Deformation Fabrics and Fabric Elements

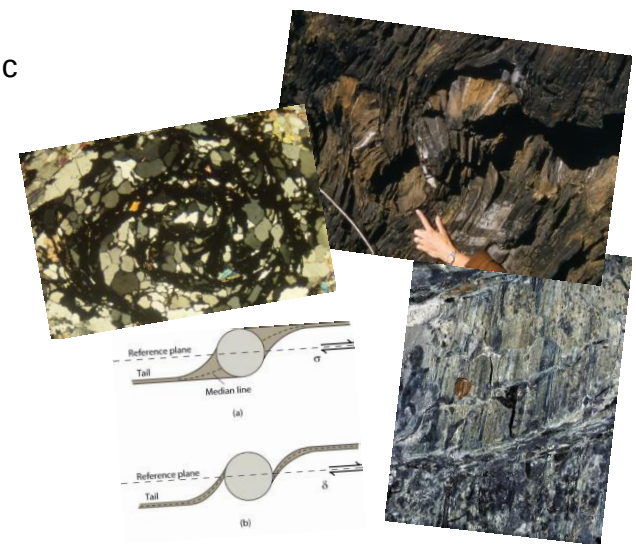
Earth Structure (2019)
(Processes in Structural Geology &Tectonics)

© Ben van der Pluijm
3/16/2019 17:03

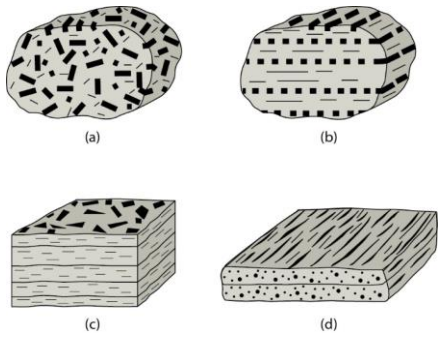
We Discuss …

Deformation Fabrics and Fabric Elements:

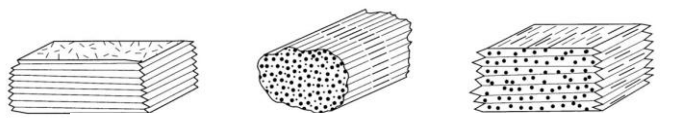
- Foliations
  - By metamorphic grade, shale to gneiss
  - Cleavage Morphology
  - (Porphyroblastesis)
  - Fabrics and Strain
- Shear Zones
  - Shear sense indicators
  - Shear zones and Strain
- Lineations
- Boudinage



Rock Fabric Categories

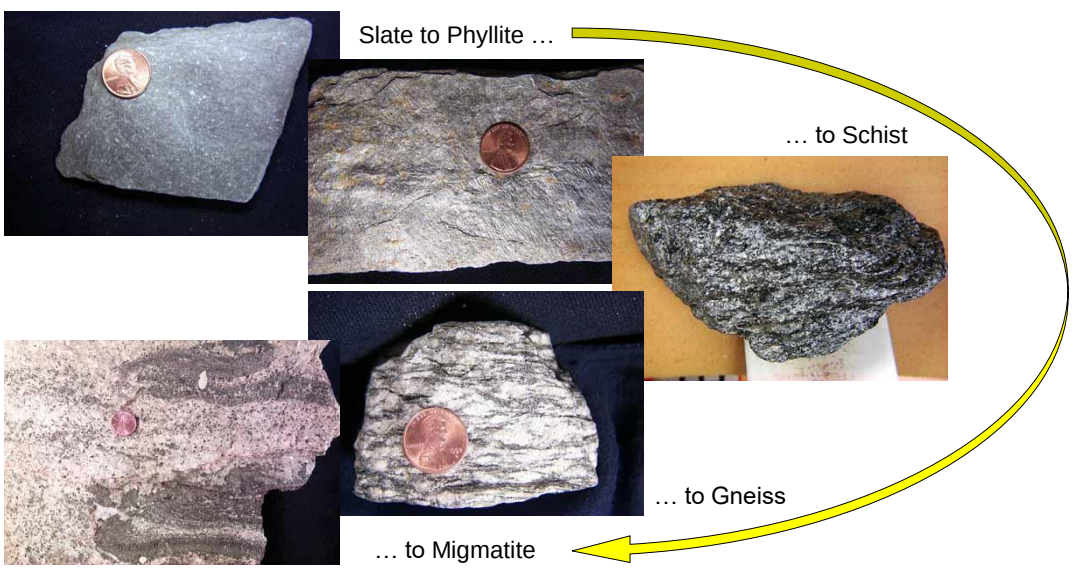


(a) Random fabric. Fabric elements are dark, elongate crystals.
(b) (1-D) preferred fabric, in which long axes of elongate crystals are aligned with one another.
(c) Foliation. Fabric elements are planar and essentially parallel to one another, creating a 2-dimensional fabric.
(d) Lineation.



