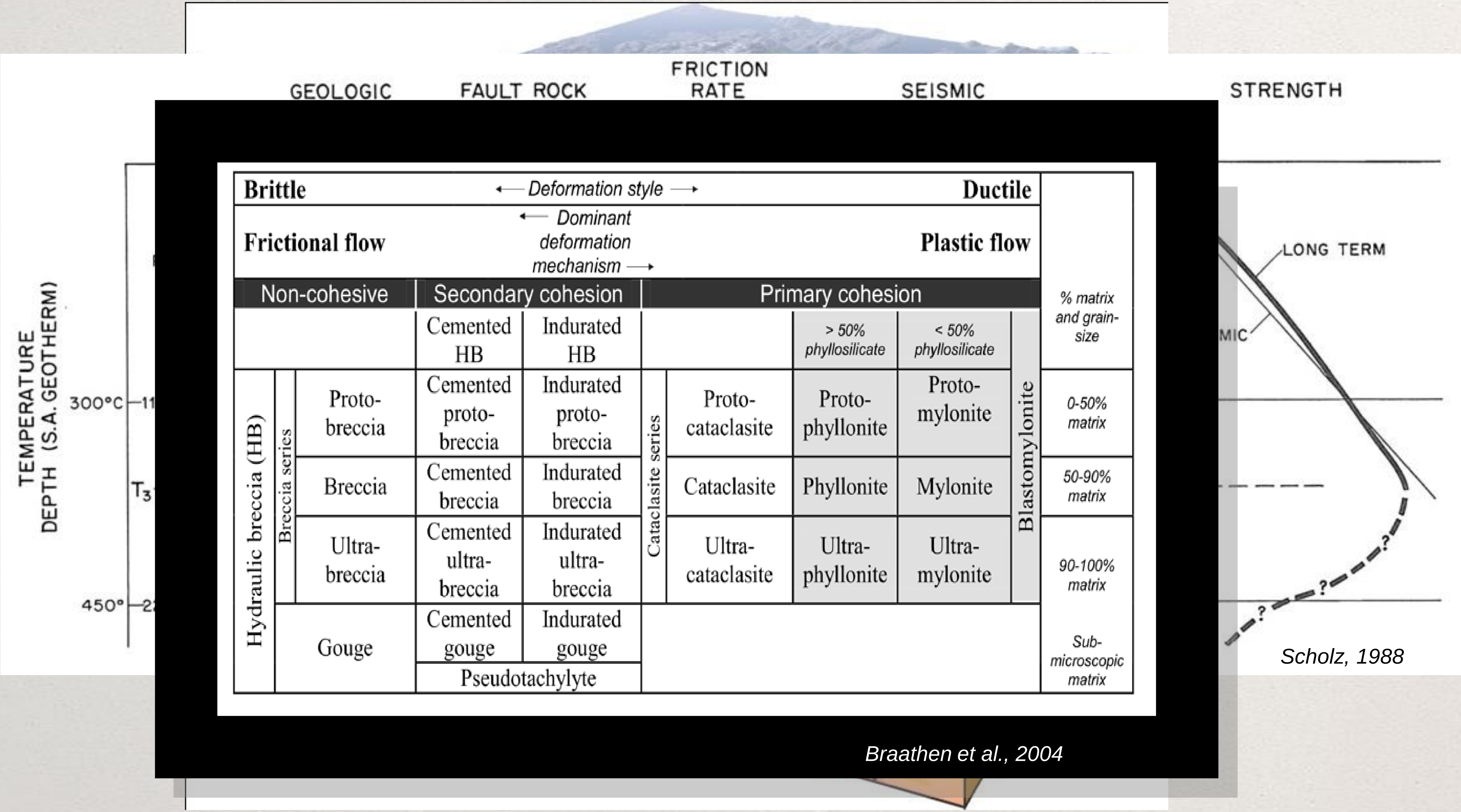
Clay formation within brittle fault zones

Giulio Viola
NGU and NTNU



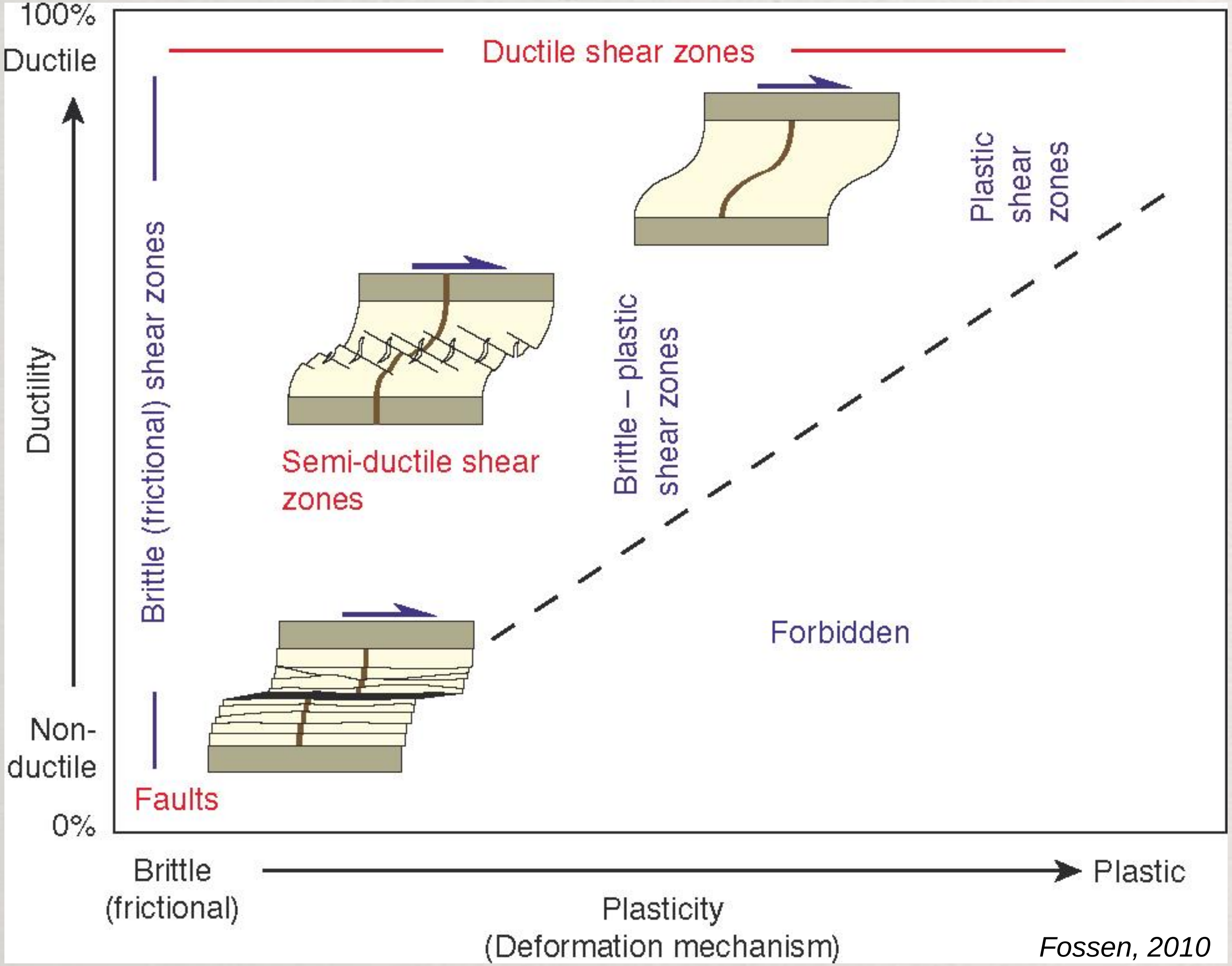
Scholz, 1988

Brittle ← Deformation style → **Ductile**

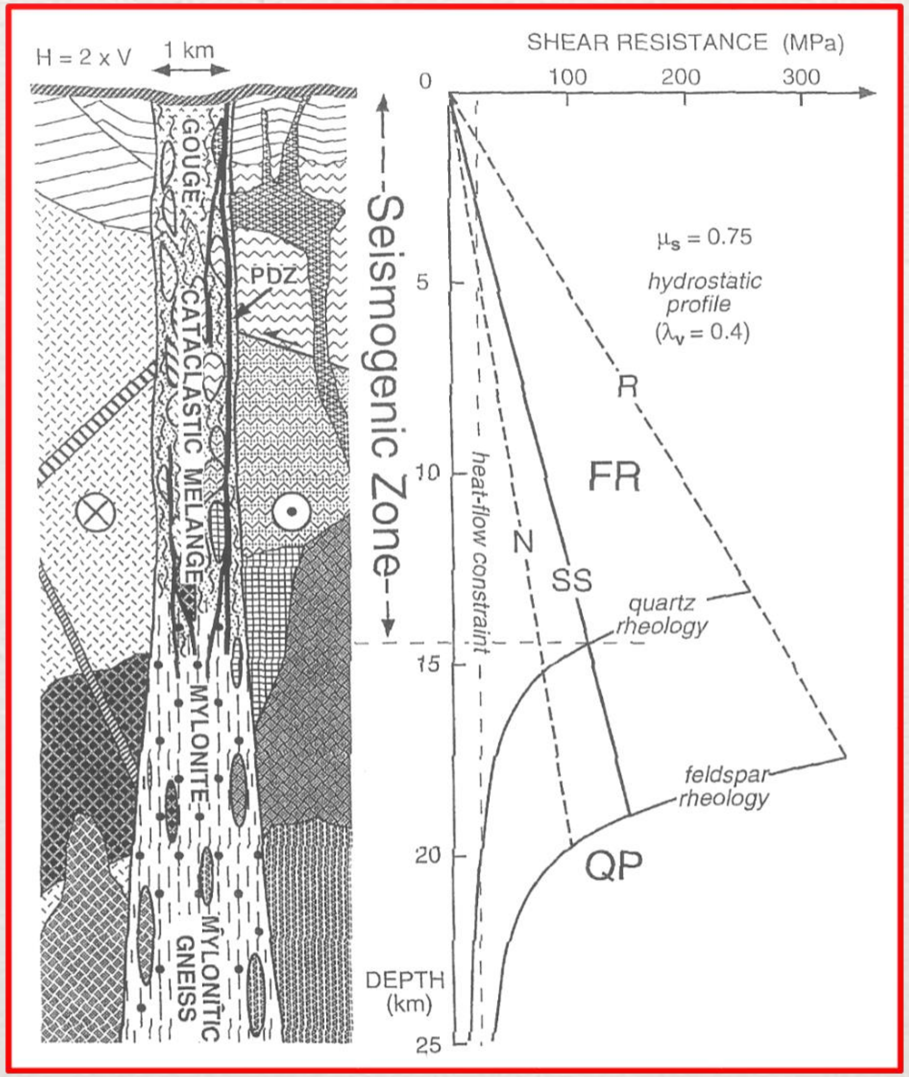
Frictional flow ← Dominant deformation mechanism → **Plastic flow**

