Fluids and earthquakes in the forearc region of subduction

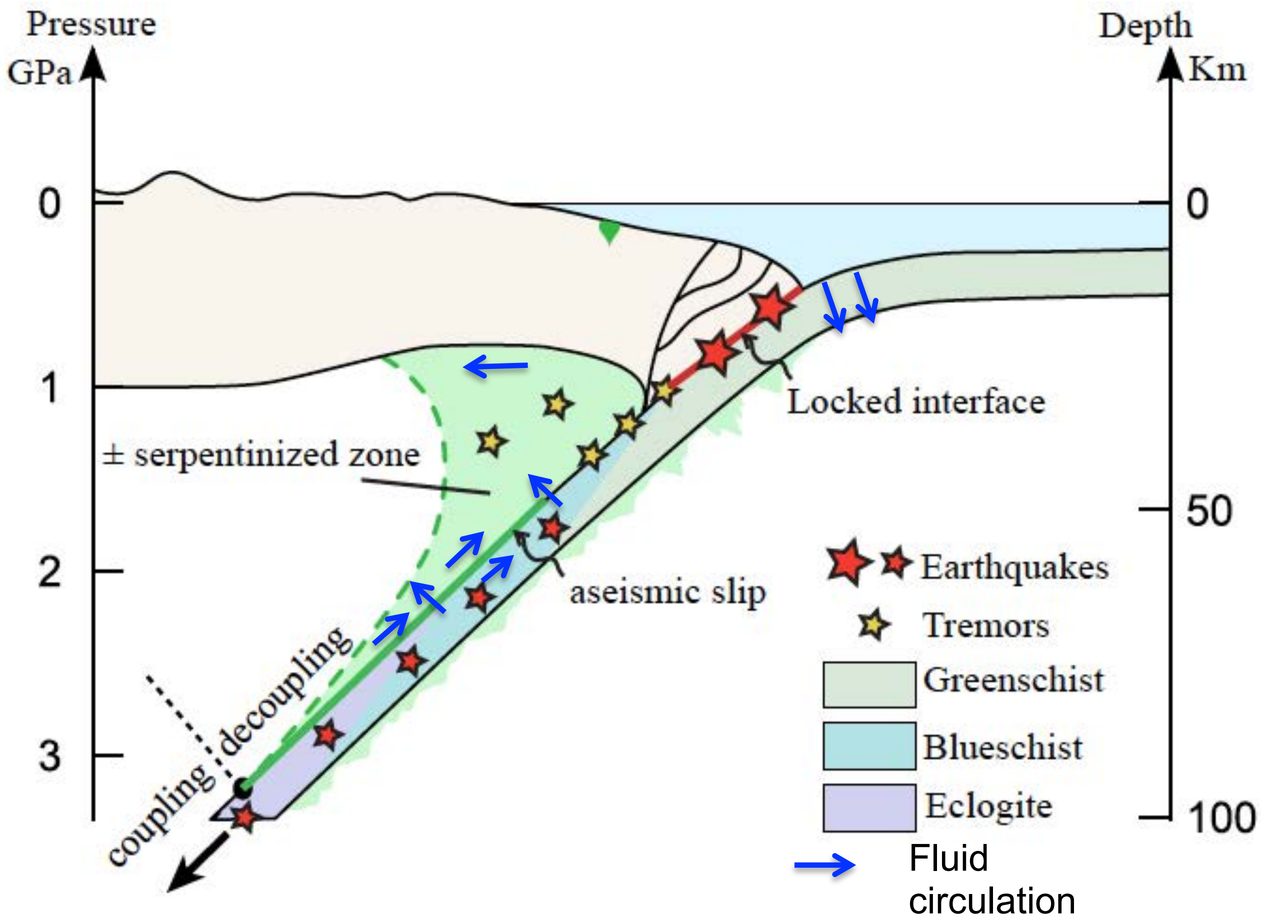
B. REYNARD
A.C. GANZHORN, H. PILORGÉ

ECOLE NORMALE SUPÉRIEURE DE LYON, CNRS, UNIVERSITÉ DE LYON, FRANCE

Fluid-rock interactions in subduction zones

Fluids released by the dehydrating plate:

- generation of earthquakes T<700°C in the forearc region
- melting and arc volcanism T>700°C



After Kirby et al. (1996); Shelly et al. (2006); Wada et al. (2008); Reynard (2013).

Fluid-rock interactions in subduction zones

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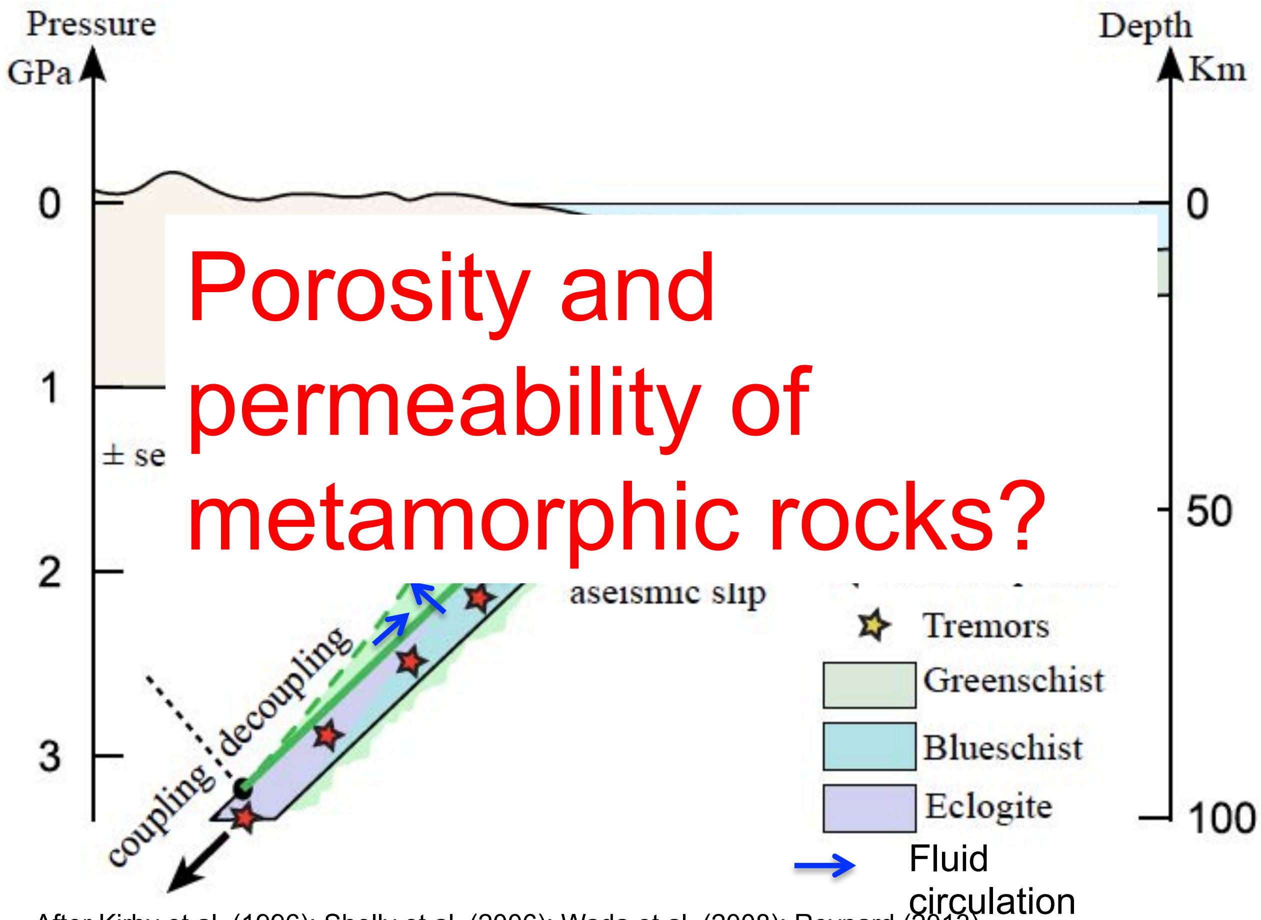
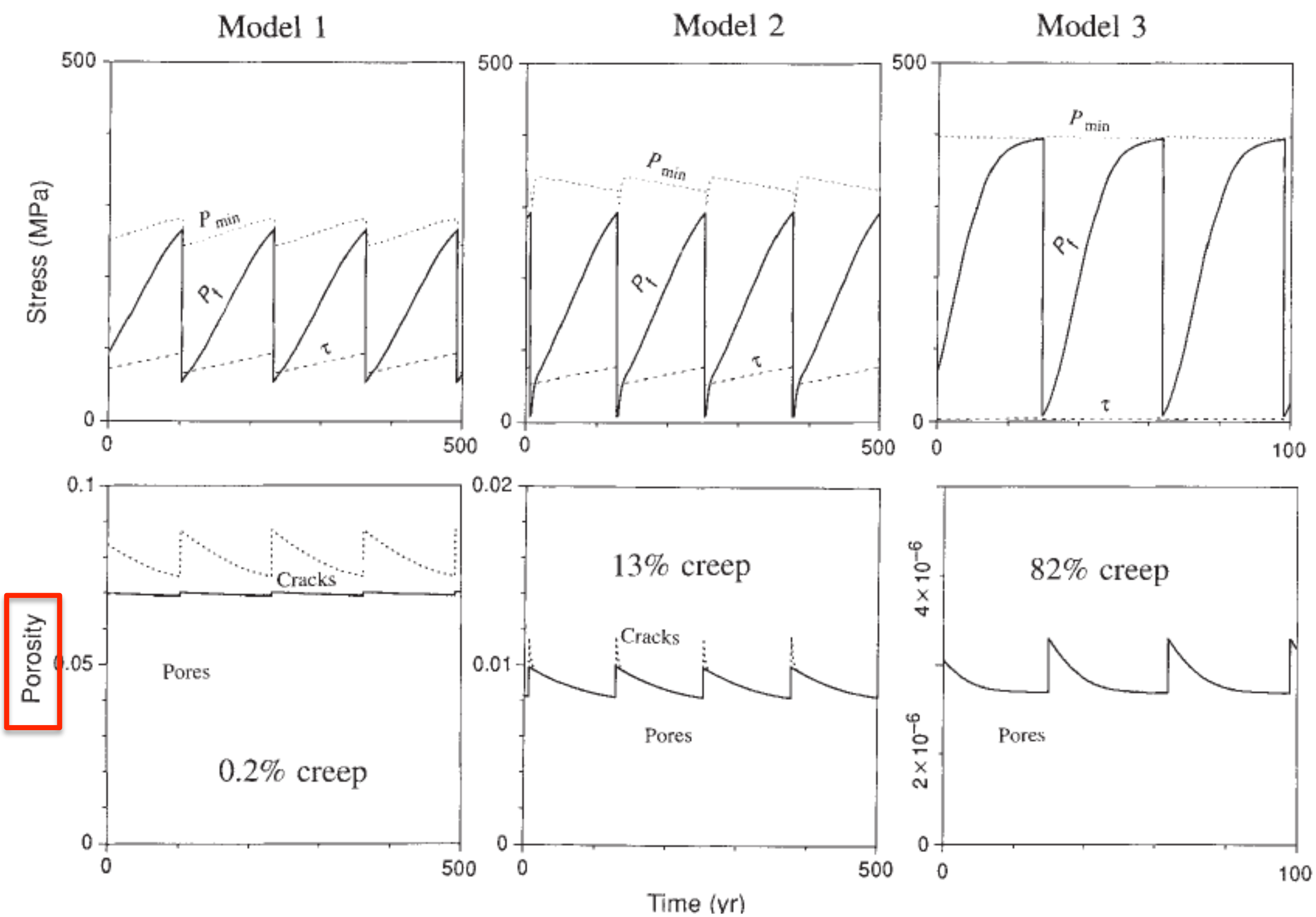


