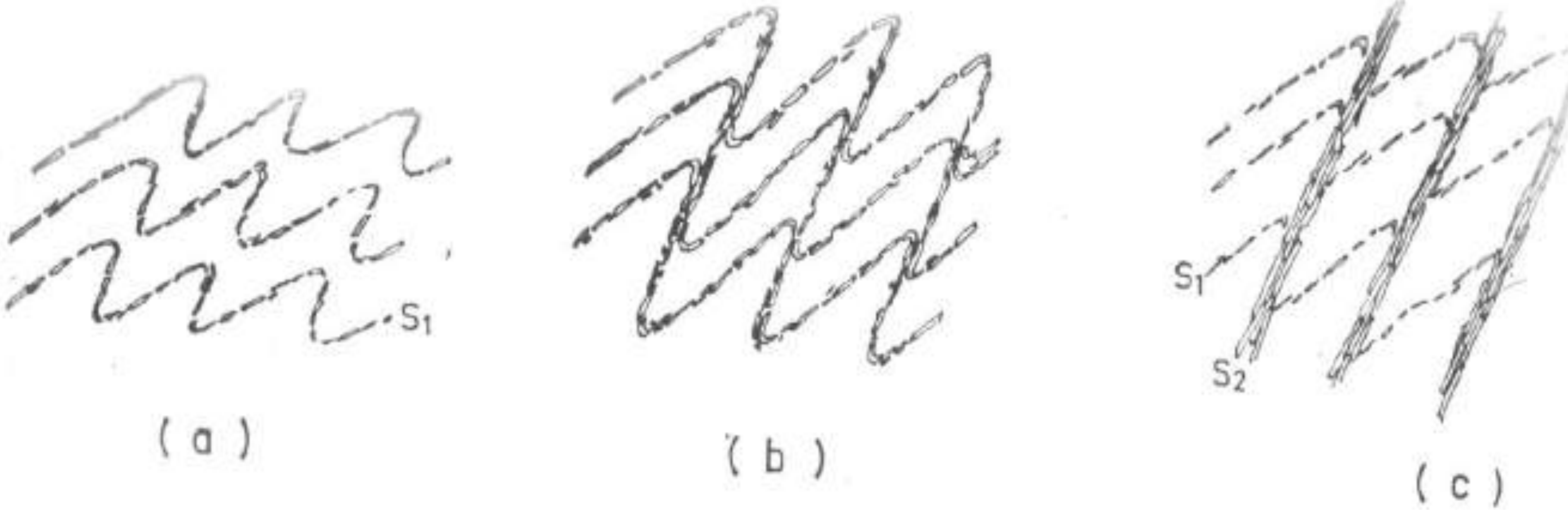
1. Symplectites (also a reaction texture): Are irregular fine-grained mineral intergrowths that form as a result of a certain reaction that did not go to completion. These intergrowths are often recognized by their wormy appearance and often occur along the boundaries of reacting minerals (or ones not in equilibrium).

Examples of commonly intergrown mineral pairs: Qz-Feldspar/ Amph-Spinel/ Plag-Mgt/ Gt-Qz/ Plag-Cpx/ Bt-Qz/ Ep-Qz/ Amph-Plag. Note that a common type of symplectitic intergrowth is the myrmekitic texture commonly observed in granites, where wormy quartz occurs in plagioclase crystals in contact with biotite. Symplectitic intergrowths are more common in high temperature rocks.

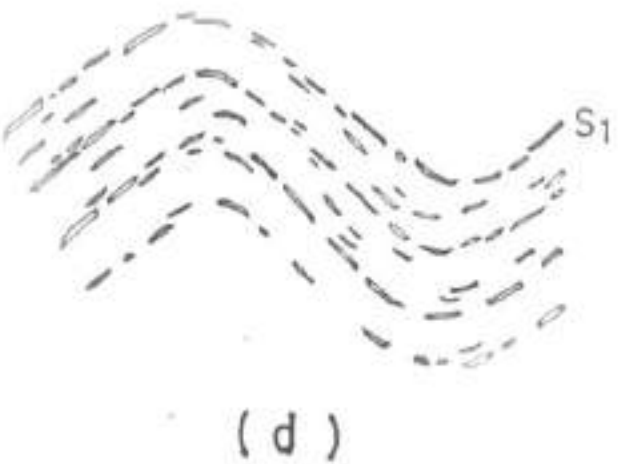
F- Polydeformational / Polymetamorphic textures

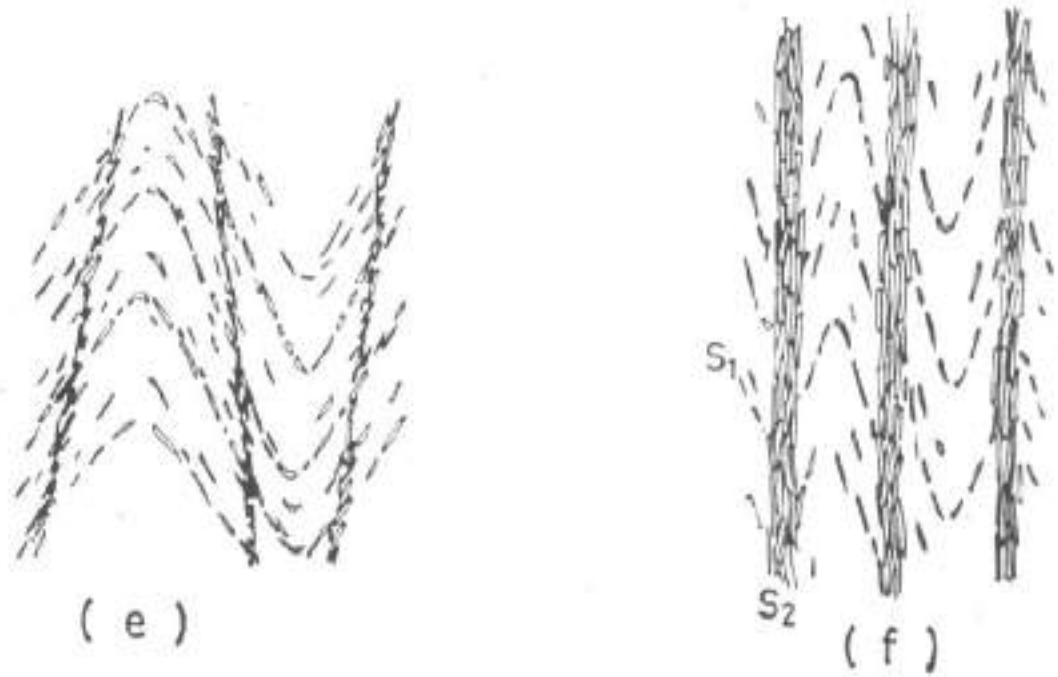
1. Crenulated cleavage/schistosity: Results from the folding of a foliation.