S L L/S Tectonites

Foliations (with metamorphic grade)



Foliation Classification

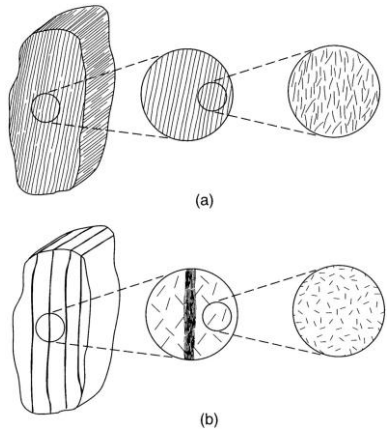
Continuous cleavage Coarse cleavage (e.g., pencil cleavage) and fine cleavage (e.g., slaty cleavage).

Spaced cleavage Disjunctive cleavage (e.g., stylolitic cleavage) and crenulation cleavage.

Phyllitic cleavage Continuous cleavage with a distinctive silky luster in low-grade metamorphic rock (lower greenschist facies).

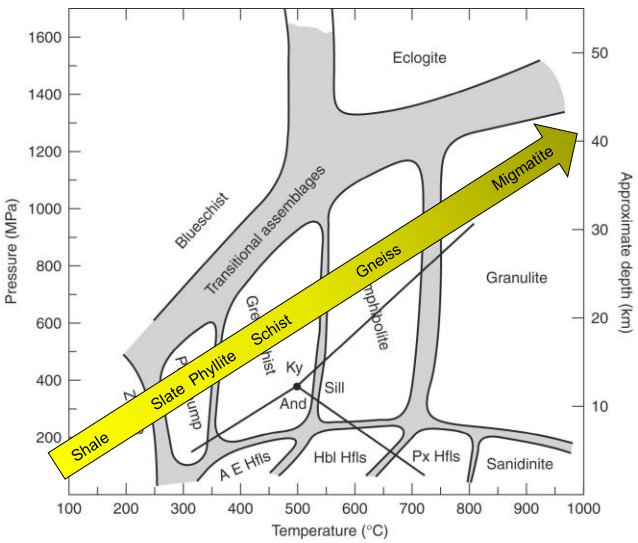
Schistosity Mica-rich foliation with a distinctive high sheen in low- to medium-grade metamorphic rock (greenschist facies).

Gneissic layering Coarse compositional banding or gneissosity in high-grade metamorphic rock (amphibolite and granulite facies).



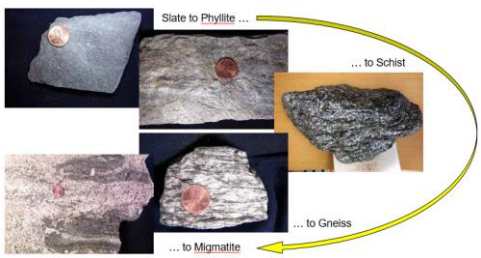
(a) Continuous Cleavage. Lines represent planar fabric elements that are visible no matter how small field of view (at least down to scale of individual grains).
(b) Spaced Cleavage. Host rock is preserved between cleavage elements.

Foliations and Metamorphic Facies

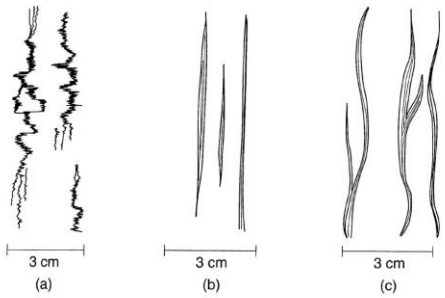


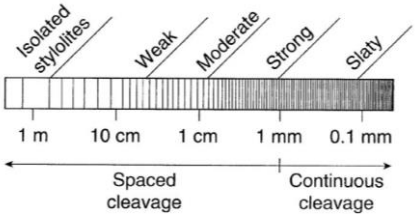
Recall P_l - T change with depth for upper crustal rocks:

- Lithostatic stress: ~27 MPa/km (or 270 bar/km)
- Temperature: ~25C/km



Cleavage Morphology



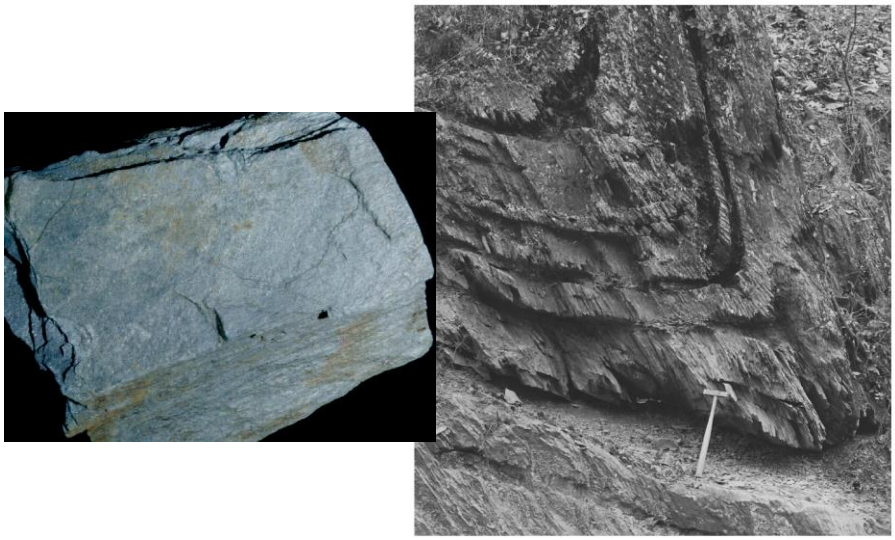


a) sutured domains (“stylolitic”)
b) planar domains
c) wavy domains
d) anastomosing domains

