Joints and Veins

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

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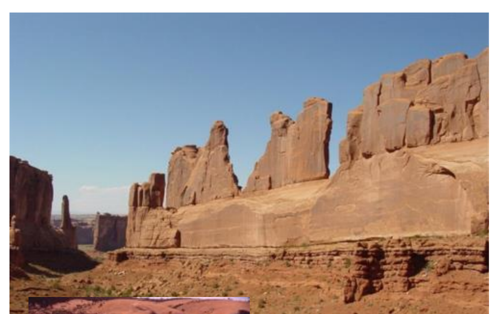
Rock Stories: Joints

Joints are tensile rock fractures that form perpendicular to the least principal stress direction (σ_3), typically in response to uplift or cooling. Unlike faults, they do not have relative displacement.

They form near the surface as systematic joint sets, with surface markings (plume structures) that reflect their propagation history.

Joints control weathering and erosion of bedrock, creating permeability that influences the circulation of near-surface fluids (incl. groundwater).



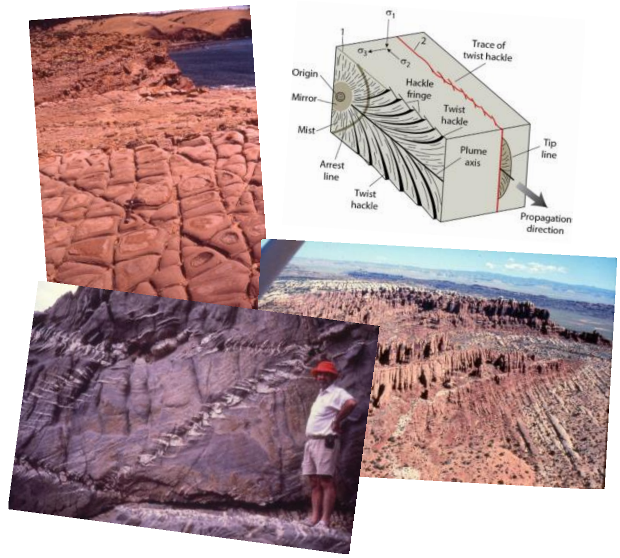
Large joint face in Entrada sandstone (Moab, Utah)

Joints in Cambrian sandstone (Kangaroo Island, Australia)

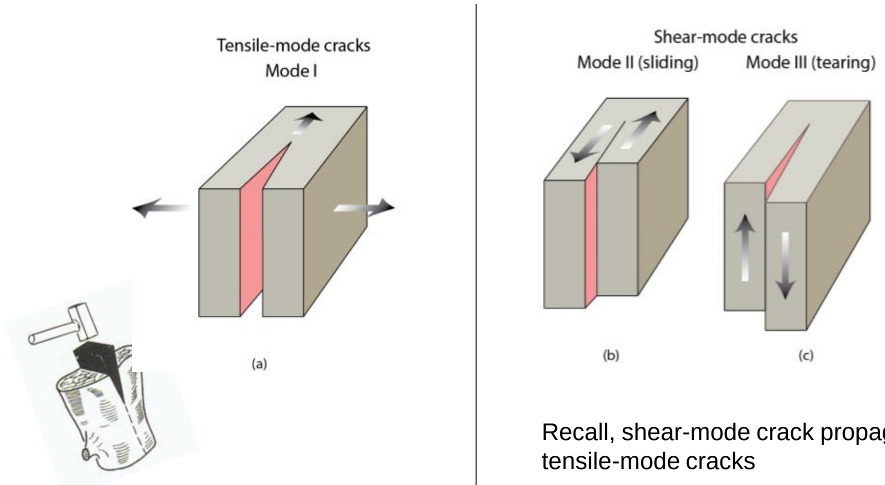
We Discuss …

Joints and Veins

- Crack Modes
- Surface Features
- Formation and Propagation
- Elasticity
- Joint Arrays
  - Joint Spacing
- Origin of Joints
- Veins
- Opening and Filling
  - Syntaxial and Antitaxial Veins
  - En-echelon Veins
- Structure and Society
  - Groundwater
  - Mineralization



