Porosity of metamorphic rocks and fluid migration within subduction interfaces

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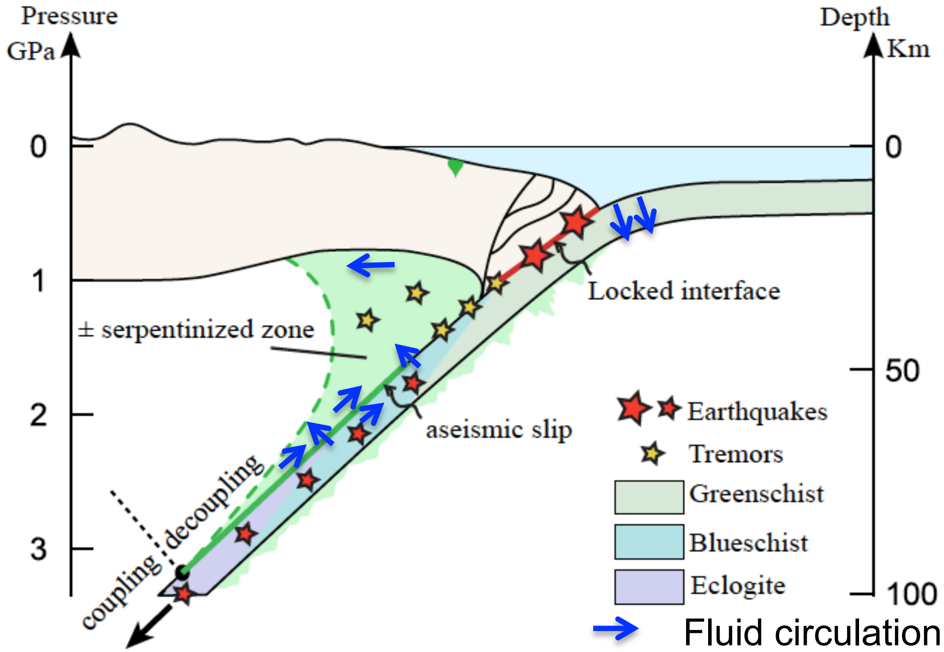
Fluid-rock interactions in subduction zones

Fluids released by the dehydrating plate:

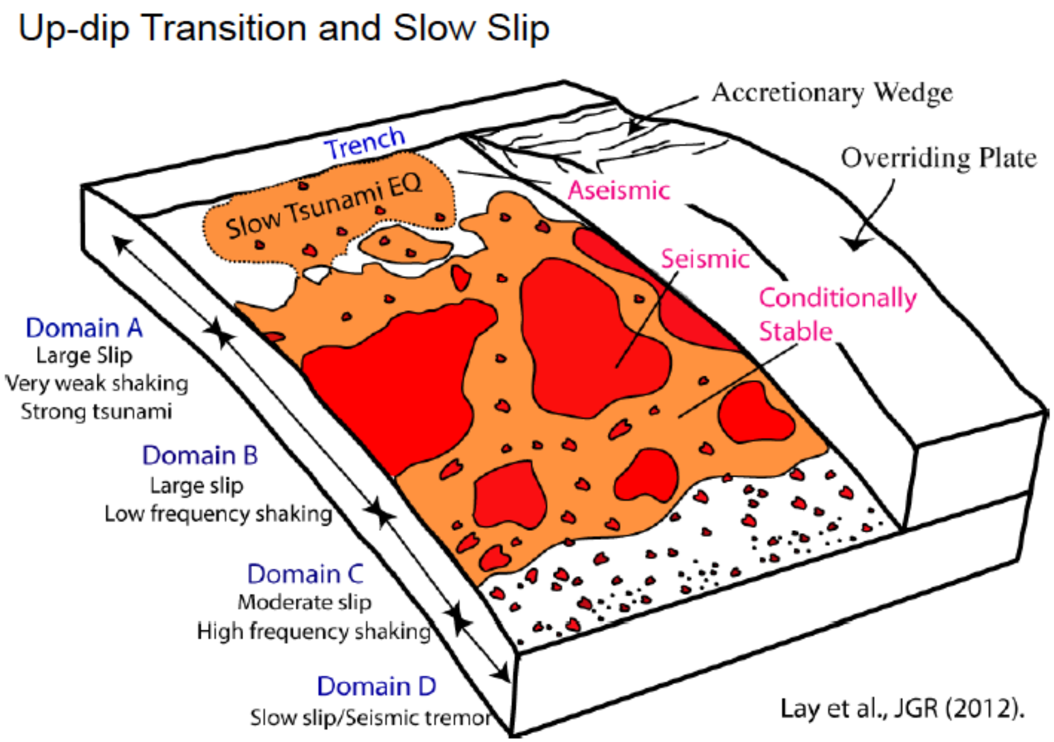
- -generation of earthquakes T<700°C in the forearc region
- -melting and arc volcanism T>700°C



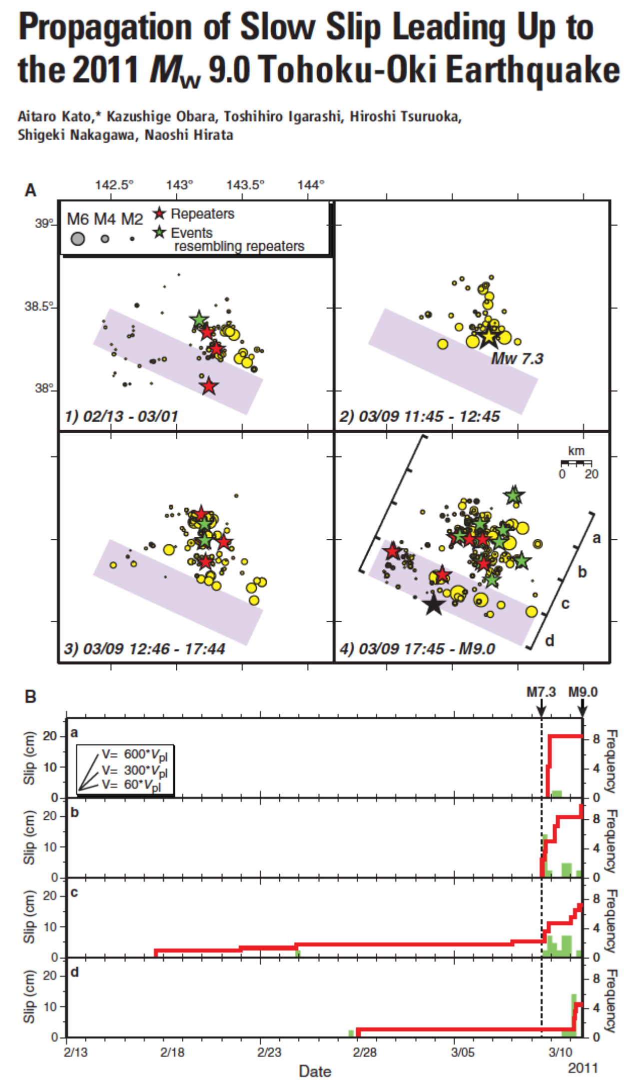
After Kirby et al. (1996); Shelly et al. (2006); Wada et al. (2008); Reynard (2013).