2. S-C fabric: A more advanced stage of crenulation, where one or more minerals are orientated along the crenulated surfaces to define a new foliation (S2) at an angle to the older one (S1). This commonly involves some form of "recrystallization".



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





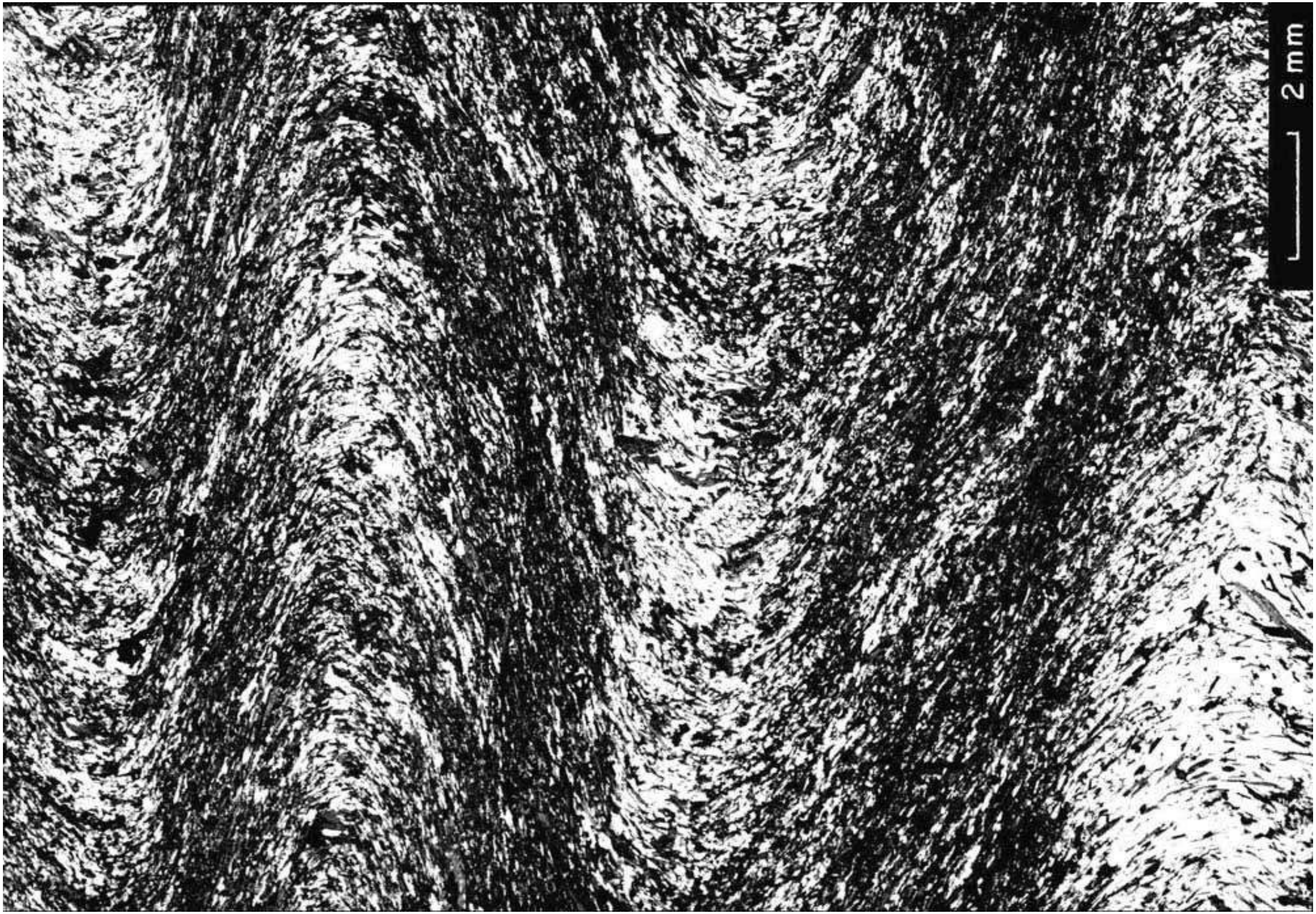


Figure. Symmetrical crenulation cleavages in amphibole-quartz-rich schist. Note concentration of quartz in hinge areas. From Borradaile *et al*. (1982) *Atlas of Deformational and Metamorphic Rock Fabrics*. Springer-Verlag.