Crack Modes



Recall, shear-mode crack propagate as tensile-mode cracks

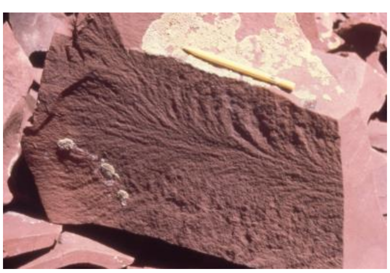
Joint Surfaces

(a)

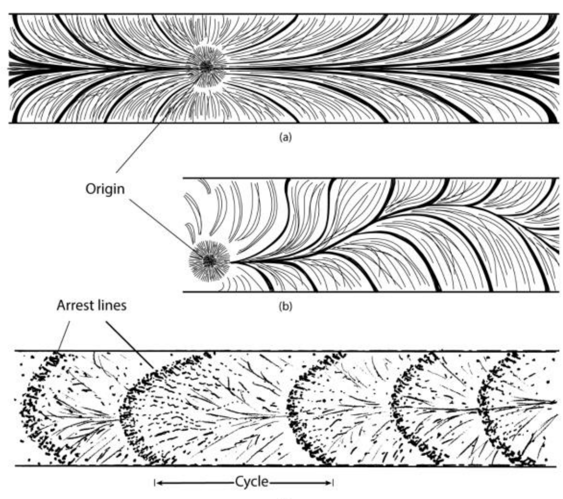
(b)

a) Shatter cones (Sudbury); impacts
b) Plumes (MD); joint propagation

Plumose Structures

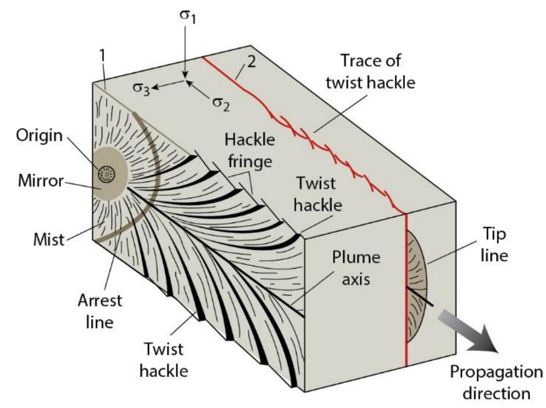


T. Engelder

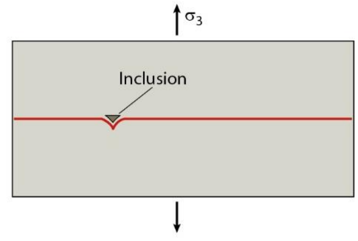


(a) Straight plume; (b) Curvy plume;
(c) Plume with arrest lines, indicating repeated opening.

Joint Structure



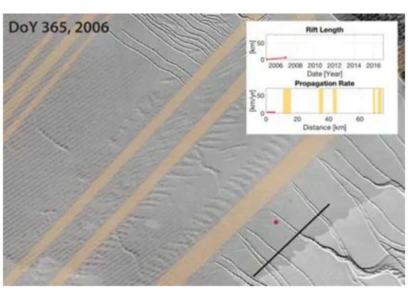
(a)



(b)

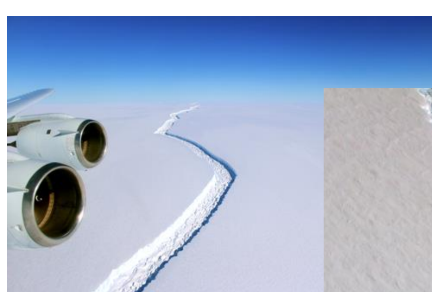
(a) Components of ideal plumose structure on a joint. Face of joint 1 is exposed; joint 2 is within rock.
(b) Cross sectional sketch showing dimple of a joint origin, controlled by an inclusion.

Extra: Larsen Ice Shelf, Antarctica



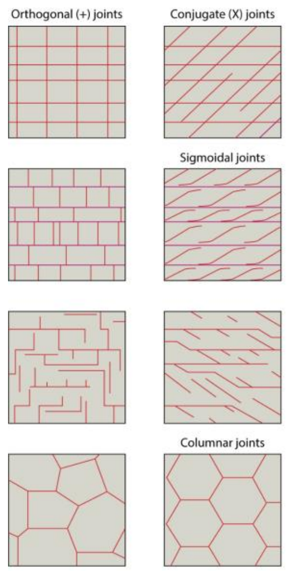
https://goo.gl/Tb2RPz

Joint propagation occurs on all scales in space and time. Video shows stops in ice crack propagation found as arrest lines on joint surfaces.
Larsen ice shelf's leading edge collapse is natural ice cap-and-shelf evolution.