After Kirby et al. (1996); Shelly et al. (2006); Wada et al. (2008); Reynard (2013).

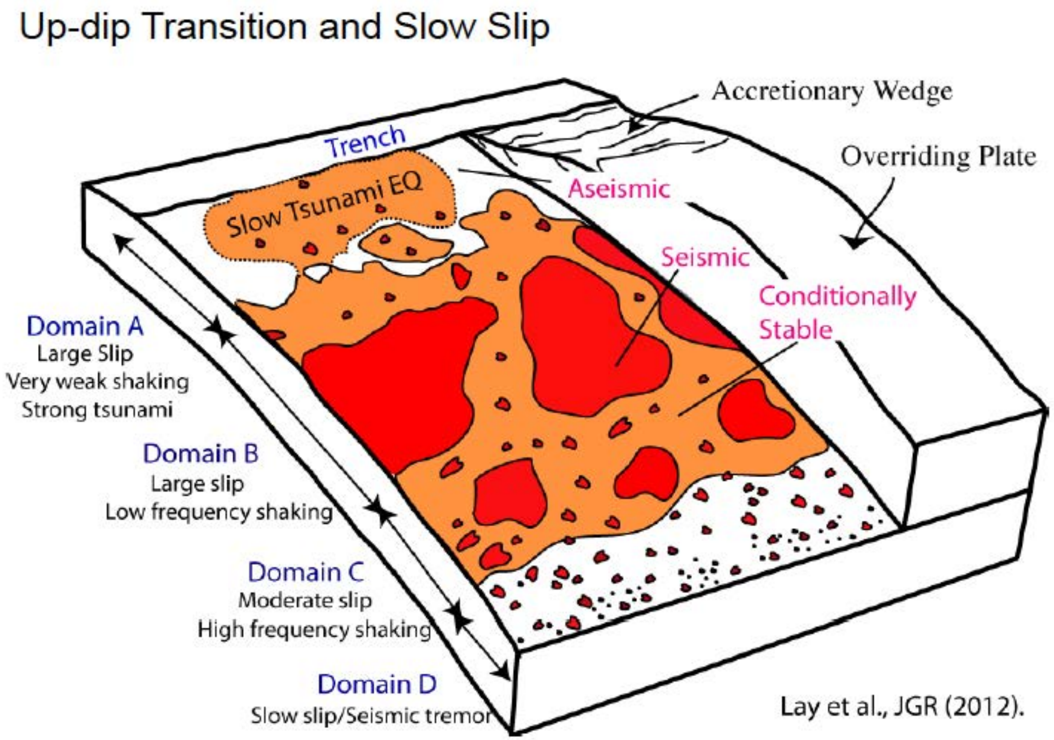
Fluids are likely involved in earthquake cycle

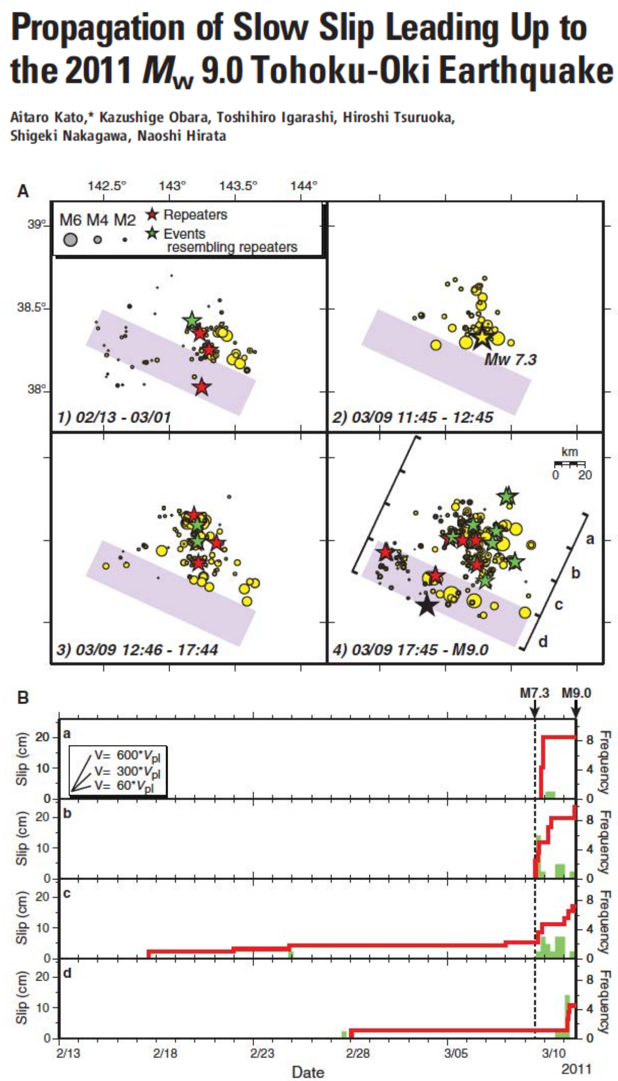
(Sibson, 1981; Sleep & Blanpied, 1994)



Sleep & Blanpied (1994)

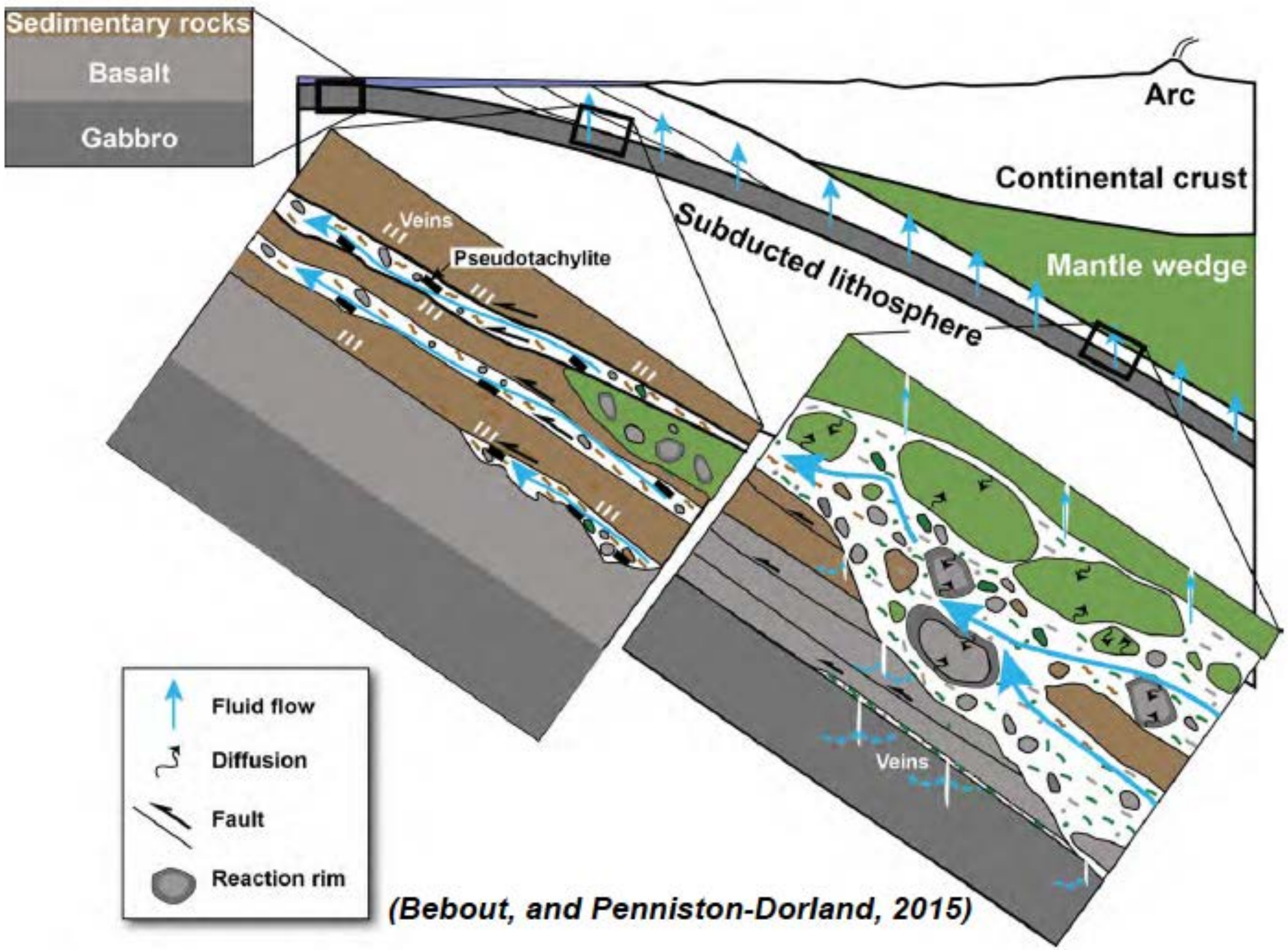
Fluids are likely involved in earthquake cycle