Non-cohesive		Secondary cohesion		Primary cohesion					
		Cemented HB	Indurated HB			> 50% phyllosilicate	< 50% phyllosilicate		% matrix and grain-size
Hydraulic breccia (HB) / Breccia series	Proto-breccia	Cemented proto-breccia	Indurated proto-breccia	Cataclasite series	Proto-cataclasite	Proto-phyllonite	Proto-mylonite	Blastomylonite	0-50% matrix
	Breccia	Cemented breccia	Indurated breccia		Cataclasite	Phyllonite	Mylonite		50-90% matrix
	Ultra-breccia	Cemented ultra-breccia	Indurated ultra-breccia		Ultra-cataclasite	Ultra-phyllonite	Ultra-mylonite		90-100% matrix
	Gouge	Cemented gouge	Indurated gouge						Sub-microscopic matrix
		Pseudotachylyte							

Braathen et al., 2004

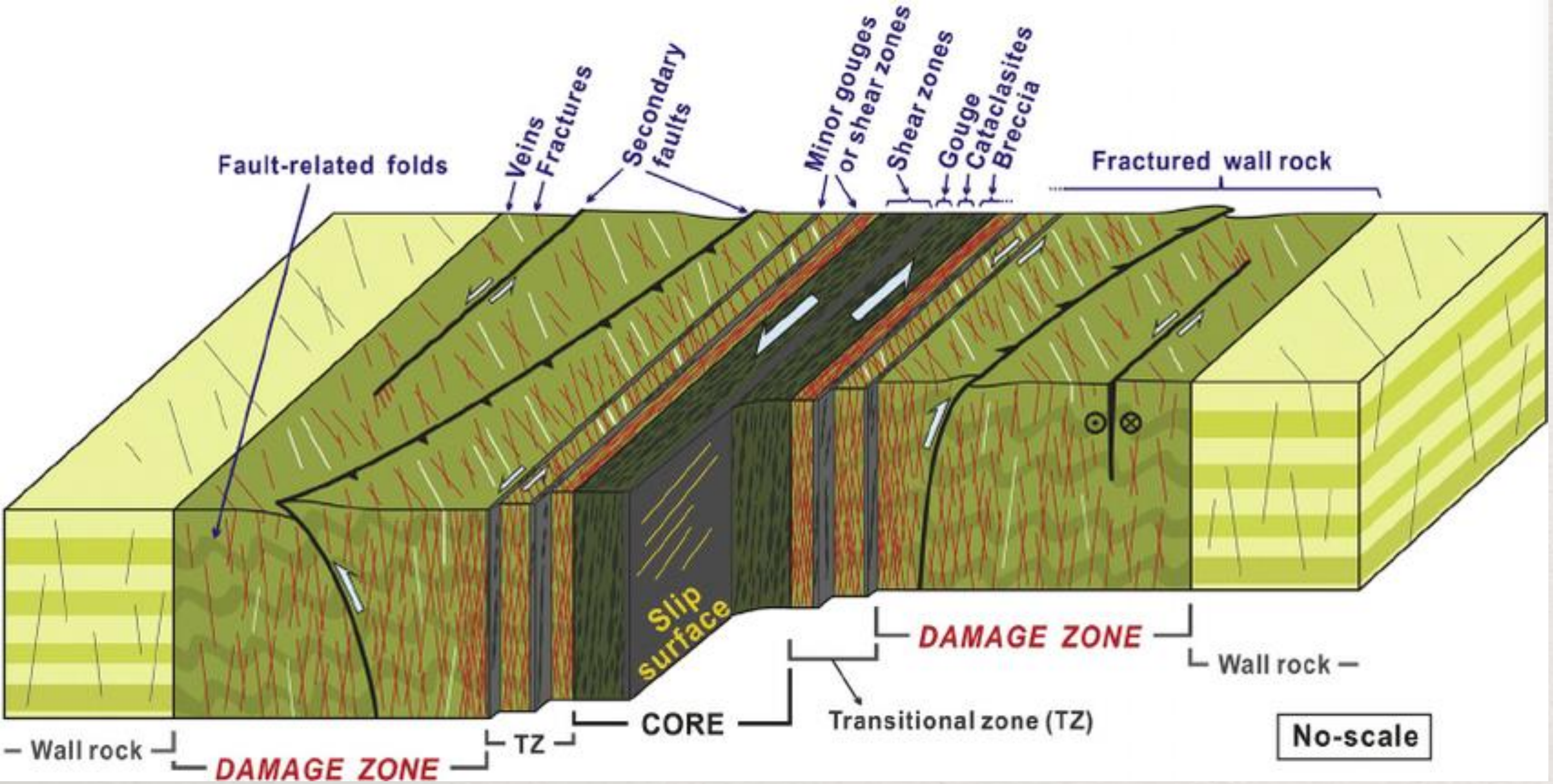


100%
Ductile
Ductile shear zones
Ductility
Brittle (frictional) shear zones
Semi-ductile shear zones
Brittle – plastic shear zones
Plastic shear zones
Forbidden
Non-ductile
Faults
0%
Brittle (frictional)
Plastic
Plasticity (Deformation mechanism)
Fossen, 2010

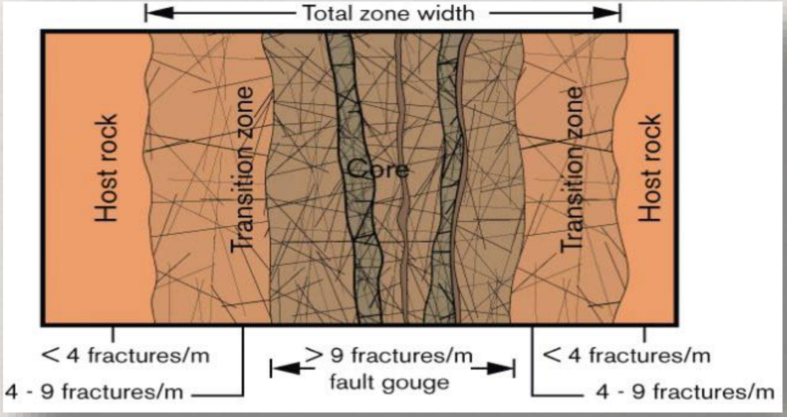


H = 2 x V
1 km
SHEAR RESISTANCE (MPa)
0
100
200
300
GOUGE
PDZ
CATACLASTIC MELANGE
MYLONITE
MYLONITIC GNEISS
Seismogenic Zone
μ_s = 0.75
hydrostatic profile
(λ_v = 0.4)
R
FR
N
SS
heat-flow constraint
quartz rheology
feldspar rheology
QP
5
10
15
20
25
DEPTH (km)

Anatomy of a fault: much effort in recent years to characterise geometrically and mechanically faults



Choi et al., 2016



Textural/fabric anisotropy

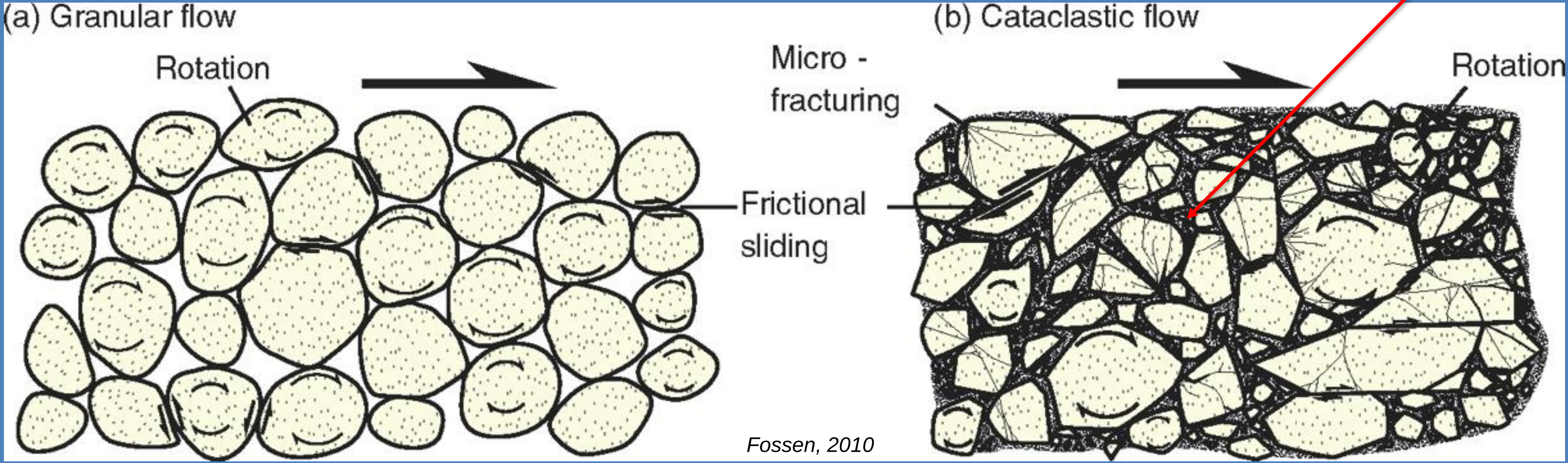
Compositional anisotropy

Dynamic character of faults vs. static characterisation - Transient evolution of properties!