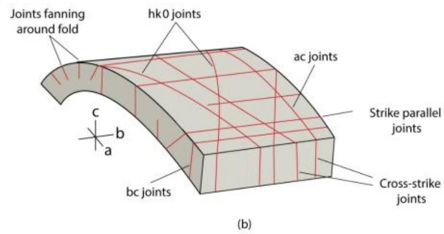


Larsen C iceberg calving, 2016 (NASA)

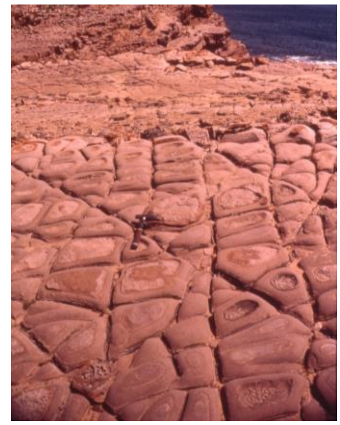
Systematic Joint Arrays



(a)



(b)



(a) Traces of types of joint arrays on a bedding surface.
(b) Arrangement of joint arrays with respect to fold geometrical axes.

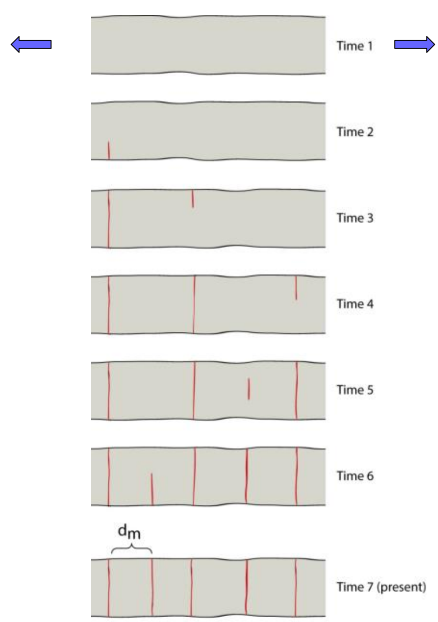
Joint Development

Sequence of joint development

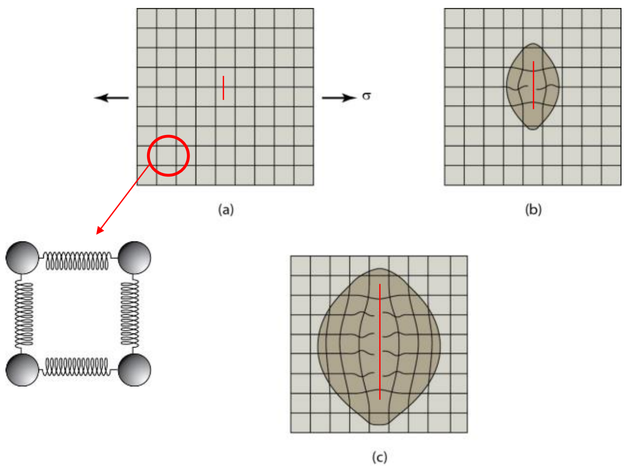
Time 1 refers to time before first joint forms, and time 7 is last.

This scenario shows that joints form in a random sequence, but result in regular spacing (d_m).

Why?