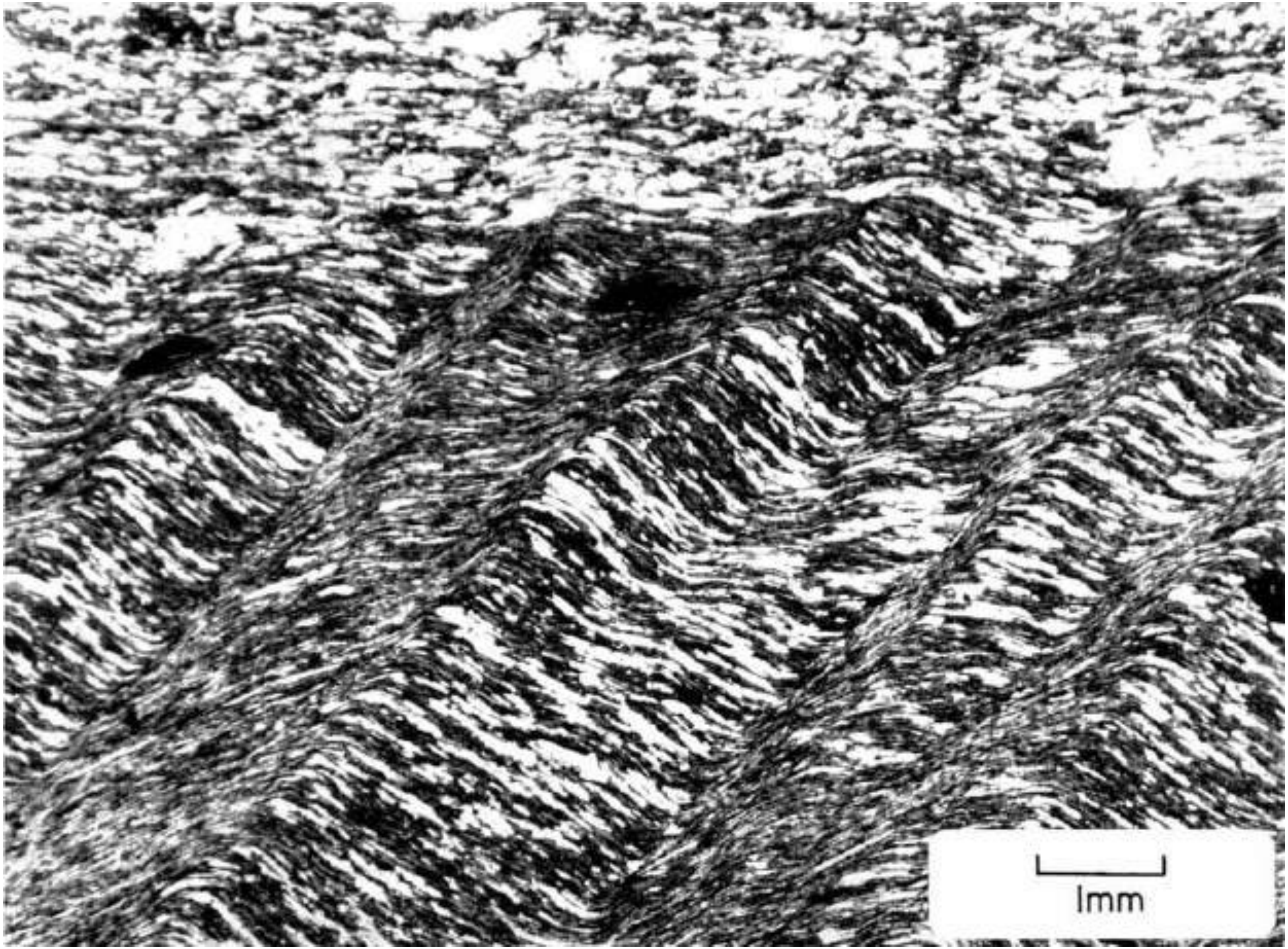
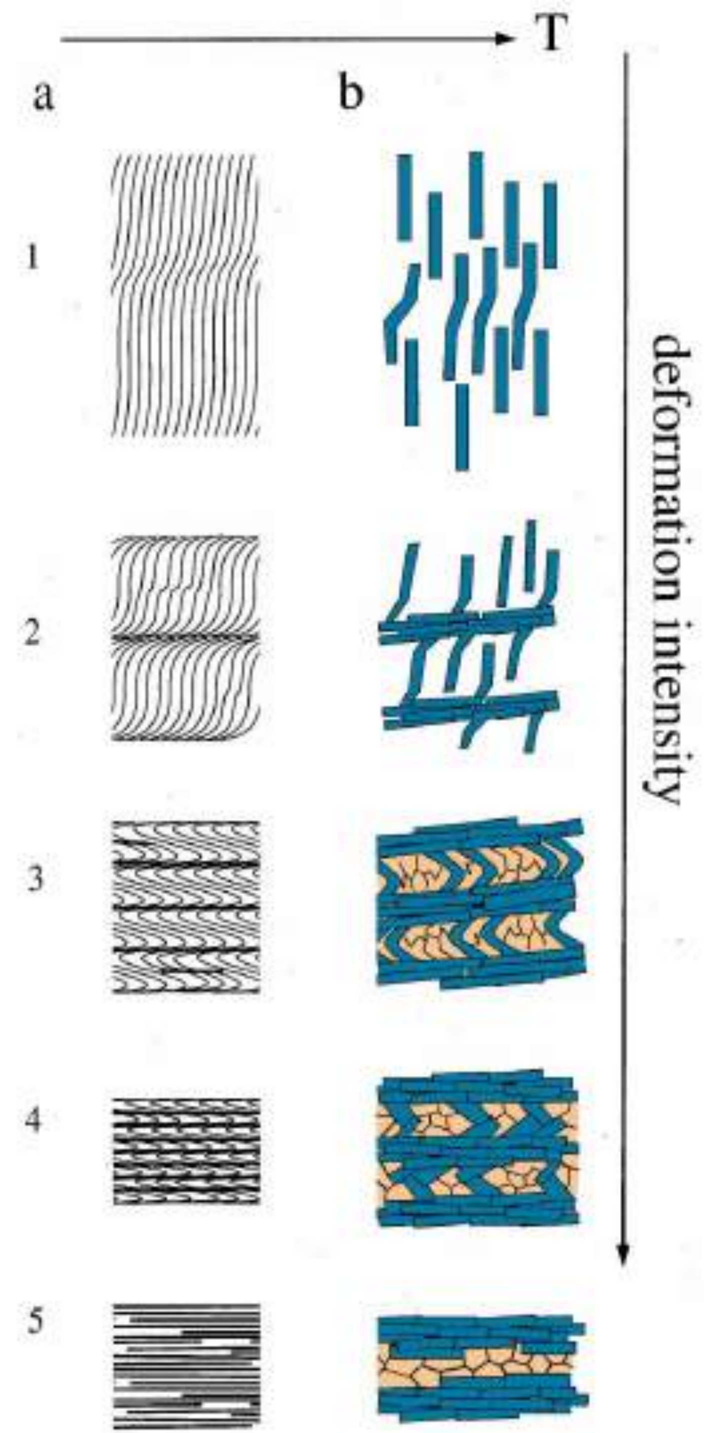