Fluids are likely involved in slow seismicity (LFE, ETS, SSE, SE, …)
Precursors of large megathrust earthquake?

Complex petrologic and metamorphic context

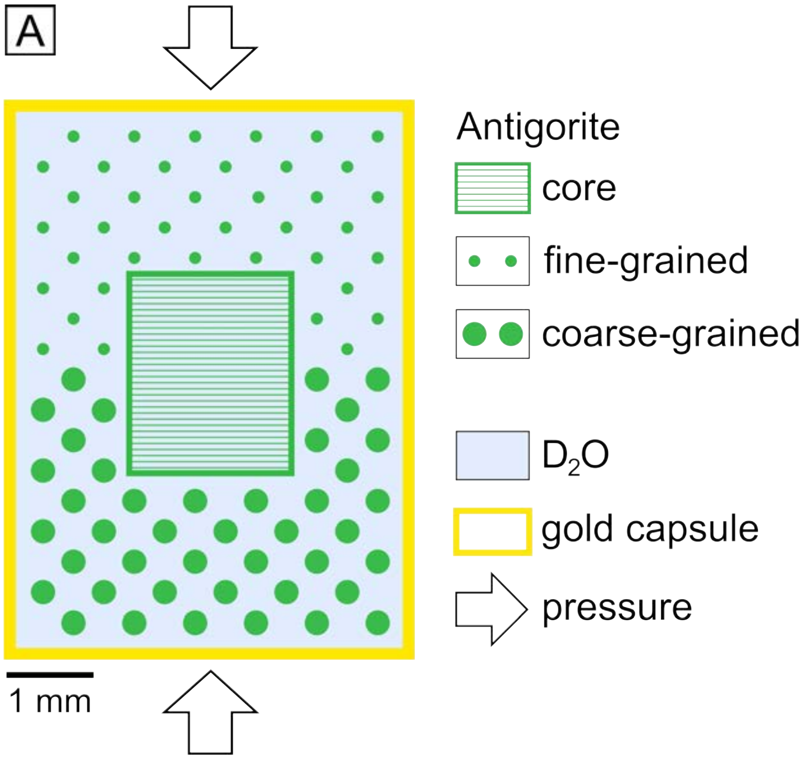


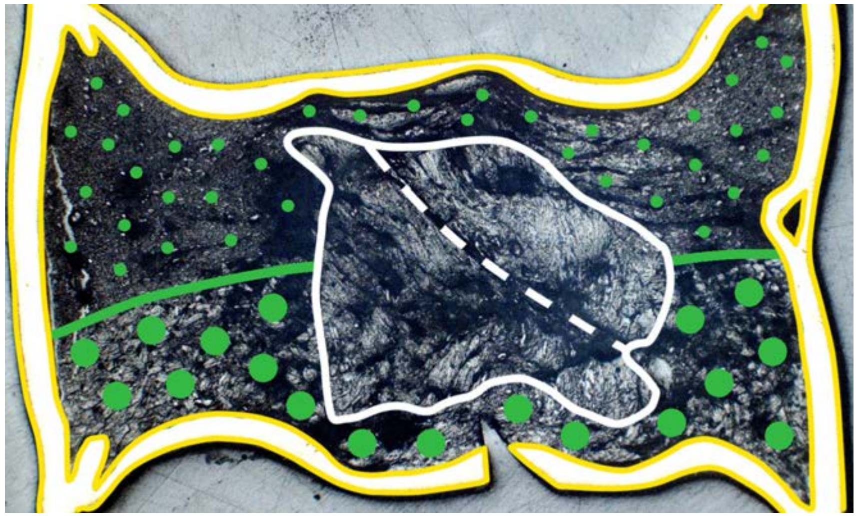
(Bebout, and Penniston-Dorland, 2015)

Monviso Alps

Track fluid interactions with minerals and rocks

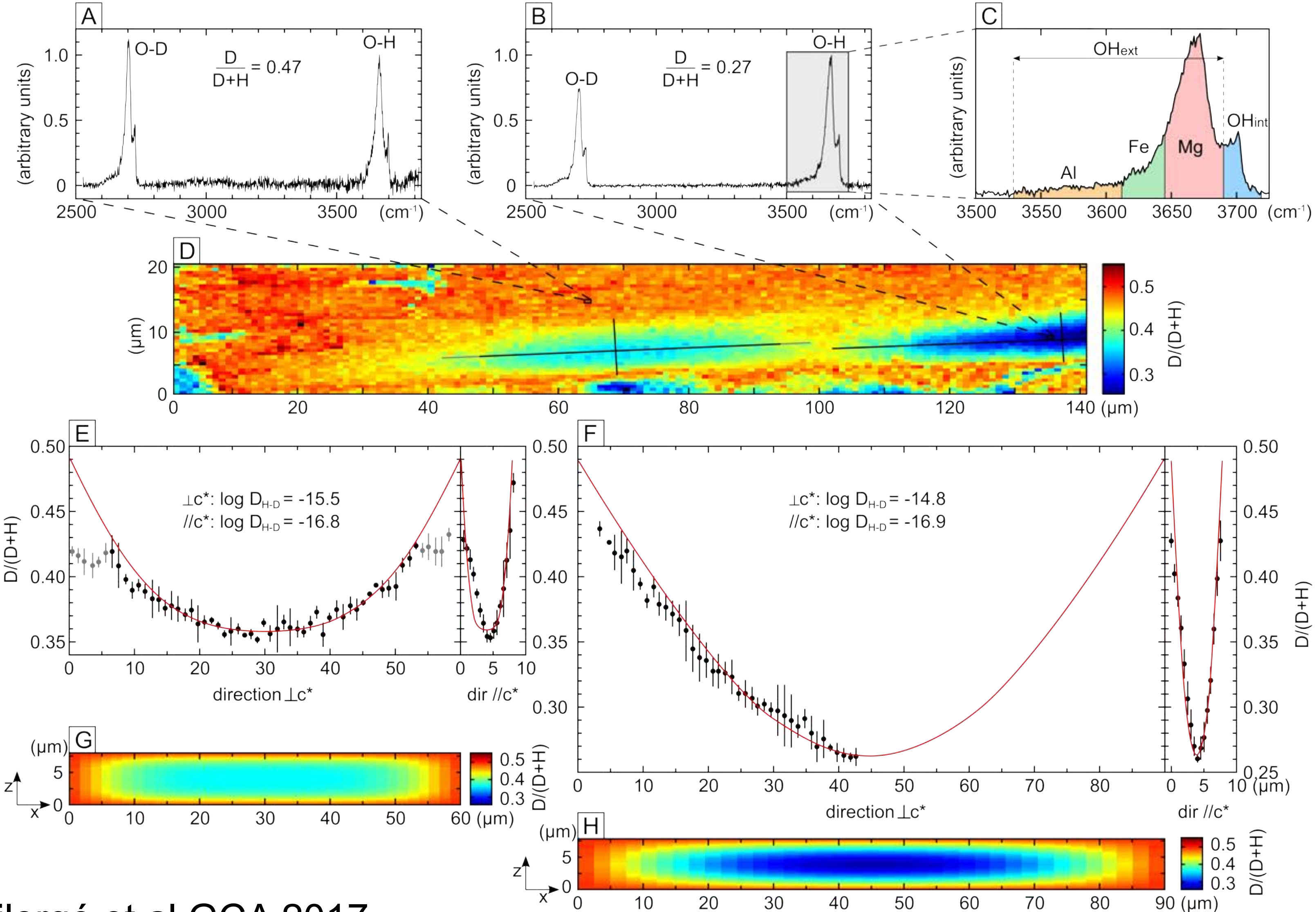
HP experiments Belt press 1.5-3 GPa 300-700°C