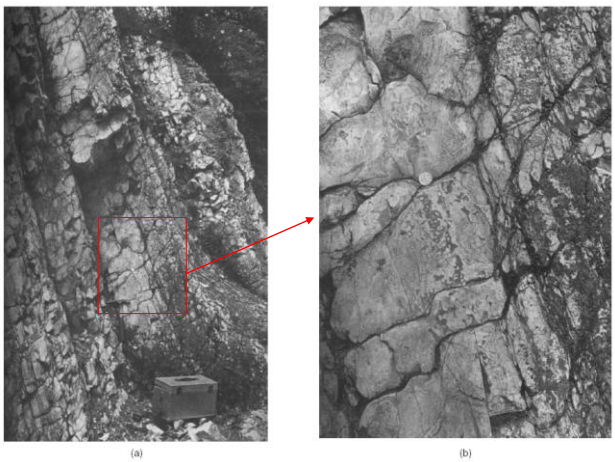
Spaced and continuous (or slaty) cleavage is based on domain spacing

Stylolites (in carbonates)

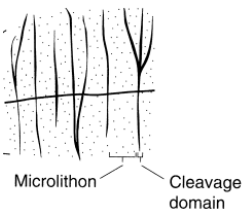
Slaty Cleavage (or Continuous Cleavage)



Spaced cleavage



Harz Mountains, Germany

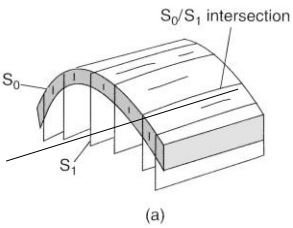


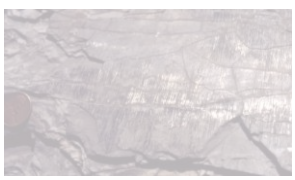
Cleavage Types and Cleavage Refraction

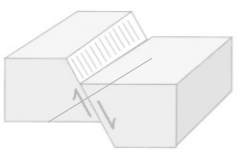
Axial plane, slaty cleavage (Cantabria, Spain)

Spaced Cleavage refraction (Eifel, Germ.);
width of view is ~15 cm

Surface and Mineral Lineations







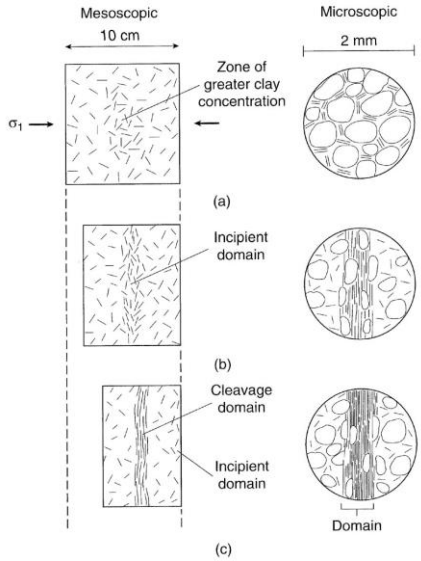
(a) Intersection lineation of bedding (S_0) and (axial plane) cleavage (S_1) in a fold
(b) Slip lineation on a (normal) fault surface
(c) Mineral lineation (hornblende)

Cleavage Formation

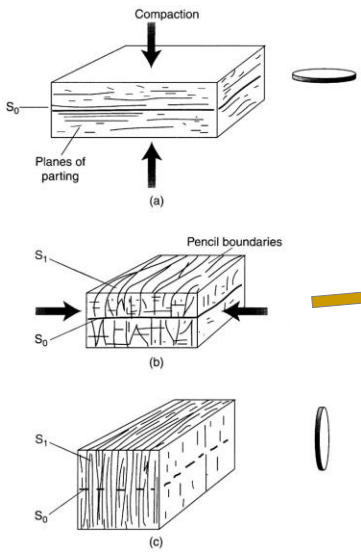
(a) Pre-cleavage. In some areas greater initial concentration of clay.