Interaction of physical and chemical processes

Scale variance of fault properties

Clay authigenesis during fluid-assisted cataclasis



Fossen, 2010

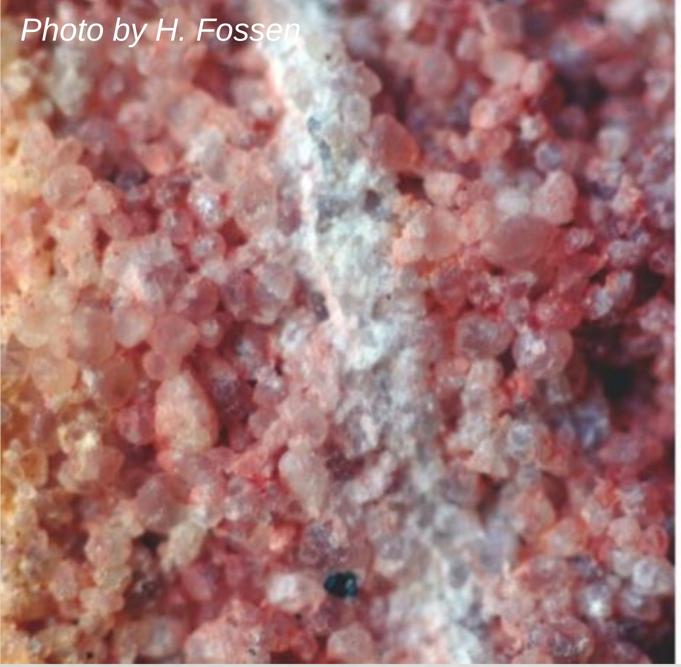
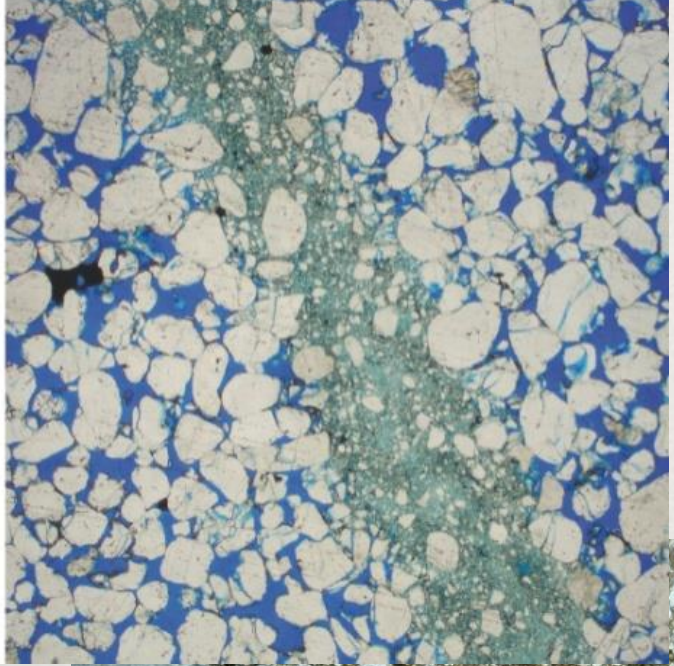
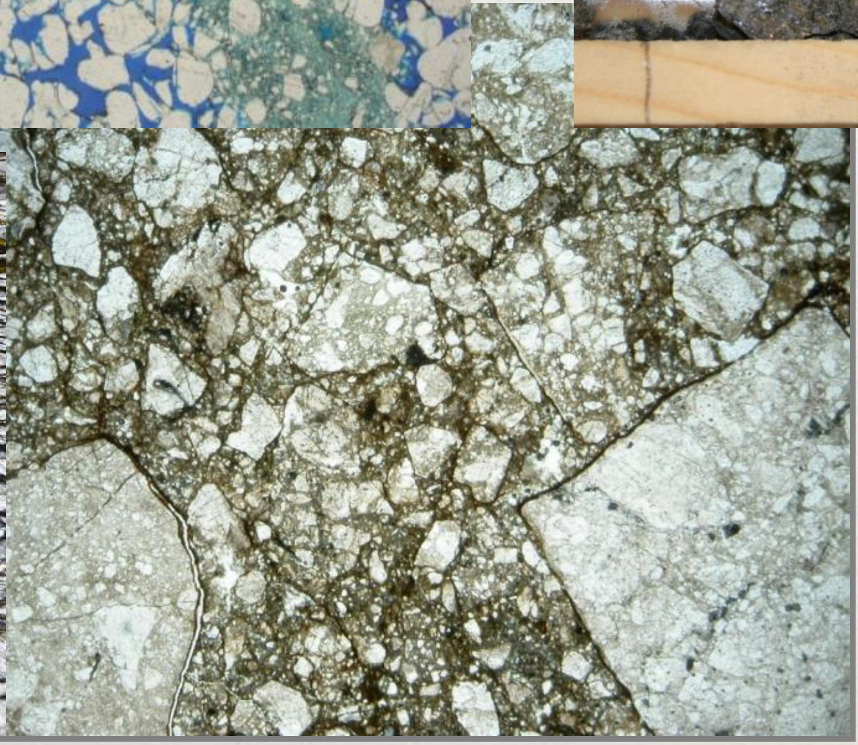


Photo by H. Fossen






f
Fault gouge
Courtesy of H.J. Kjøll

Dynamic and complex system, continuously evolving in space and through time!!

Clays track and permit the developing texture and compositional changes of fault rocks and as such become valuable archives of the physical and chemical conditions at the time of initial faulting, but also of later slip events during reactivation!

Viola et al., in review

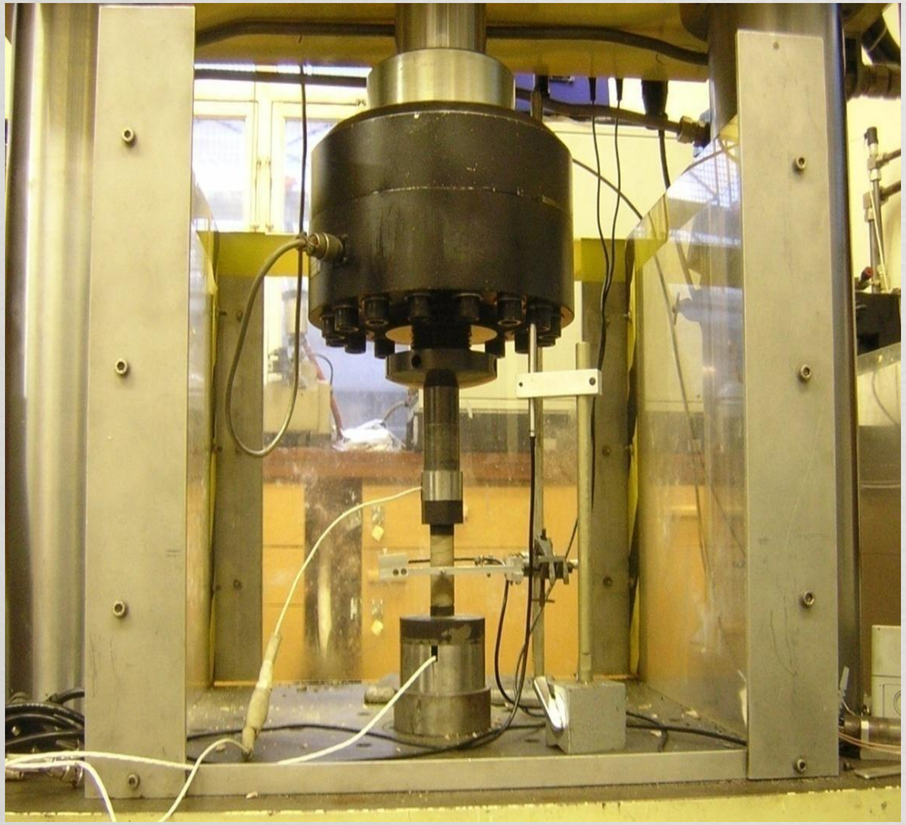
Figure 3

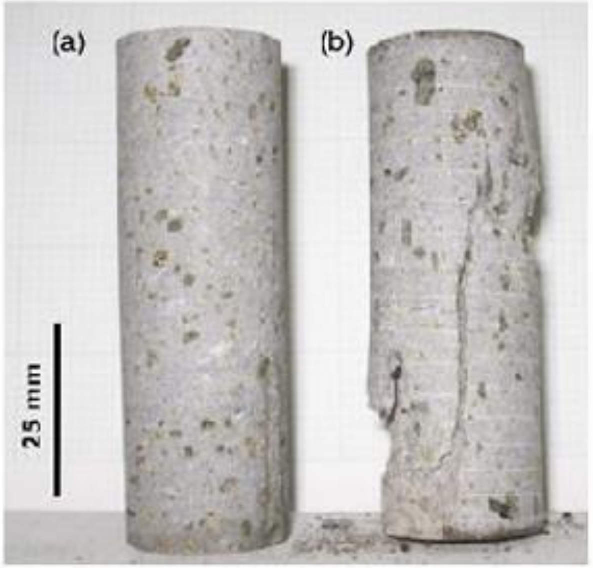
- Complex clay assemblages in different types of brittle fault rocks!

