Influence of Fault Infrastructure and Physical Conditions on Slip Style

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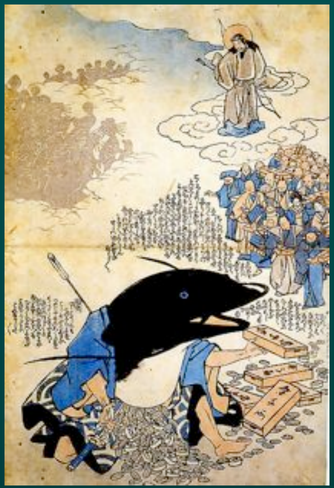


"I heard among the solitary hills
Low breathings coming after me, and sounds
Of undistinguishable motion, steps
Almost as silent as the turf they trod."

- Wordsworth - The Prelude

UNIVERSITY of OTAGO
SAPERE AUDE
Te Whare Wānanga o Otāgo

Earthscope Institute - The Spectrum of Fault Slip Behaviors - Oct. 11-14, 2010

What do fault zones look like at different structural levels?

Slip Zone Geometry

- shear localization at different structural levels

PLANAR ⇔ VOLUMETRIC
(planar → tabular → parallelepiped → irregular blob)

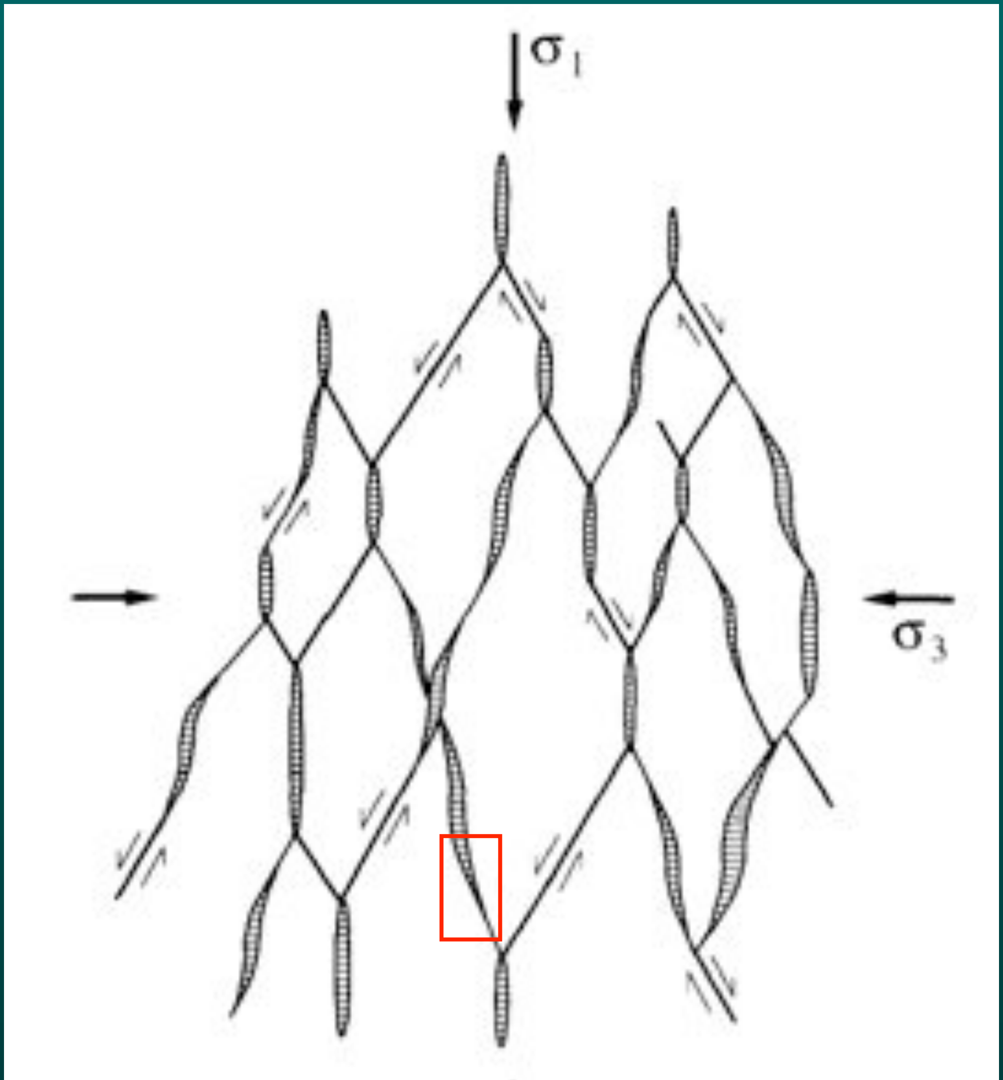
Monolithologic vs. Polylithologic Shear Zones