(b) Incipient cleavage. As shortening and grain solution occur, zones with greater clay concentration evolve into incipient cleavage domains. Grains are preferentially dissolved on faces perpendicular to σ_1 and clay flakes rotate. (pencil cleavage; next)

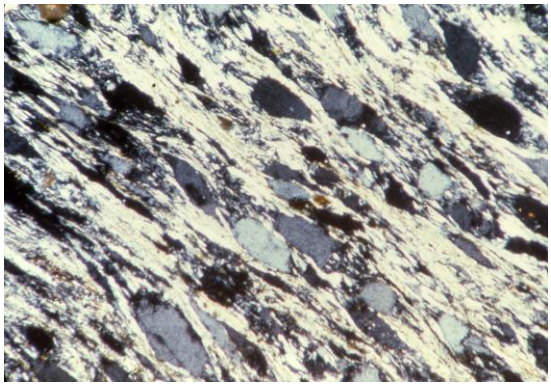
(c) Cleavage. Clay flakes packed tightly together and only small relicts of soluble mineral grains visible. (continuous/slaty cleavage)



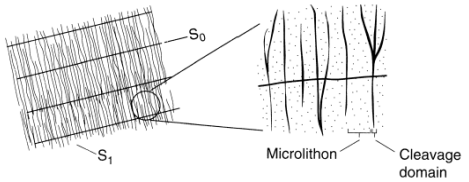
Pencil Cleavage (early cleavage development stage)

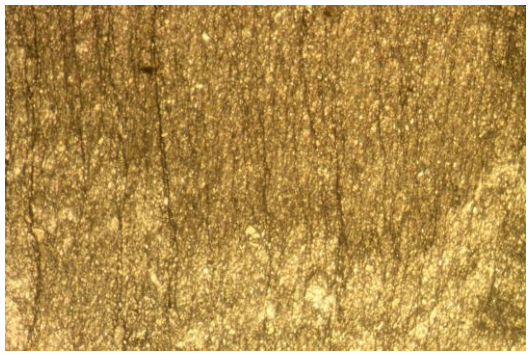


Microstructure of Cleavage



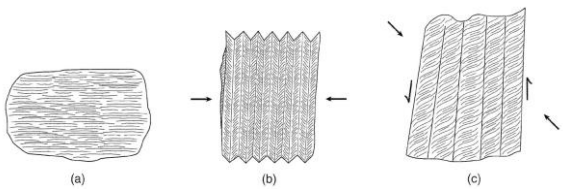
slaty (=continuous) cleavage
(2mm width of view)



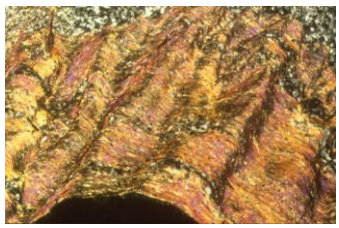


spaced cleavage
(6mm width of view)

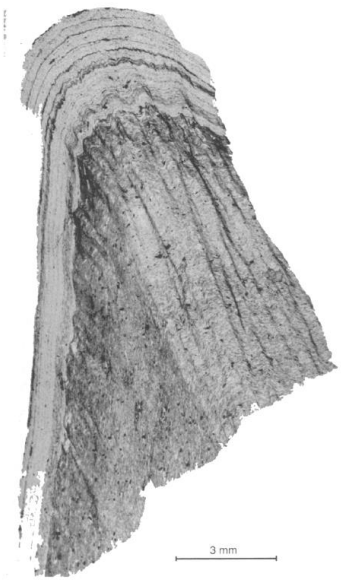
Crenulation cleavage



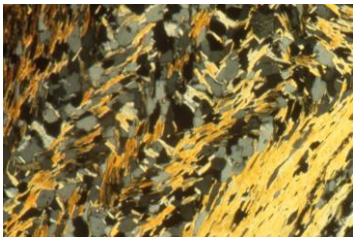
Categories of crenulation cleavage; (b) symmetric crenulation cleavage; (c) asymmetric (sigmoidal) crenulation cleavage.



(3mm width
of view)

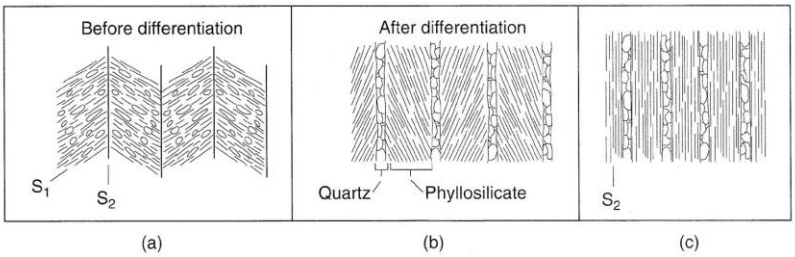


Differentiated Crenulation Cleavage



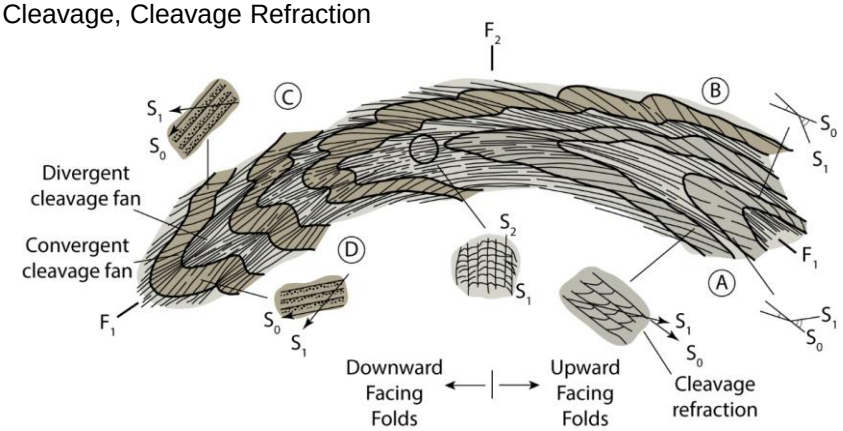
(0.5mm width of view)