Expansive (!) oxidation of biotite as the mechanism for profound intergranular cracking that mechanically disaggregates the rock and abruptly increases its **connected** porosity and permeability.

Once the disaggregation and hydrologic modification takes place, high pore-water velocities apparently facilitate the creation of additional pore-space through plagioclase dissolution-> *until new clay authigenesis*

Transient, that is, continuously evolving, property of faults: PERMEABILITY, leading to FLUID INGRESS



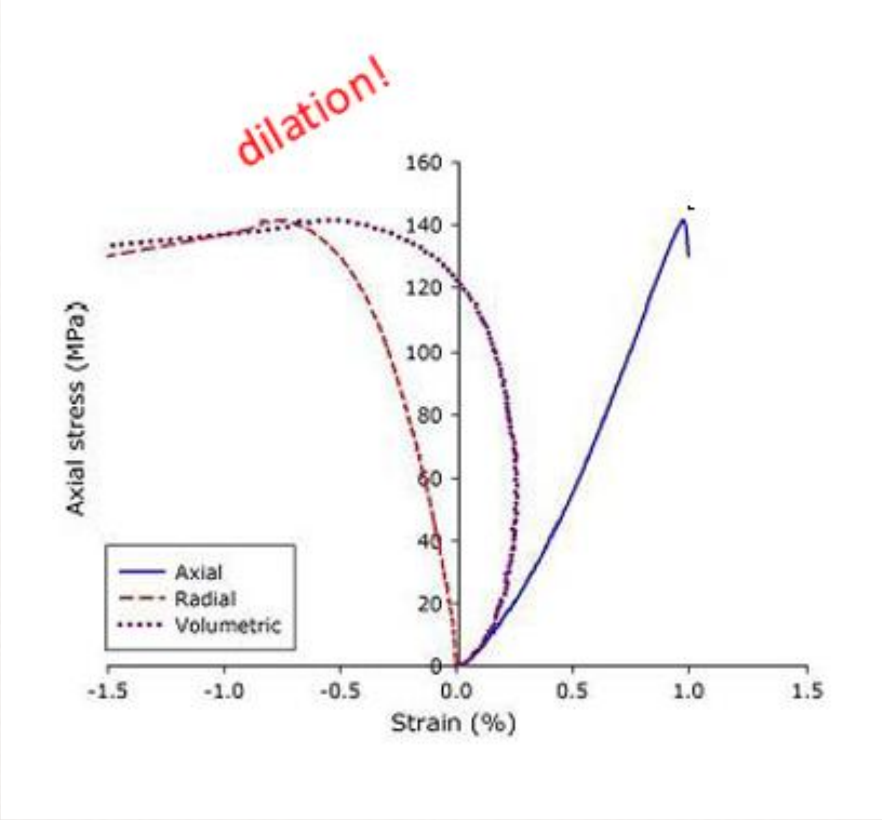


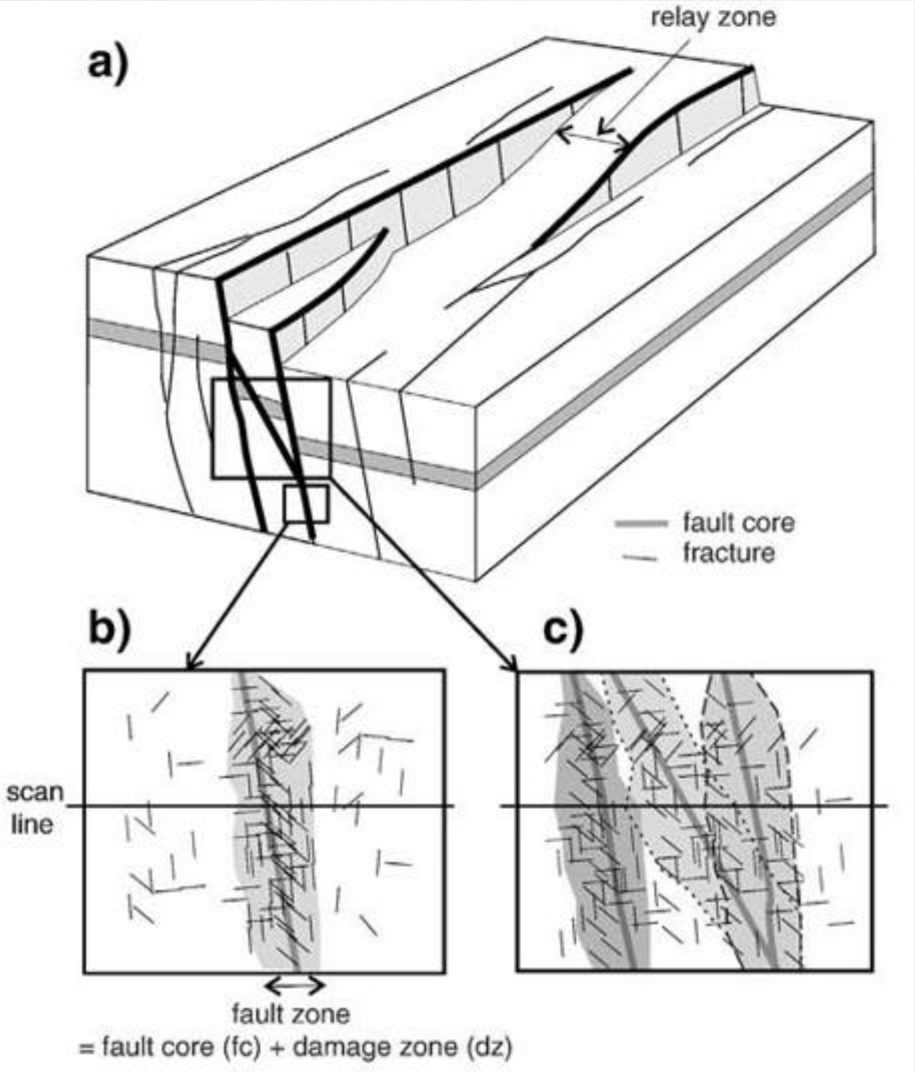
Key piece of information:

Fault zones can **transiently** be like open conduits and so facilitate important fluid ingress!

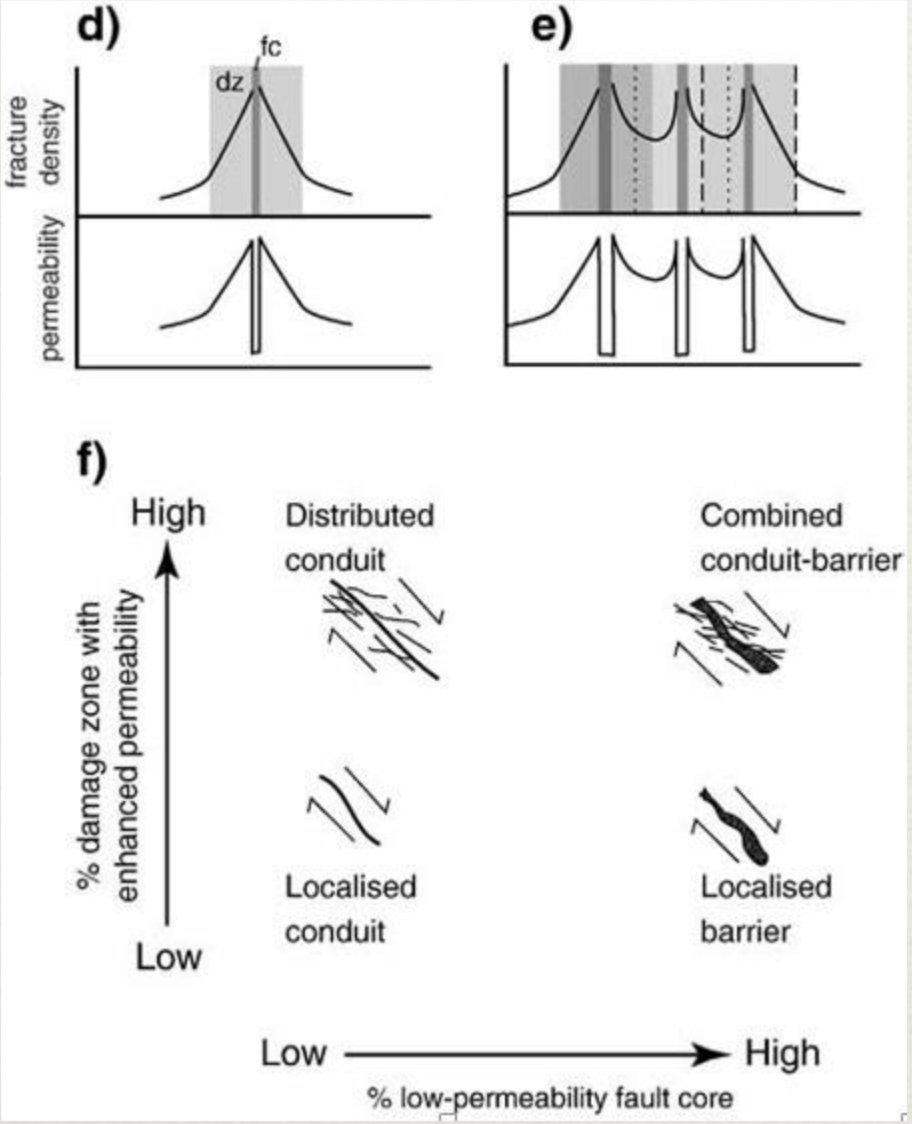
Authigenesis and synkinematic clay blastesis!