mélange shear zones

competence / incompetence ratio

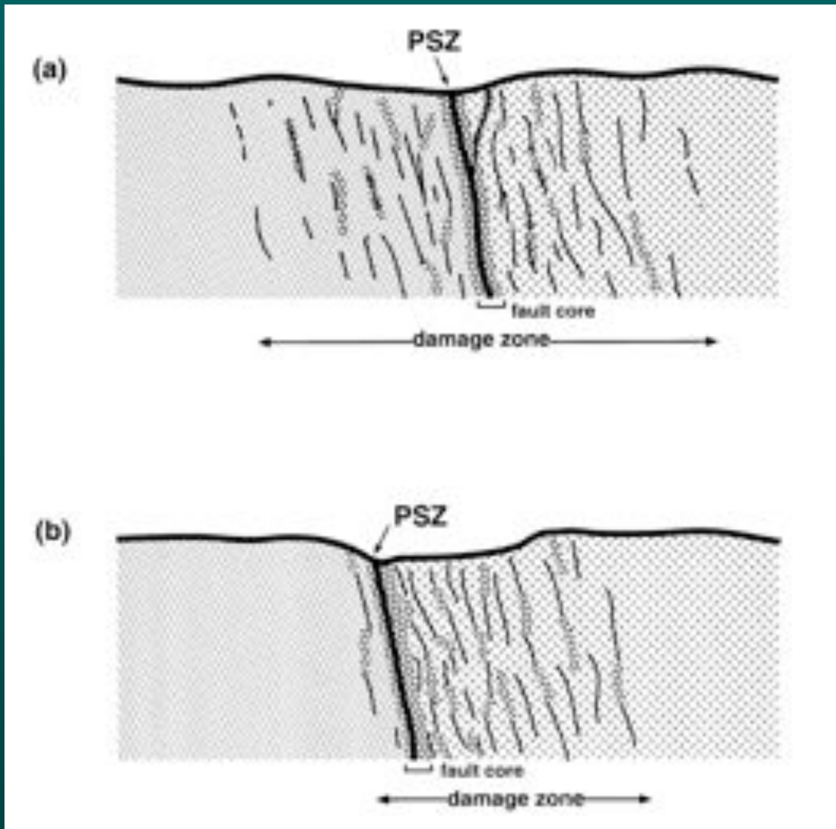
subduction channel shear zones

Volumetric Swarm Activity from Distributed Fault-Fracture Meshes

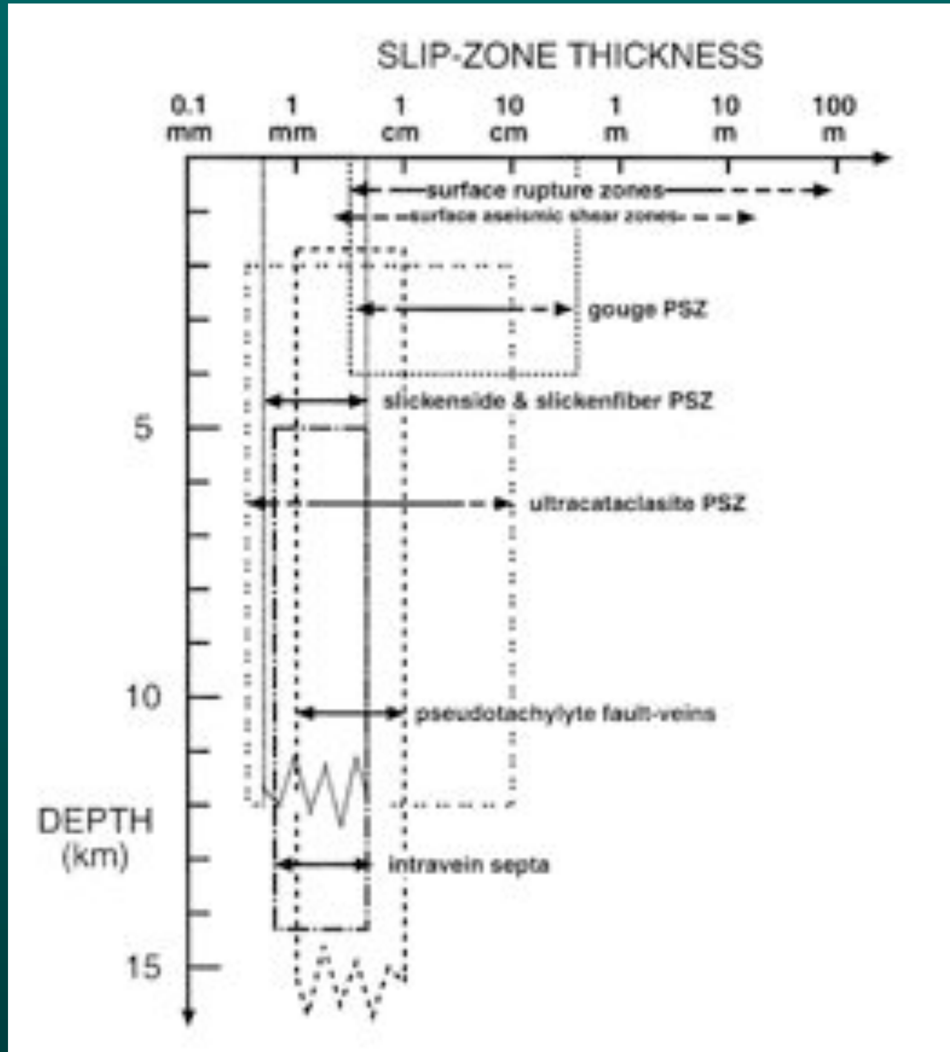


- after Hill, 1977: J. Geophys. Res. 82, 1347-1352

Brittle Fault Infrastructure



Localization of PSZ within fault infrastructure

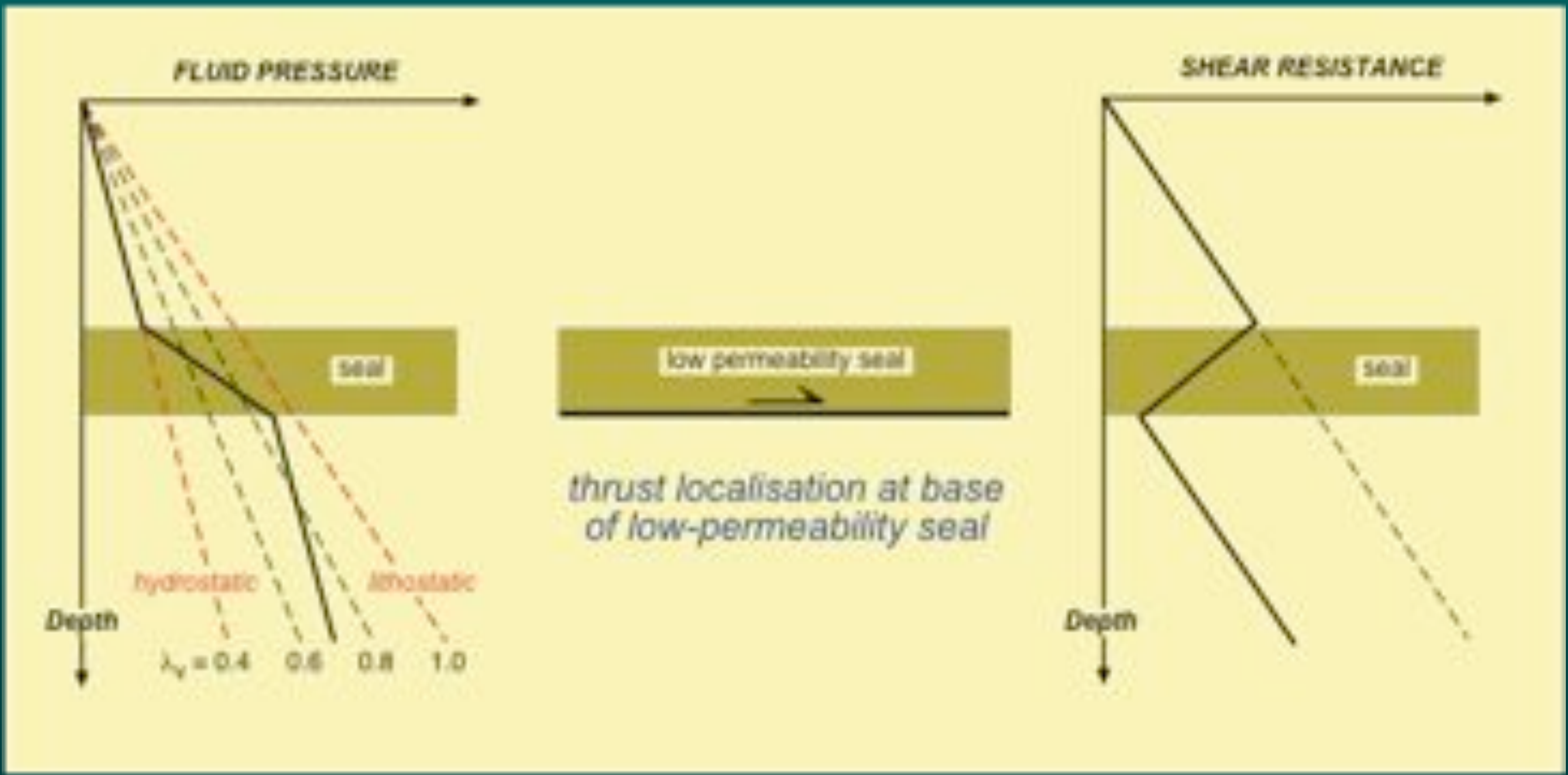


Geological constraints on PSZ thickness

- Sibson, 2003: BSSA 93, 1169-1178

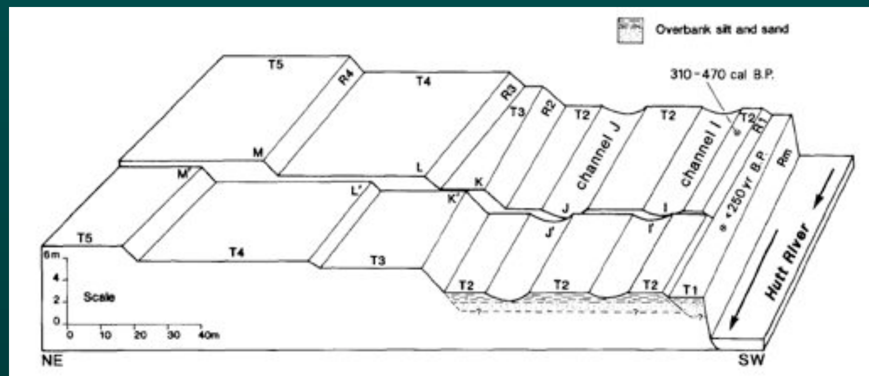

Apennine Thrust Fault, Spoleto

Thrust Localization



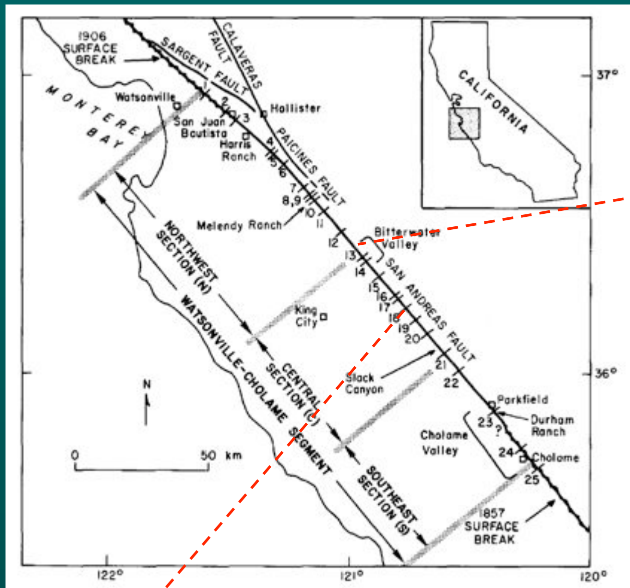
Persistent Localization of Strike-Slip Faults

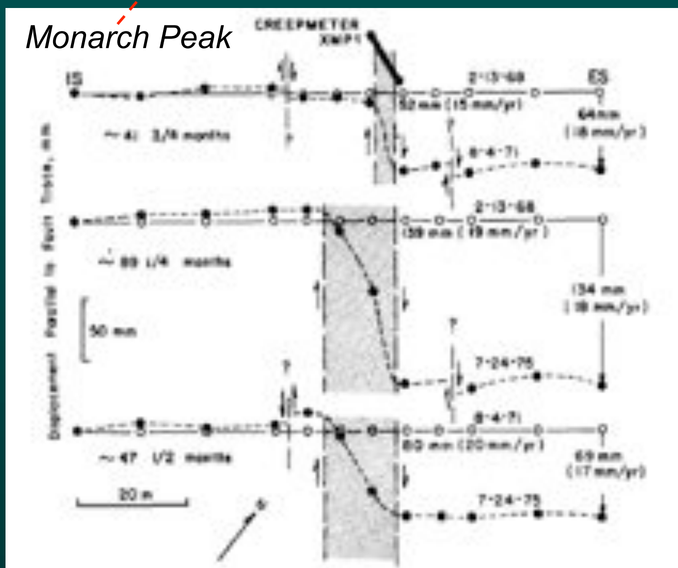
Wairau Fault, progressive dextral displacement of Branch River terraces - GNS Science

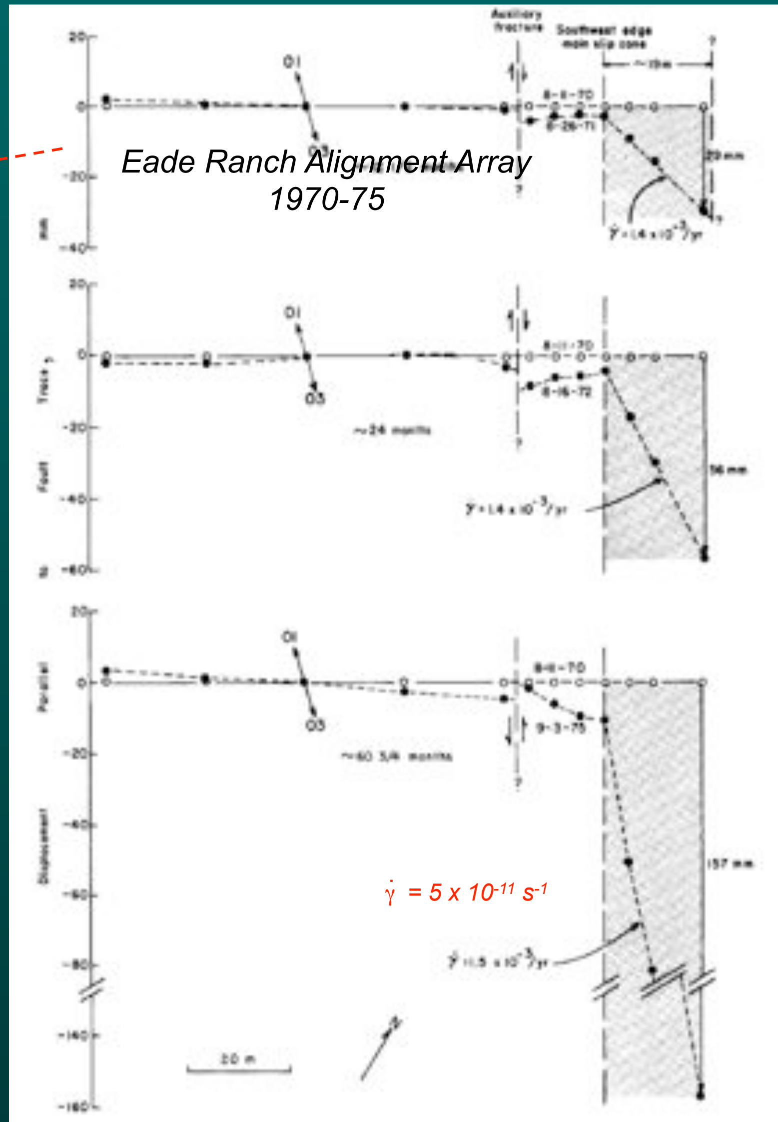


Wellington Fault, Te Marua terraces
Van Dissen et al. 1992: N.Z.J.G.G. 35, 165-176

Creeping San Andreas Fault





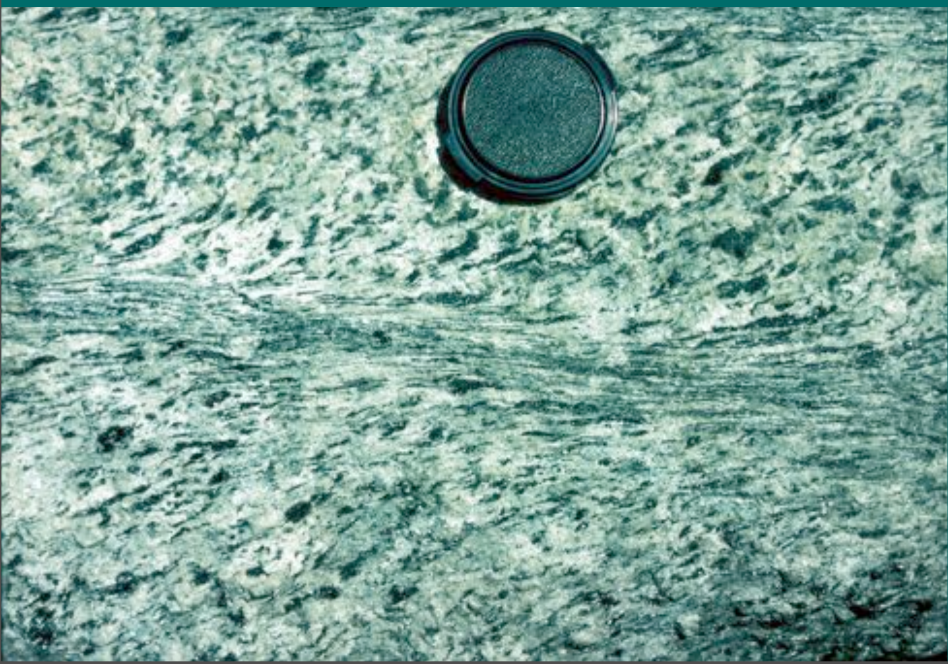


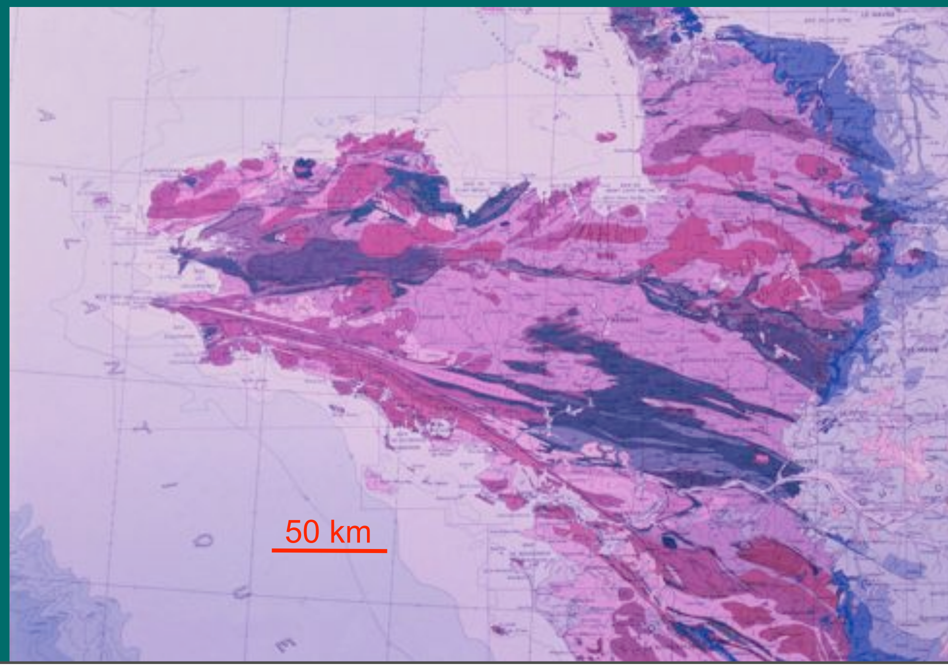
– Burford & Harsh, 1980: BSSA 70, 1233-1261

Continuous Ductile Shear Zones

"Flowing like a crystal river;
Bright as light, and clear as wind"