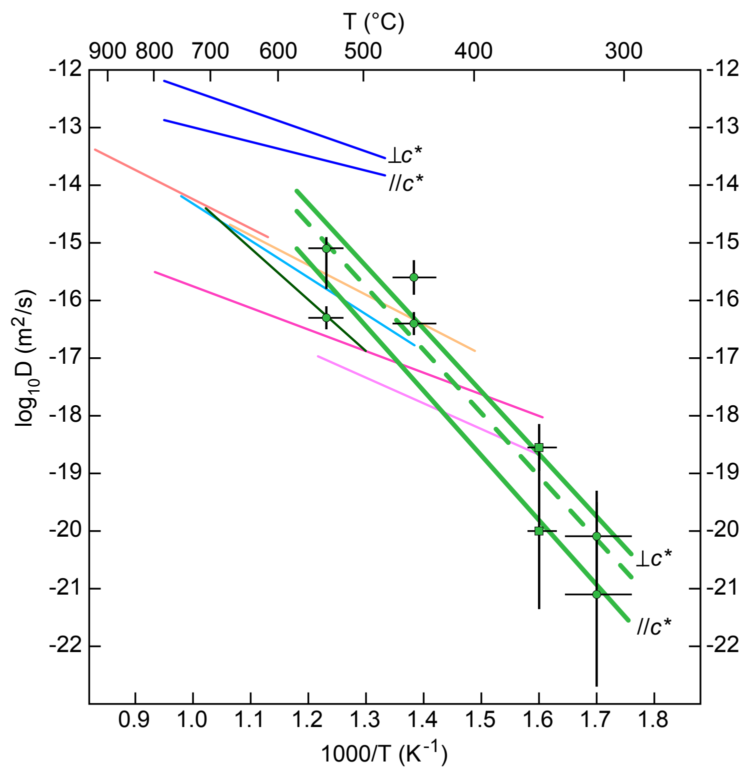
Fluid/rock interaction is elusive: isotopic tracer D/H
Raman mapping of D/H ratio in H-bearing minerals

Raman imaging (540°C)

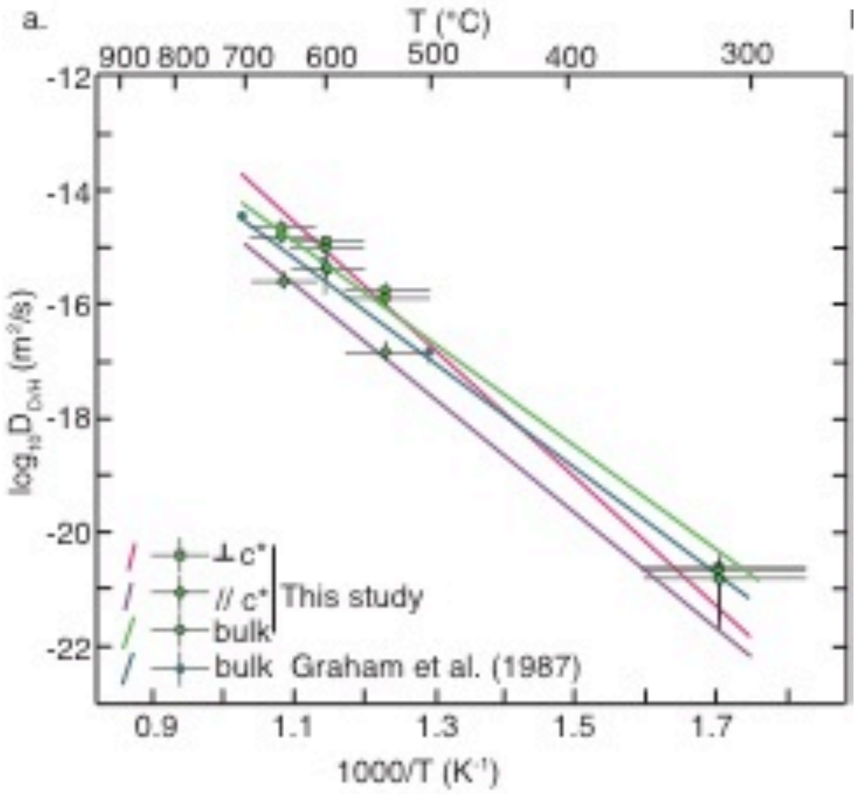


Pilorgé et al GCA 2017

Arrhenius laws for D/H solid state diffusion in hydrous minerals



Antigorite Pilorgé et al GCA 2017

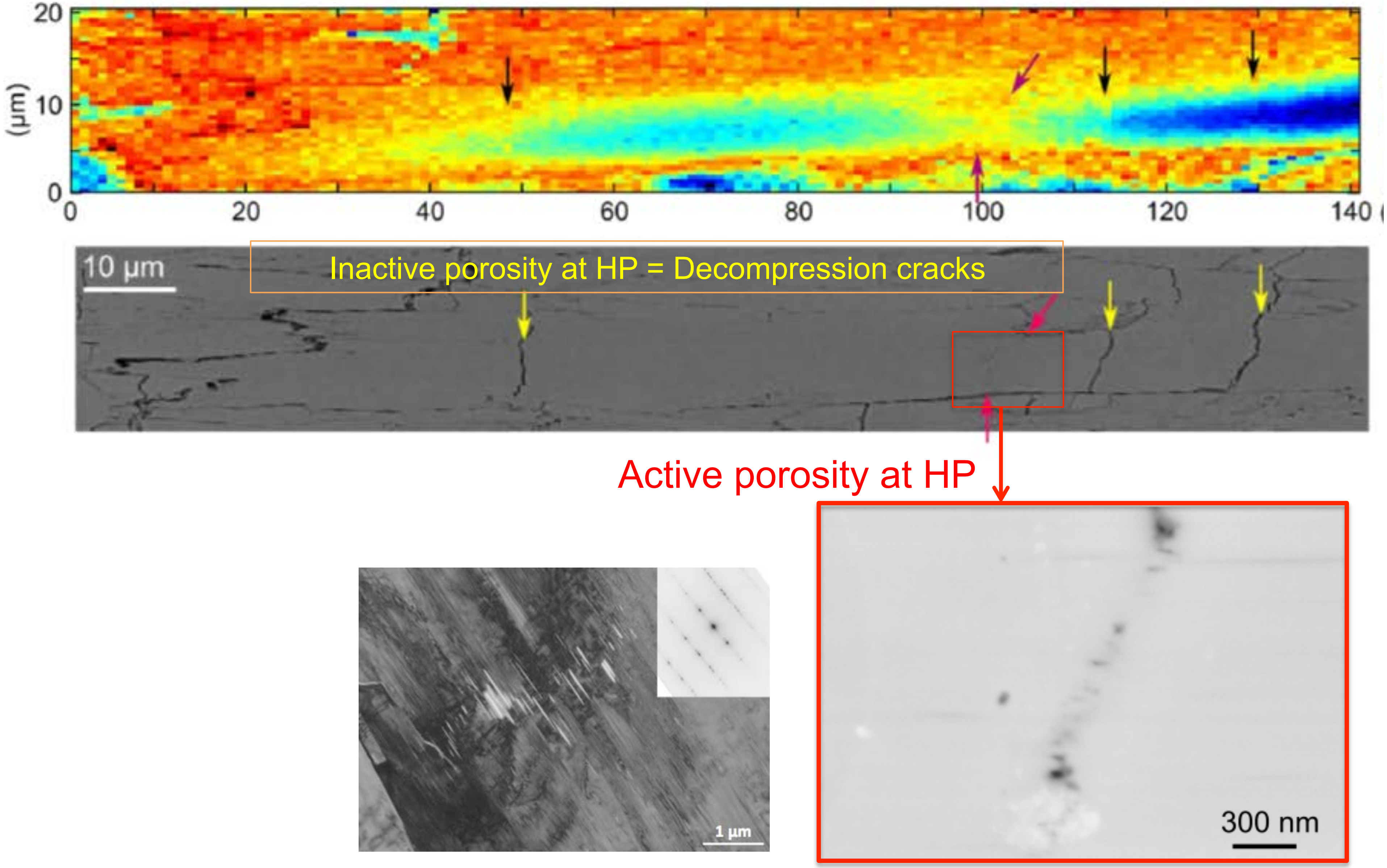


Chlorite Ganzhorn et al CG 2018

High activation energies ~ 170 kJ/mol instead of <130 kJ/mol for other minerals

Reinvestigation of D/H diffusion in Ca-Al hydrous phases and amphiboles

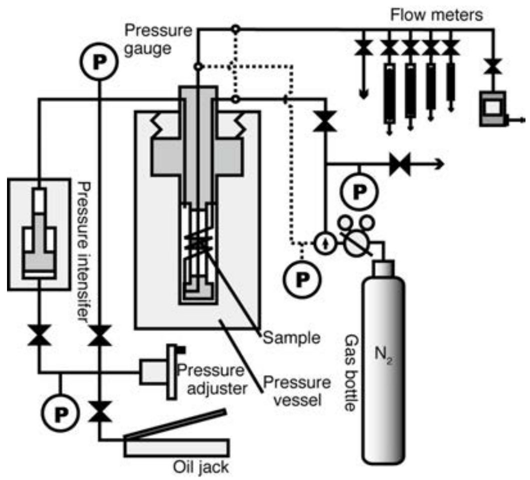
From D/H ratio to active porosity at HP-HT



What do we know about rock porosity in subduction zone?