(a) Near homogeneous fabric, before migration of quartz.
(b) Quartz accumulates in hinges of crenulations, and phyllosilicates concentrated in limbs, resulting in compositionally distinct bands.
(c) Complete **transposition** of S_1 foliation into a new S_2 cleavage (or schistosity).



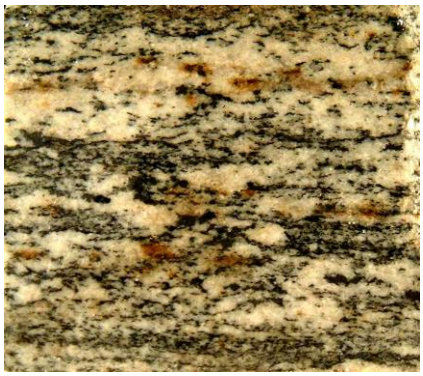
Synopsis: Fold-Cleavage Relationships

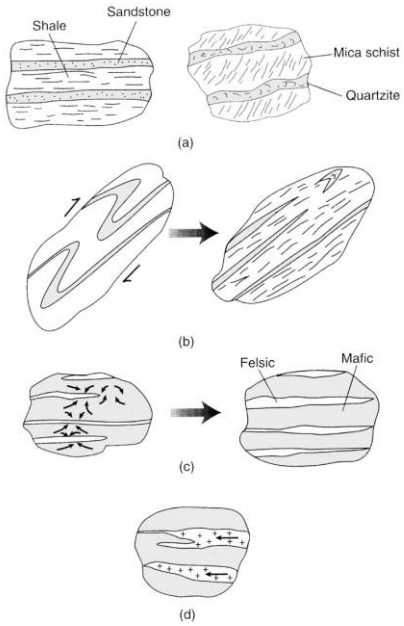
Folds, Fold Facing, Fold (a)symmetry,
(axial plane) Cleavage, Cleavage Refraction



Note cleavage-bedding relationships and cleavage refraction in upright and overturned limbs of upward-facing and downward-facing folds.

Gneissic Layering



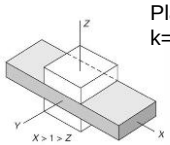


(a) Inheritance from original lithology
(b) creation of new compositional banding via transposition
(c) Metamorphic differentiation
(d) lit-par-lit intrusion

Fabrics and Strain

Ellipsoidal reduction spots in slate (elliptical in x-section) after strain and volume change, Δ (Appalachians, USA).

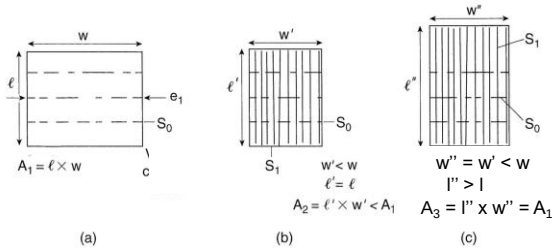
Plane strain
k=1: X>Y=1>Z



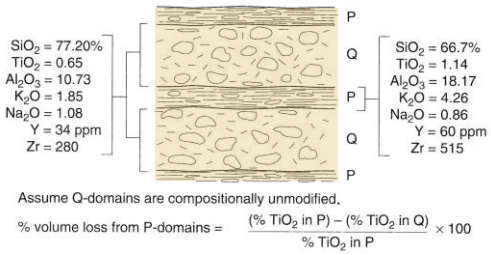
k=1, Δ=0 k=1, Δ= -0.5 (50% vol loss)

Region representing hundreds of strain analyses in slates

Foliations and Strain: Volume Change

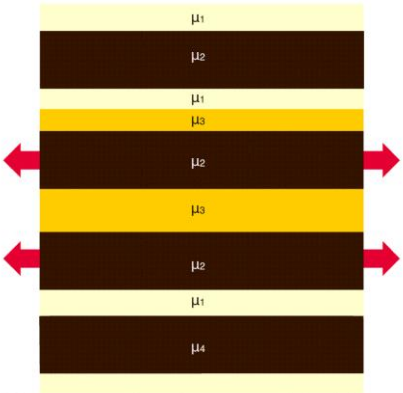


b. Volume loss
c. Constant volume



Volume change based on immoveable phases (TiO_2, Y, Zr): ~45% volume loss in slates