Figure. Asymmetric crenulation cleavages in mica-quartz-rich schist. Note horizontal compositional layering (relict bedding) and preferential dissolution of quartz from one limb of the folds. From Borradaile *et al*. (1982) *Atlas of Deformational and Metamorphic Rock Fabrics*. Springer-Verlag.

Figure. **Stages in the development of crenulation cleavage as a function of temperature and intensity of the second deformation. From Passchier and Trouw (1996) *Microtectonics*. Springer-Verlag.**



Development of S_2 micas depends upon T and the intensity of the second deformation

G- Special textures and features

1. Pressure shadows: are ellipsoidal regions adjacent to a rigid crystal where minerals grow developing textures that differ from those defined by the same minerals in the rest of the sample. Growth in a pressure shadow is therefore influenced by the crystal faces of the rigid mineral which seem to "protect" the minerals in its immediate vicinity from the deformation affecting the same minerals in other parts of the sample. Accordingly, the foliation wraps around the rigid crystal and its shadow.

G- Special textures and features

2. Mica fish: Are lenticular porphyroblasts of mica which commonly develop in a shear stress environment and can be used to indicate the sense of shear.

3. Kink bands (deformational bands): Are bends and twists within some minerals as a result of their deformation. Kink bands develop in pre-tectonic minerals.

4. Zoning: Compositional change of a crystal, often accompanied by a change in some of its optical properties.

G- Special textures and features

5. Twinning: Some twinning may be induced by deformation.

6. Exsolution texture: results from the incomplete miscibility between two components (end-members) of a solid solution series. A decrease in temperature may result in the separation of these two phases, one in the other commonly along cleavage planes. Common in high grade rocks that cooled slowly.