Porosity and permeability of metamorphic deformed rocks?

Fluids involved in earthquake cycle

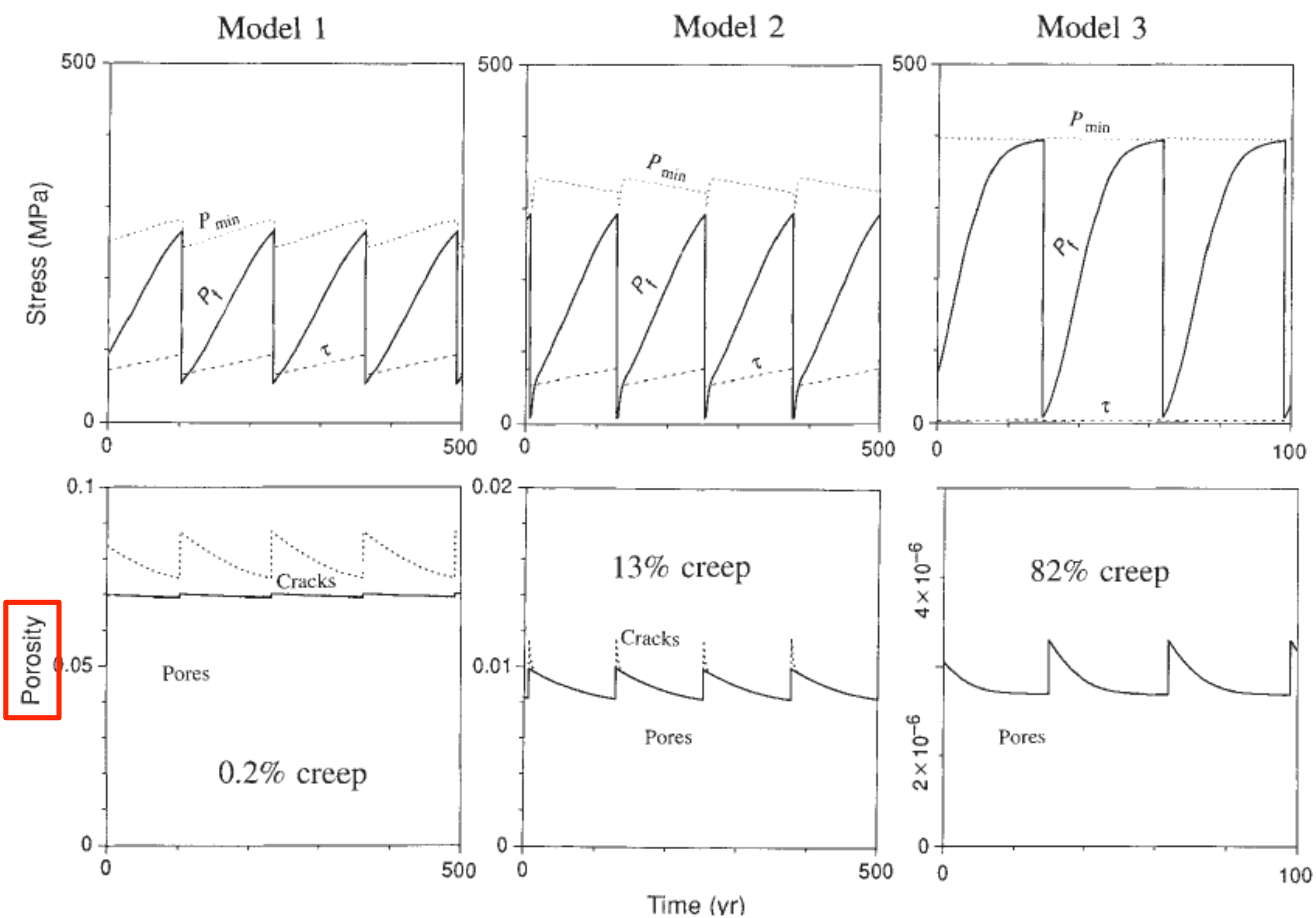


Lay et al., JGR (2012).



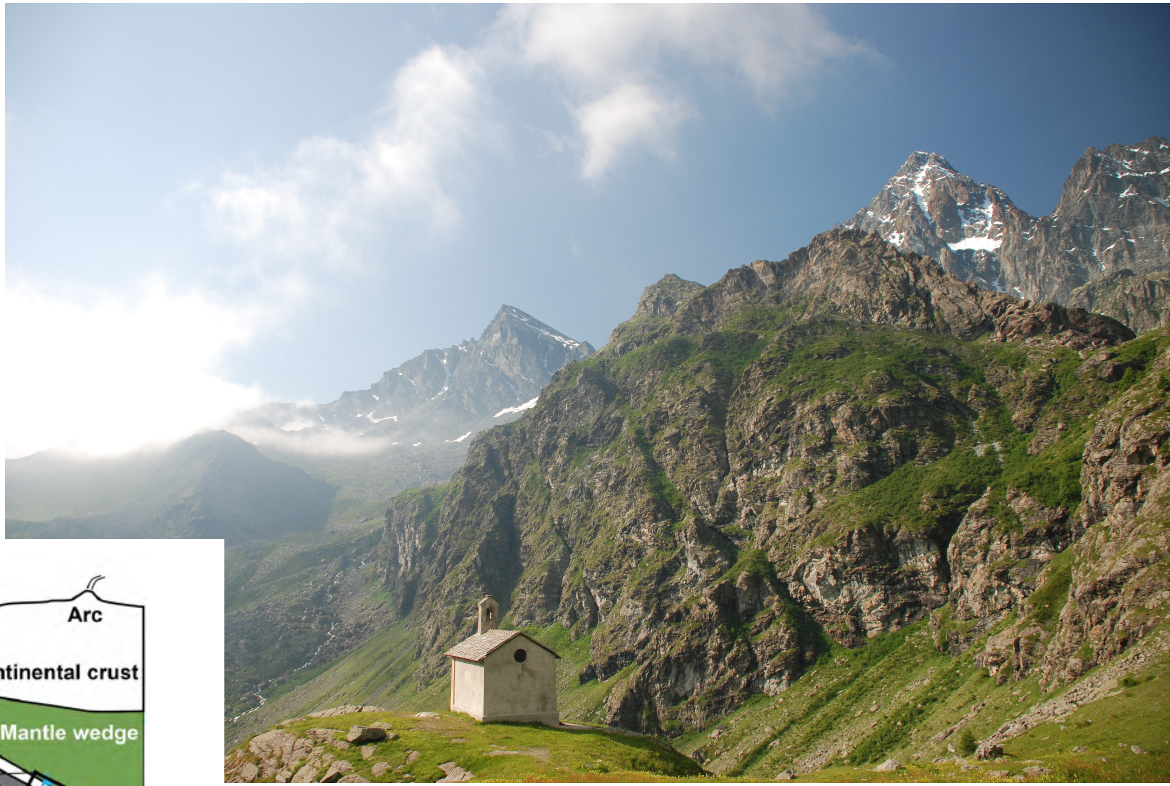
Fluids are likely involved in slow seismicity (LFE, ETS, SSE, SE, …)
Precursors of large megathrust earthquake?