– Tennyson





Transition from Discontinuous to Continuous Shearing

Surface Rupture

5-10 km

SEISMOGENIC ZONE

DISCONTINUOUS

Type Mylonite Eriboll

c. 15 km
T ~ 350°C

CONTINUOUS

c. 20-25 km

Transition from Discontinuous to Continuous Shearing

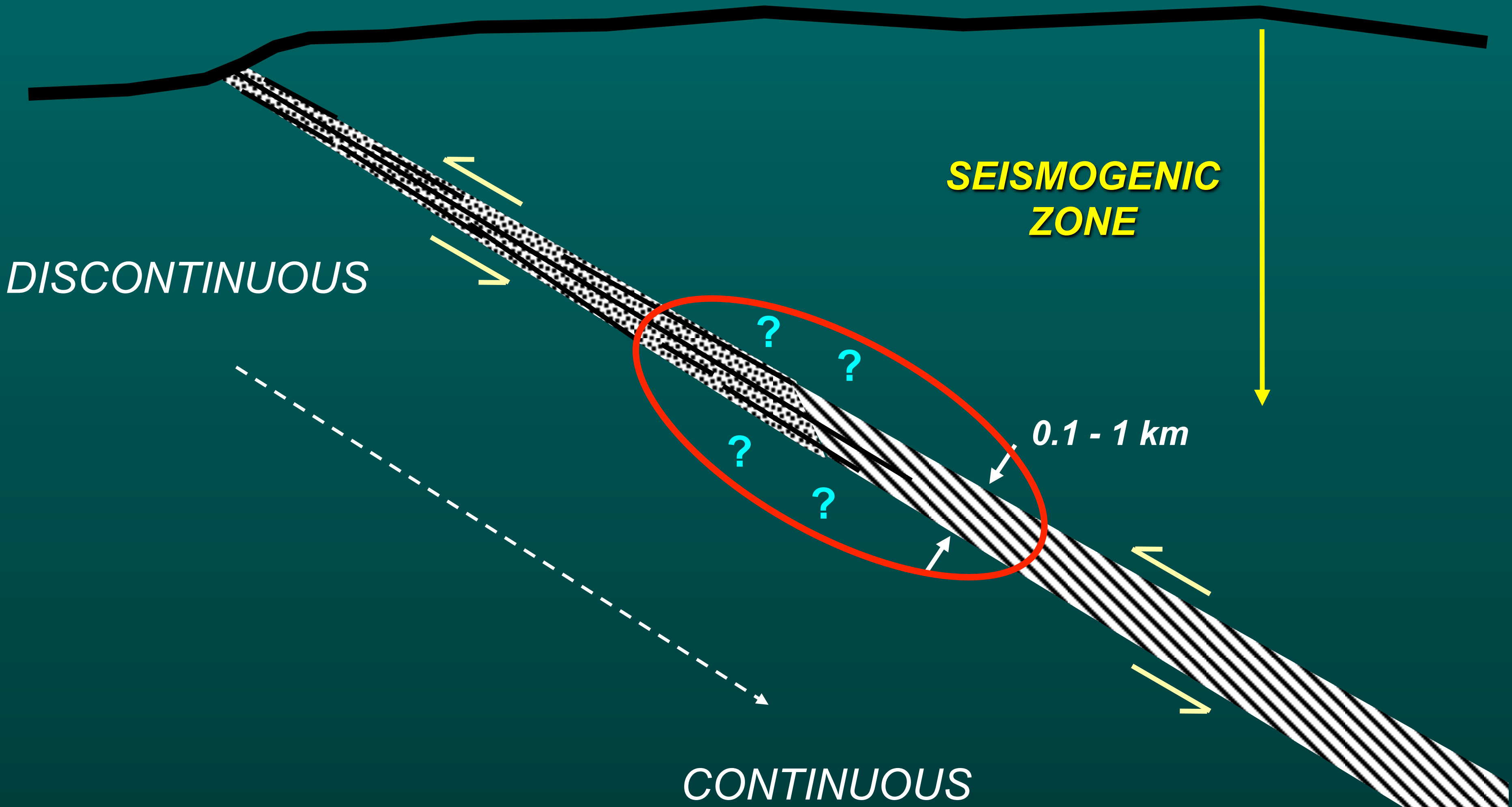
Surface Rupture

5-10 km

*c. 15 km; T ~ 350*C*

c. 20-25 km

Transition from Discontinuous to Continuous Shearing



Time-Dependent Slip Transfer

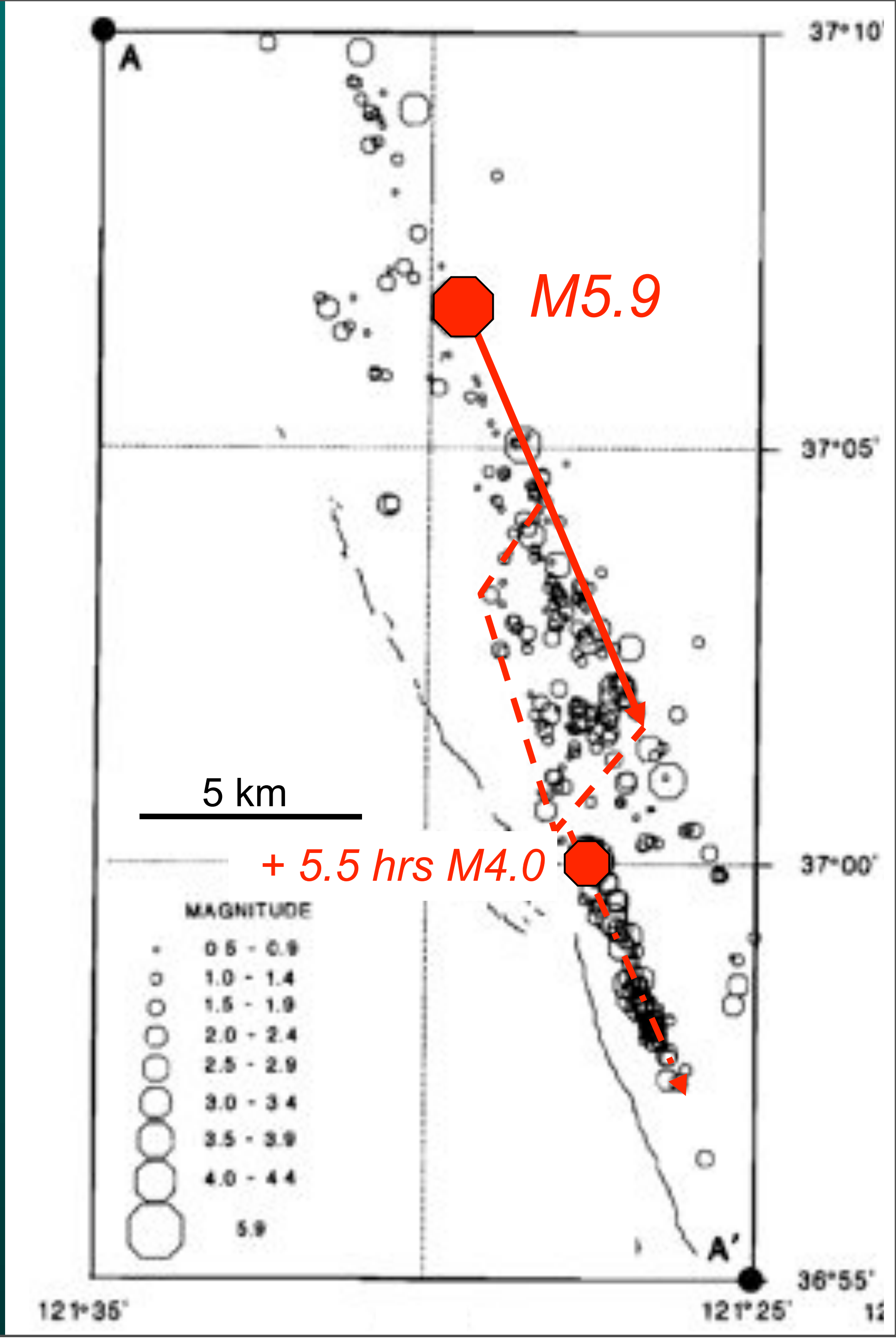
- associated dilational stepovers

- attributed to fluid infiltration

1979 M5.9 Coyote Lake Earthquake Sequence

- *time-dependent slip transfer across a dilational stepover*

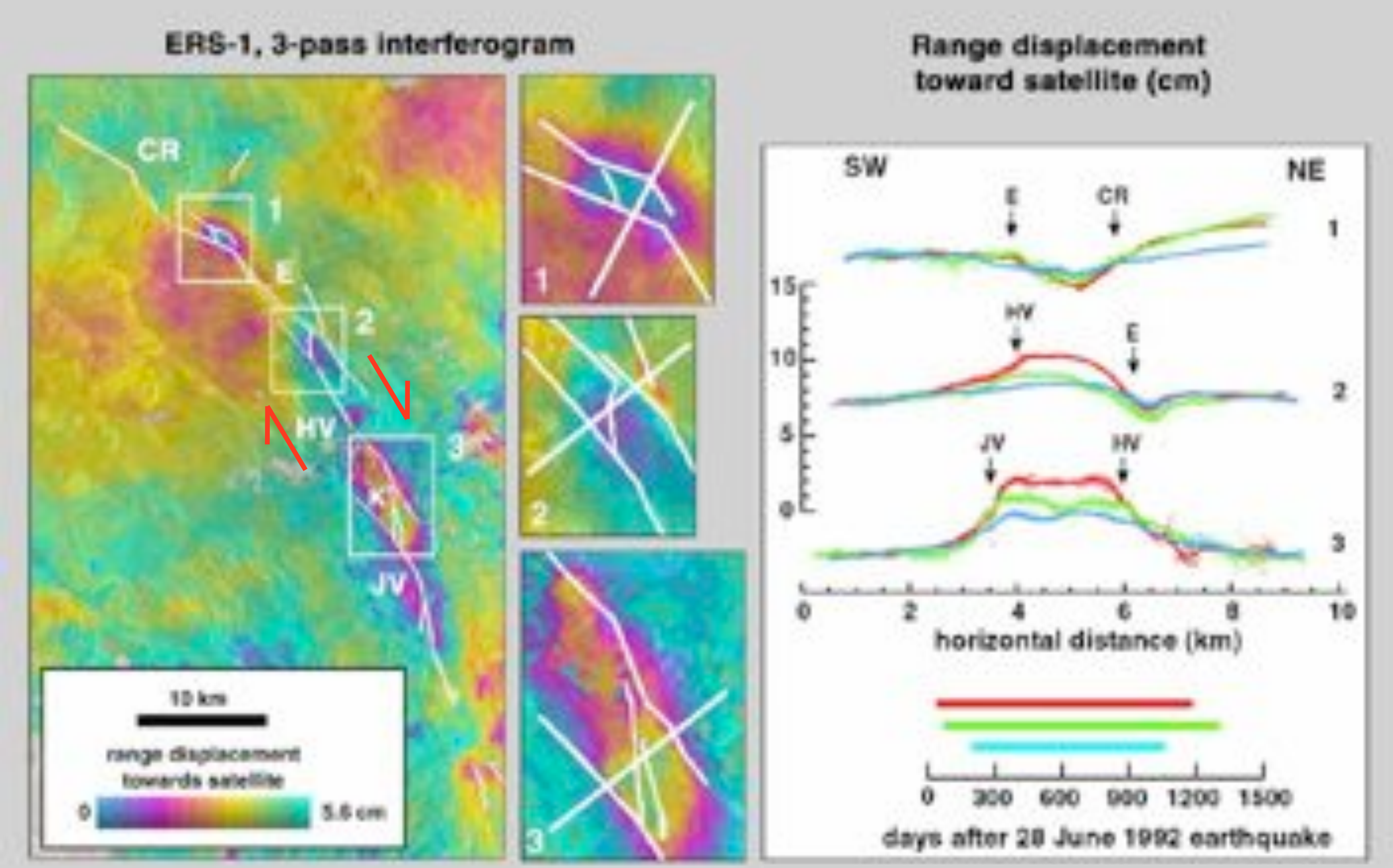
- from Reasenberg & Ellsworth, 1982: *J. Geophys. Res.* 87, 10,637-10,655



1992 M7.3 Landers Rupture Zone

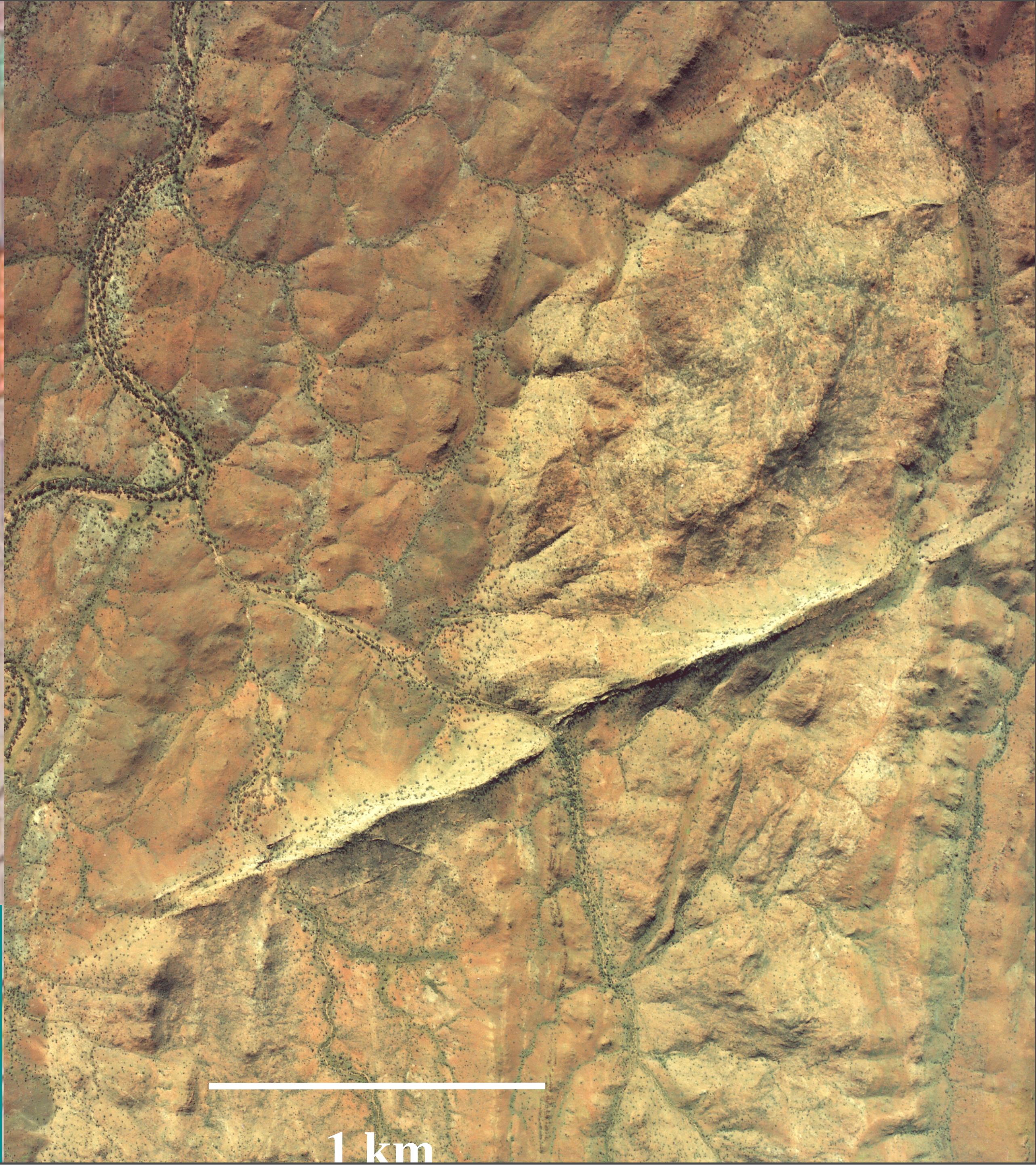
- rupturing in high strength *crystalline assemblage*
- *low finite displacement* on fault strands ~ 300 m (Zachariasen & Sieh 1995)
- *persistent aftershock activity* localized in dilational jogs
- *postseismic rebound of jog areas* following coseismic subsidence (Pelzer *et al.* 1996)