EXAMPLE 1

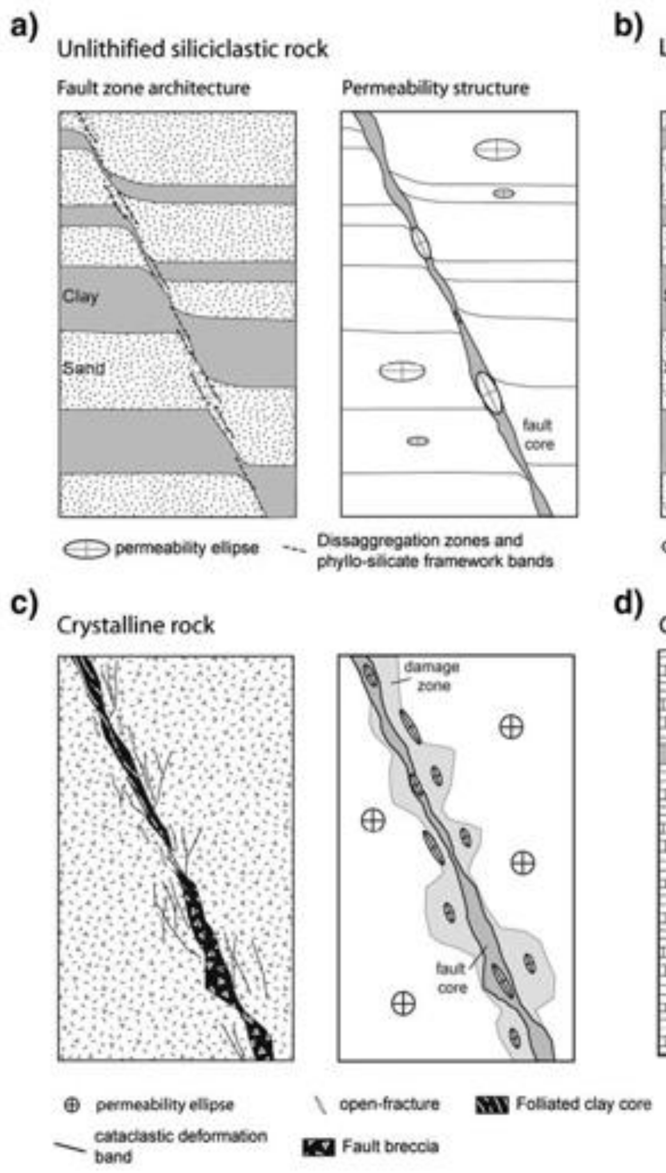




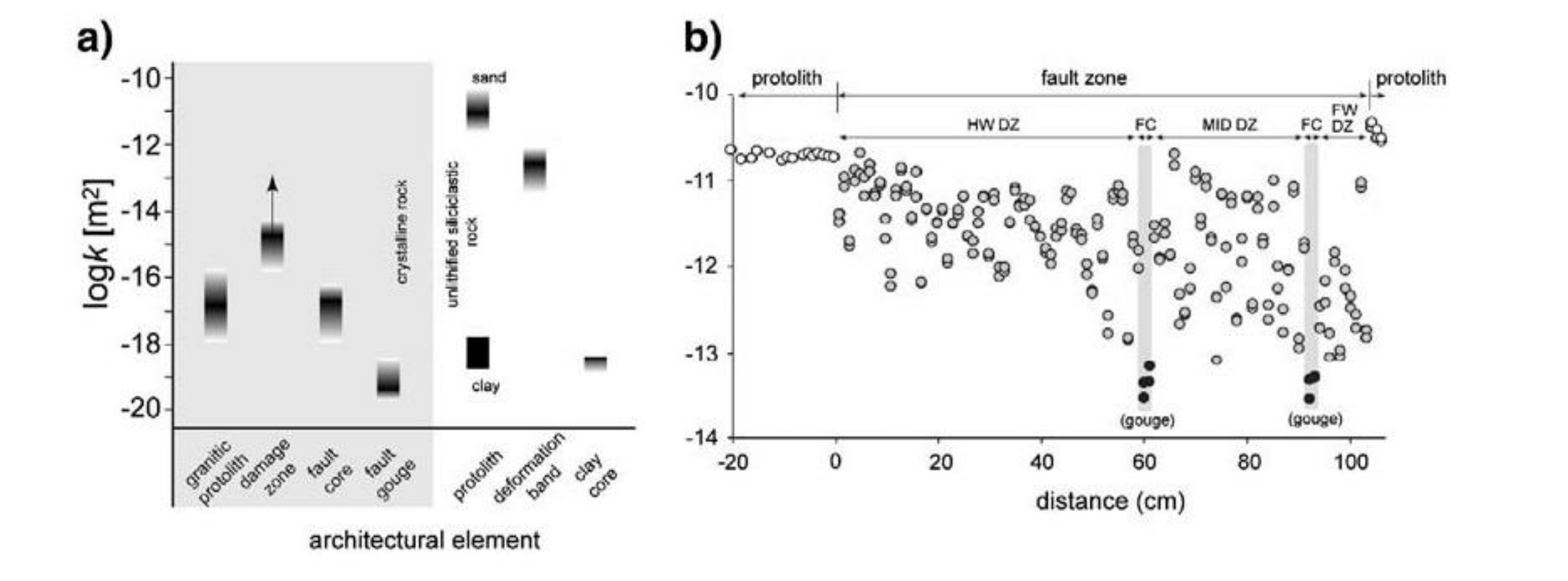
Bense et al., 2013



Concept of heterogeneous and transient evolution of fault transmissivity

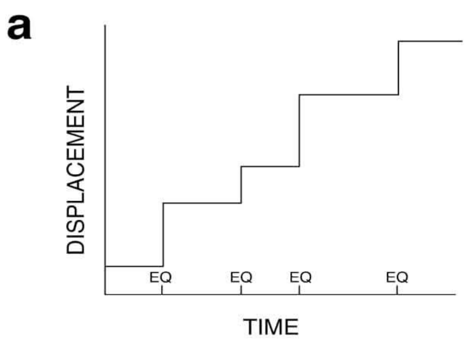


Bense et al., 2013

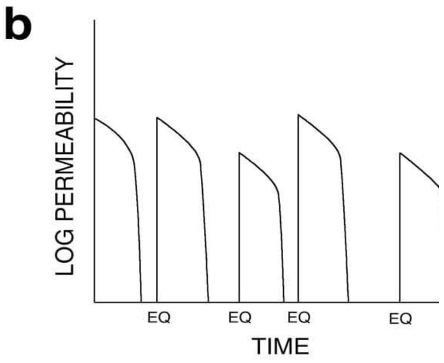


Bense et al., 2013

Permeability evolution with time in seismogenic faults



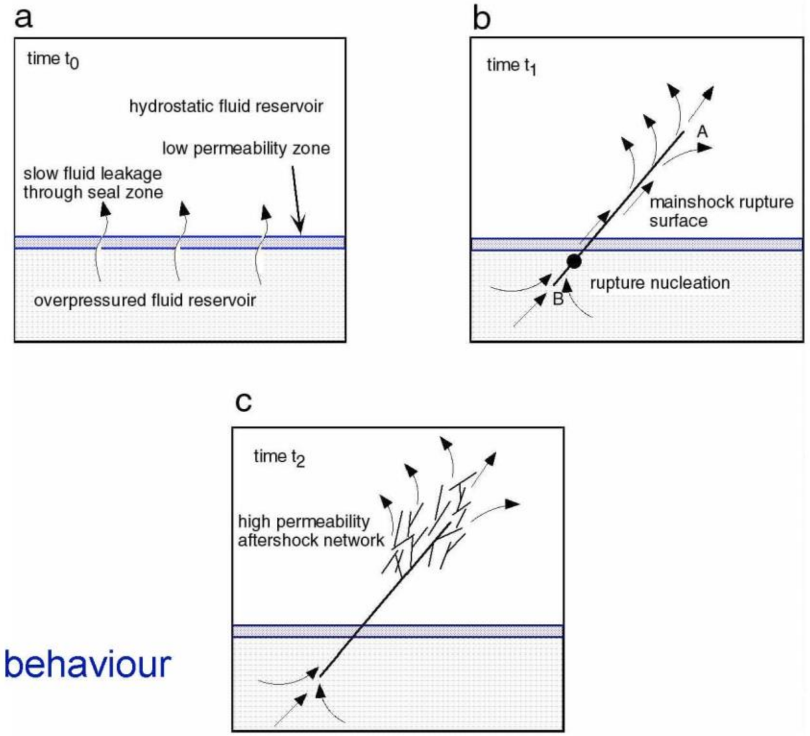
Cyclic changes in
- stress state
- fluid pressure
- permeability



Permeability “toggle switch”