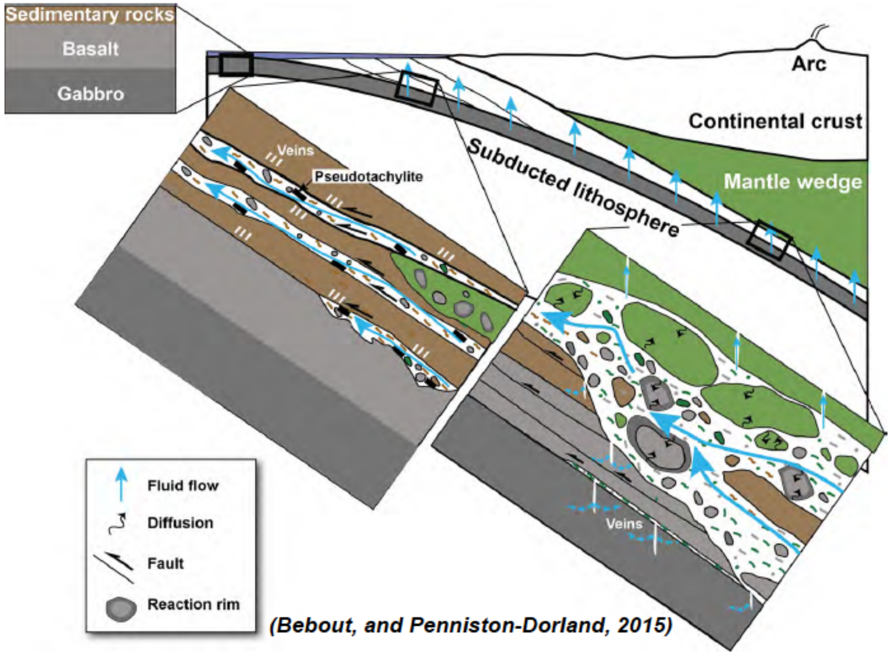
Fluid pressure and porosity cycle during earthquake cycle



Sleep & Blanpied (1994)

Complex petrologic and metamorphic context





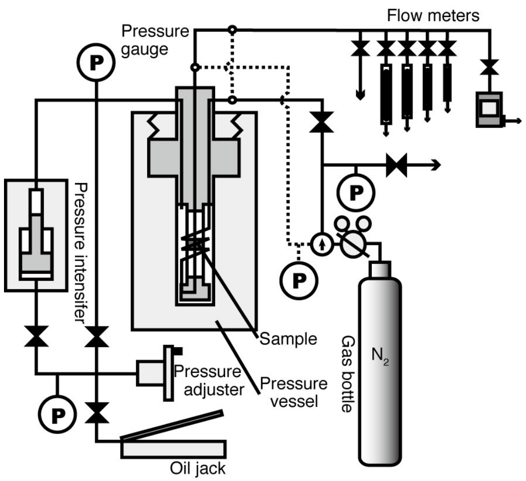
(Bebout, and Penniston-Dorland, 2015)

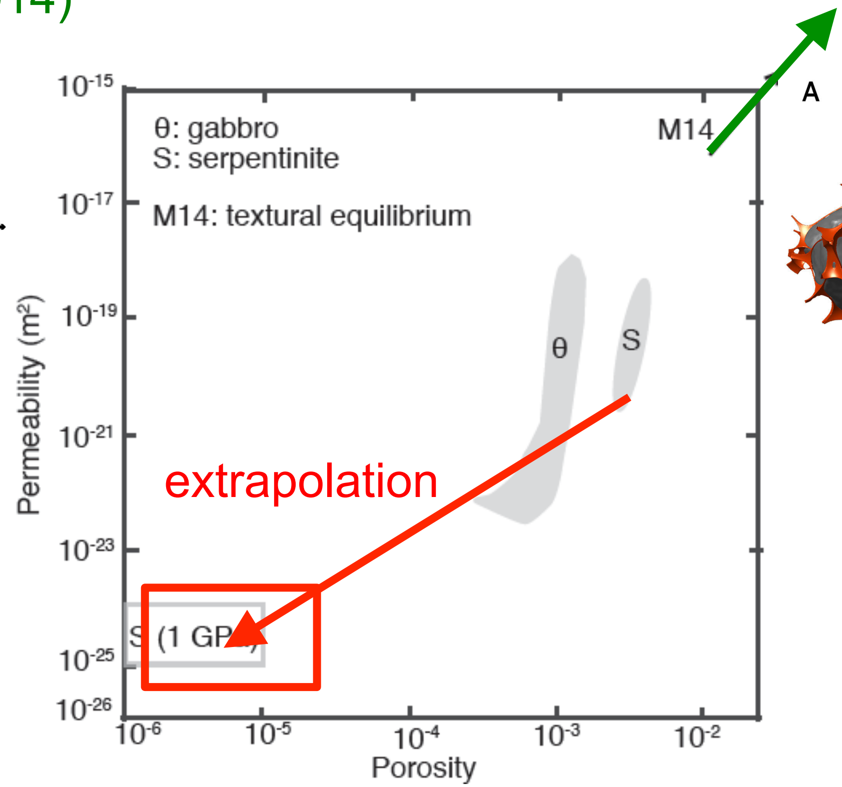
Exhumed subduction zones
Monviso ophiolite W Alps
Rock samples

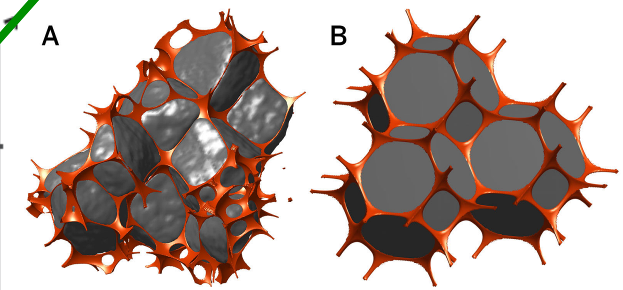
Rock porosity in subduction zones

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; Mibe et al. 1999; Miller et al., 2014)