Stress Shadows and Joints

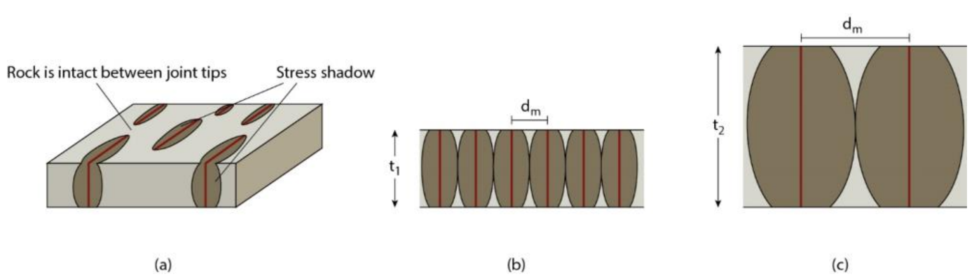


Joint stress shadows

(a) A grid of springs.
(b) Cutting one spring causes a few springs to relax around cut, so only relatively small area is affected.
(c) Cutting many springs in a row causes a wider band of springs to relax; thus, larger area is affected.

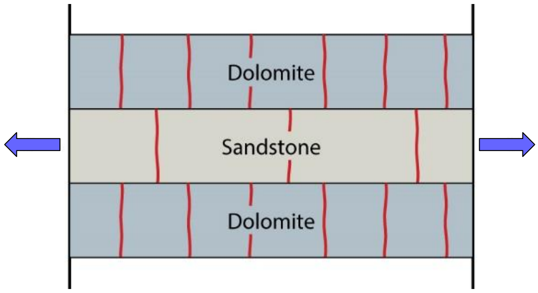
Stress Shadows and Joint Spacing

Thins beds have shorter joints, meaning smaller shadows.
Thus, closer spacing.



Stress shadow (shaded area) exists around each joint.
Note how stress is transmitted across regions that are unfractured in 3D.

Joints and Lithology (and Elasticity)



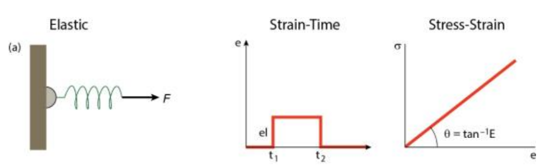
Multilayer with different elasticities (Young's moduli).

Stiffer layers (dolomite) develop more closely spaced joints.
Why?

Young's modulus E (elasticity, measure of stiffness) and stress.
E = σ / **e** (Hooke's Law).

For same extension (**e**):
Large E (80GPa, stiffer) means large σ, so more fractures (and earlier).
Small E (20GPa) means small σ, so fewer fractures.

Elasticity

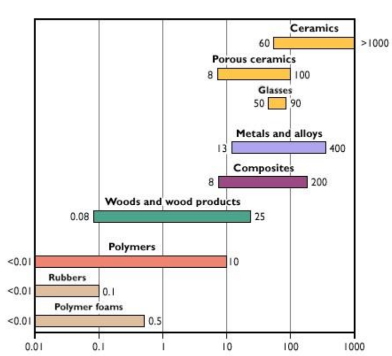


Elastic (or Hookean) Behavior:

σ = E . **e**

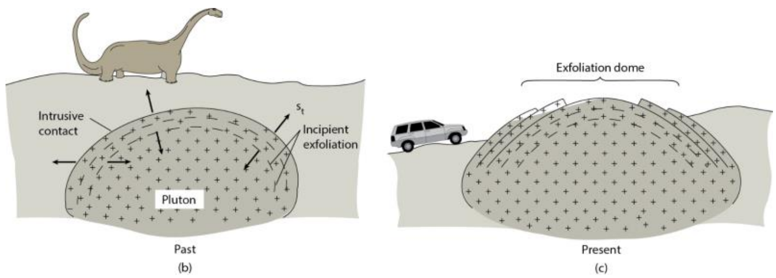
E = Young's Modulus

(rubber band)



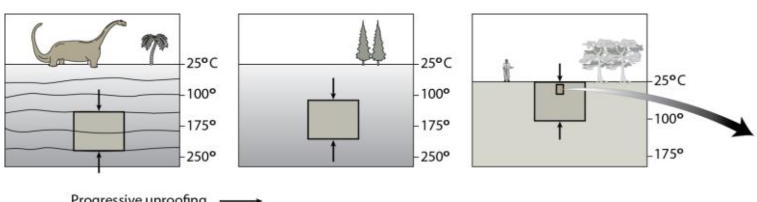
Medium	*E* (GPa)
Iron	196
Rubber	0.01–0.1
Quartz	72
Salt	40
Diamond	1050–1200
Limestone	80
Sandstone	10–20
Shale	5–70
Gabbro	50–100
Granite	~50
Amphibolite	50–110
Marble	50–70