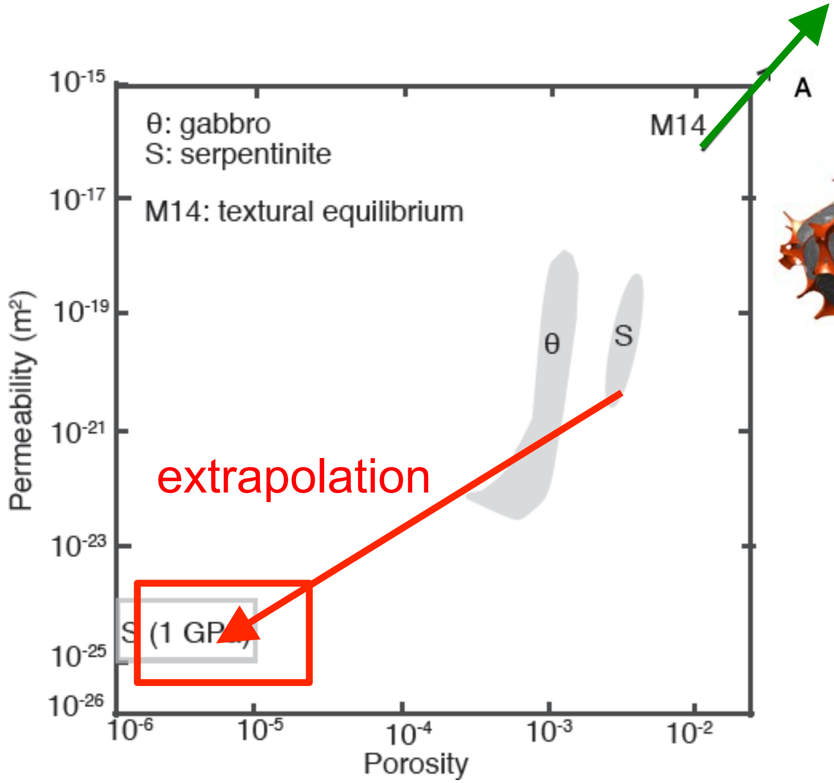
low pressure (<50 MPa) measurements for serpentinites and gabbro (Katayama et al., 2012 ; Kawano et al., 2011)

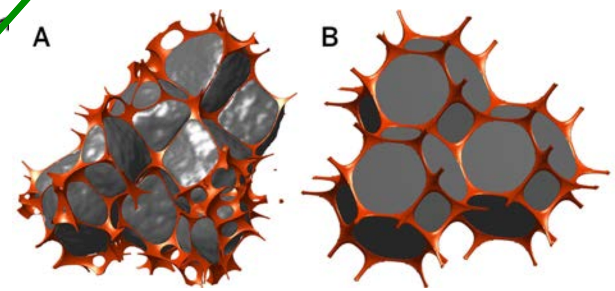
textural equilibrium experiments 1 GPa (e.g. Wark & Watson, 1998; Miller et al., 2014).



Low P, room T

No fluid reactivity





High T (>800°C) to reach equilibrium texture

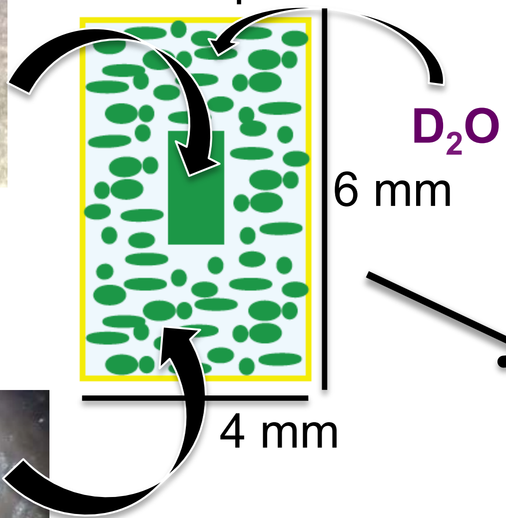
Little anisotropy assumed

Domain of interest : 100 < T < 700°C, 0.1 < P < 3 GPa
Highly anisotropic minerals (clays)

Our approach: HP experiment with isotopic tracer (D) diffusion

Natural rock chip/core

Gold capsule

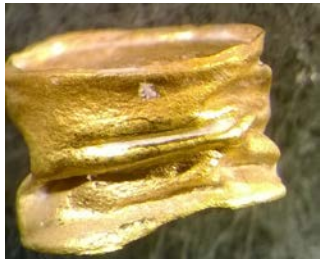


Powder of natural rock

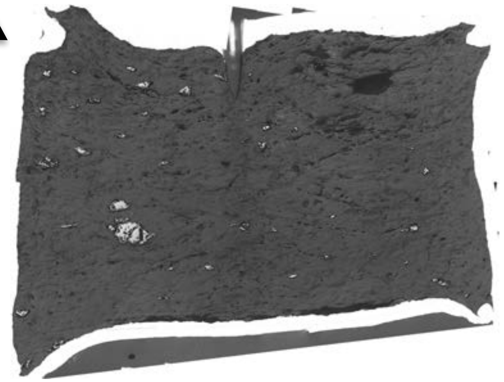
Belt press:
1.5-3 GPa, 315-550°C, 12-48h

31 experiments

5 mm



2-3 mm

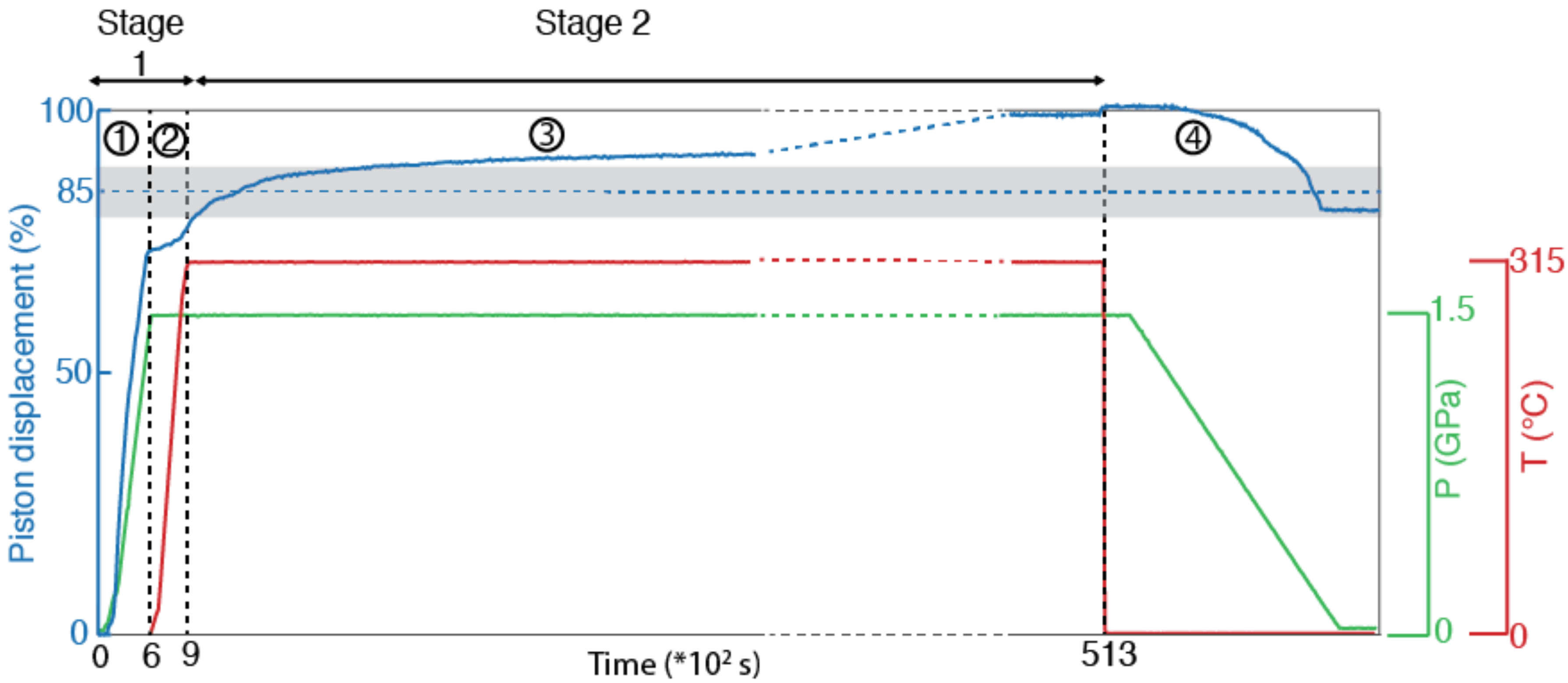


SEM image

Principle: - Track fluid-rock interactions with and take advantage of lattice diffusion (D/H inter-diffusion)

« Earthquake »
10^{-3} s^{-1}

Relaxation and isotopic exchange
$<10^{-5}$ s^{-1}

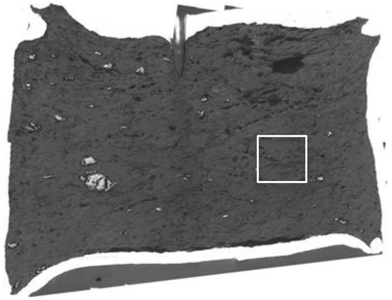


3 target natural rocks:

- blueschist: metamorphic oceanic crust
- serpentinite: hydrated mantle wedge
- chlorite schist: metasomatic plate interface

Ganzhorn et al., in prep.