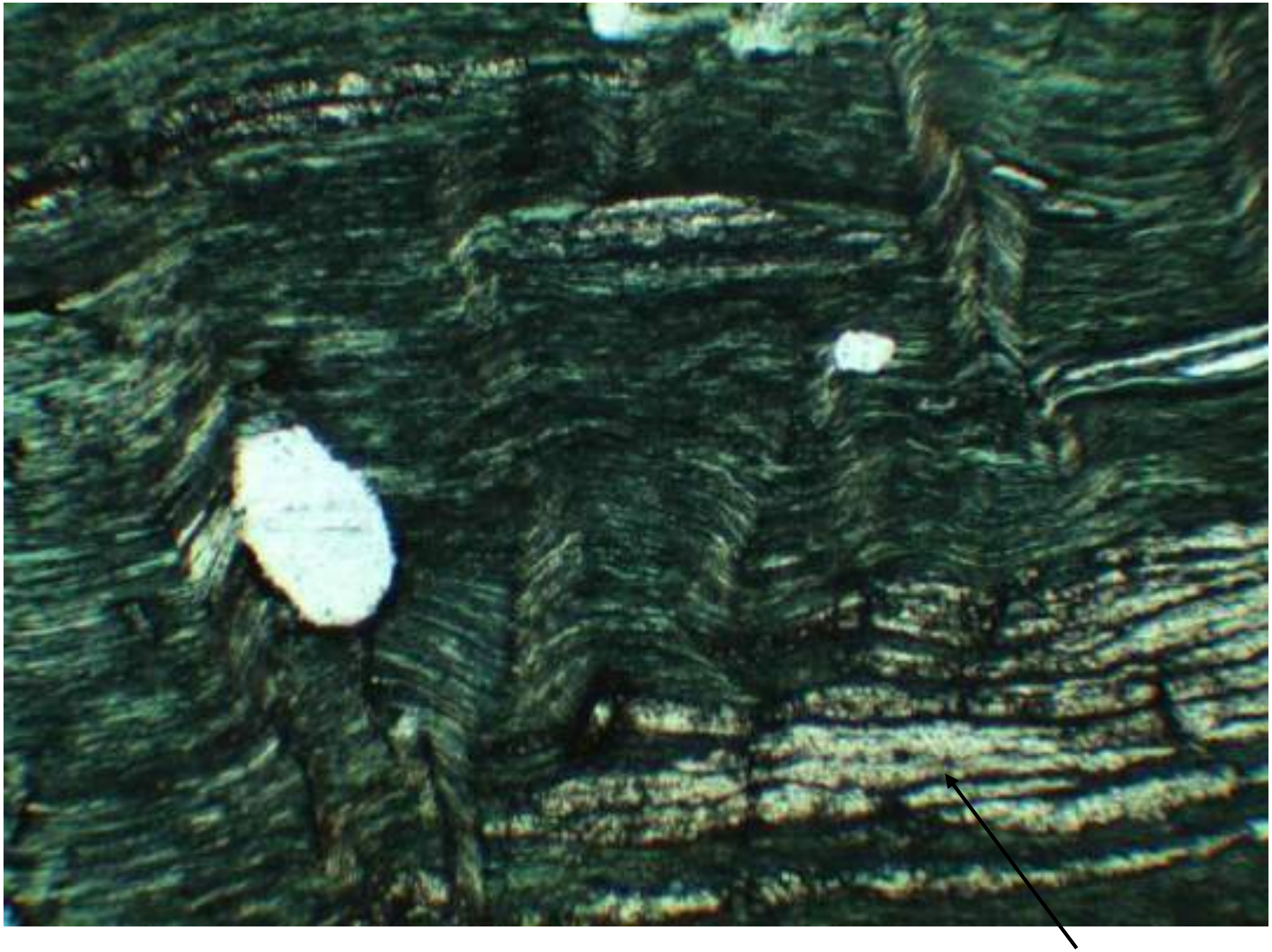
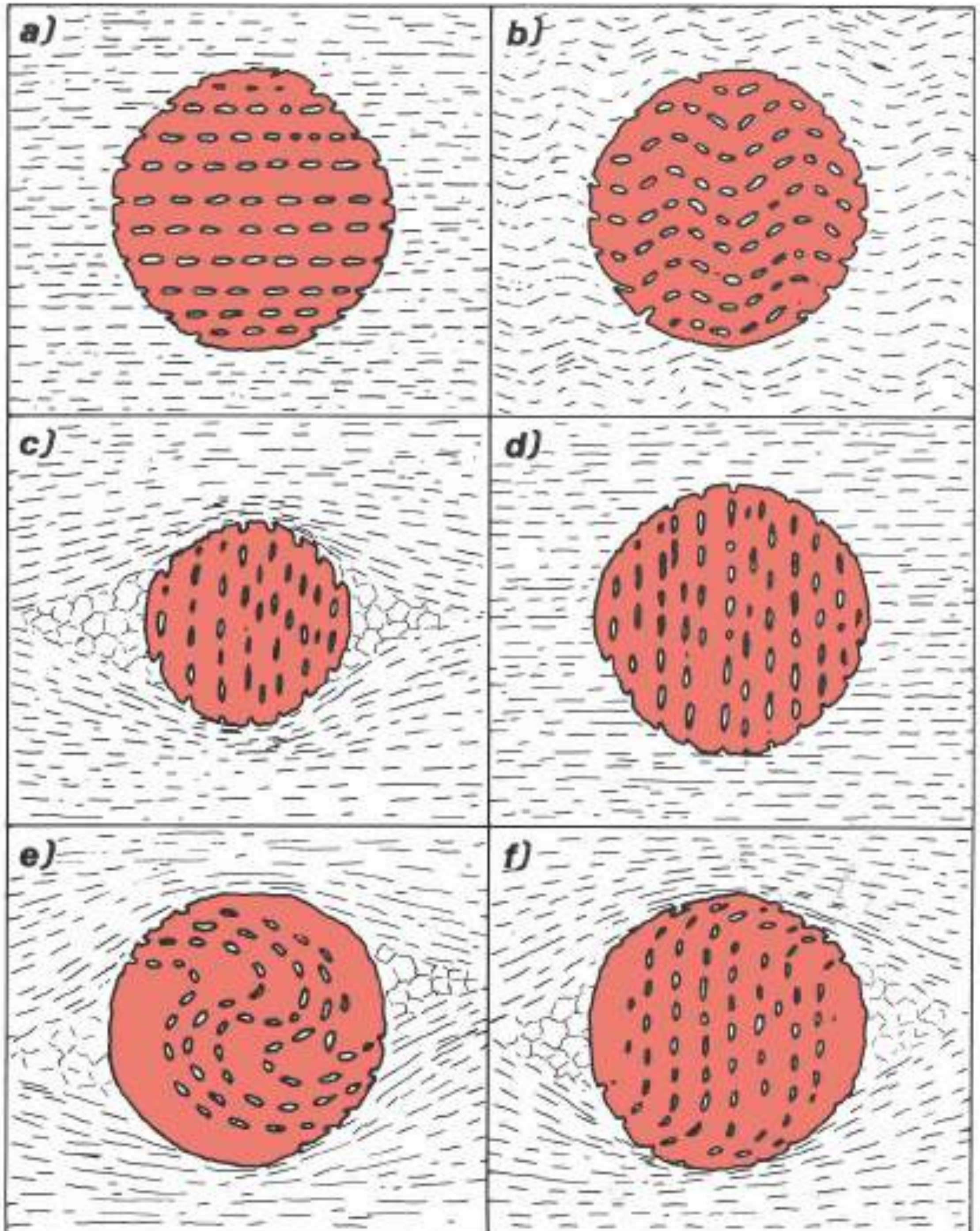


Figure. Kink bands involving cleavage in deformed chlorite. Inclusions are quartz (white), and epidote (lower right). Field of view ~ 1 mm. Winter (2010) An Introduction to Igneous and Metamorphic Petrology. Prentice Hall.

6- Relationship between deformation and metamorphism:

Through the identification of
pre-, syn- and post-tectonic minerals.



i=internal; e=external

Post-kinematic: S_i is identical to and continuous with S_e

Pre-kinematic: Porphyroblasts are post-S_2. S_i is inherited from an earlier deformation. S_e is compressed about the porphyroblast in (c) and a pressure shadow develops.

Syn-kinematic: Rotational porphyroblasts in which S_i is continuous with S_e suggesting that deformation did not outlast porphyroblast growth.

From Yardley (1989) An Introduction to Metamorphic Petrology. Longman.