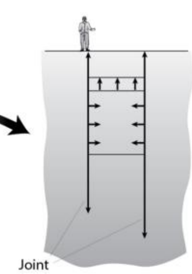
Other Joints: Sheeting (or Unroofing) Joints

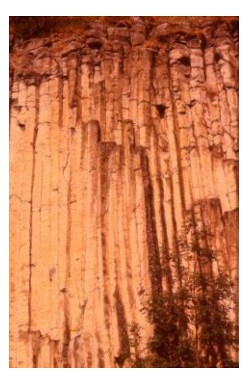


Unloading (relaxing):
Vertical extension, horizontal contraction (Poisson effect) as rock expands from unloading

Other Joints: Columnar (or Cooling) Joints

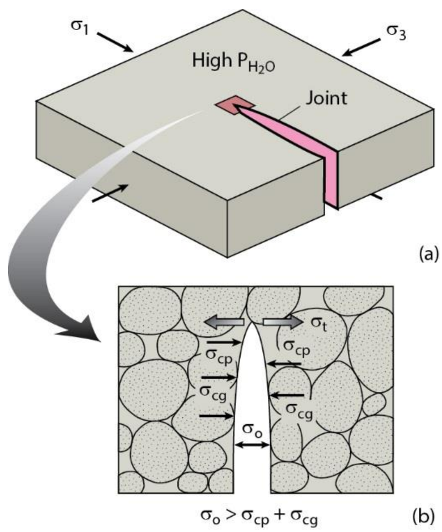






Cooling:
Horizontal stress as rock contracts vertically from cooling.

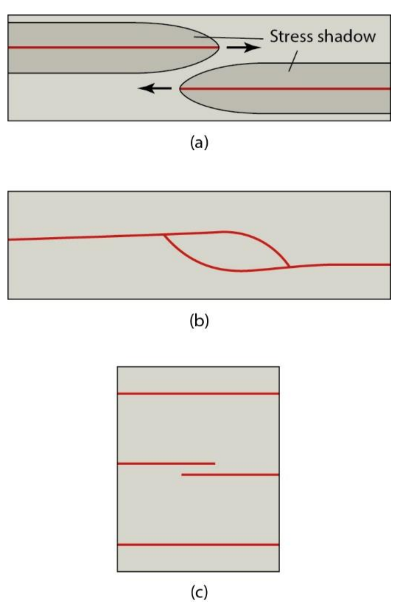
Other Joints: Hydraulic Fractures



(a) Stresses near crack with fluid pressure that exceeds magnitude of σ_3, resulting in tensile stress, σ_t, along crack.

(b) Enlargement of crack tip. Opening stress (σ_o) due to fluid pressure exceeds closing stresses ($\sigma_{cp/cg}$).

Joint terminations

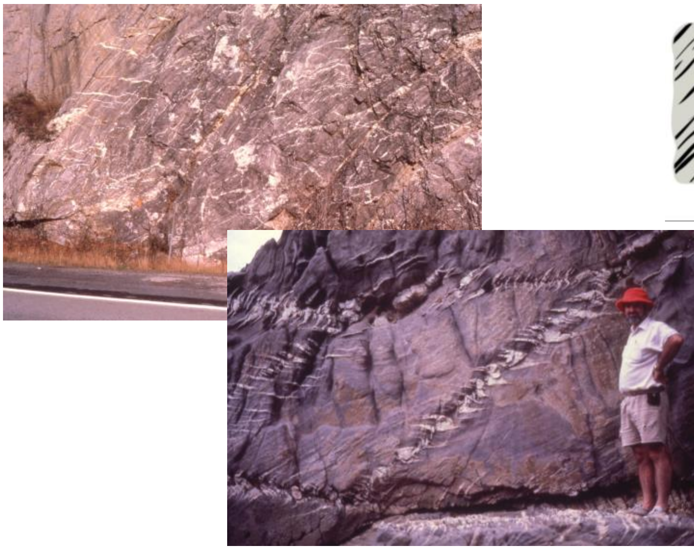


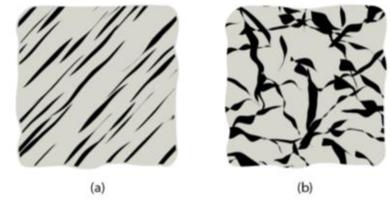
(a) Joints terminate without curving when they approach one another.