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

Little anisotropy

Low P, room T

No fluid reactivity

Domain of interest : 100 < T < 700°C, 0.1 < P < 3 GPa

Highly anisotropic minerals (clays) no experimental data

HP experiment with isotopic tracer (D) diffusion

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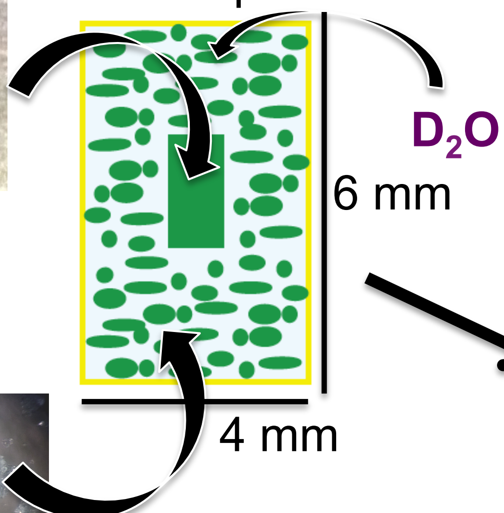
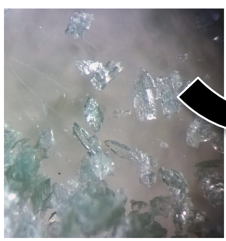
Natural rock chip/core

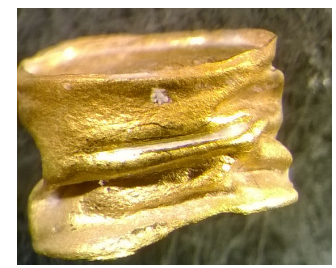




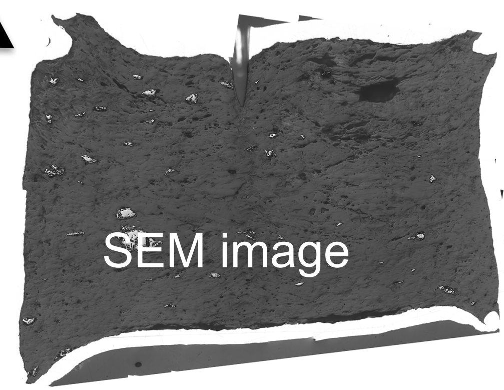
Powder of natural rock

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

5 mm

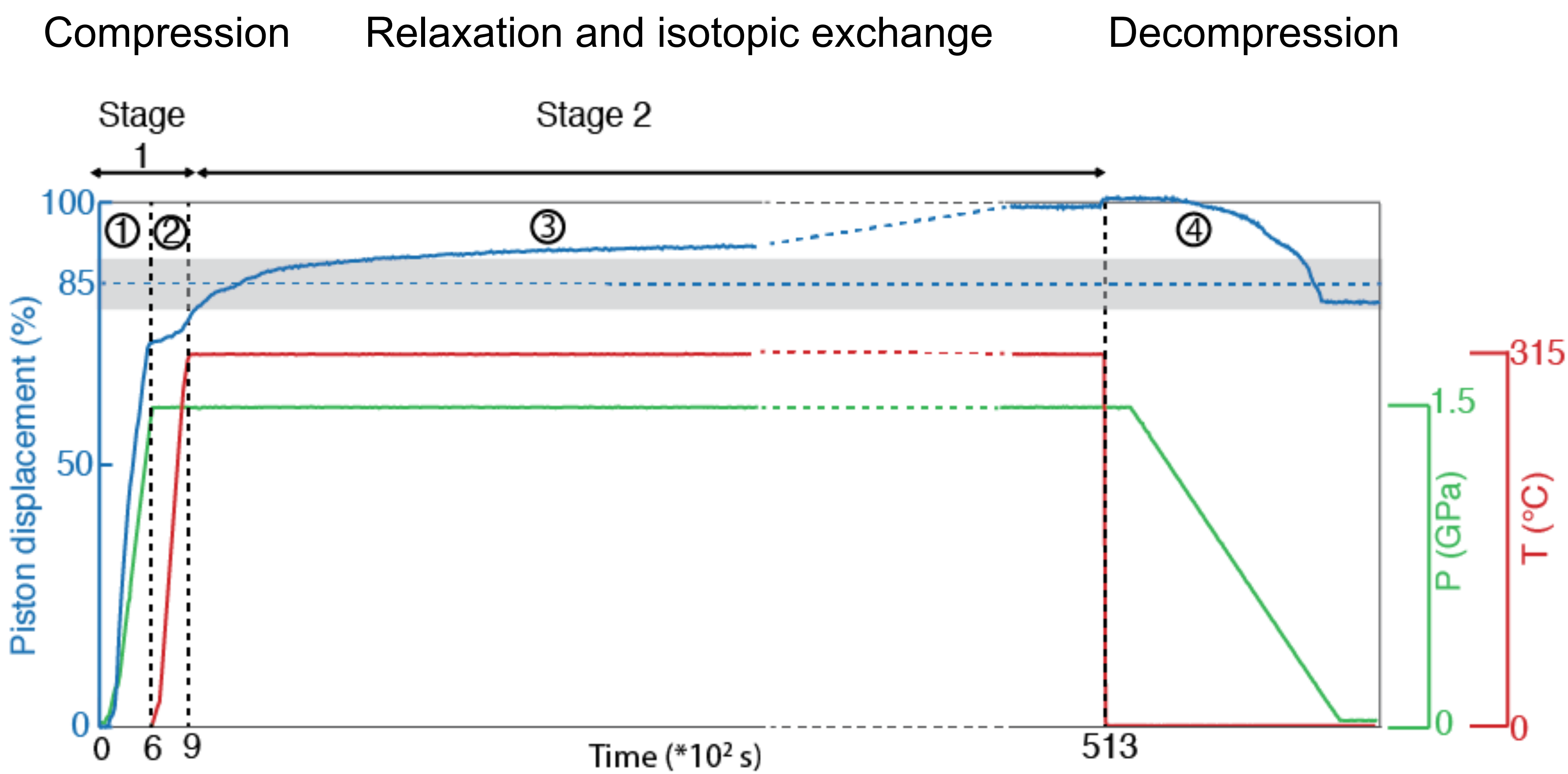


2-3 mm



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

HP experiment with isotopic tracer (D) diffusion



3 target natural rocks:

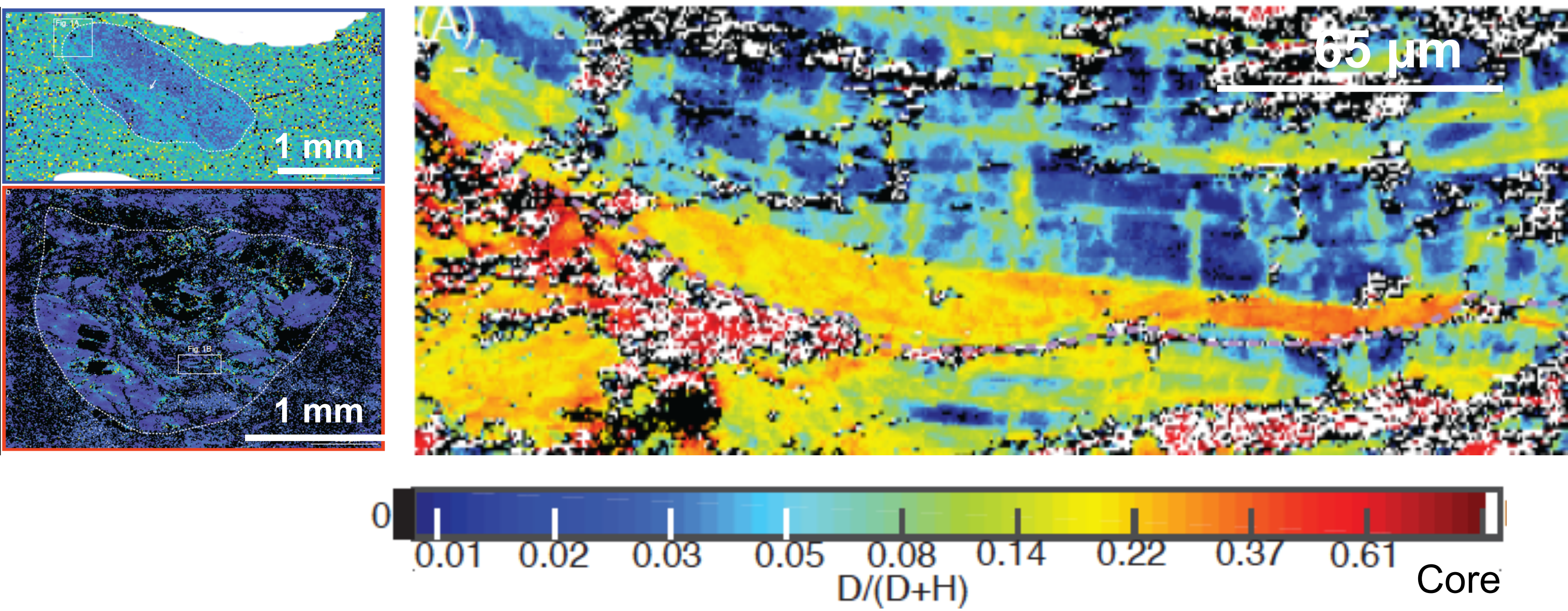
- blueschist: metamorphic oceanic crust
- serpentinite: hydrated mantle wedge
- chlorite schist: metasomatic plate interface

Isotopic exchange map

Raman mapping (Pilorgé et al., 2017) Serpentinite, 315°C, 3 GPa, 12h

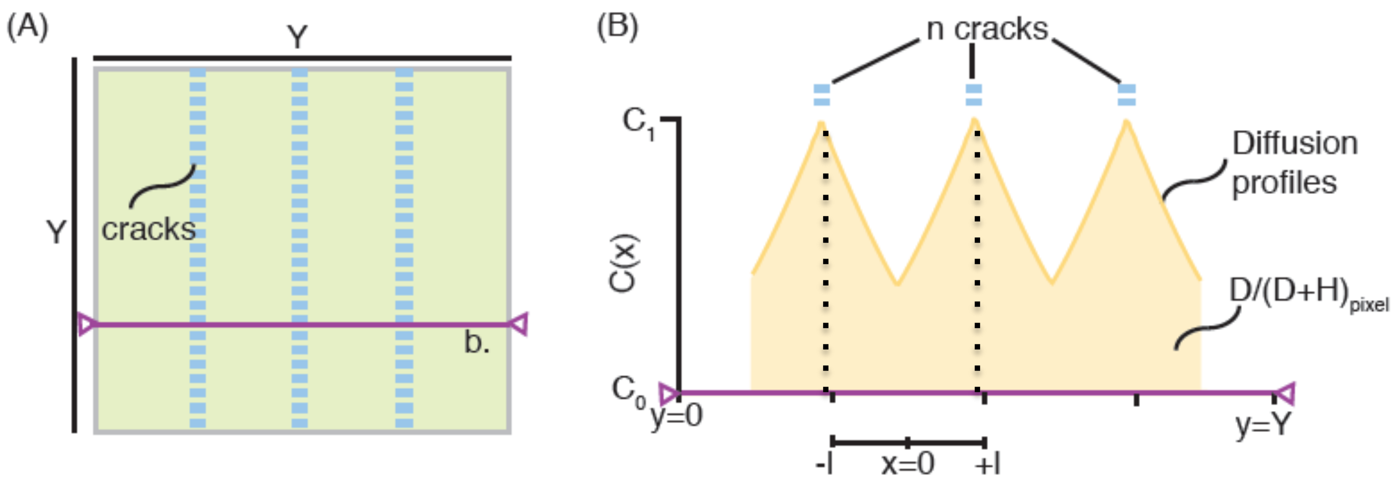
D-bearing zones = locations of fluid-rock interfaces (cracks or grain boundaries)

D concentration proportional to their number/unit length



From "exchange" map to porosity.

Principle: the D/(D+H) ratio of one pixel is proportional to the number of cracks or grain boundaries per unit length when x ≈ √(D*t) ≈ 20 nm (< 500 nm = beam size)



solution of the diffusion equation for a plane sheet over small time (Crank, 1975)

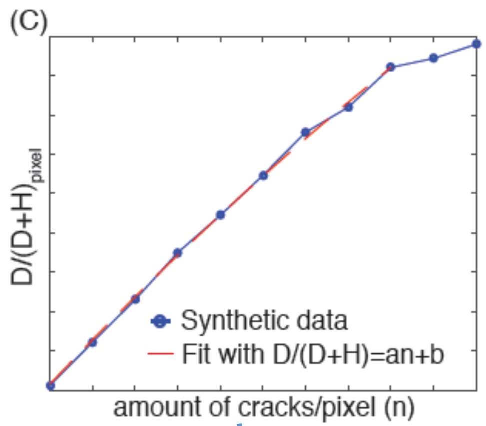
$$\frac{C(x)-C_0}{C_1-C_0}=\sum_{m=0}^{\infty}(-1)^m erfc\left(\frac{(2m+1)l-x}{2\sqrt{Dt}}\right)+\sum_{m=0}^{\infty}(-1)^m erfc\left(\frac{(2m+1)l+x}{2\sqrt{Dt}}\right)$$

$$\frac{D}{D+H}=\frac{2n}{Y}\int_{x=0}^{l}C(x)\,dx$$

n number of grain boundaries

From “exchange” map to porosity.

Principle: the D/(D+H) ratio of one pixel is proportional to the amount of cracks or grain boundaries.