→ **EPISODIC FLUID FLOW**

Flow transience in the seismogenic regime

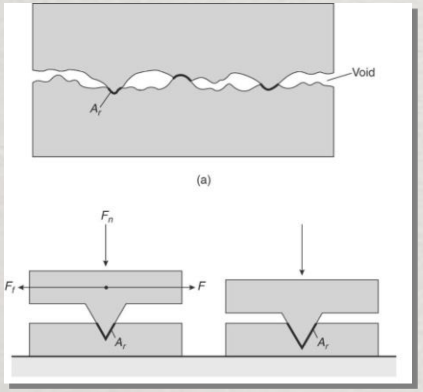


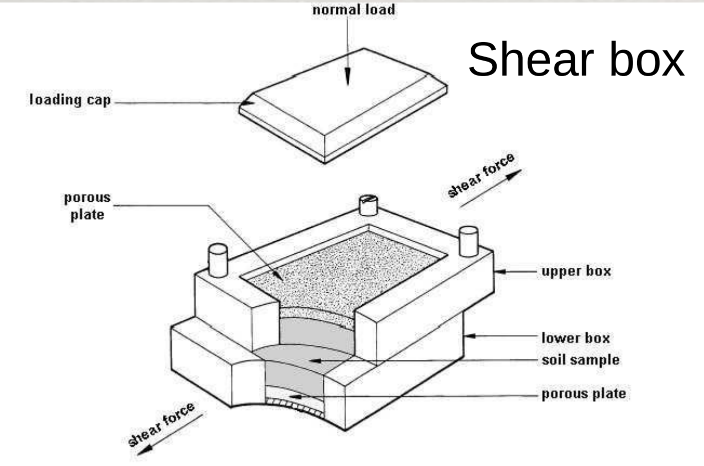
Fault-valve behaviour

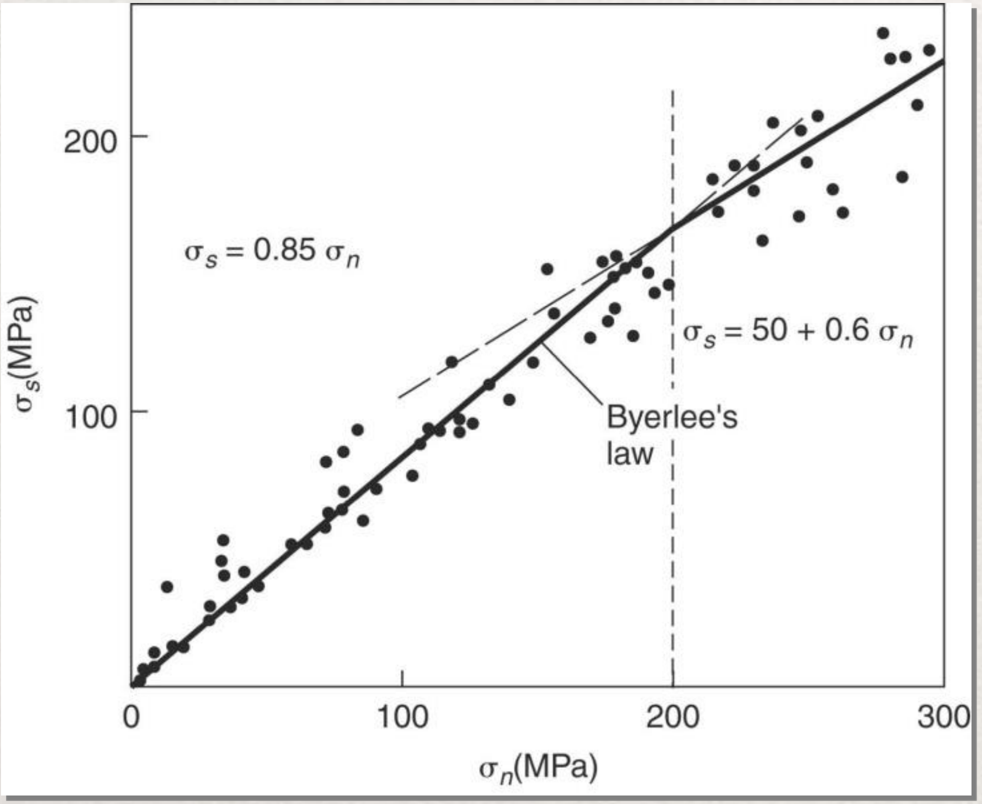
Cox, 2010

EXAMPLE 2 Frictional Sliding and effects upon mechanical strength

Our knowledge of frictional sliding was improved dramatically by the work of Byerlee (1978; Byerlee's Friction Law). This resulted from experimental data on frictional sliding in various environments, such as surface engineering, mining and shallow as well as intermediate to deep crustal conditions.

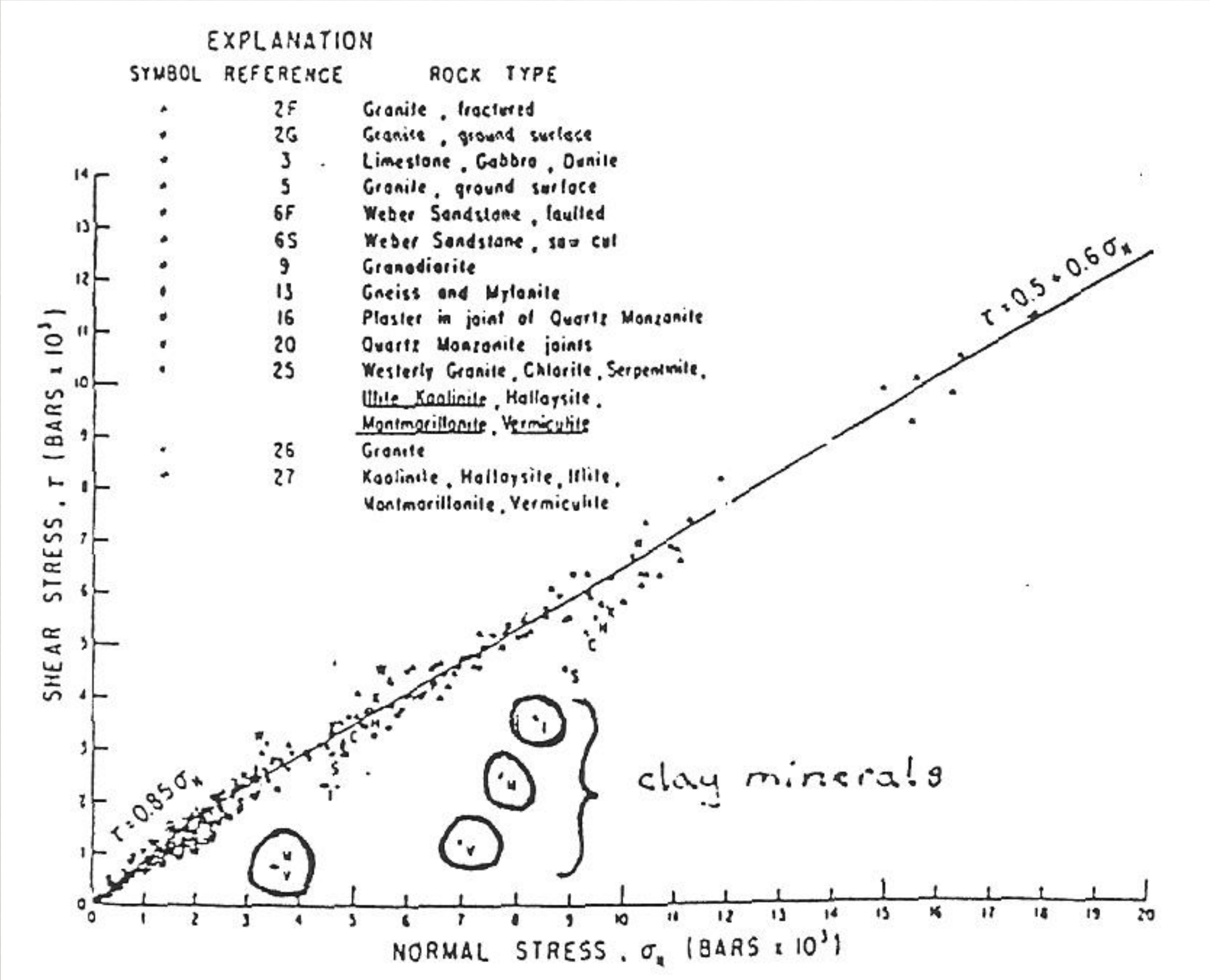




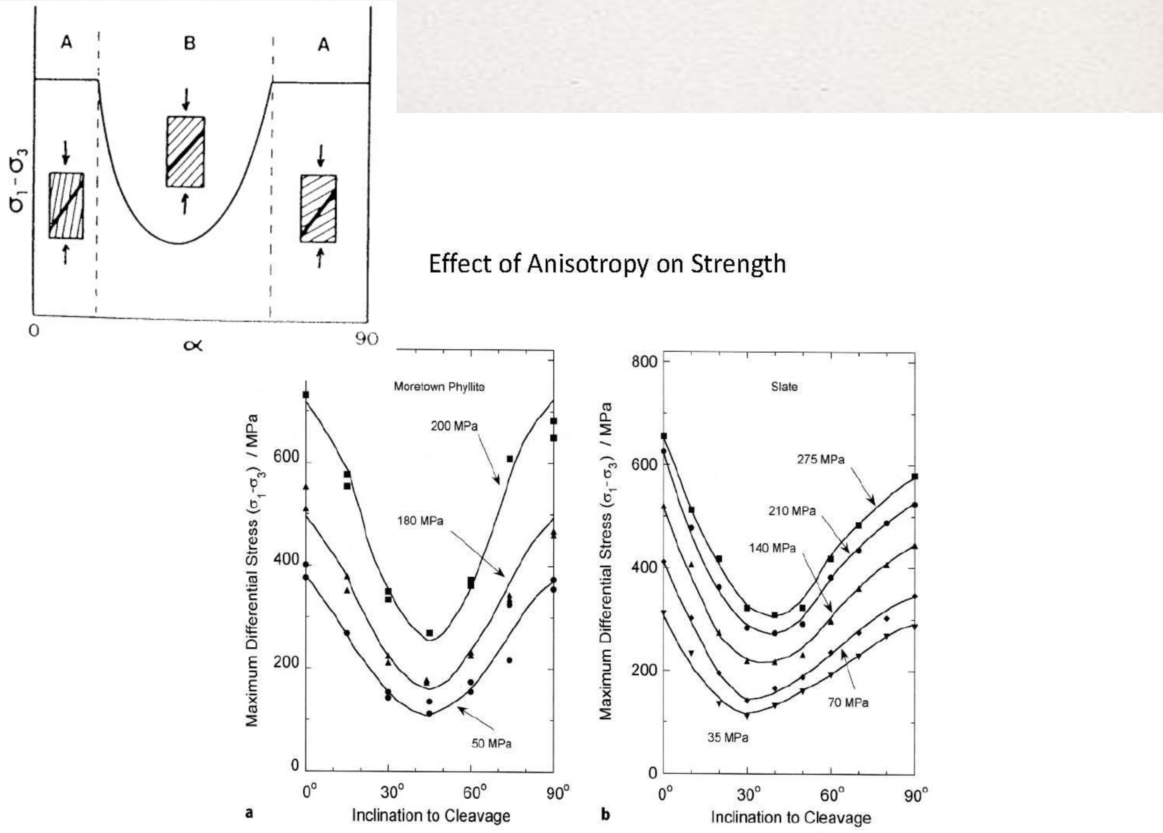


⇨ Independent of rock type

First-order compositional and textural control of clay/phyllosilicate rich fault rocks on fault strength