(b) Joints curving into each other and linking.

(c) Joint spacing is fairly constant because joints that grow too close together cannot pass each other.

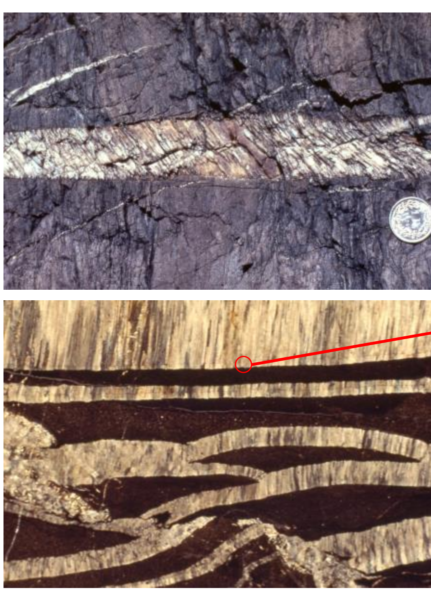
Veins (=filled joints and fractures) and Vein Arrays

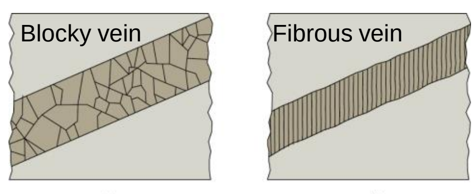


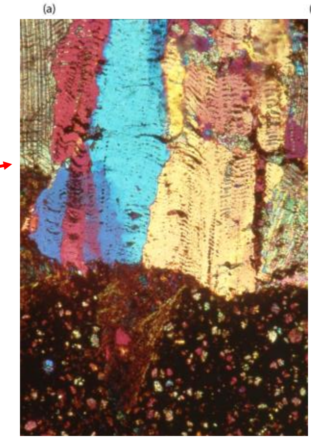


(a) Planar array of veins.
(b) Stockwork array of veins.
(Vein fill is dark)

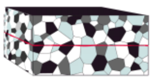
Vein Morphology

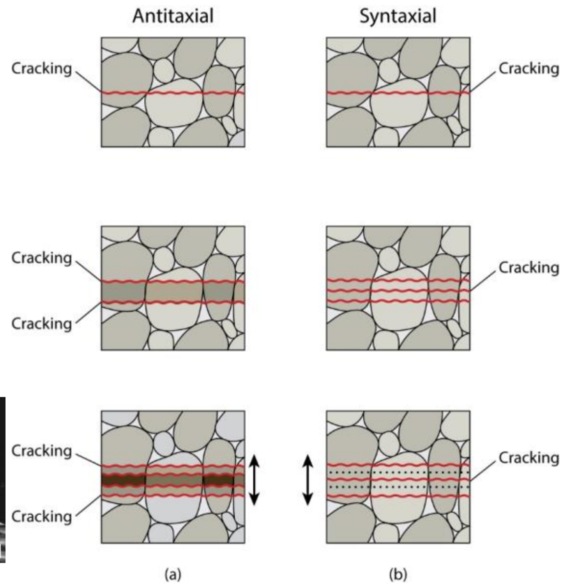


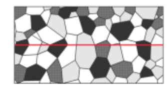




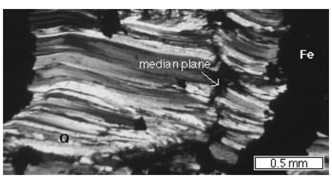
Antitaxial and Syntaxial Veins



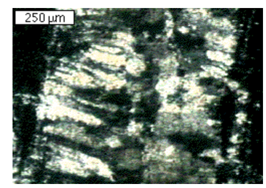




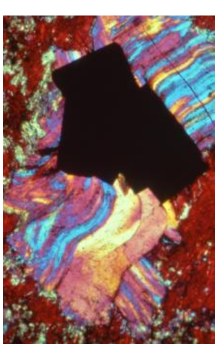
Antitaxial veins where fill and wall contrast ("weak weld"); e.g., carbonate vein in sandstone or pyrite inclusion.