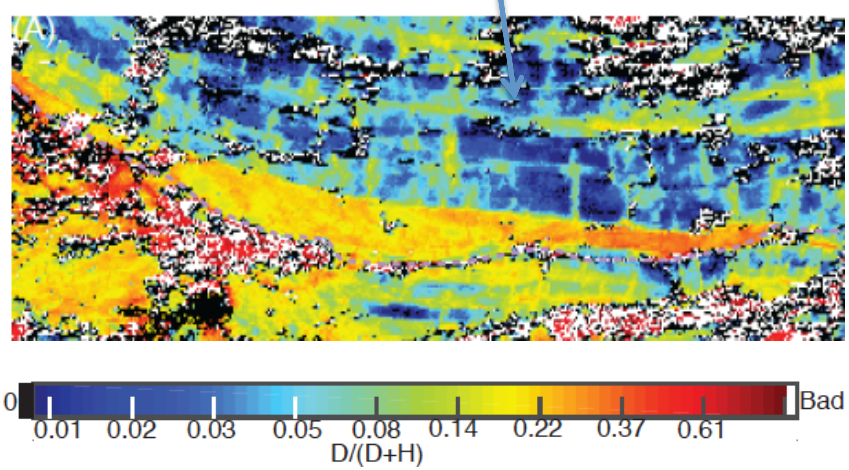
2D porosity:

$$\Phi_{2D} = d * 10^{-3}$$

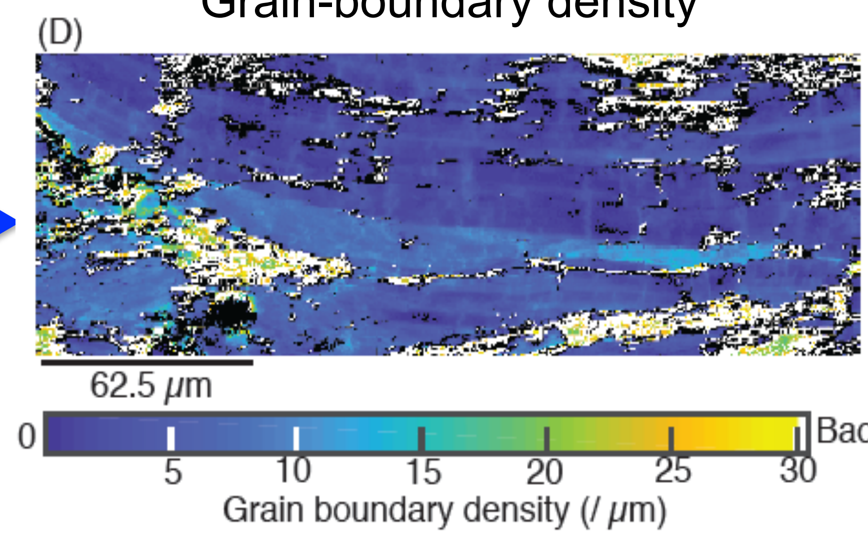
Average density

Grain boundary thickness (0.5-2 nm)

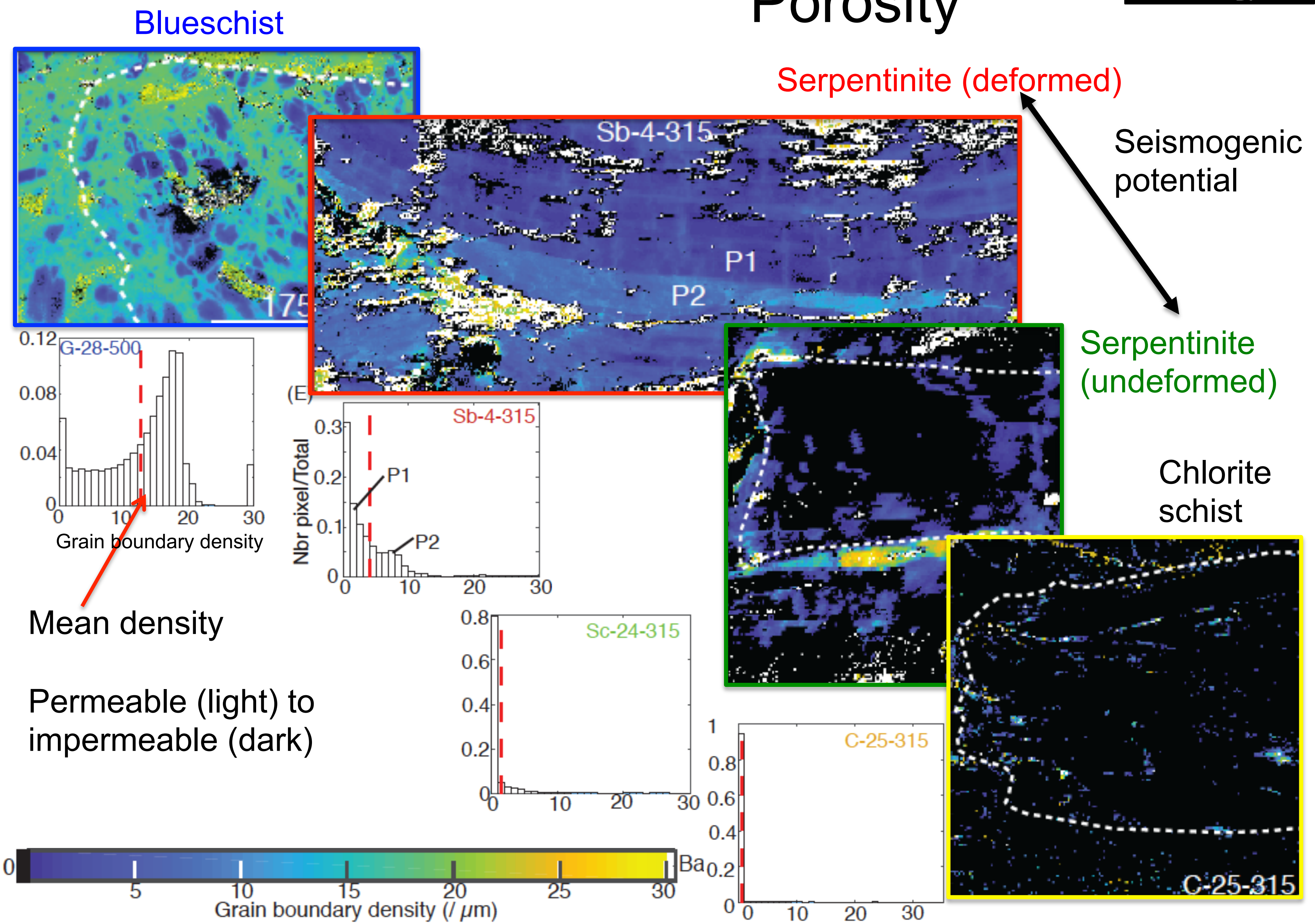
D/(D+H)