Fabrics and Viscosity: Boudinage



Viscosity contrast: $\mu_1 < \mu_2 < \mu_3 < \mu_4$

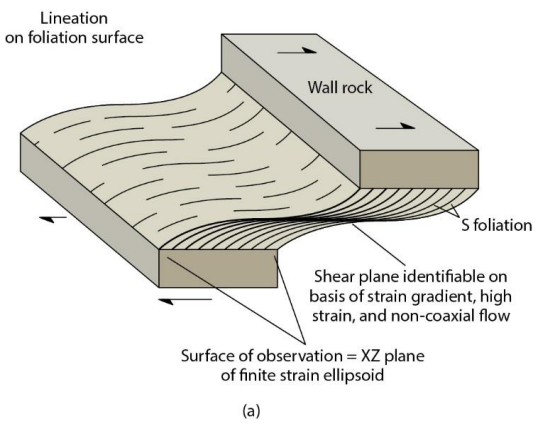
Animation from Fossen, 2016

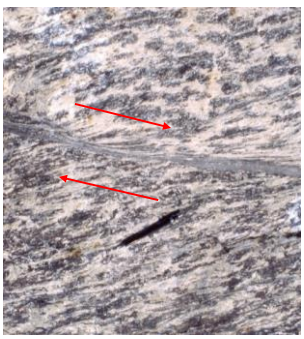
High-strain Zones or Shear Zones

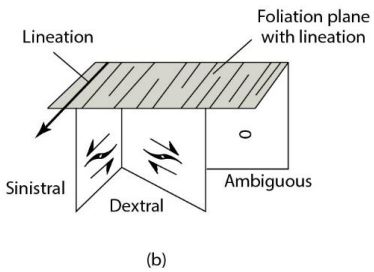
Shear Zone is narrow region where deformation is highly concentrated (relative to adjacent host rock). Deformation rock is called mylonite.

Characteristics:
- metamorphic conditions (300+ ^{o}C)
- fine-grained (relative to host rock)
- foliated (parallel to shear zone boundary)
- lineated (parallel to displacement direction)
- fold transposition (high strain)
- grain shape fabric from dynamic recrystallization
- (grain crystallographic fabric from dislocation creep)
- +/- shear-sense indicators

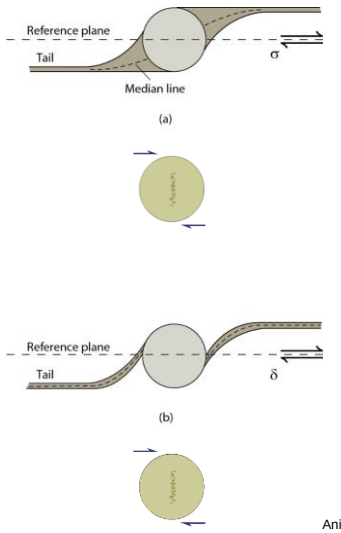
Shear Zone Geometry and Displacement



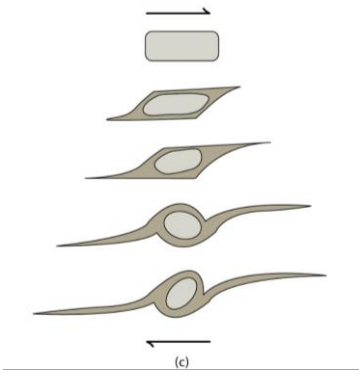




Shear-sense Indicators - Grain-Tail Complexes

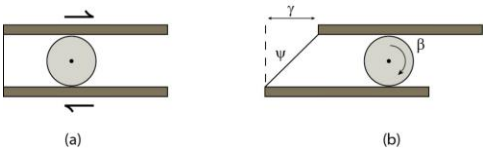


From σ to δ



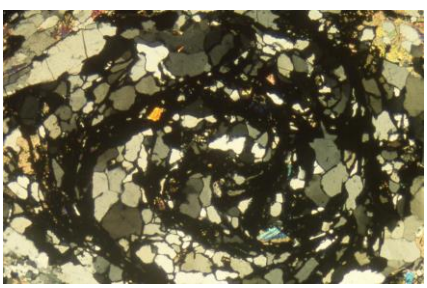
Animations from Fossen, 2016

Foliations and Strain: Shear Zones



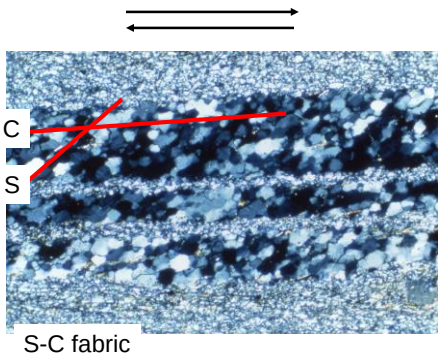
$$\beta = \Omega \tan \psi = \Omega \gamma$$

β is rotation angle in radians
(1 radian is 180°/π)
ψ is angular shear
γ is shear strain
Ω is mechanical coupling