Pre-kinematic crystals

a. Bent crystal with undulose extinction
b. Foliation wrapped around a porphyroblast
c. Pressure shadow or fringe
d. Kink bands or folds
e. Microboudinage
f. Deformation twins

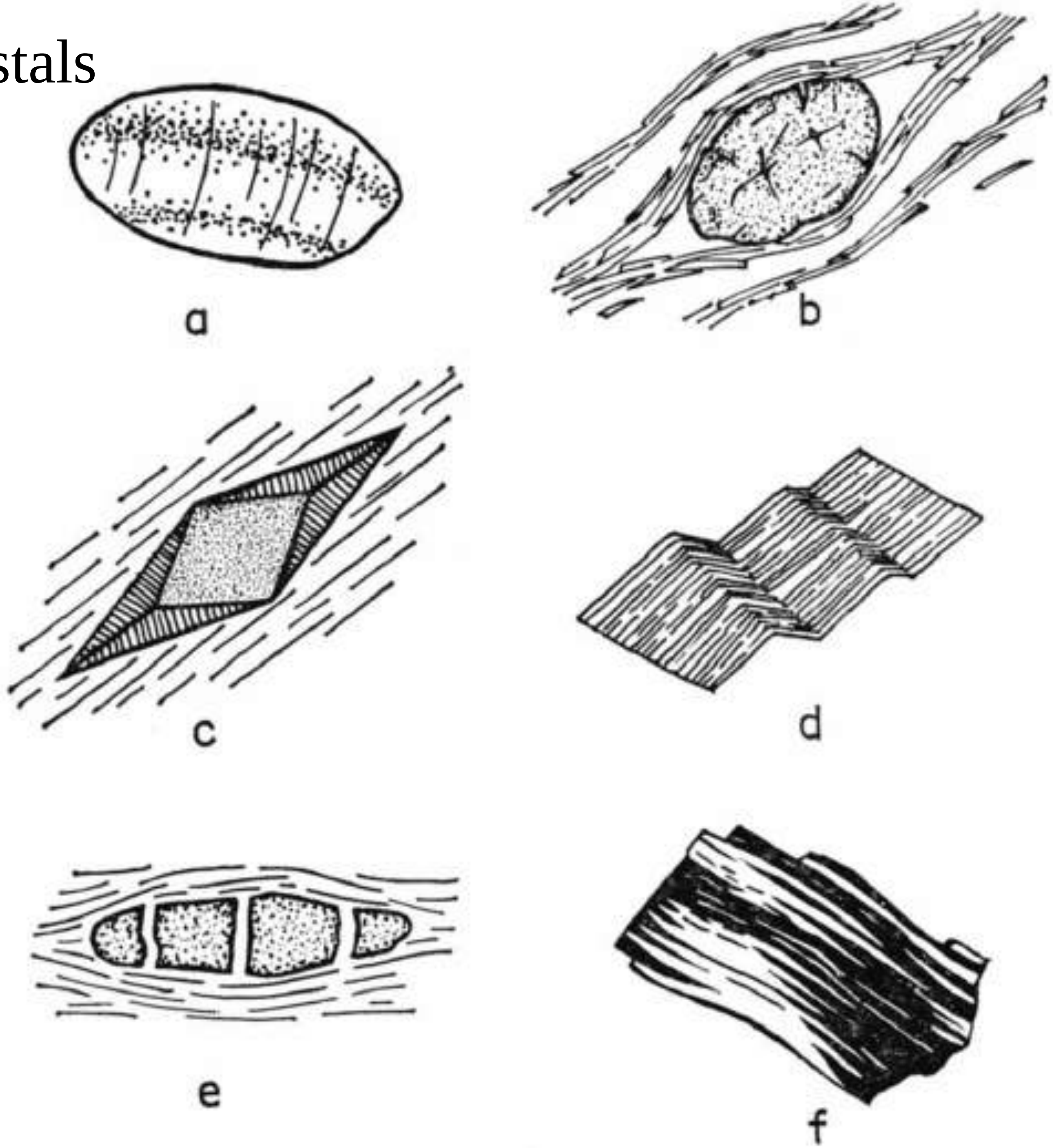


Figure. Typical textures of pre-kinematic crystals. From Spry (1969) *Metamorphic Textures*. Pergamon. Oxford.

Post-kinematic crystals

a. Helicitic folds **b.** Randomly oriented crystals **c.** Polygonal arcs
d. Chiastolite **e.** Late, inclusion-free rim on a poikiloblast (?)
f. Random aggregate pseudomorph