Quantification of H-D exchange

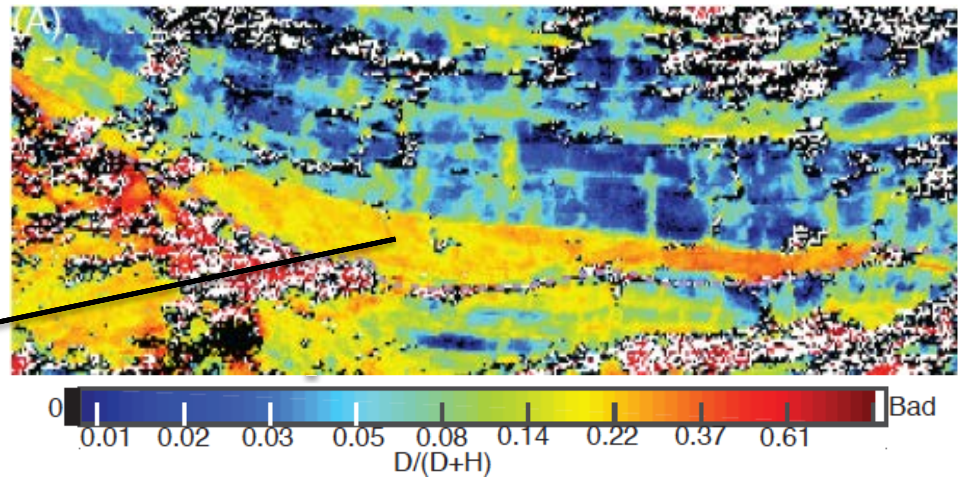


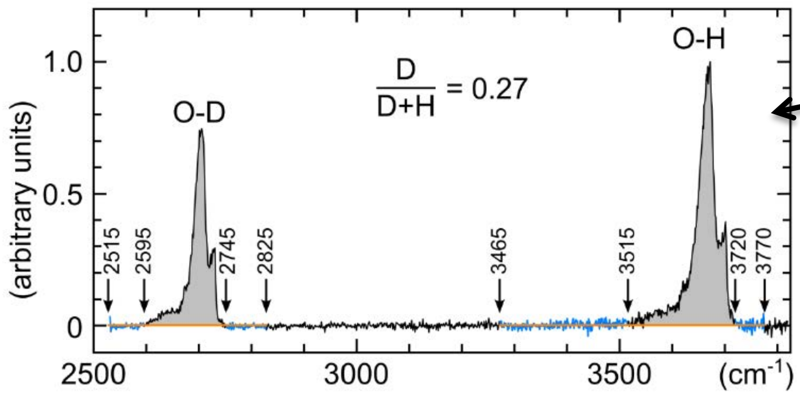
Raman spectrometry

Initially in mineral

D_2O

D/(D+H)





Ganzhorn et al.,
in prep.

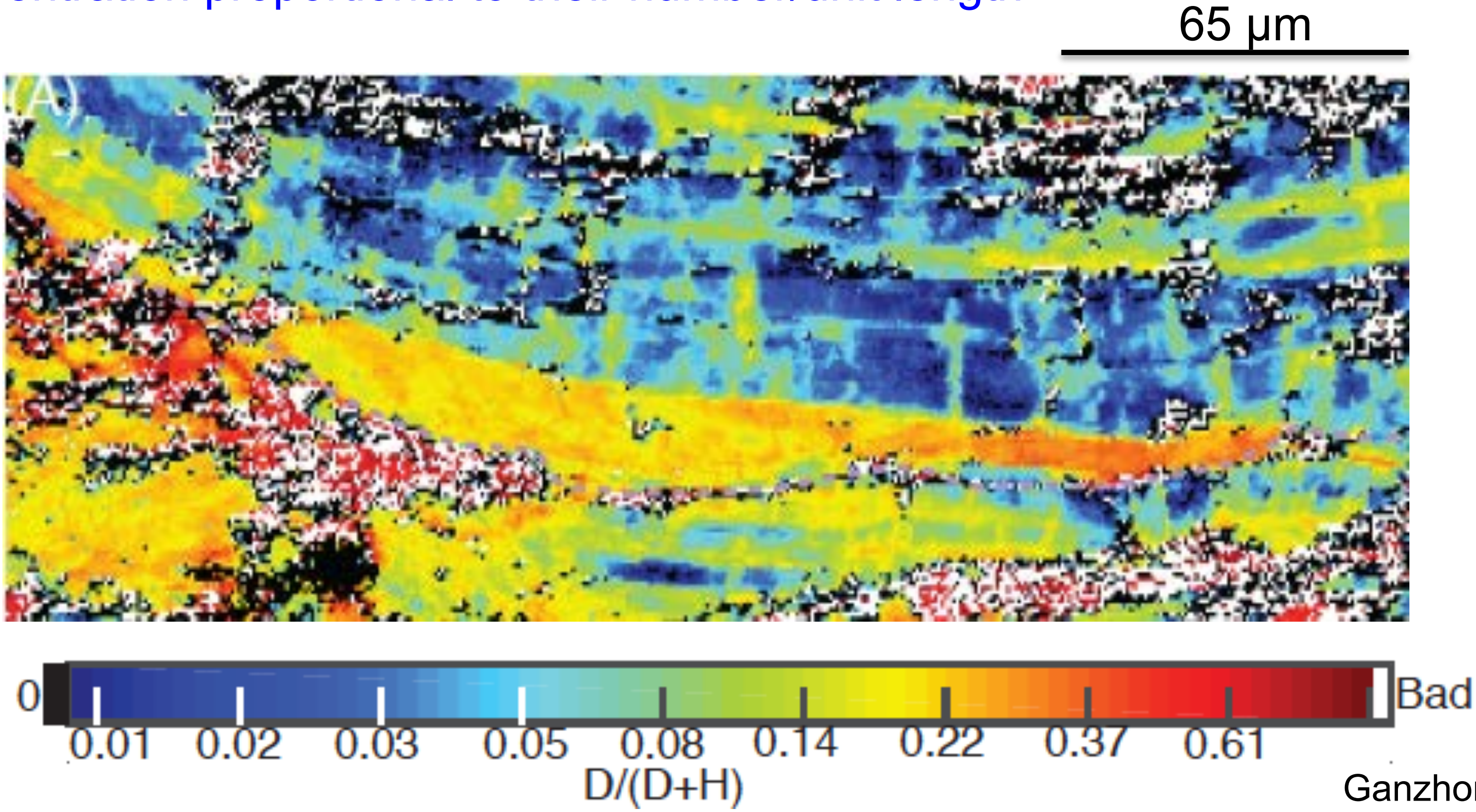
Isotopic exchange map

Serpentinite, 315°C, 3 GPa, 12h

$D \approx 10^{-20}$ m²/s (Pilorgé et al., 2017)
$x \approx \sqrt{(D*t)} \approx 20$ nm (< 500 nm = beam size)

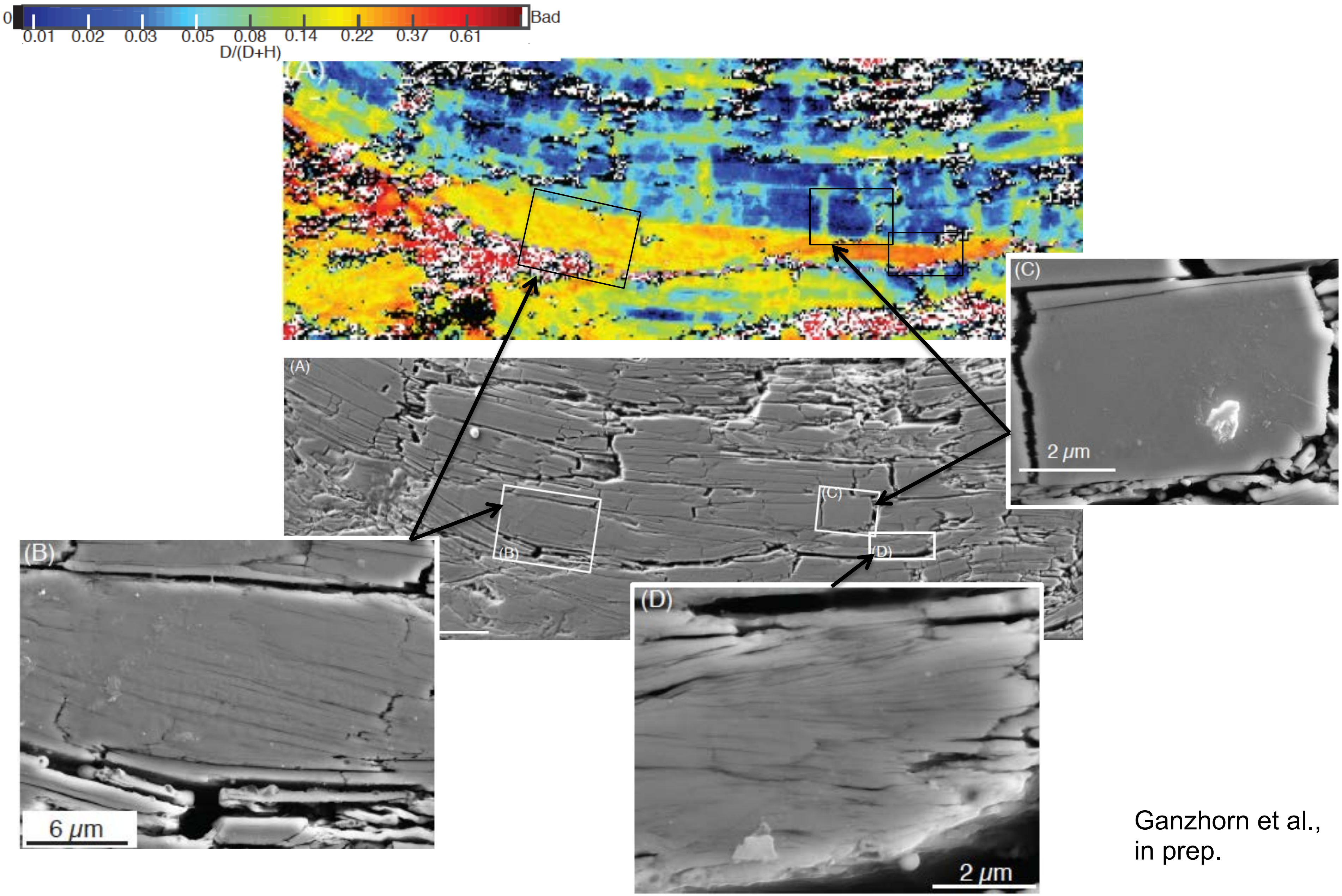
D-bearing zones = locations of fluid-rock interfaces (cracks or grain boundaries)
D concentration proportional to their number/unit length