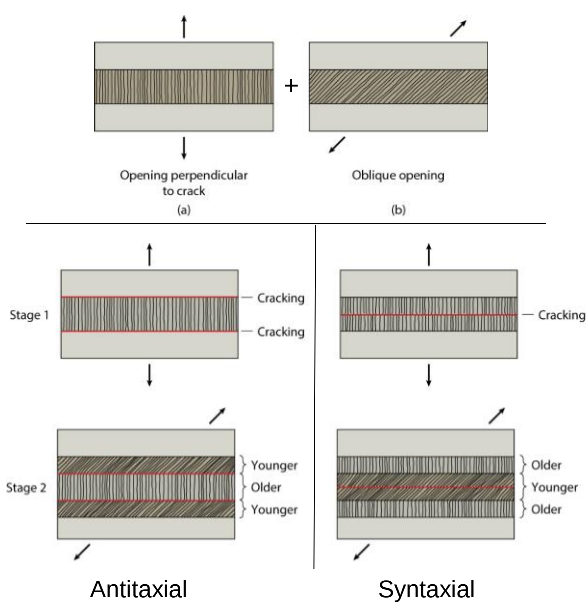


Syntaxial veins where vein fill same as wall rock ("strong weld"); e.g., quartz vein in quartzite.



Crack Opening and Fibers





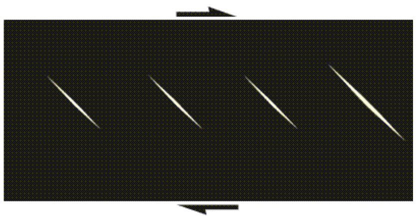
Long axis of vein fibers tracks direction of extension, and change in extension direction leads to curved fibers.

Antitaxial veins where fill and wall contrast ("weak weld"); e.g., calcite vein in quartzite, pyrite inclusion.

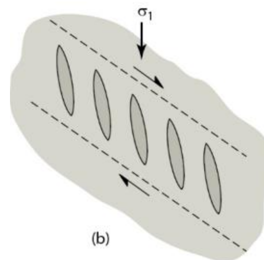
Syntaxial veins where vein fill same as wall rock ("strong weld"); e.g., quartz vein in quartzite.

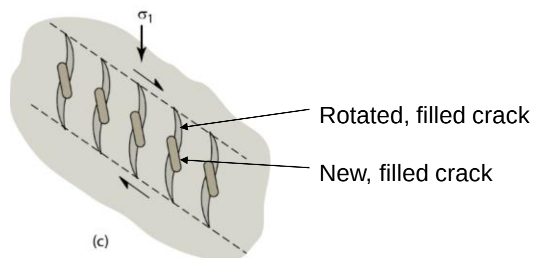
En-echelon and Sigmoidal Veins

b) Formation of en-echelon array.
c) Formation of sigmoidal en echelon veins, due to rotation of older, central part of veins, and growth of new vein material at original angle to shear surface.

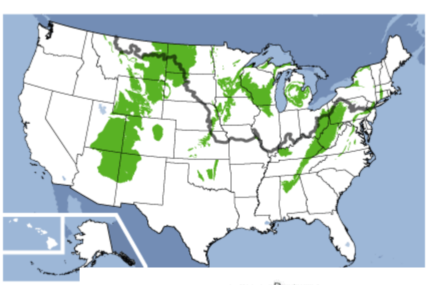


Fossen, 2016

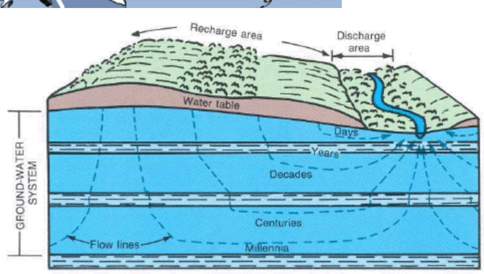




Structure and Society: Fractures and Veins



Fractures: Aquifers and groundwater (e.g., Ogallala Aquifer)



All USGS

Veins: Mineralization