Postseismic Rebound in Stepovers Along the 1992 Landers Fault Rupture



- *Peltzer et al. 1996: Science 273, 1202-1204*

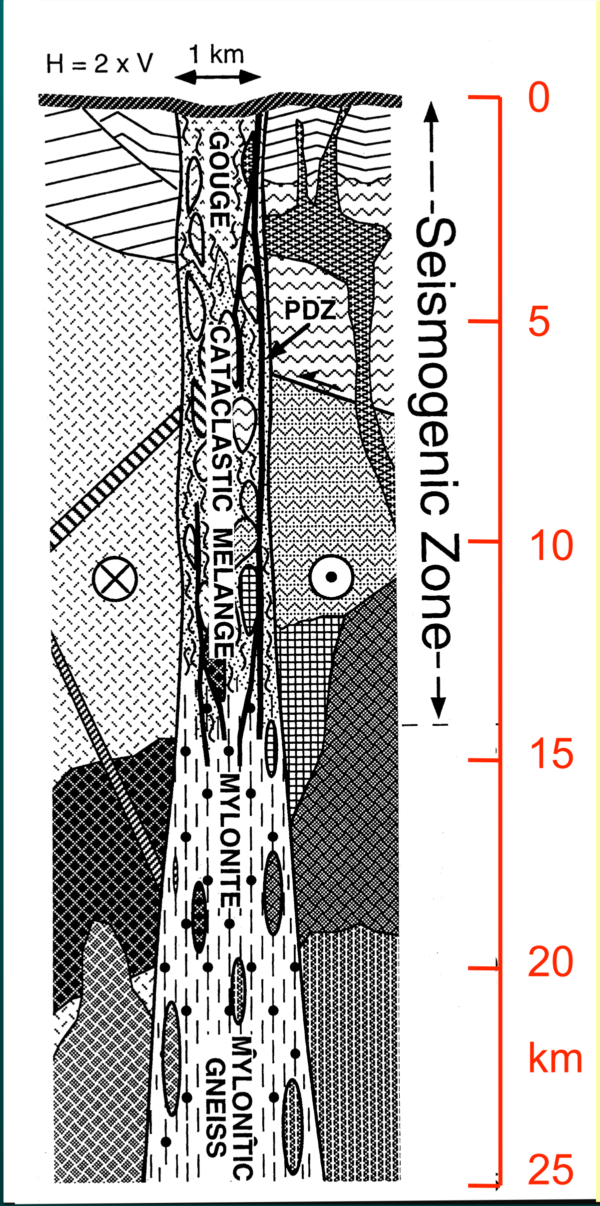
Overlander Fault
(~1.5 km dextral slip)




NNW
Overlander Fault
SSE


extensional dilation 15-20%

Transcrustal Continental Fault Zone



large transcrustal fault zones are ***polylithologic****, incorporating a range of rock types of contrasting competence*

e.g. SAF likely incorporates a mixture of Salinian granites, Franciscan metavolcanics and metasediments, Great Valley flysch, serpentinites and gabbros, Tertiary volcanics

Gwna Mélange Anglesey

Mélange Shear Zones

- COMPETENCE / INCOMPETENCE ratio

- varying strain-rate amplification in matrix

- variable stress states with fiber stresses developed in competent phacoids

- imposition of length scales

COMPETENCE / INCOMPETENCE

ELASTIC

- *relative shear moduli, G_c/G_i*
- *relative tensile strength, T_c/T_i*

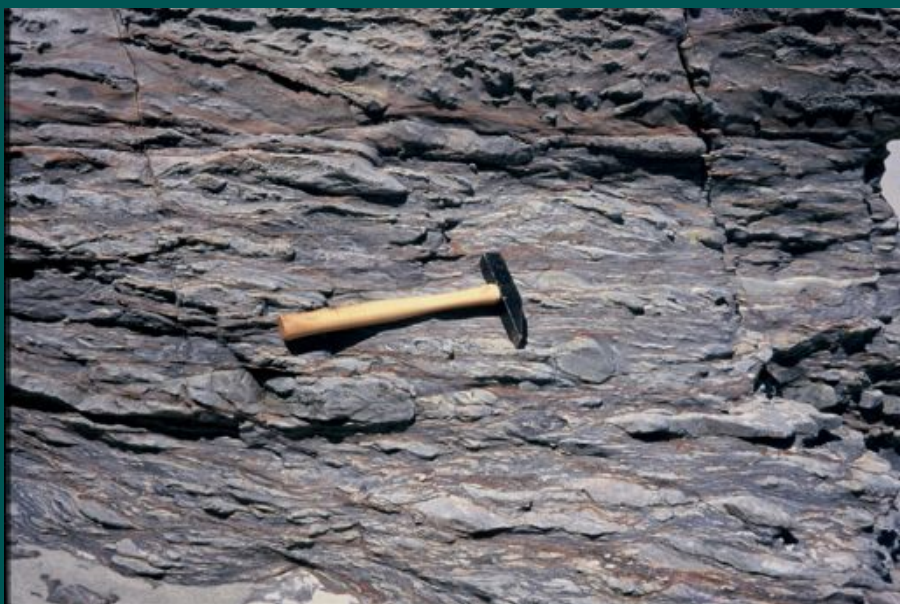
VISCOUS

- *relative viscosity, η_c/η_i*

CRITICAL RATIO

For bulk 'brittle-frictional' behavior:

$$\frac{\text{Competent}}{\text{Incompetent}} > 70\text{-}90\% \text{ by volume}$$



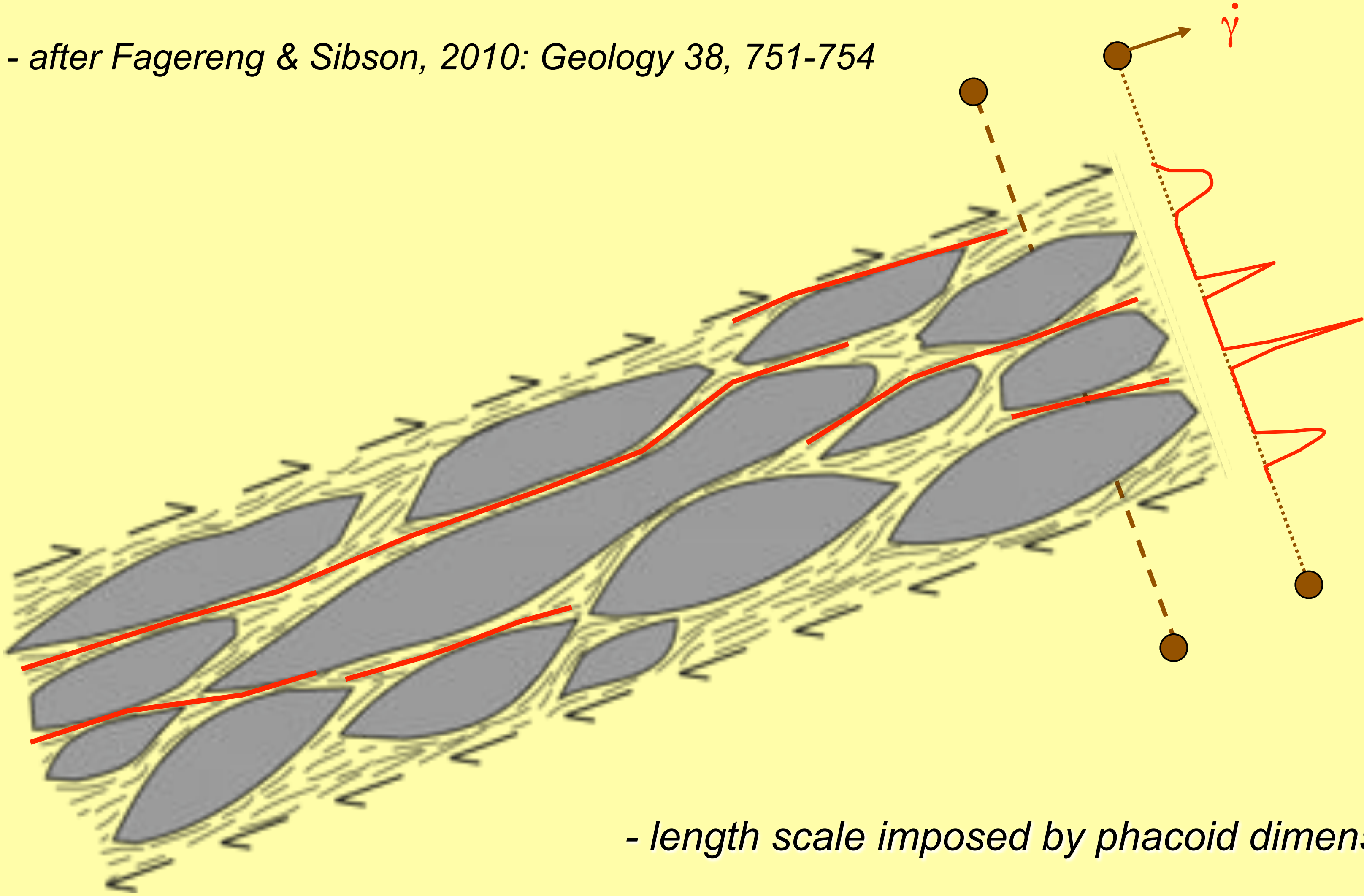
For bulk 'ductile- viscous' flow:

$$\frac{\text{Competent}}{\text{Incompetent}} < 70\text{-}90\% \text{ by volume}$$

- after Fagereng & Sibson, 2010: Geology 38, 751-754

Locally Amplified Shear Strain Rates in Mélange Shear Zones Inducing Distributed Brittle Failure

- after Fagereng & Sibson, 2010: Geology 38, 751-754



- length scale imposed by phacoid dimensions

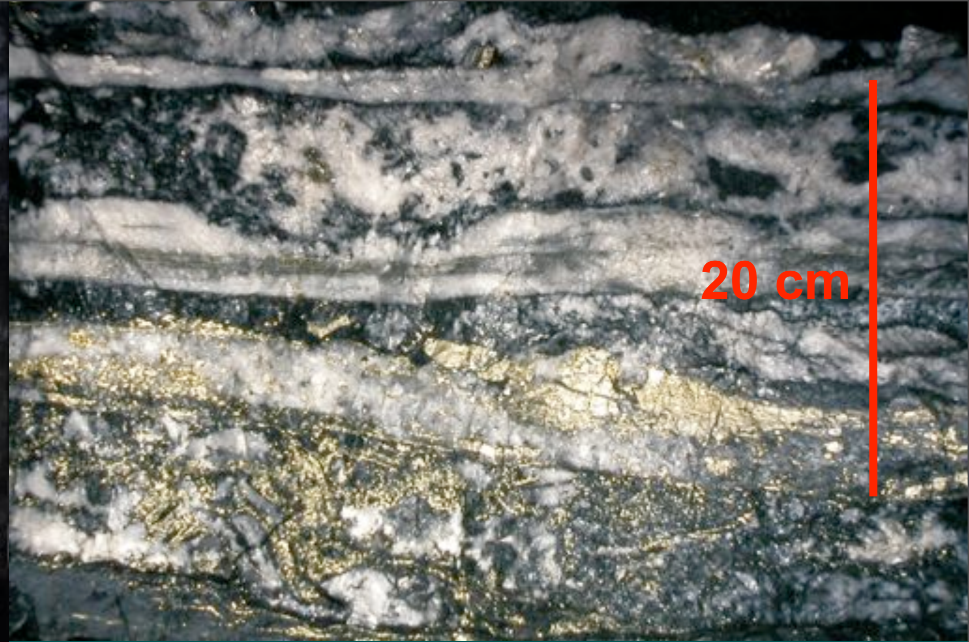
Influence of Extreme Fluid Overpressure

- tensile overpressure condition, $P_f > \sigma_3$

- mixed-mode brittle failure - shear failure in weak material interlinked by extension fractures in 'strong' material