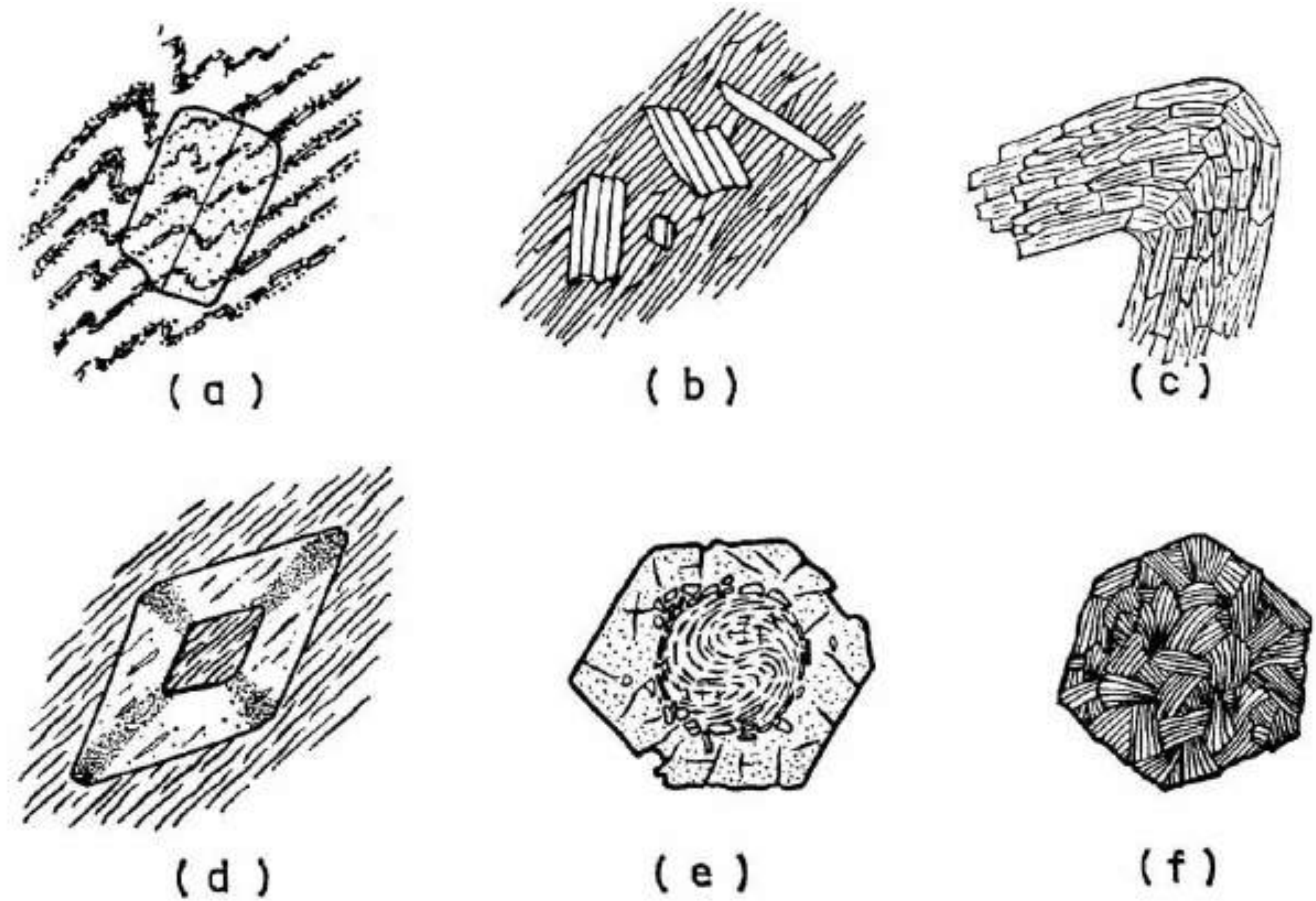


Figure. **Typical textures of post-kinematic crystals. From Spry (1969) *Metamorphic Textures*. Pergamon. Oxford.**

Syn-kinematic crystals

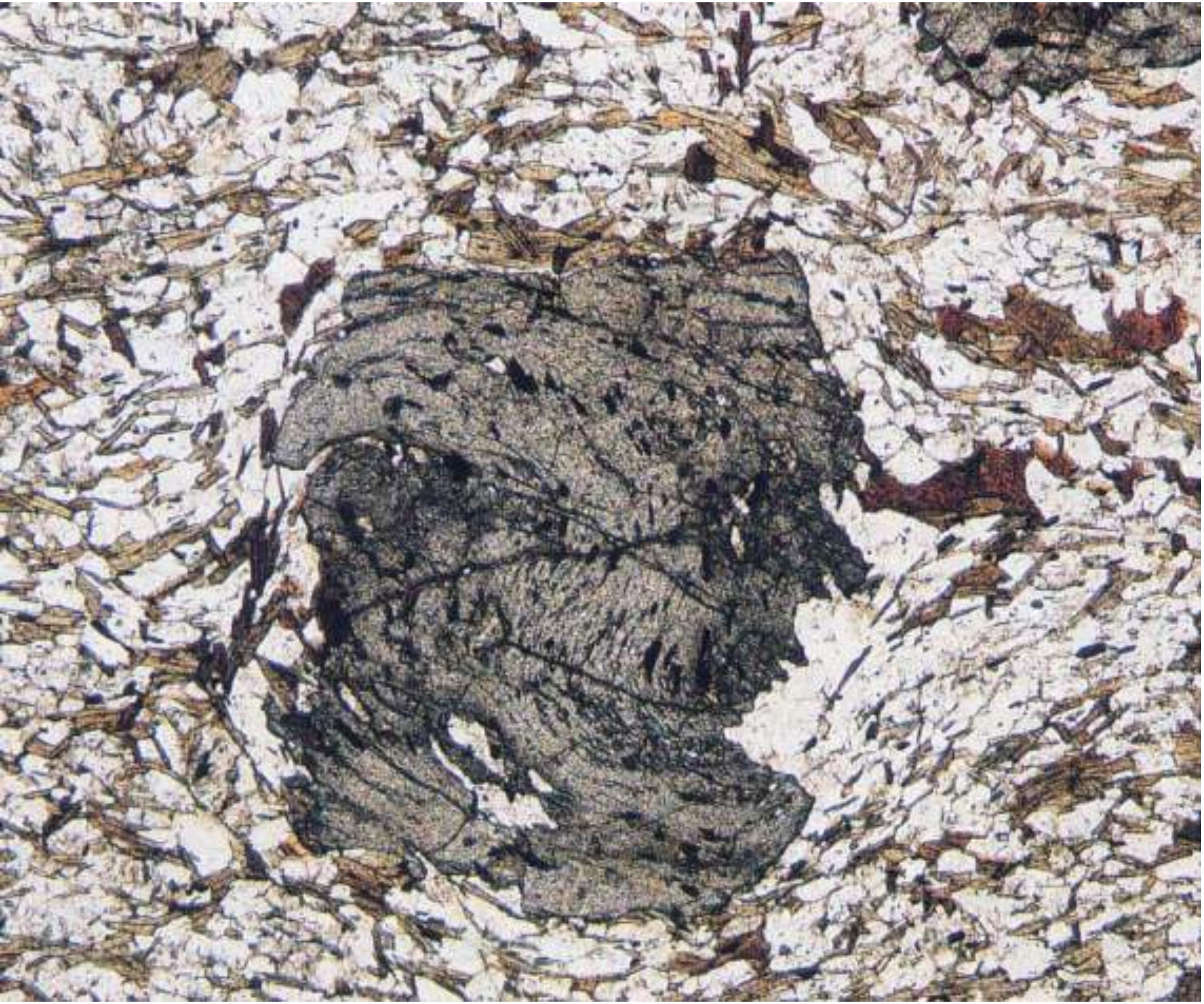


Figure. Spiral S_i train in garnet, Connemara, Ireland. Magnification ~20X. From Yardley *et al*. (1990) *Atlas of Metamorphic Rocks and their Textures*. Longmans.