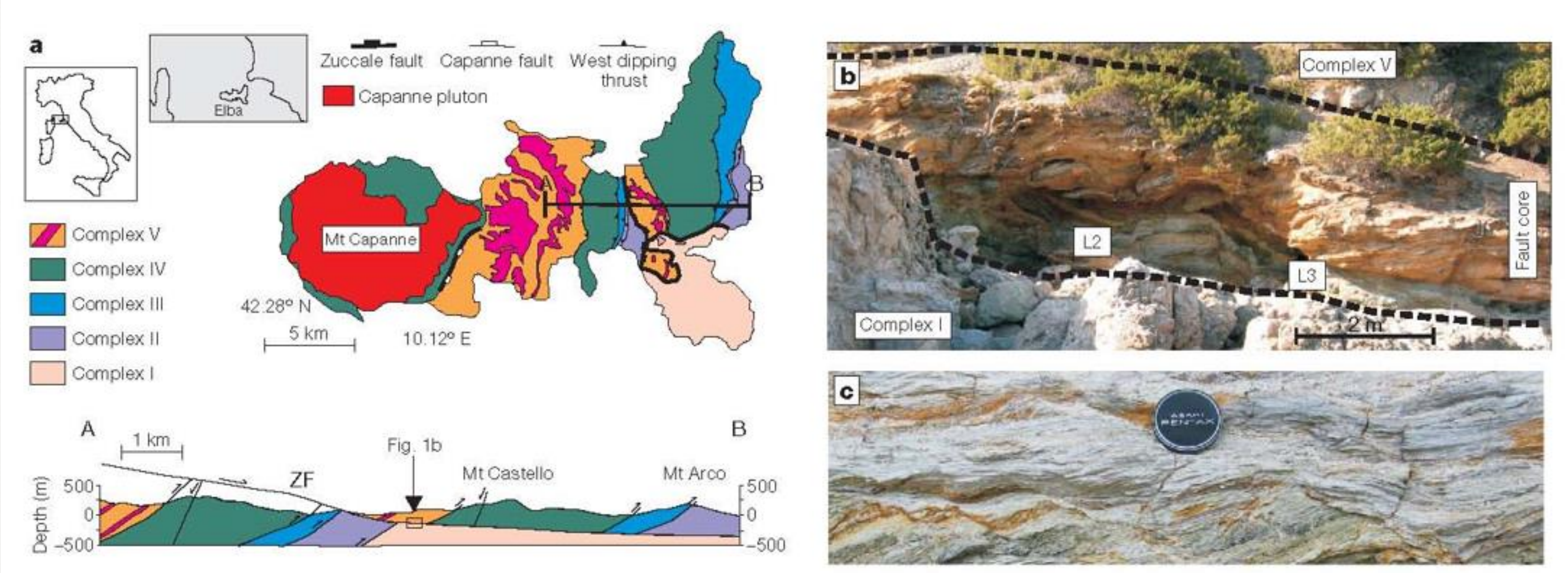


Byerlee, 1978



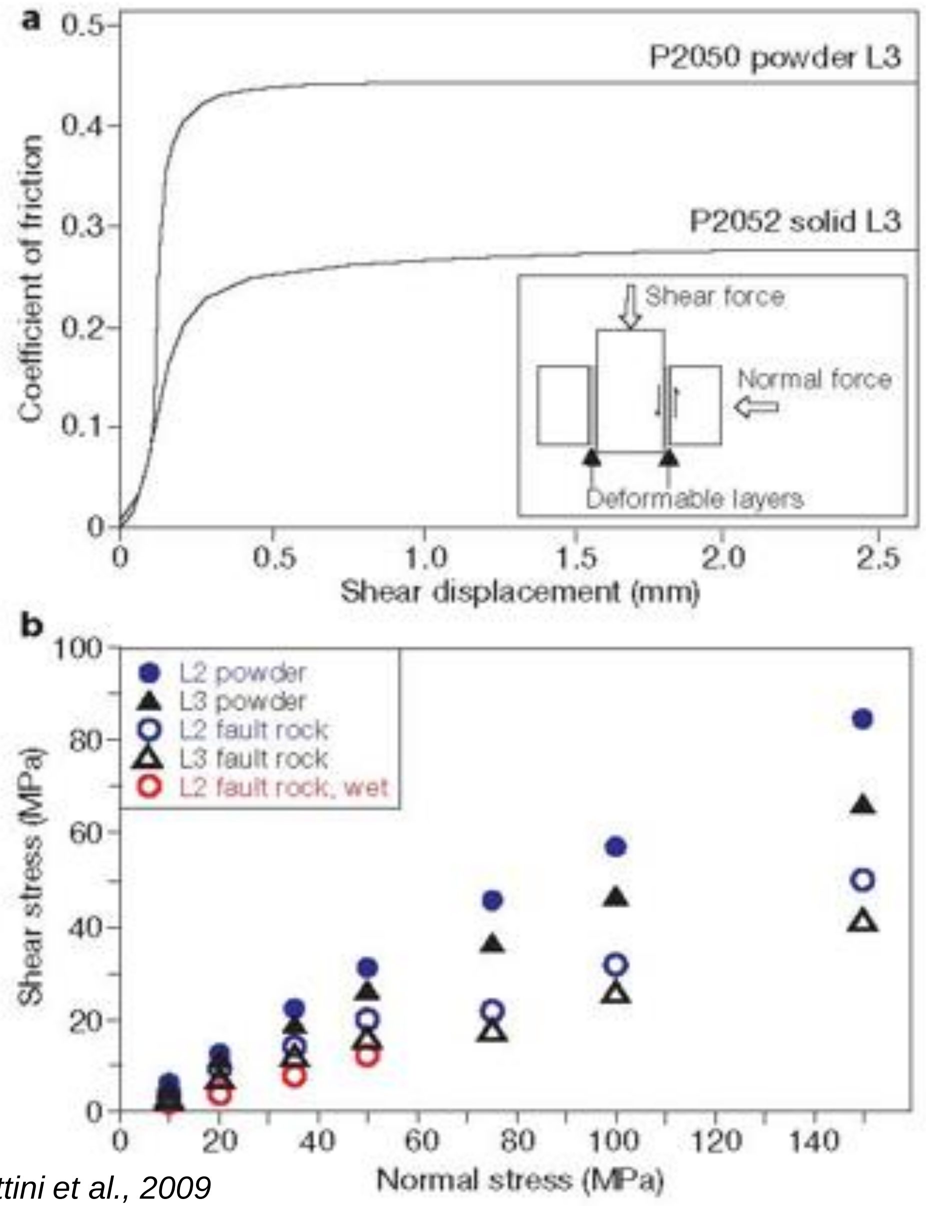
Paterson&Wong, 05

Why are some faults weak? That is, why did they ever form/slip? Issues with mechanical misorientation.