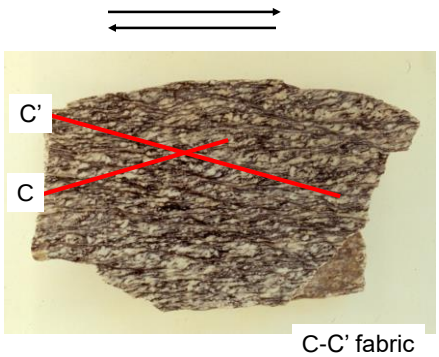


"snowball garnet"

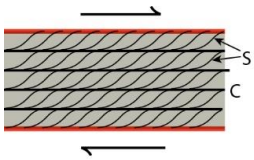
Shear-sense Indicators – Foliations (S, C, C')

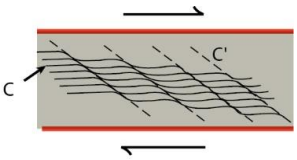


S-C fabric

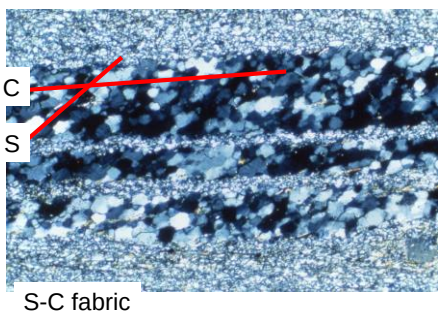


C-C' fabric

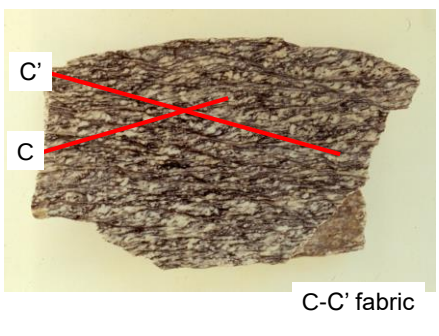




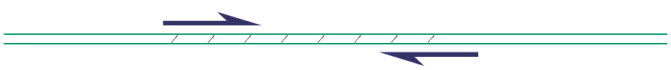
Shear-sense Indicators – Foliations (S, C, C')



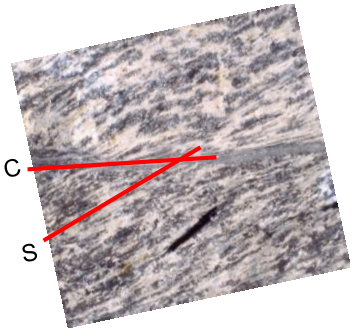
S-C fabric

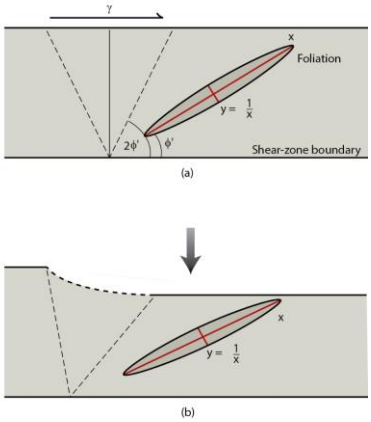


C-C' fabric

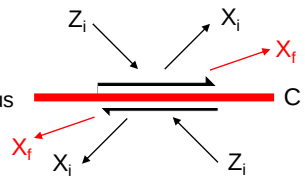


Foliations and Strain: Shear Zones





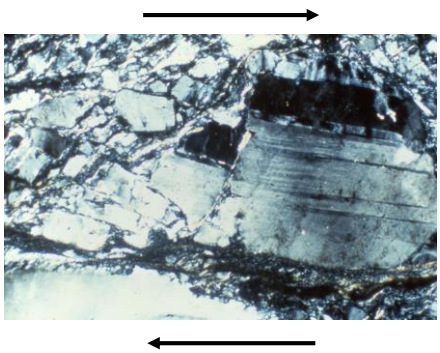
Strain State:
Z = shortening
X = extension
i = instantaneous
f = finite

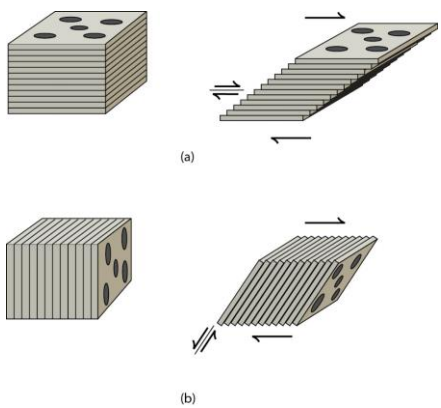


$\gamma = 2/\tan 2\varphi'$

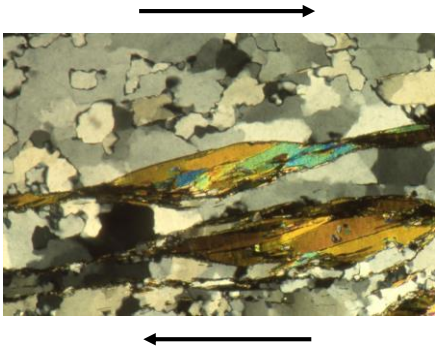
φ′ is angle between foliation (S) and shear-zone boundary (C)