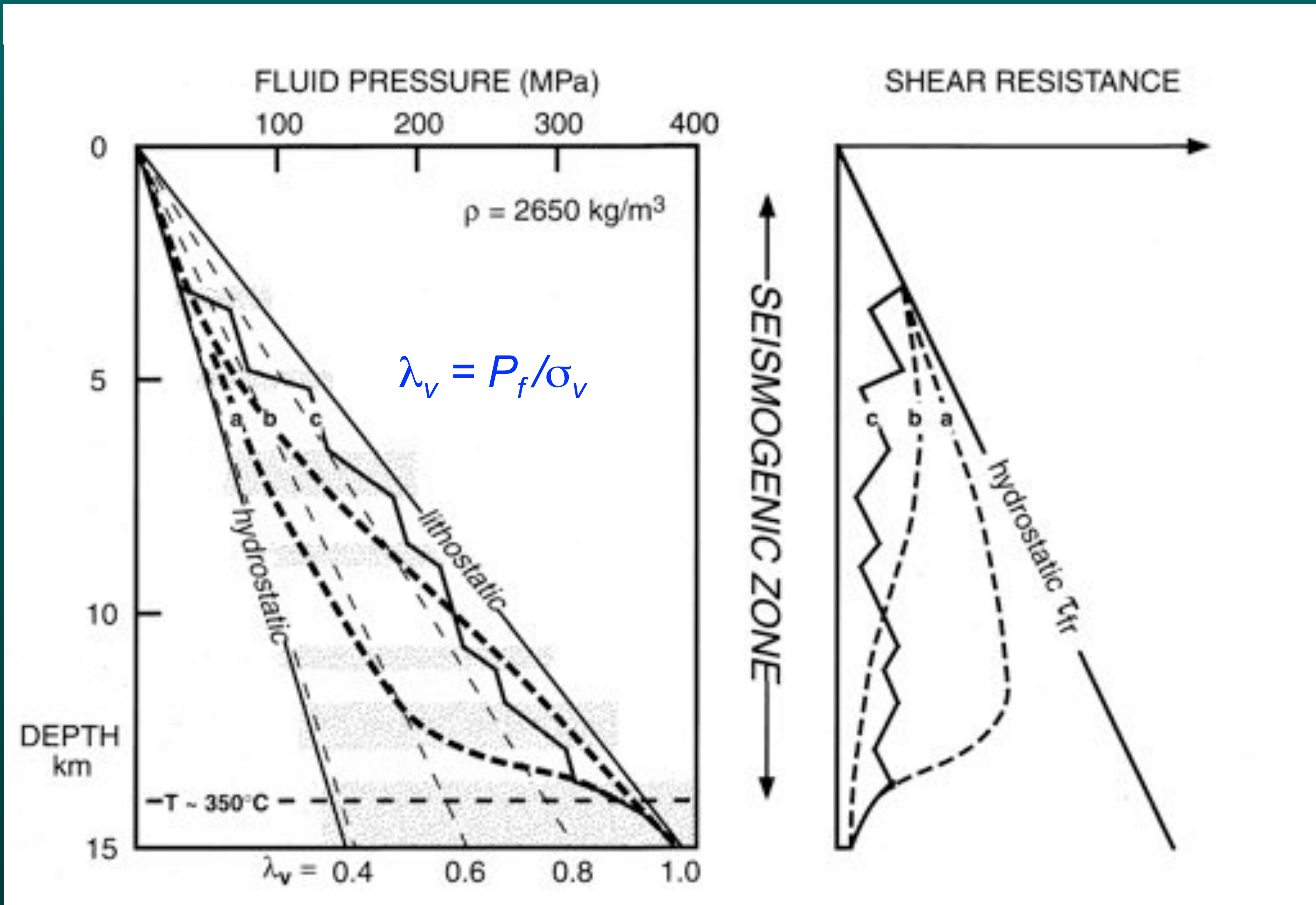
- chemical activity - dissolution and precipitation

- shearing accommodated by tabular fault-fracture meshes

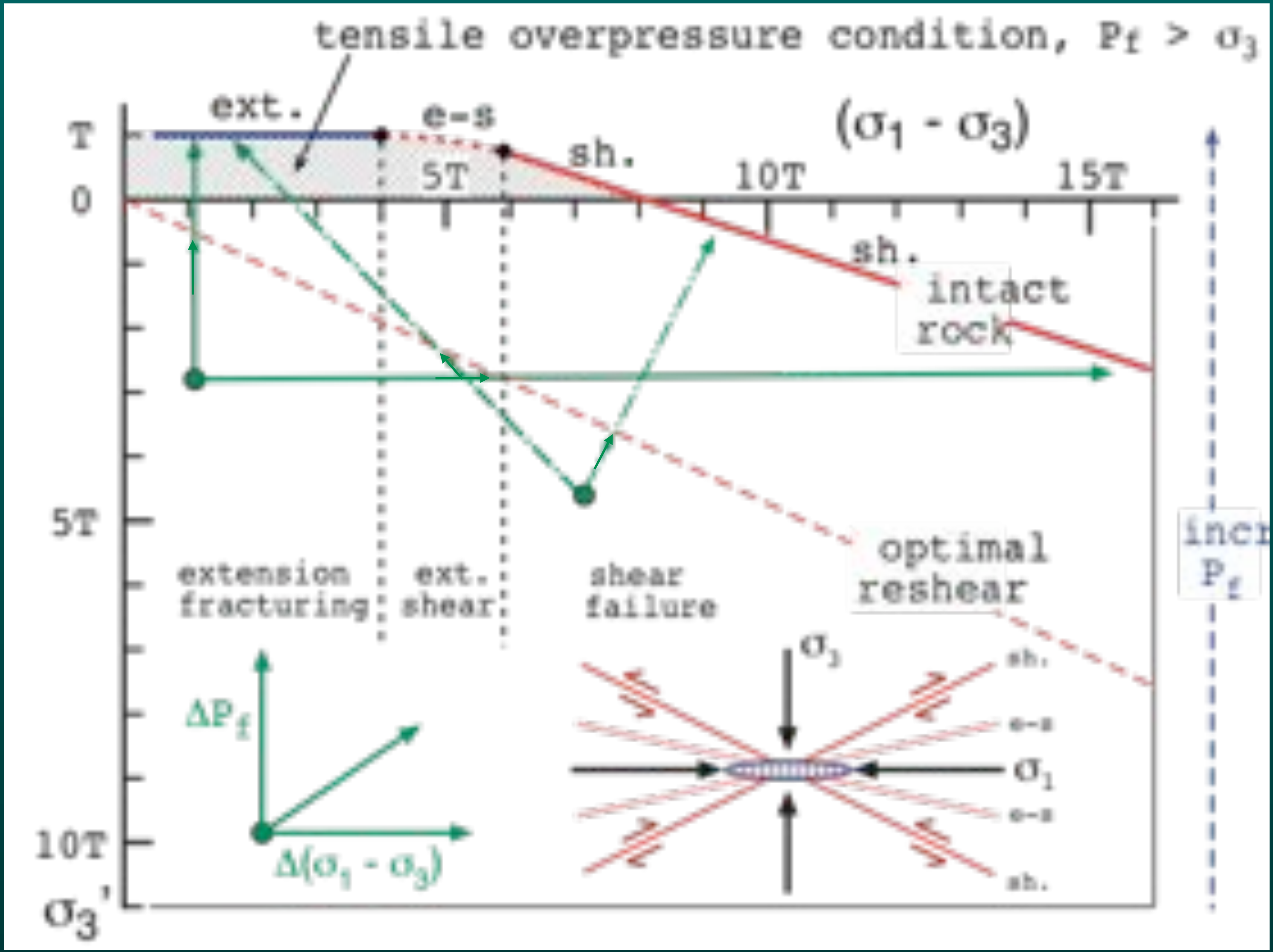


Overpressured Fluids Around the Base of the Seismogenic Zone

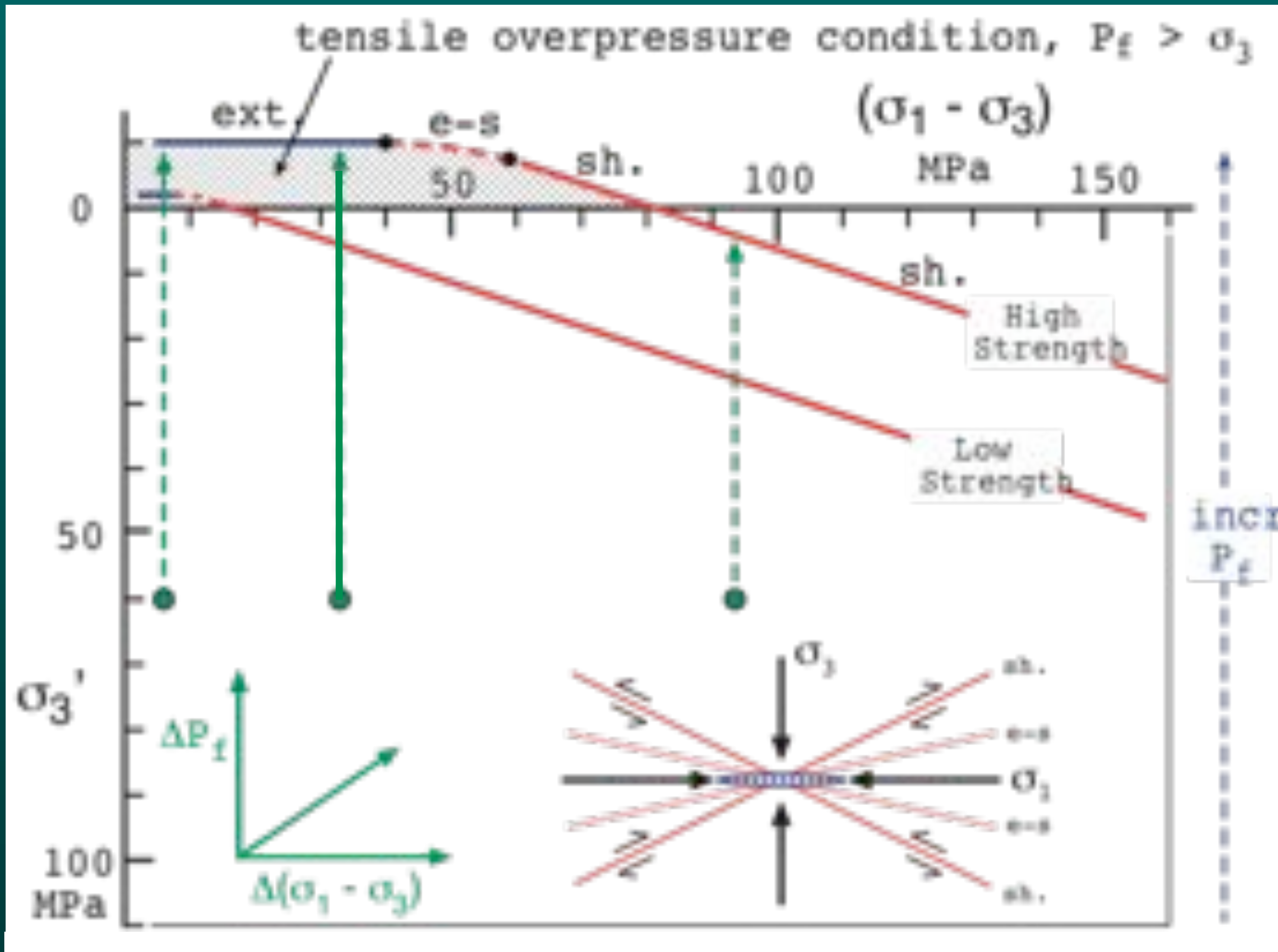
Fluid-Pressure Regimes and Frictional Fault Strength