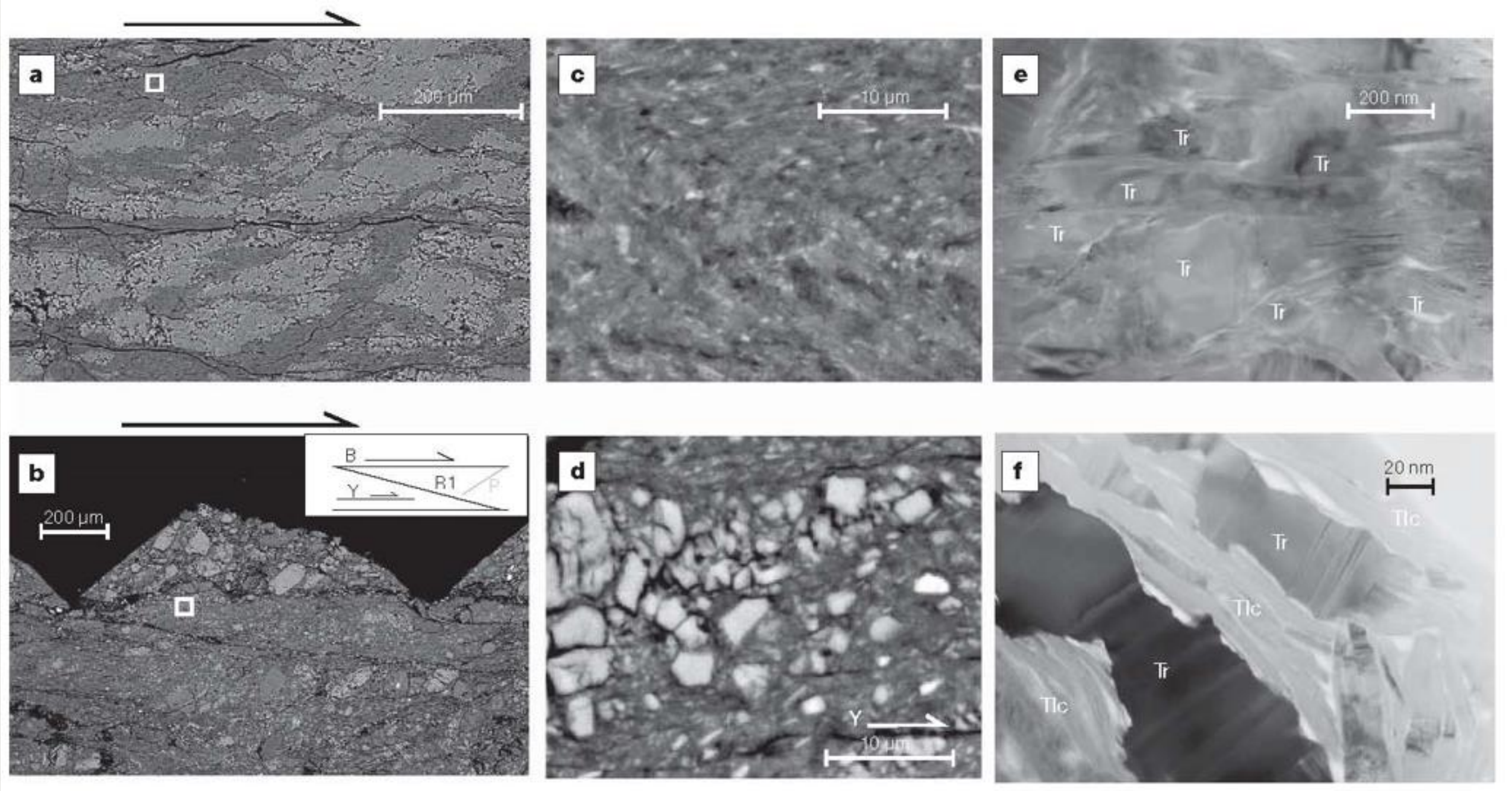


Collettini et al., 2009

Zuccale Fault, Elba Island, Italy

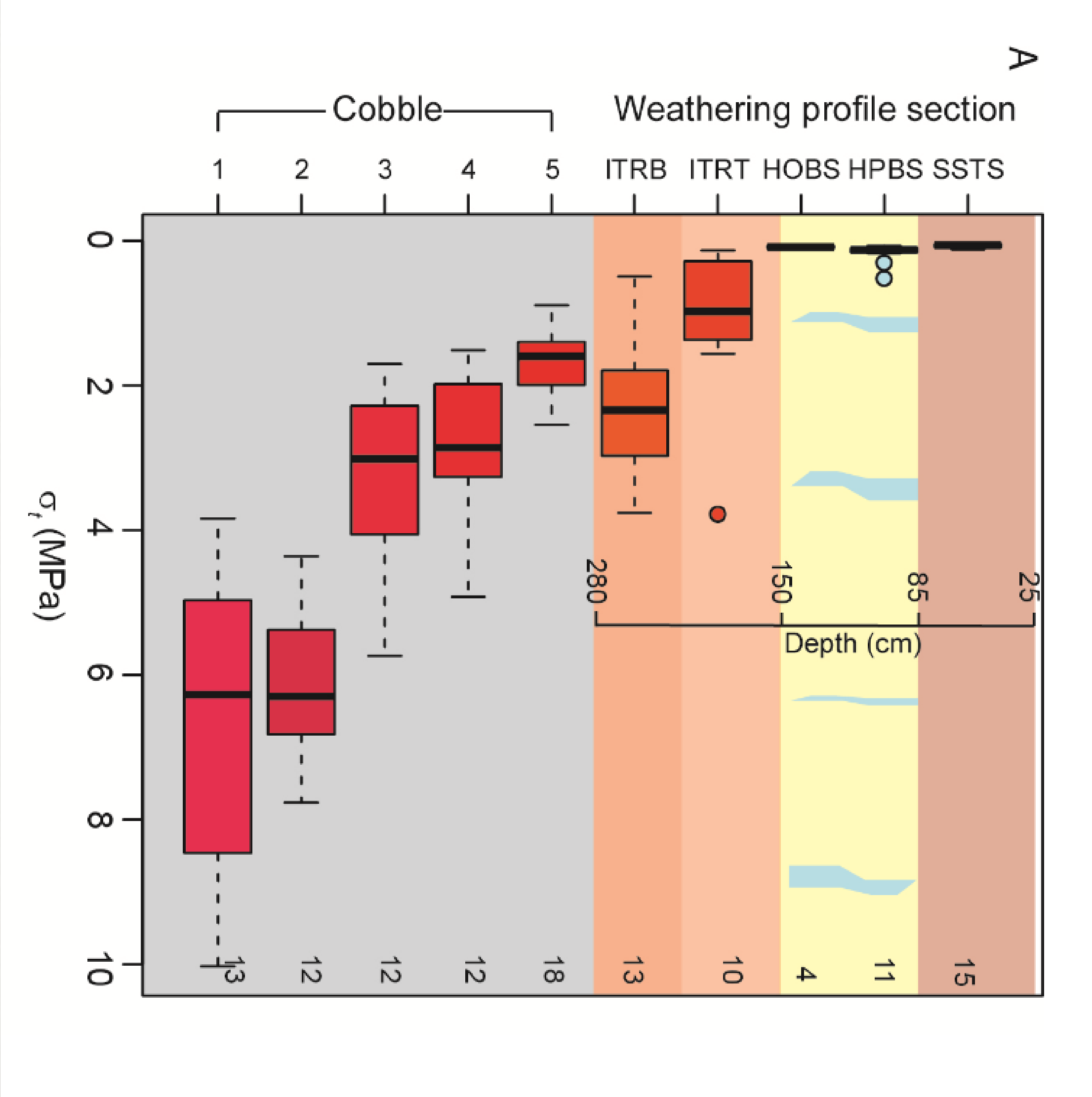


Collettini et al., 2009



Collettini et al., 2009

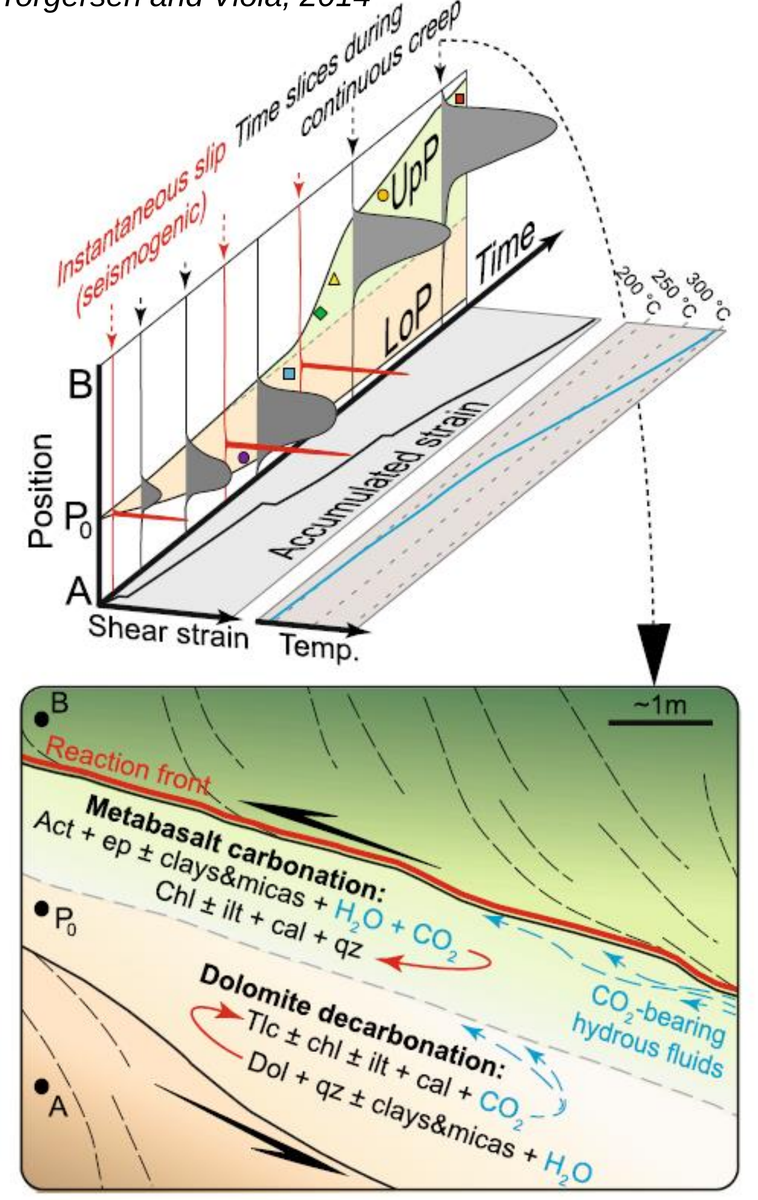
Content and degree of physical interconnectivity of fine-grained, mechanically weak minerals such as phyllosilicates and clays is a key factor for the multiscalar intrinsic mechanic weakness of faults and brittle deformation features and for their pronounced hydrological anisotropy.



Goodfellow et al., 2016

Deteriorating tensile strength T for a fossil weathered profile as a function of the intensity of weathering.

Torgersen and Viola, 2014



Take home messages:

- Clays are rich archives of the physical and chemical conditions at the time of faulting(s).
- They steer key petrophysical properties of brittle and brittle/ductile fault zones (examples of transmissivity and mechanical strength of faulted rock domains).
- Clay synkinematic authigenesis (and the effects thereof) has to be read in combination with the «time» dimension of a fault's evolution: what we see at the outcrop is only the result of often a long-lasting and heterogeneous structural, textural, petrological and chemical evolution → Delicate balance between grain size comminution/grinding by cataclasis and synkinematic authigenesis.