Grain-boundary density

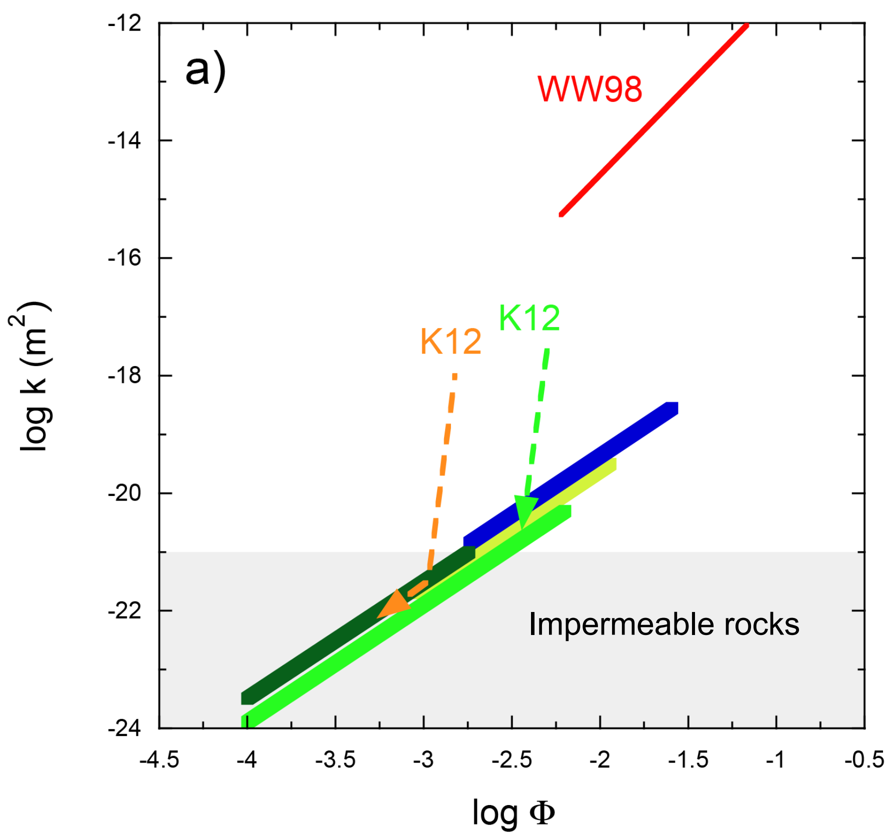


Porosity


Blueschist
175
Serpentinite (deformed)
Sb-4-315
P1
P2
Seismogenic potential
Serpentinite (undeformed)
Chlorite schist
C-25-315
G-28-500
0.12
0.08
0.04
0
10
20
30
Grain boundary density
Mean density
(E)
Sb-4-315
Nbr pixel/Total
0.3
0.2
0.1
P1
P2
Sc-24-315
0.8
0.6
0.4
0.2
C-25-315
1
Permeable (light) to impermeable (dark)
5
15
25
Ba
Grain boundary density (/ μm)

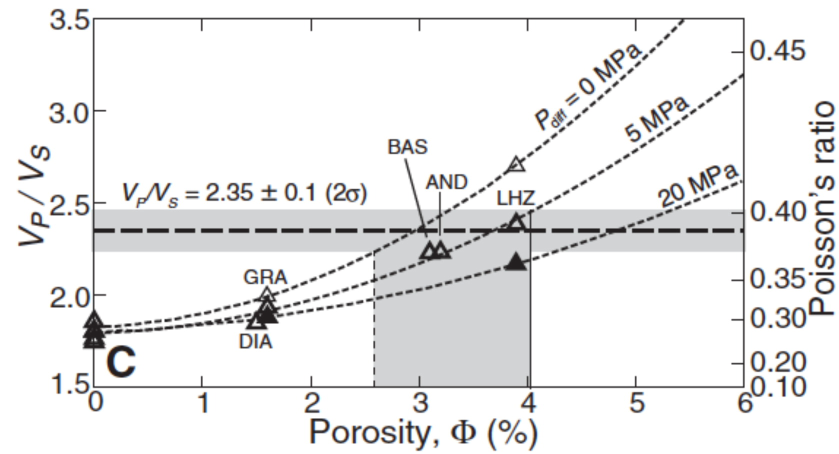
Porosity Φ (and permeability k)

- Rock behavior from impermeable (chlorite schist) to slightly permeable (serpentinite) with porosity variations in response to deformation, and permeable (blueschist)
- Chlorite schist impermeable because highly deformable (low plastic yield stress)
- Consistent with geophysical estimates



Ganzhorn et al. EPSL 2019

$k=k_0*(\Phi/\Phi_0)^n$ (Kawano et al., 2011)