Generic Brittle Failure Mode Plot
Normalised to Tensile Strength

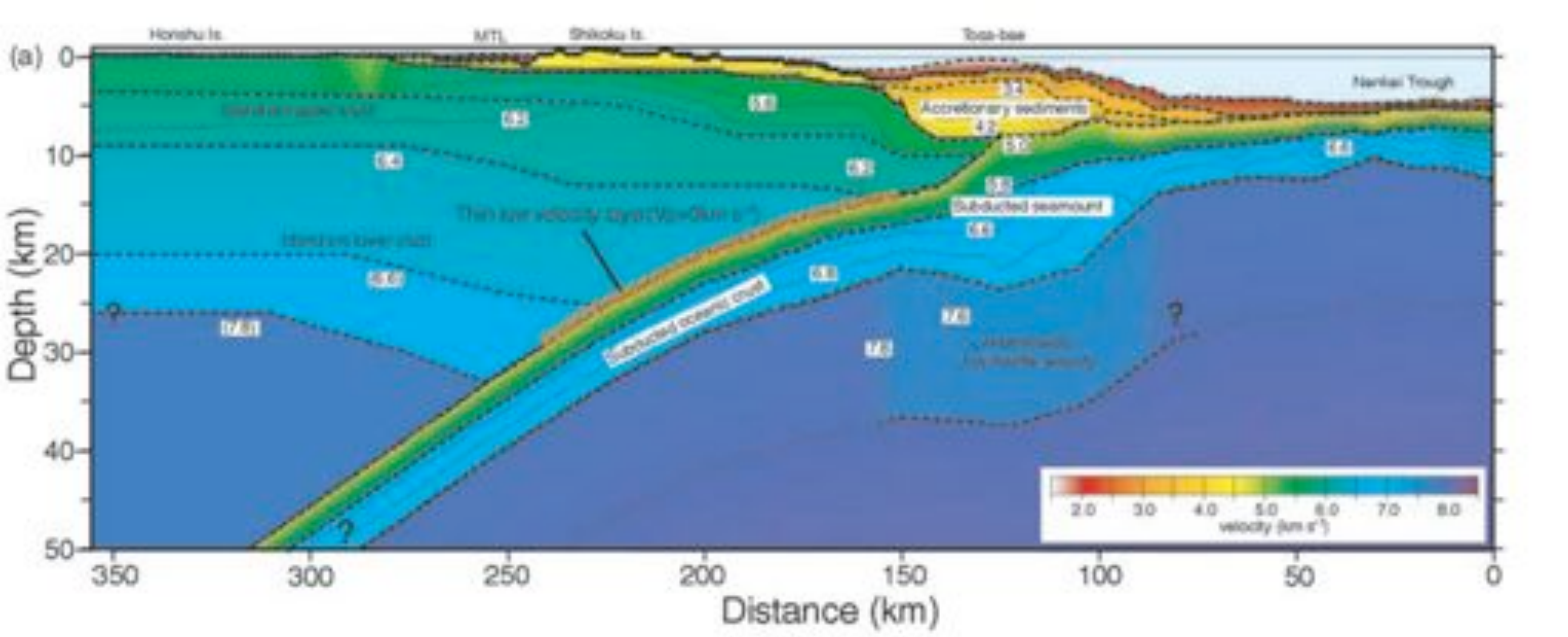


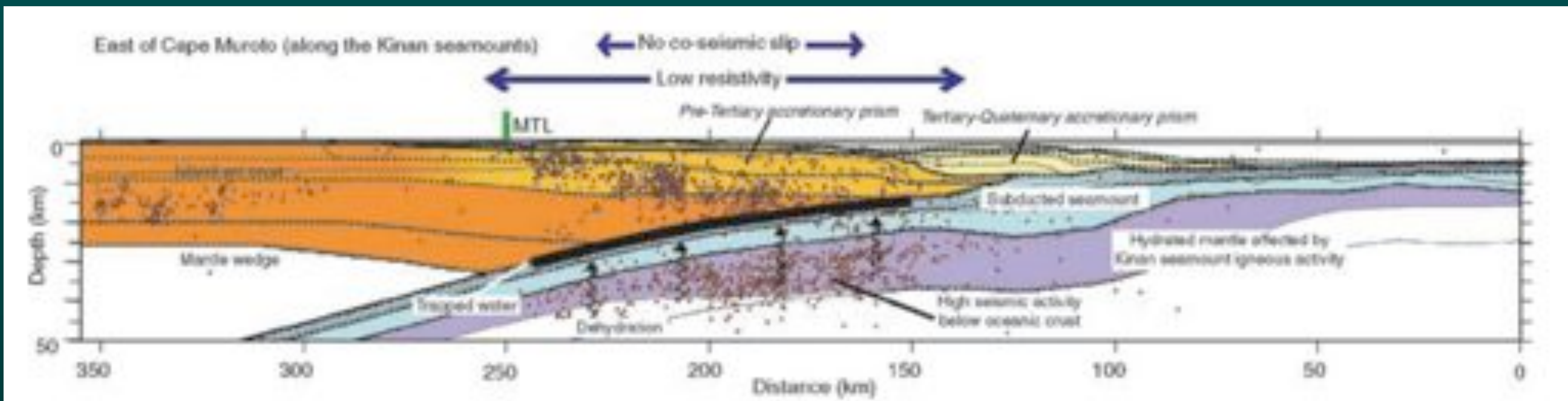
Mixed-Mode Brittle Failure



Seismogenic Thrust Interface

- *100-150°C < T < 350-450°C*
- *10 km < z < 35 km*
- *in very fine-grained rocks under high fluid-pressure, particulate flow, cataclastic fragmentation, and diffusive mass transfer become significant slow strain-rate mechanisms for ductile flow at T > 150°C*





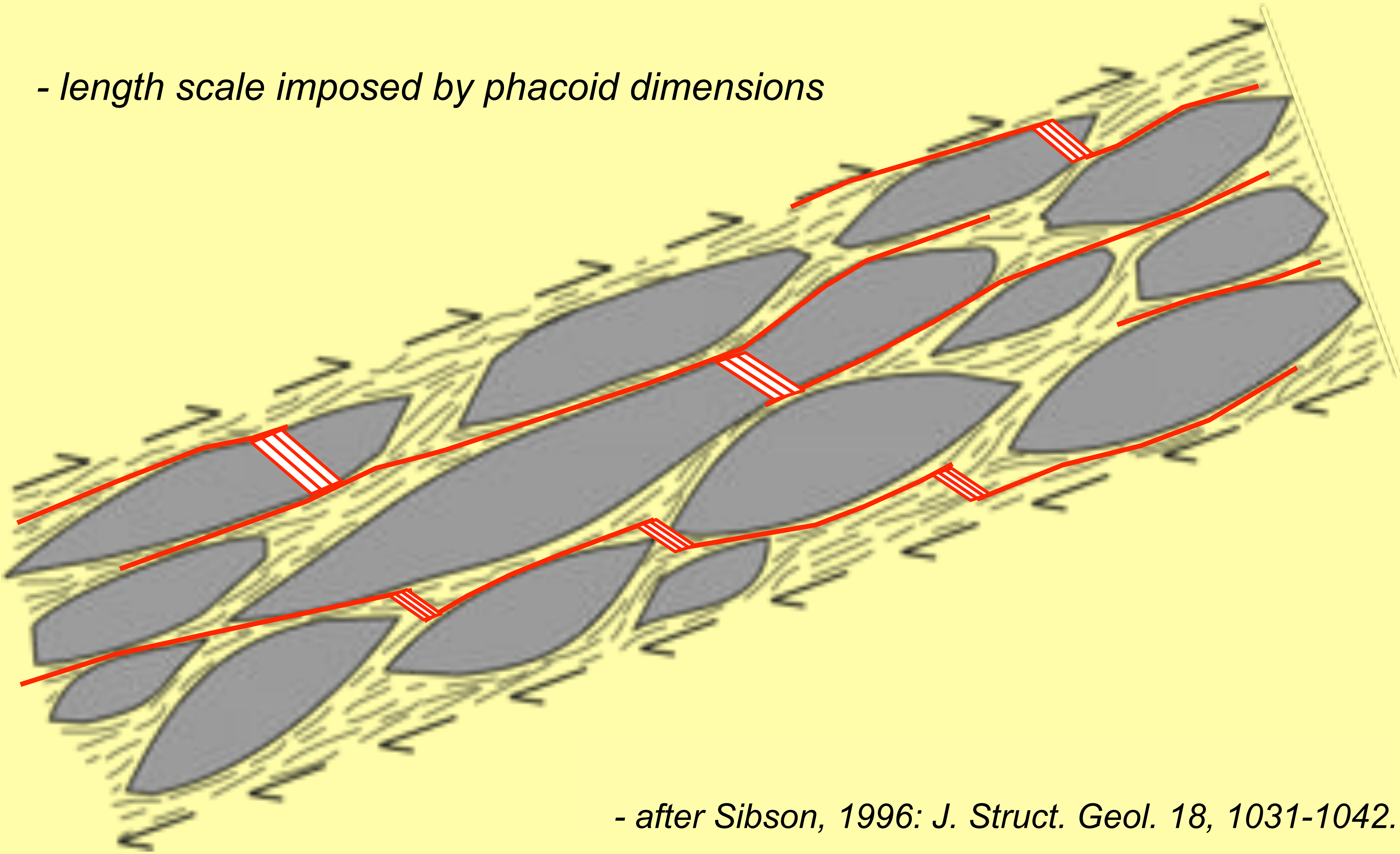
- *Kodaira et al., 2002: Geophys. J. Int. 149, 815-835*

Subduction Channel Shear Zones: Observations and Inferences

- *commonly 1-5 km thick*
- *anomalously high $V_p/V_s \Rightarrow$ fluid overpressured*
- *anomalously low V_p,*
- *high attenuation $\Rightarrow$ low Q_p*
- *distributed microseismicity?*
- *variable coupling between plates*
- *fluid-rich infill of trench sediments - predominantly sandstones and mudstones, plus ocean-floor cherts, fragments of oceanic crust, and seamounts*
- *mélange structure involving mixed discontinuous - continuous shearing*

Distributed Fault-Fracture Mesh from Mixed-Mode Failure in a Mélange

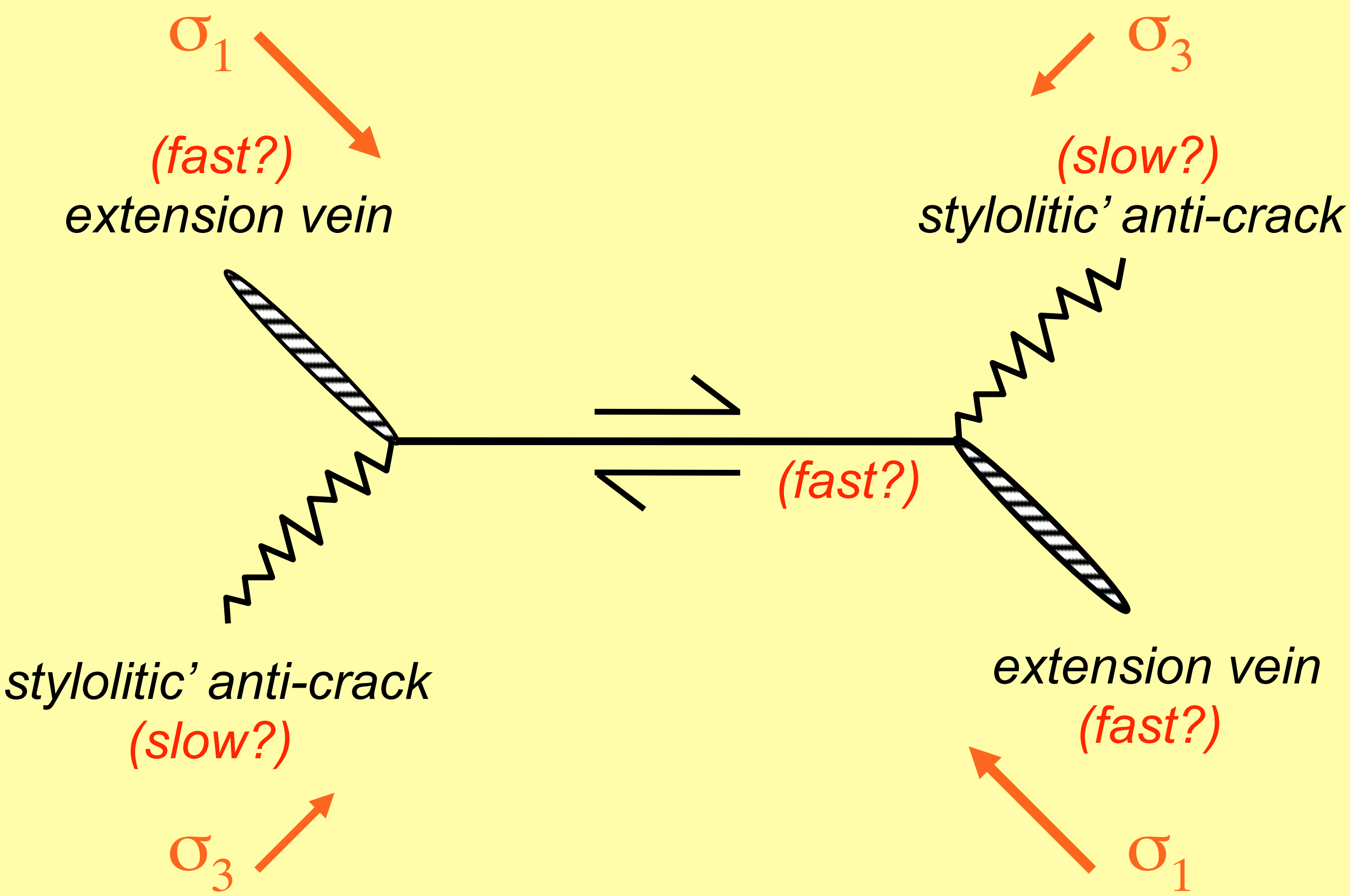
- length scale imposed by phacoid dimensions



- after Sibson, 1996: J. Struct. Geol. 18, 1031-1042.