Core



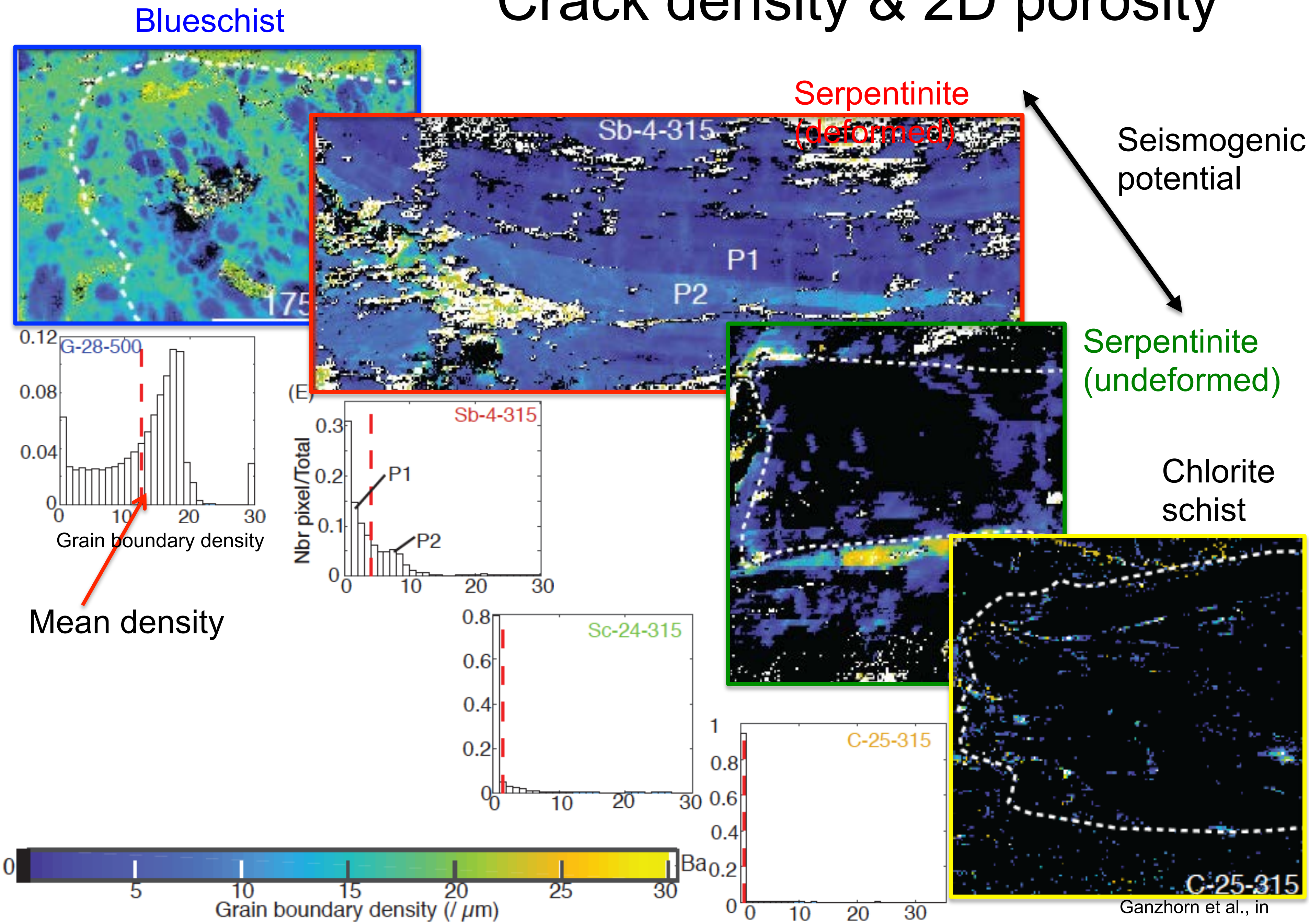
Ganzhorn et al., in prep.

Exchange map vs. SEM observations

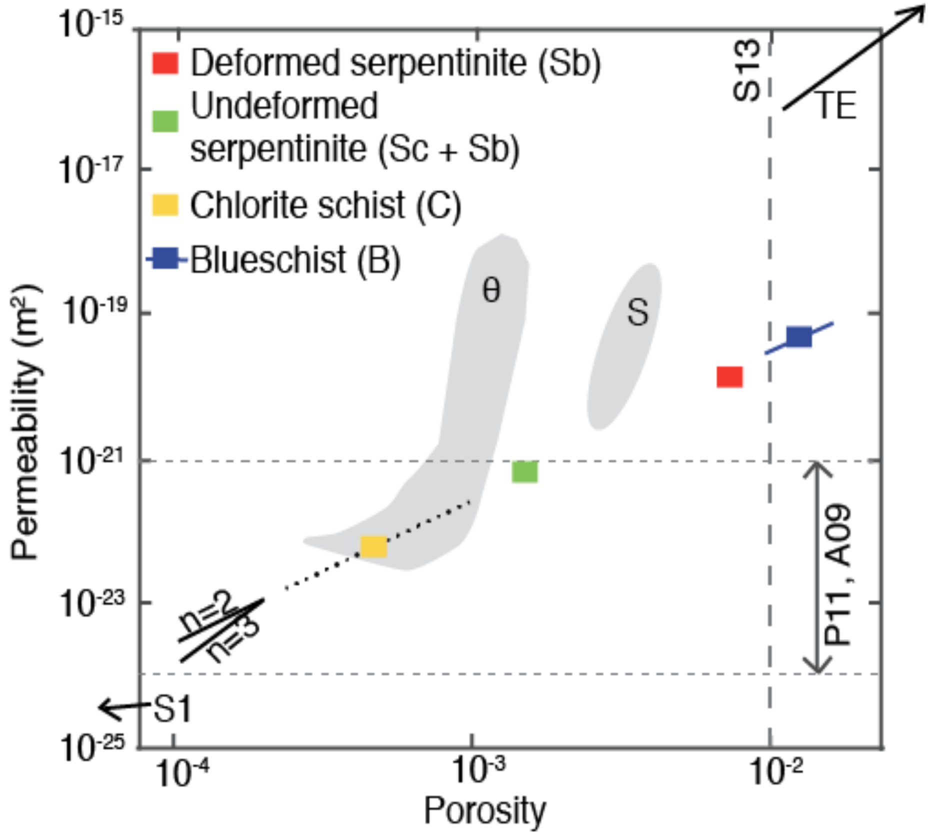


Ganzhorn et al.,
in prep.

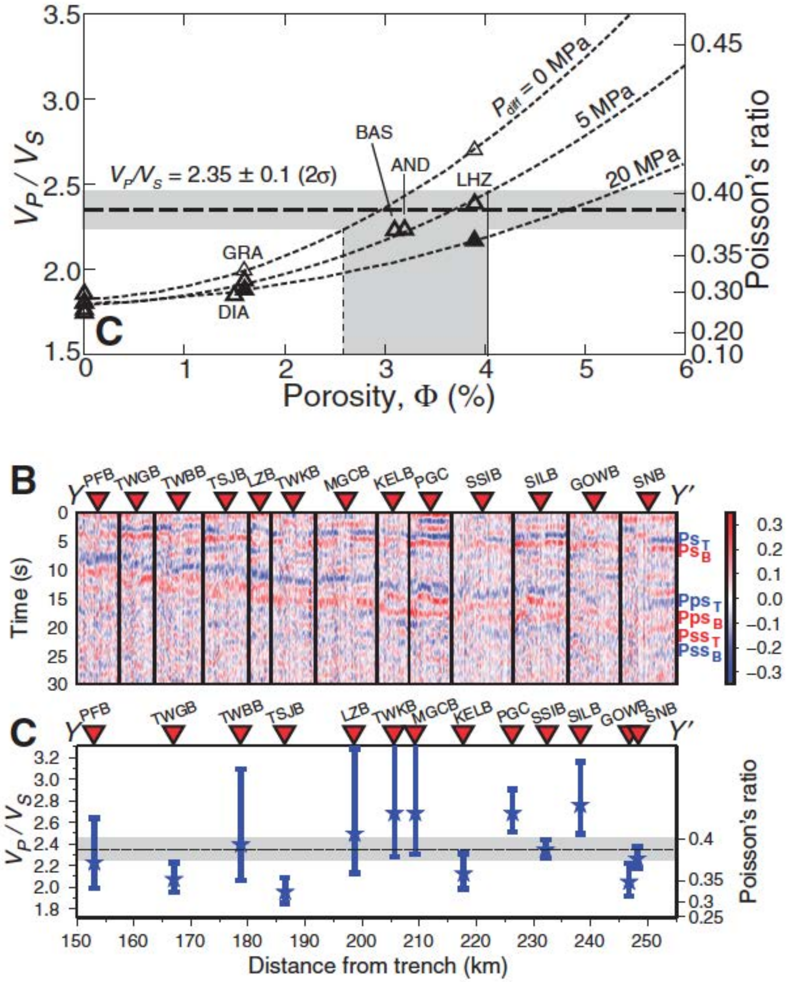
Crack density & 2D porosity



Active porosity (and permeability)