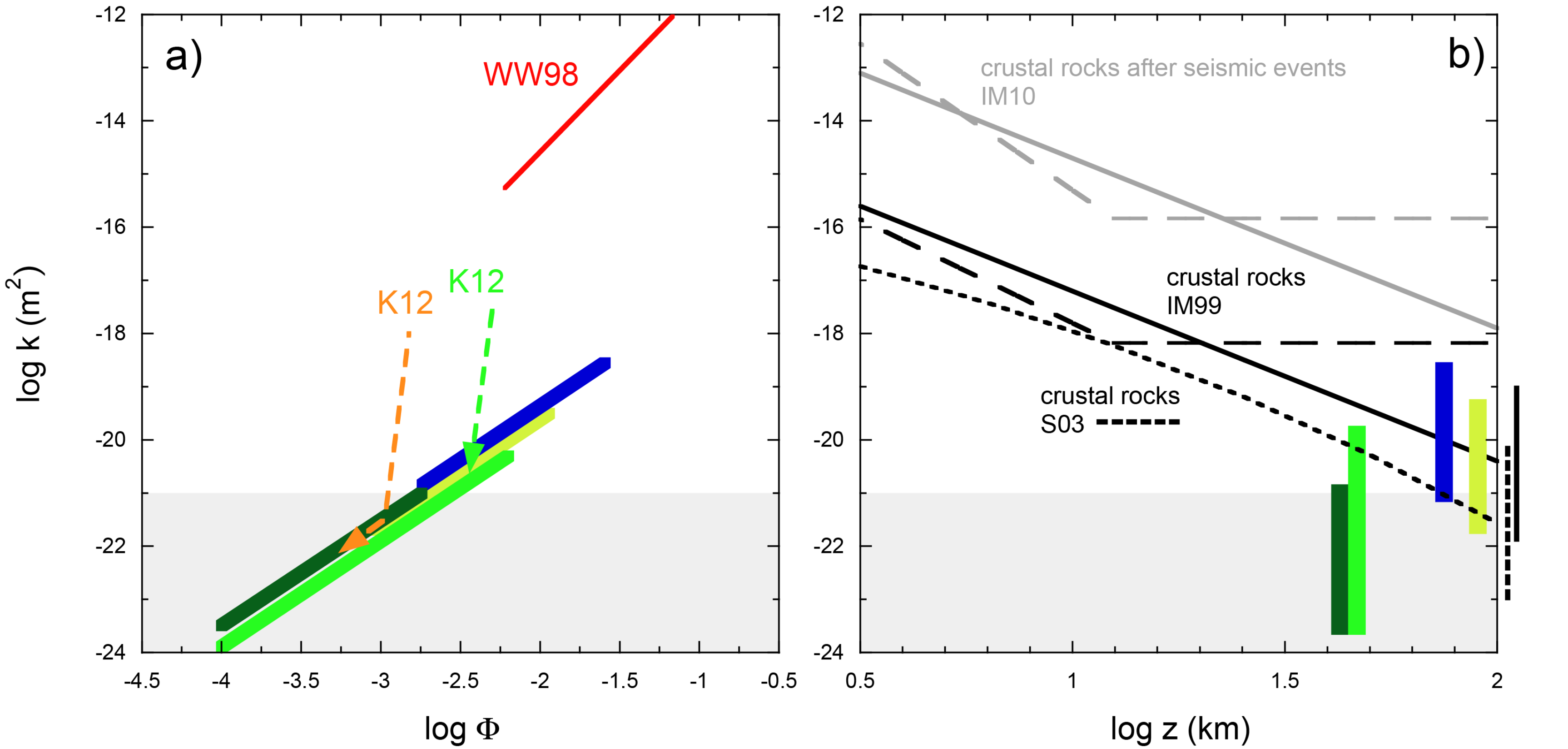
Oceanic crust porosity

Hot subduction Cascadia N America
Φ = 2.5-4%
log k_{seal} = -21 to -23
Audet et al. Nature 2009; Peacock et al., Geology 2011

Cold subduction Tohoku NE Japan
Φ = 1-2%
Shiina et al. JGR 2013

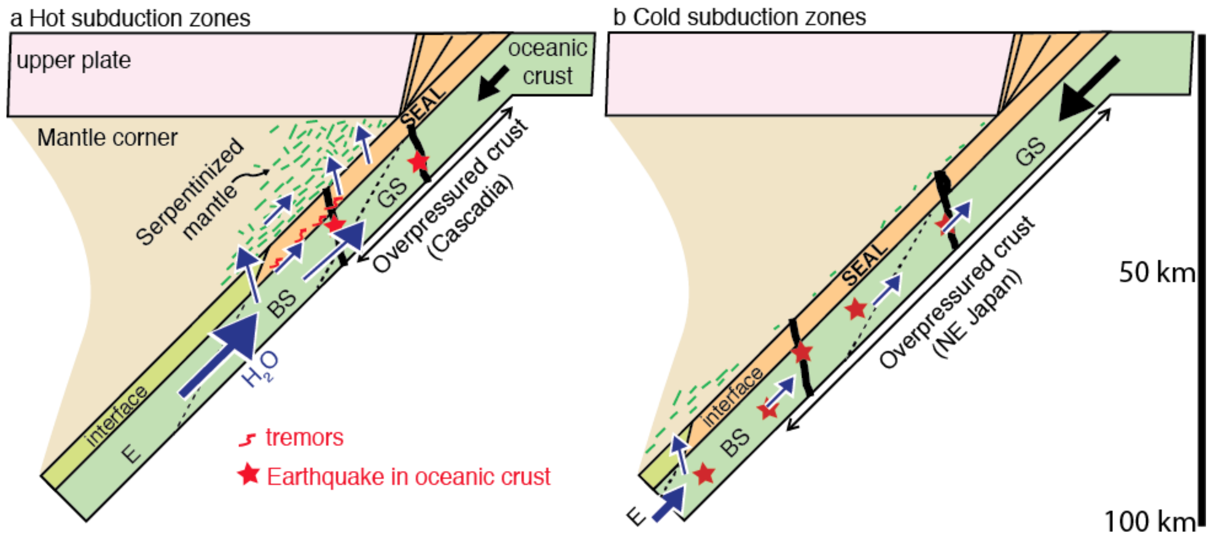
Porosity Φ (and permeability k)

- Comparison with estimates for crustal rocks (Ingebritsen and Manning 1999, 2010)
- Permeability at subduction interface is much lower than continental crustal rocks
- Permeability of oceanic crust is similar to slightly lower than continental crustal rocks

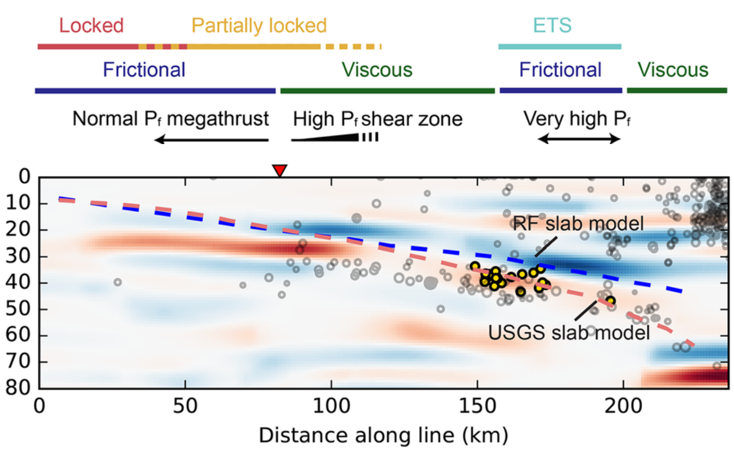


Ganzhorn et al. EPSL 2019

Conclusions

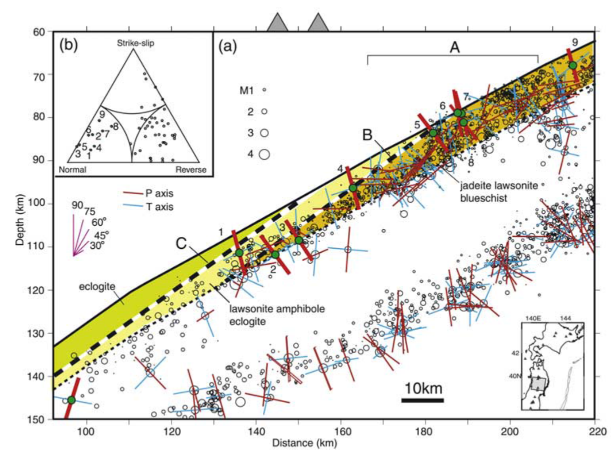


Ganzhorn et al. EPSL 2019: chlorite schist seal at the subduction interface



Cascadia: Audet & Schaeffer, Science Adv. 2018

Sealed down to ~40 km



NE Japan: Kita et al., GRL 2006

Sealed down to ~90 km