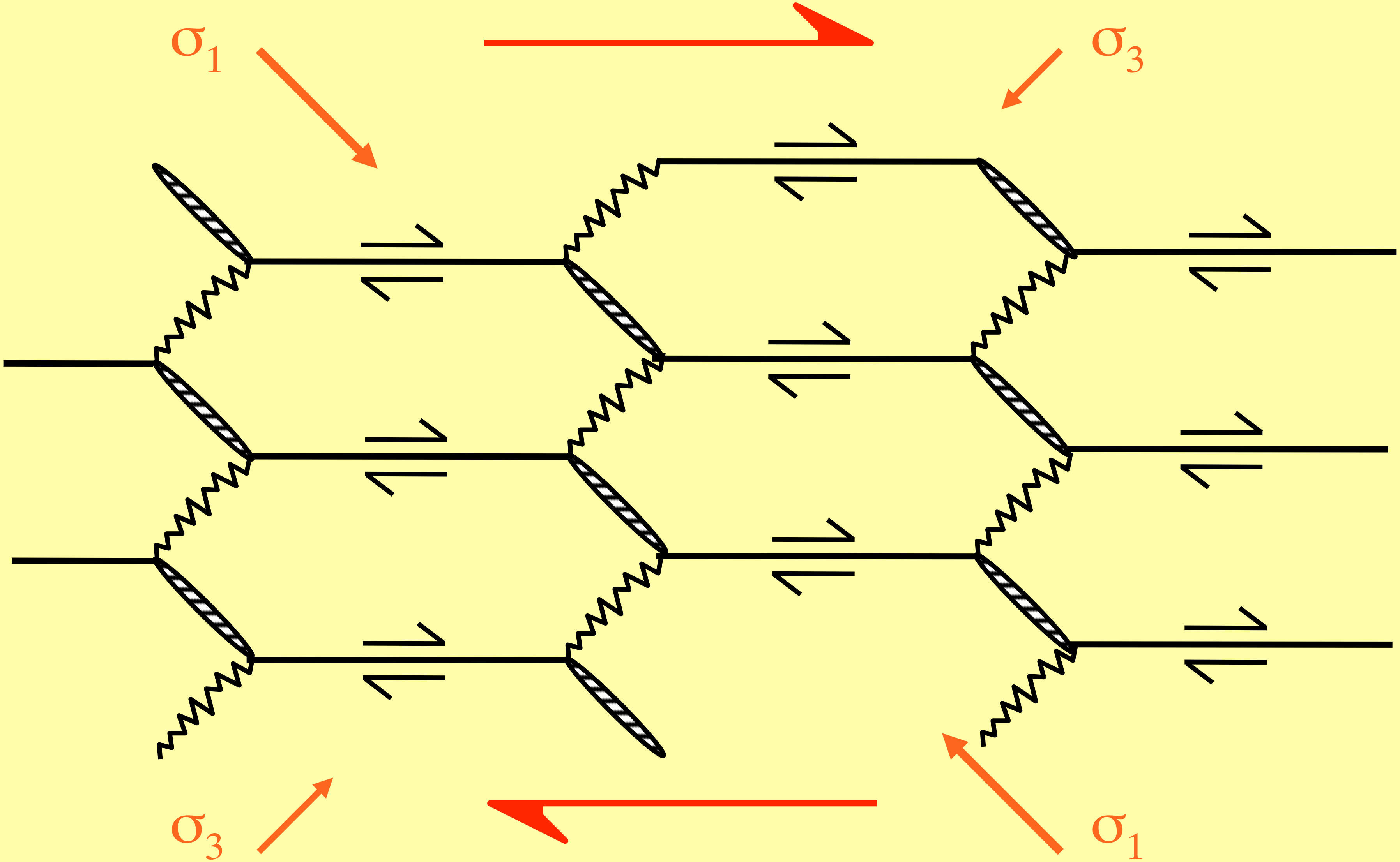
Cellular Shear Mesh in Solution Transfer Environment
(200-400°C in fine-grained siliceous metasediments)

'Unit cell' after Fletcher and Pollard, 1981: Geology 9, 419-424



Tensile Overpressure Condition $P_f > \sigma_3$ locally met through stress and fluid-pressure heterogeneity

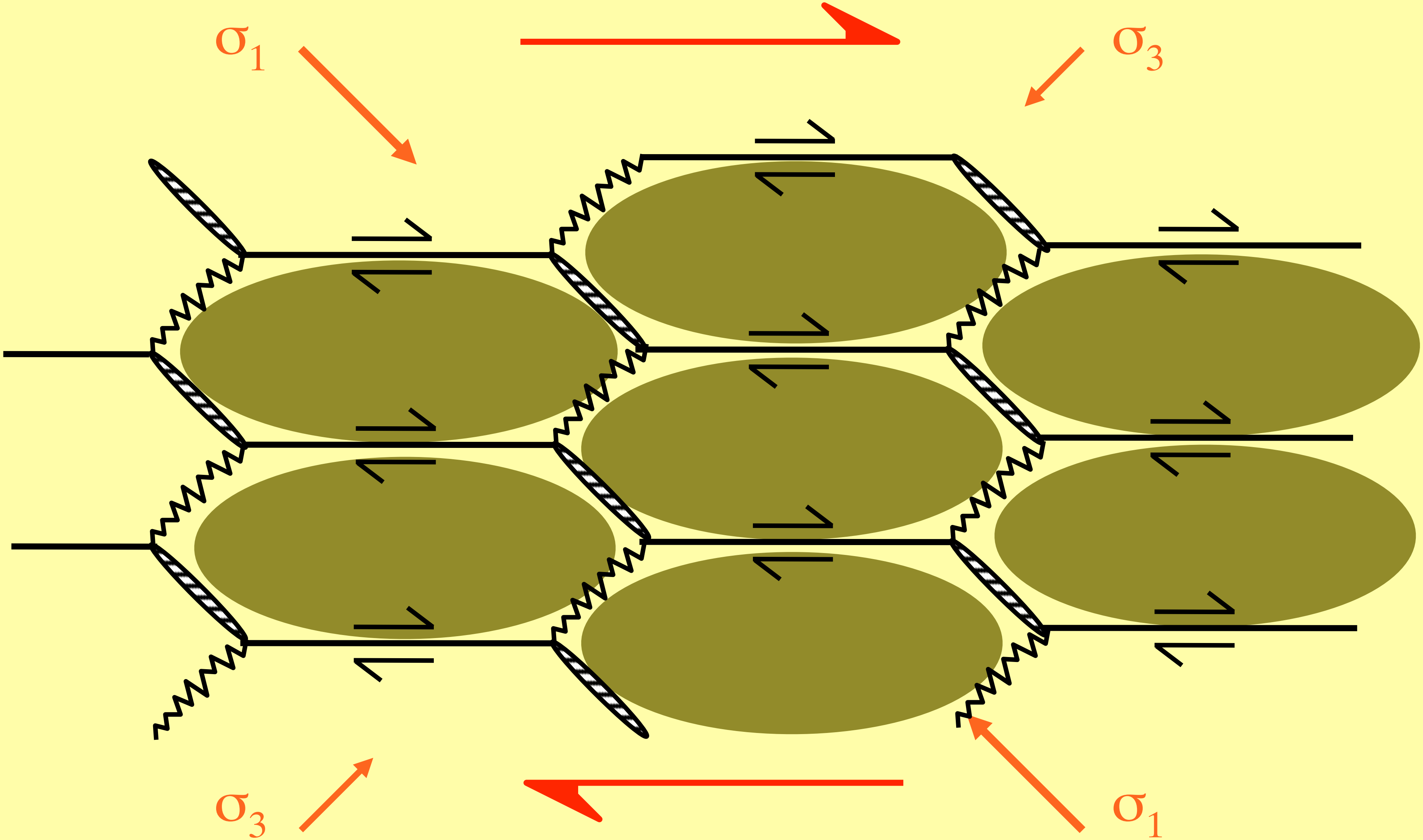
Cellular Shear Mesh in Solution Transfer Environment
(200-400°C in fine-grained siliceous metasediments)



- *unit cell after Fletcher and Pollard,1981: Geology 9, 419-424*

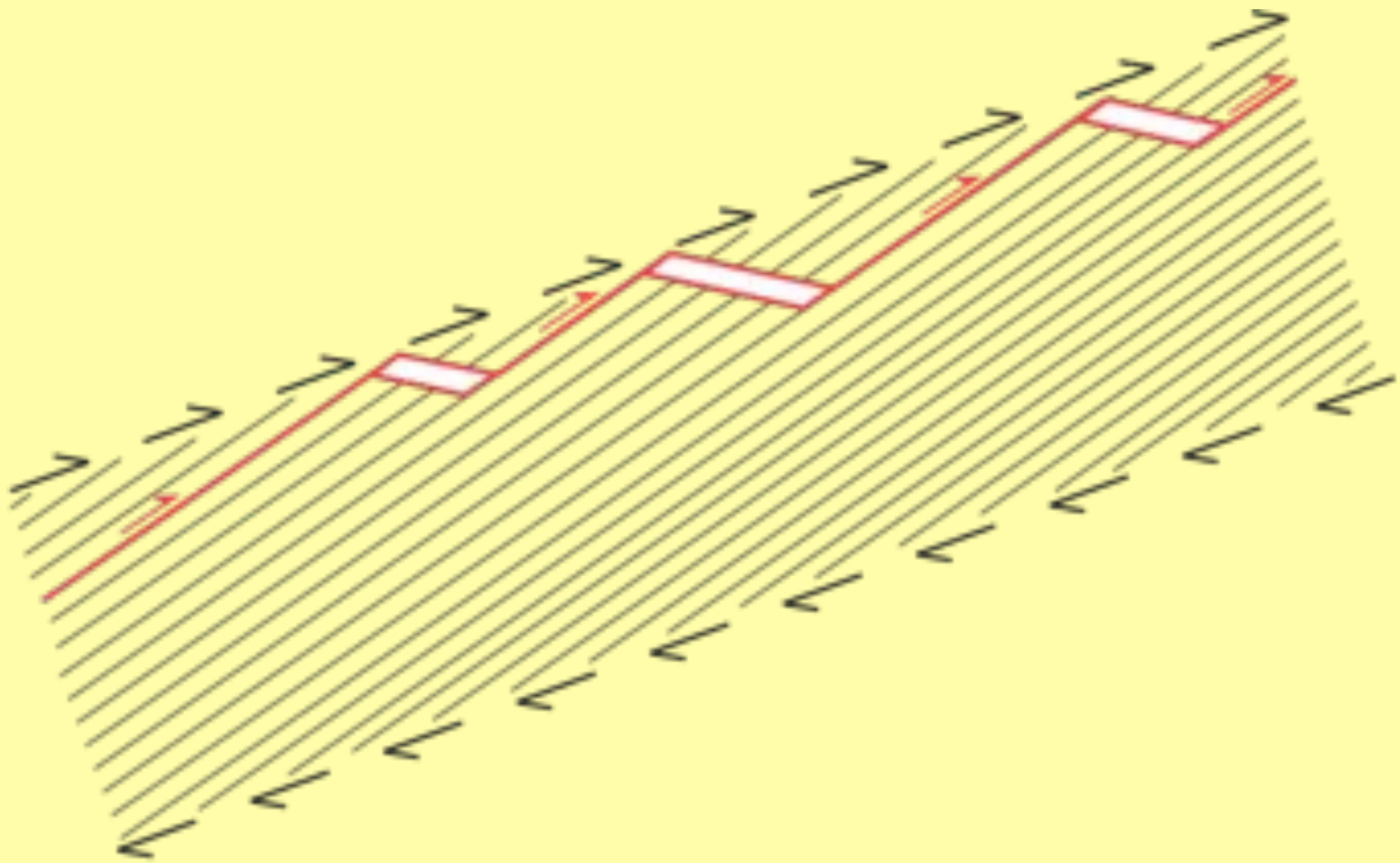
Monday, November 1, 2010

Cellular Shear Mesh in Solution Transfer Environment
(200-400°C in fine-grained siliceous metasediments)