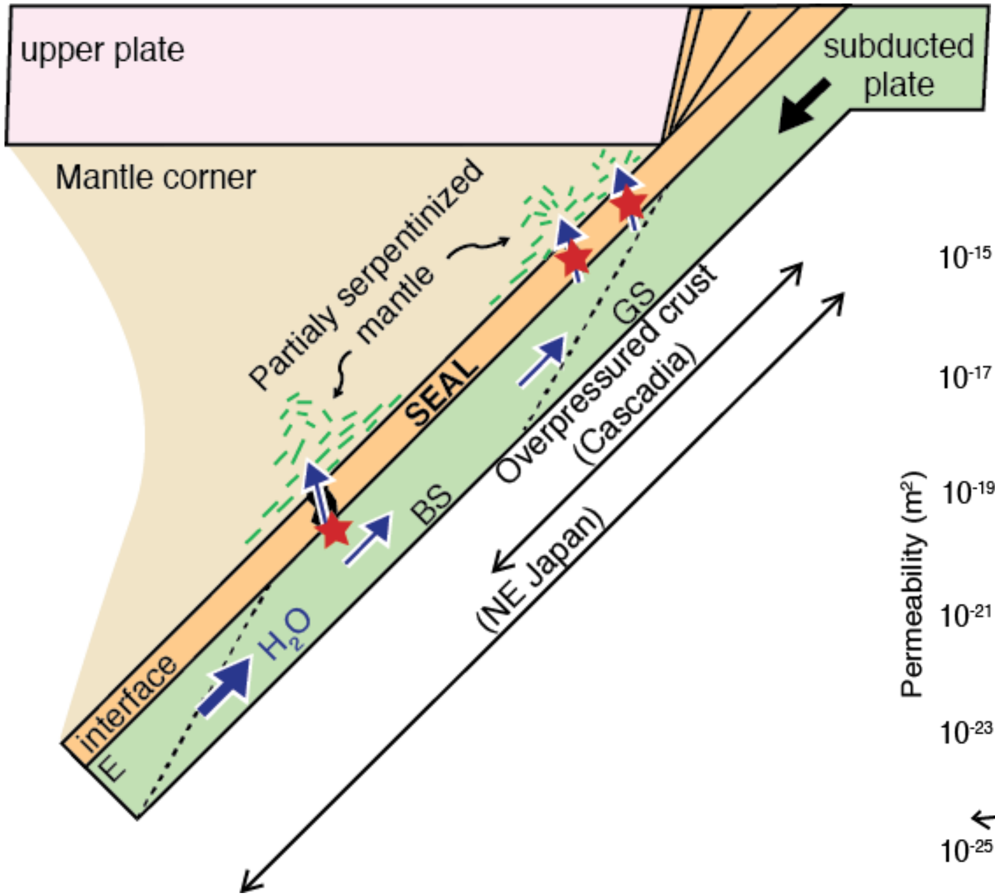
Ganzhorn et al.,
in prep.

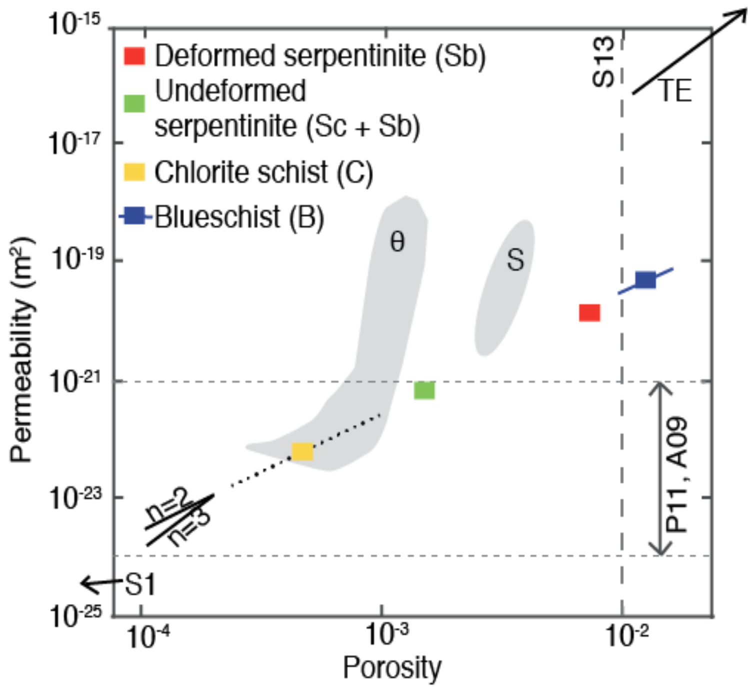


Peacock et al., Gology 2011

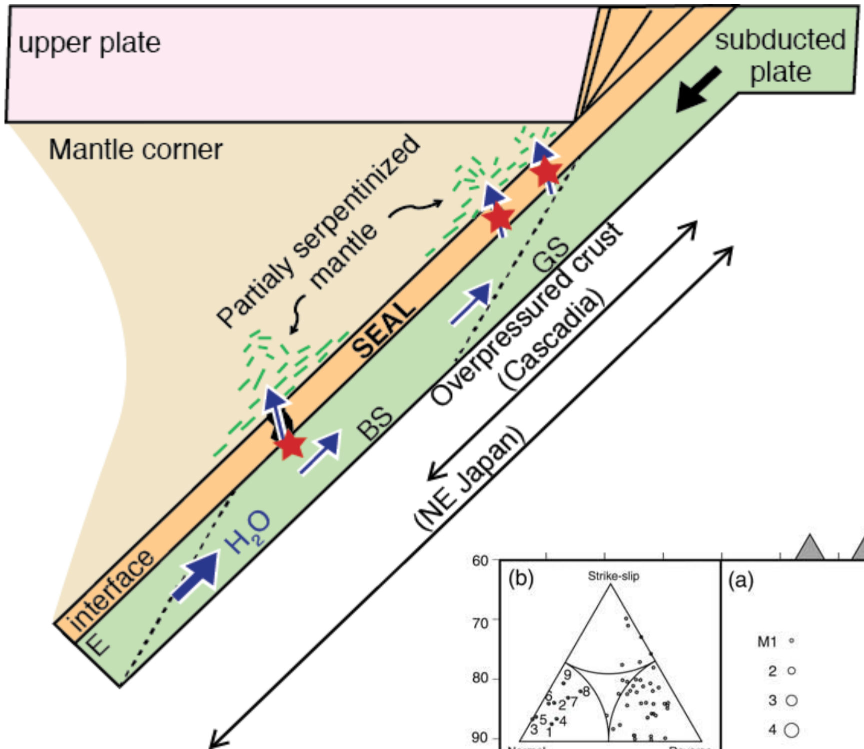
Conclusions

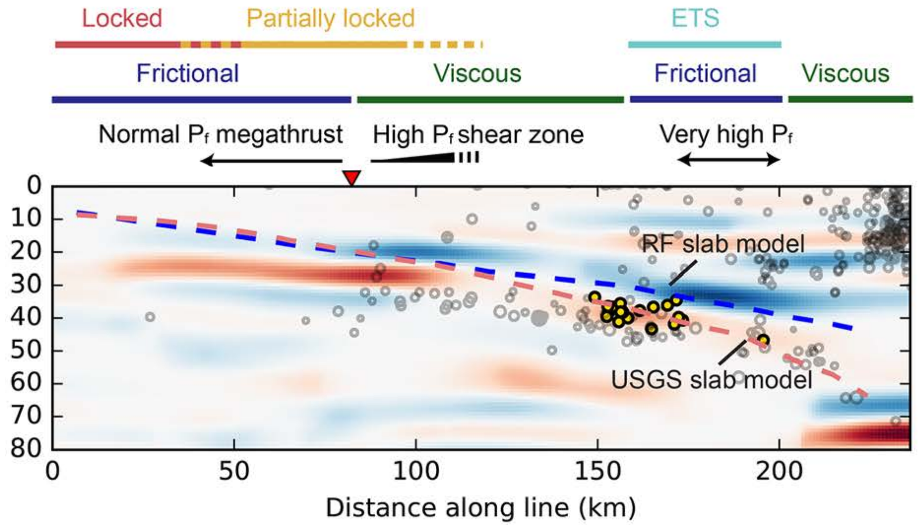
- A new method to constrain active porosity at high-pressure based on isotopic tracing at P-T relevant to subduction zones
- A broad range of behaviors from impermeable (chlorite schist) to permeable (serpentinite, blueschist) with pororsity variations in response to deformation





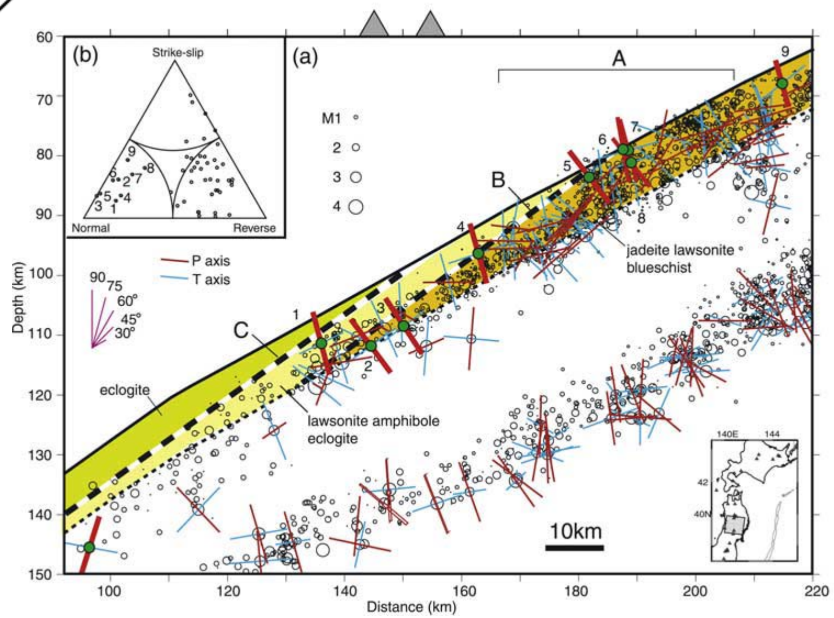
Conclusions





Audet & Schaeffer, Science Adv. 2018

Cascadia



Kita et al., GRL 2006

NE Japan