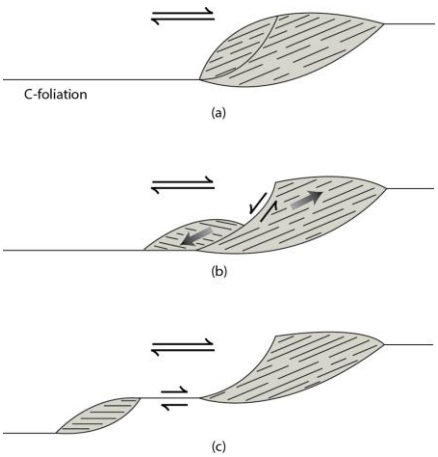
Shear-sense Indicators – Fractured Grains



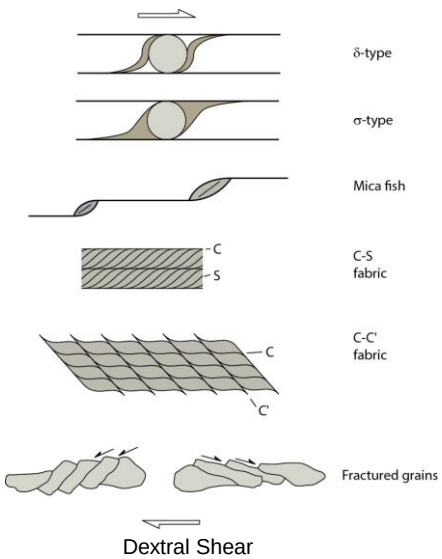


Shear-sense Indicators – Mica Fish



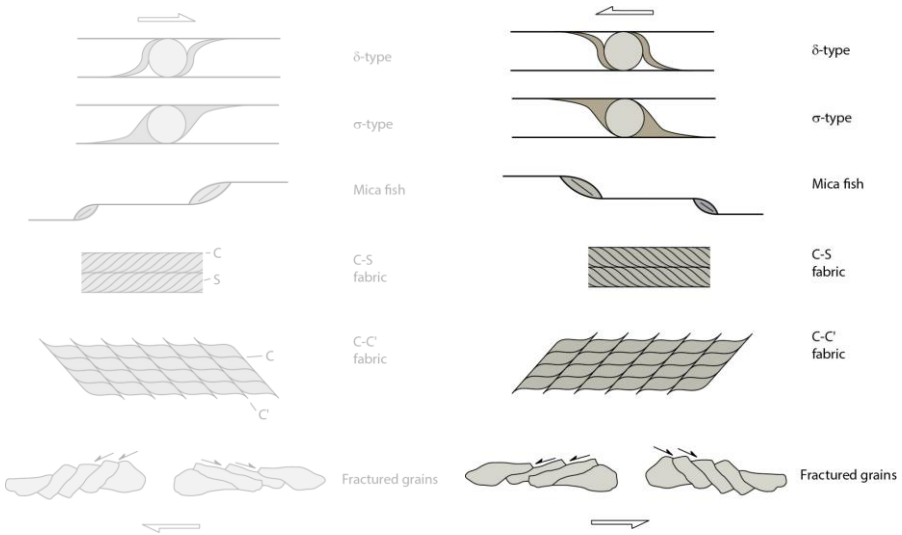


Shear-sense Indicators – Summary (dextral)



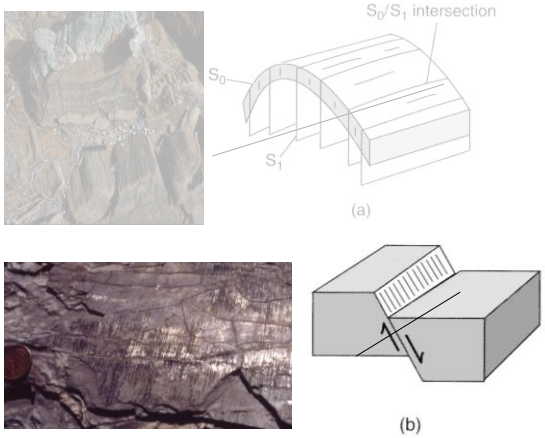
Dextral Shear

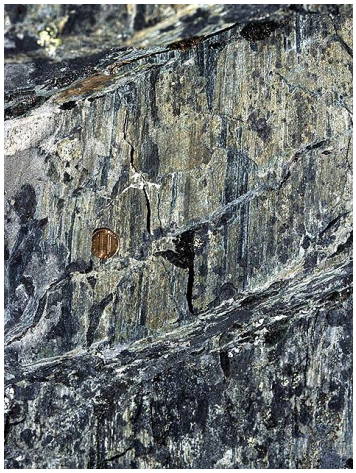
Shear-sense Indicators – Summary (sinistral)



Sinistral Shear

Surface and Mineral Lineations





(a) Intersection lineation of bedding (S_0) and (axial plane) cleavage (S_1) in a fold

(b) Slip lineation on a (normal) fault surface

(c) Mineral lineation (hornblende)

(c)