- unit cell after Fletcher and Pollard,1981: Geology 9, 419-424

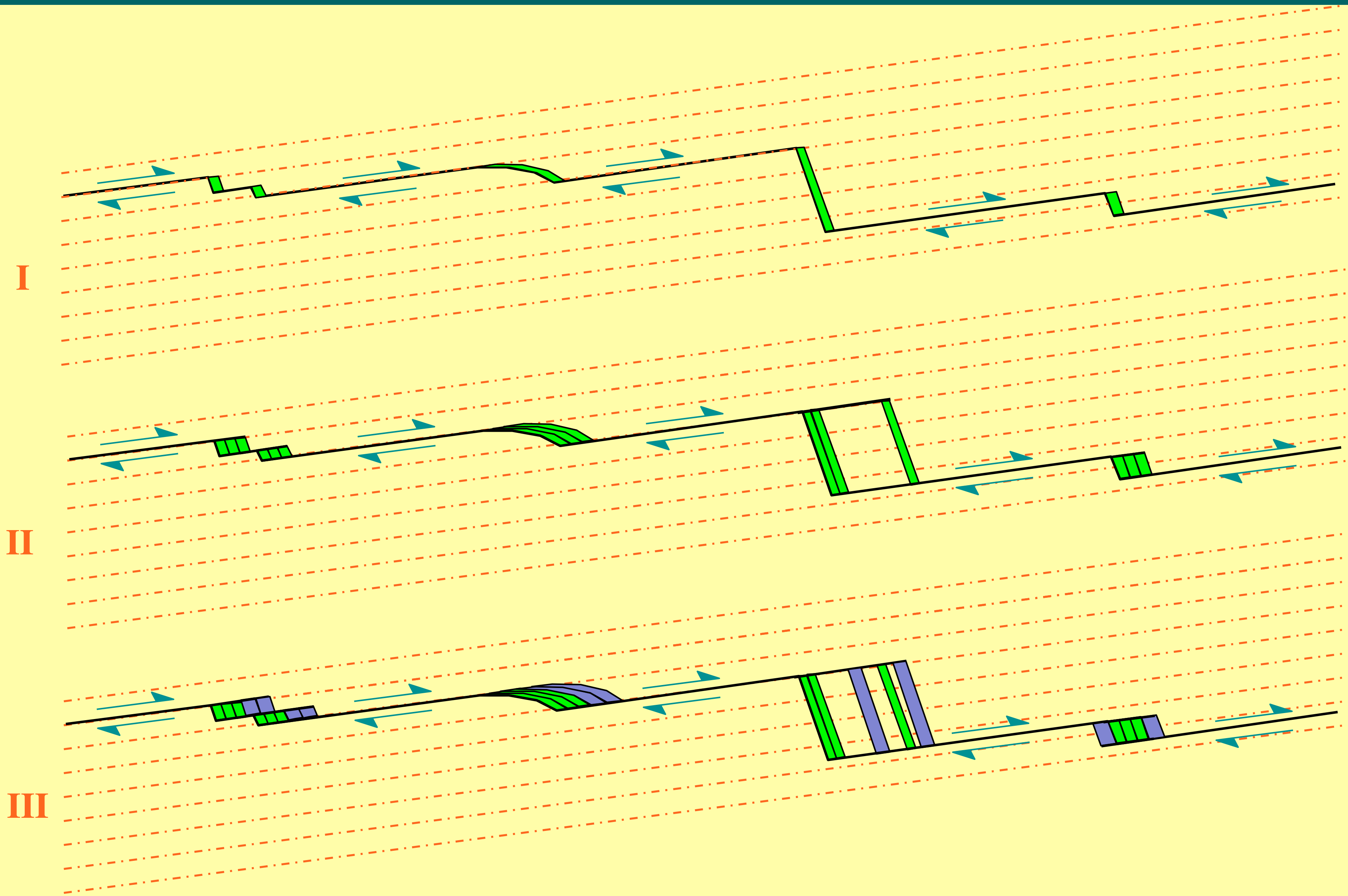
Rupture Deflection by Oblique Shear Zone Foliation to form Dilational Stepovers



Chrystalls Beach Complex, SE Otago

- *Late Triassic subduction-accretion complex*
- *exhumed subduction channel shear zone?*
- *Sandstone/mudstone > cherts, tuffs, local basaltic pillow lavas*
- *mélange structure - mixed discontinuous - continuous shearing*
- *250° < T < 300°C; 4.5 - 5.5 kbar, 18-22 km*

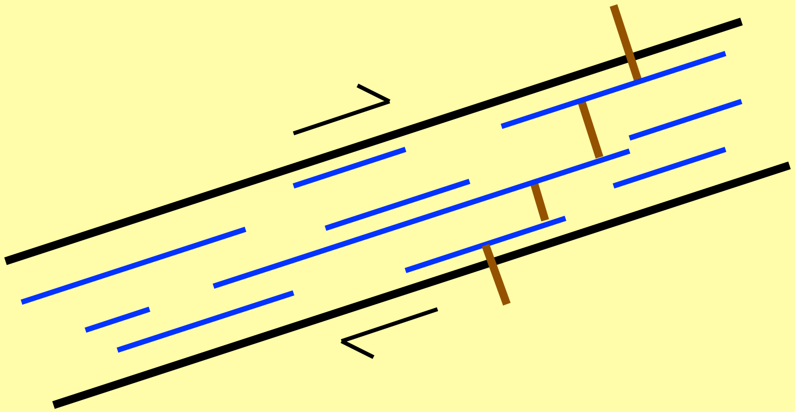
Incremental Growth Model



Under EXTREME FLUID OVERPRESSURE where the *tensile overpressure condition* *($P_f > \sigma_3$) is locally met, mixed-mode brittle failure becomes widespread in heterogeneous rock assemblages with shearing accommodated by tabular fault-fracture meshes involving varying degrees of extensional dilation*

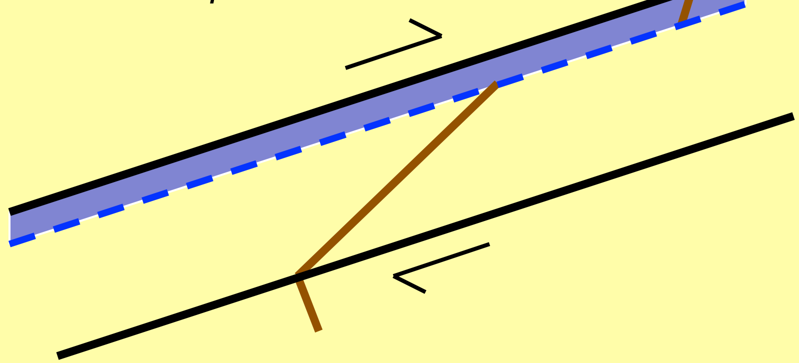
Volumetric Shear Zone Models

MULTIPLE DISCONTINUITIES

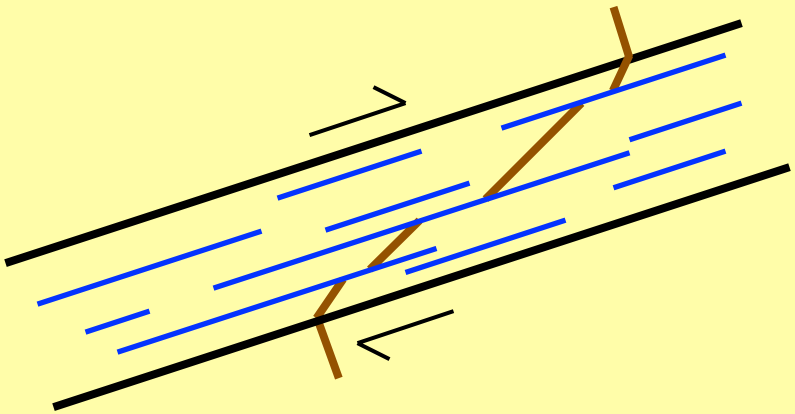


MIXED CONTINUOUS-DISCONTINUOUS S.Z.

dominant planar discontinuity localised
at base of impermeable seal ?

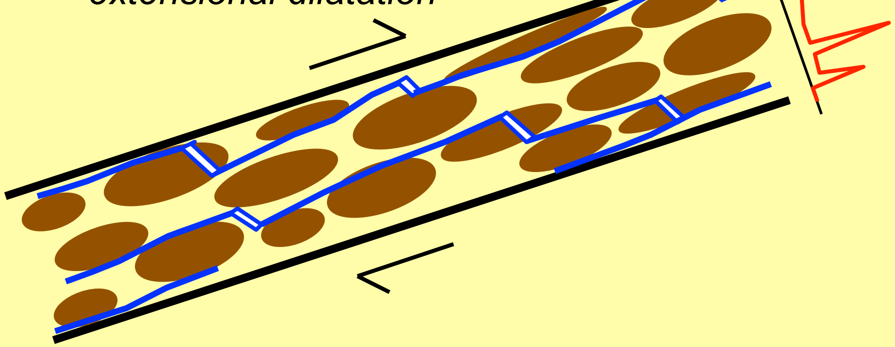


MIXED CONTINUOUS-DISCONTINUOUS S.Z.

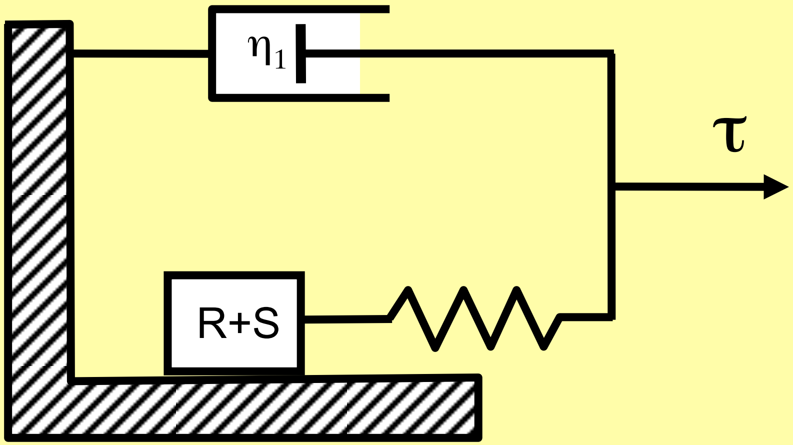


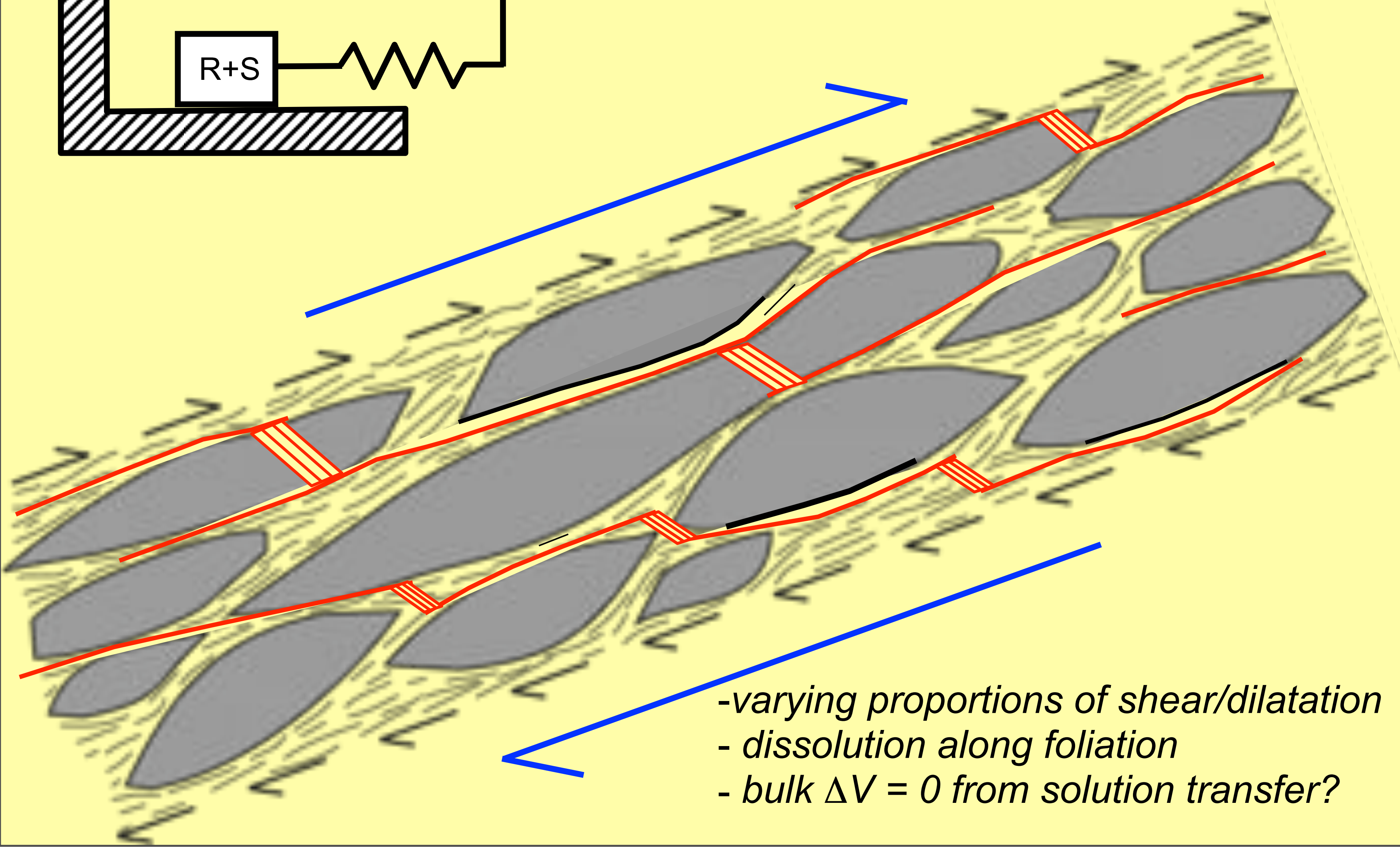
MIXED COMPETENCE MÉLANGE S.Z.

locally intense strain-rates
→ brittle discontinuities
tensile overpressuring
→ extensional dilatation



Damped Stick-Slip in a Fault-Fracture Mesh within a Tabular Shear Zone





-varying proportions of shear/dilatation
- dissolution along foliation
- bulk $\Delta V = 0$ from solution transfer?

Asperity Models for SCSZ

- *Seamounts (Cloos, 1992)*
- *Irregular wall contacts SCSZ*
- *Competence / Incompetence > c. 80% ? - log jams*
- *Marginal localisation*
- *local fluid pressure lows within s.z. - drain-off regions*