Veins

What are veins?

- Veins are mineral aggregates that formed
  - In space created in a rock by dilation (Ausdehnung)
  - By precipitation of dissolved material from a fluid

- First exception: replacement veins:
  - The vein forms by overgrowing the wall rock (Nebengestein)

- Stylolites (Stylolithen) are the opposite of veins ("Anti-veins" or "anti-cracks")
  - The form by dissolution perpendicular to shortening direction

Stylolites

- Stylolites form by pressure solution (Drucklösung)
  - Minerals are more soluble at higher pressure
- Stylolites are recognised by
  - Cutting off structures (e.g. veins)
  - Dark seams of insoluble material (Tonrückstände)
3 Main vein types

• 1. "Classical" lenticular or crack-like veins

Calcite veins in shale, Arkaroola, S. Australia

• 2. Pressure fringes (Druckschatten)

Quartz-fringe on a pyrite grain, Yilgarn, Australia

• 3. Slickensides (Faserharnische)

Chlorite (left) and calcite (right) slickensides, Corsica

• Stylolite in calcite veins, Aliaga, Spain
Crack-sealing (Riß-Siegelbildung)

- Crack-sealing is the repeated process of:
  - Opening of narrow crack (typically 10-100 µm)
  - Sealing of crack by precipitation of vein mineral(s)

- Typical characteristics
  - Inclusion bands indicating narrow crack events
    - Fluid inclusions, wall rock inclusions
  - Radiator structures
  - "ghost-fibres"

Mechanism of crack-sealing

- Low fluid pressure: no open cracks: fluid cannot drain
- Increase fluid pressure: Mohr circle moves to left
- Mohr-circle hits envelope: cracks form
- Fluid escapes: fluid pressure drops
- Minerals precipitate in the cracks and seal the cracks

Crack-seal: inclusion bands

Crack seal inclusion bands in middle of calcite vein, Sestri Levante, Italy

Stretching vein in sandstone (plane polarised light)
Crack-seal: radiator structures

Ghost fibres

Calcite vein, Arkaroola

Growth direction and crystal shapes

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Syntaxial veins

- Syntaxial veins grow from the wall rock inwards
  - From both sides (symmetric syntaxial)
  - From one side mainly (asymmetric syntaxial)
Growth in open space

- Vuggy or blocky crystals
- Facetted surfaces
- Growth competition

Syntaxial veins: elongate-blocky crystals

Elongate-blocky vein in sandstone (crossed polarisers)

Calcite growth in voids, Aliaga, Spain

Symmetric syntaxial calcite vein, Biure, Spain
Ataxial (stretching) veins

- Ataxial or stretching veins grow in cracks that change position (jump) in time
- Always inside vein
- Inside vein and wall rock

Stretching veins

- Stretching veins in calcareous flysch, Corsica

Stretching veins - micro-scale

- Stretching veins in calcareous shale, Arkaroola, S. Australia
Crossings of veins in cracks - 1

• New veins cut through old veins
• Old veins become passive part of the wall rock

Crossings of veins in cracks - 2

• New veins cut through old veins
• Old veins become passive part of the wall rock

Antitaxial veins

• Antitaxial veins grow
  • From the inside out
  • On the two outer surfaces

• Characteristics of antitaxial veins:
  • Fibrous crystals, often curved fibres
    • No growth competition
  • Crystals span across the median line/zone
  • Tracking of "opening trajectory"
  • No inclusion bands or radiator structures
  • Old veins keep growing when new veins form

Antitaxial fibrous veins - fibres

Antitaxial fibrous calcite vein in shale
Antitaxial veins: median zone/line

Antitaxial fibrous calcite vein in shale

Antitaxial veins: crossings

- Old veins **keep growing** when new veins form
- Fibres curve with changing widening direction

Crack seal inclusion bands in middle of calcite vein, Sestri Levante, Italy

Antitaxial veins: crossings

- Old veins **keep growing** when new veins form
- Fibres curve with changing widening direction
Antitaxial veins: crossings

Antitaxial veins - how do they form?

- Still poorly known
- Crack-sealing?
  - No inclusion bands, radiator structures, etc ????
  - Two cracks at same time ????
  - How to inhibit growth competition ????
- No fracturing?
  - What reason for supersaturation (Übersättigung) ????
- Recent discovery:
  - Bacteria in fibrous veins (5 km deep, 585 Ma old)
  - Do bacteria perhaps help growth of antitaxial fibrous veins?

Bacteria in antitaxial fibrous veins

Pressure fringes/shadows

- A rigid object in a deforming rock has high- and low-pressure sides: pressure shadows (Druckschatten)
- Minerals dissolve at the high-P side
- Minerals precipitate at the low-P side

SEM-images of fossil bacteria in veins, 4-6 km deep (±100°C), 585 My old
Pressure shadow (Druckschatten)

- Pressure shadow has vague boundaries, no fibres

Pressure fringe (faserge Druckschatten)

- Pressure fringe has sharp boundaries & fibres

Antitaxial/Syntaxial fringes

- Syntaxial fringes:
  - Fibres grow away from object
  - Growth on outside of fringe system
  - Relatively rare

- Antitaxial fringes:
  - Fibres grow towards object
  - Growth between object and fringes
  - Most common type

Pressure fringes: curved fibres

- Pressure fringes often have delicate internal structures with curved fibres
  - Displacement-controlled
  - Face-controlled
Pressure fringes: curved fibres

- The fibre-patterns can give information on
  - The type of deformation
  - Amount of deformation (finite strain)
  - Multiple deformation phases

Examples of fringe development - 1
Examples of fringe development - 2
Examples of fringe development - 3