Syn-kinematic crystals

Spiral Porphyroblast

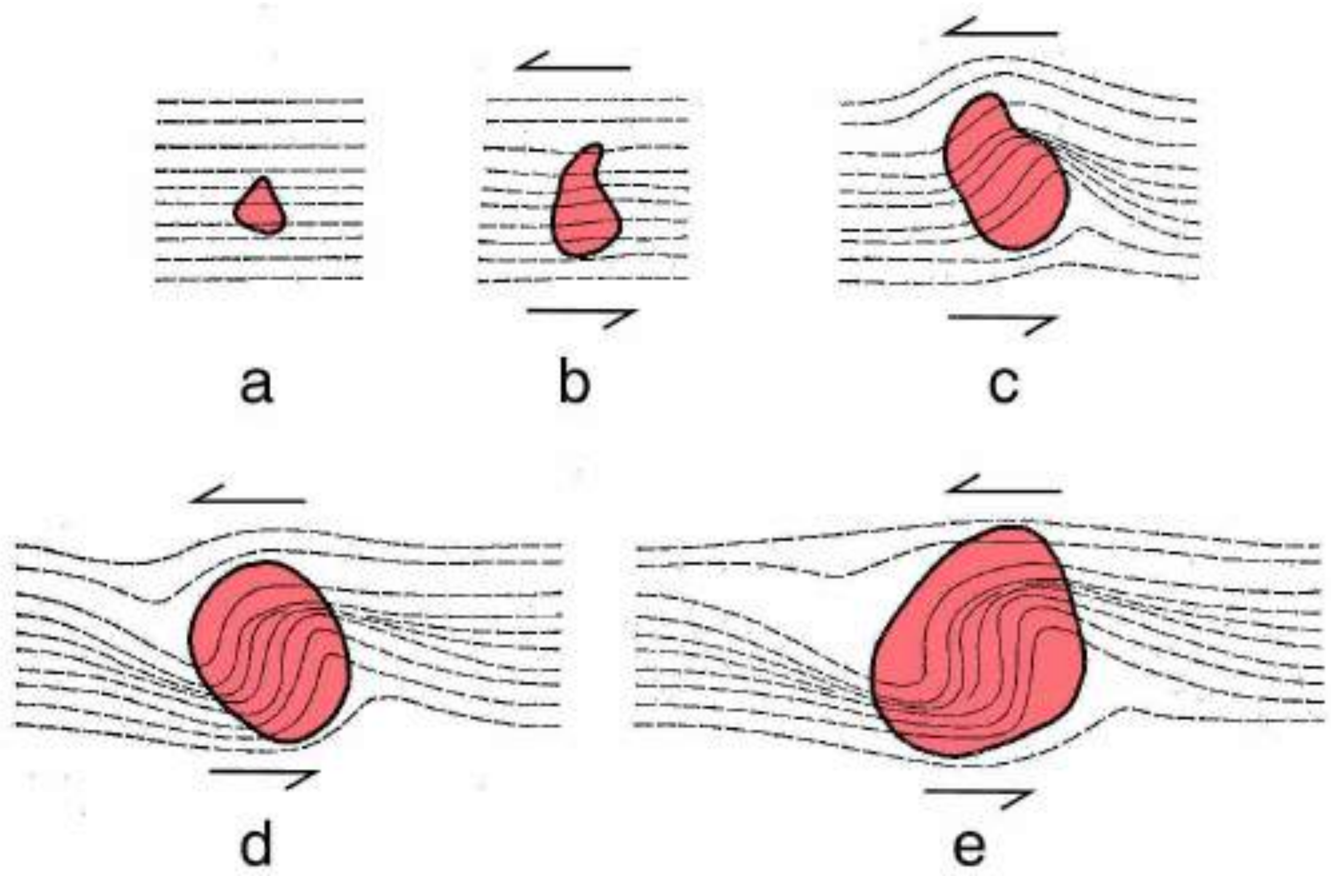


Figure. Traditional interpretation of spiral S_i train in which a porphyroblast is rotated by shear as it grows. From Spry (1969) *Metamorphic Textures*. Pergamon. Oxford.

Syn-kinematic crystals

Figure. **"Snowball garnet" with highly rotated spiral S_i. Porphyroblast is ~ 5 mm in diameter. From Yardley *et al*. (1990) *Atlas of Metamorphic Rocks and their Textures*. Longmans.**

Importance of studying metamorphic textures

1- They provide a means for classifying metamorphic rocks, and hence for their nomenclature.

2- They may help identify the original rock type prior to metamorphism (see relict textures above).

3- They help identify which minerals may have formed with each other (in equilibrium?) and which minerals are definitely out of equilibrium, and hence help establish the order of crystallization and paragenetic sequences which are essential in understanding the P-T history of the sample (see 4 & 5 below)

4- They help identify metamorphic reactions that may have taken place during the rock's history, and are therefore essential for deriving the P-T paths of such rocks.

5- They help identify the relationship between deformation and mineral growth, which is essential for any tectonic interpretations.

6- They are critical for determining the number of deformational and/or metamorphic events affecting an area.