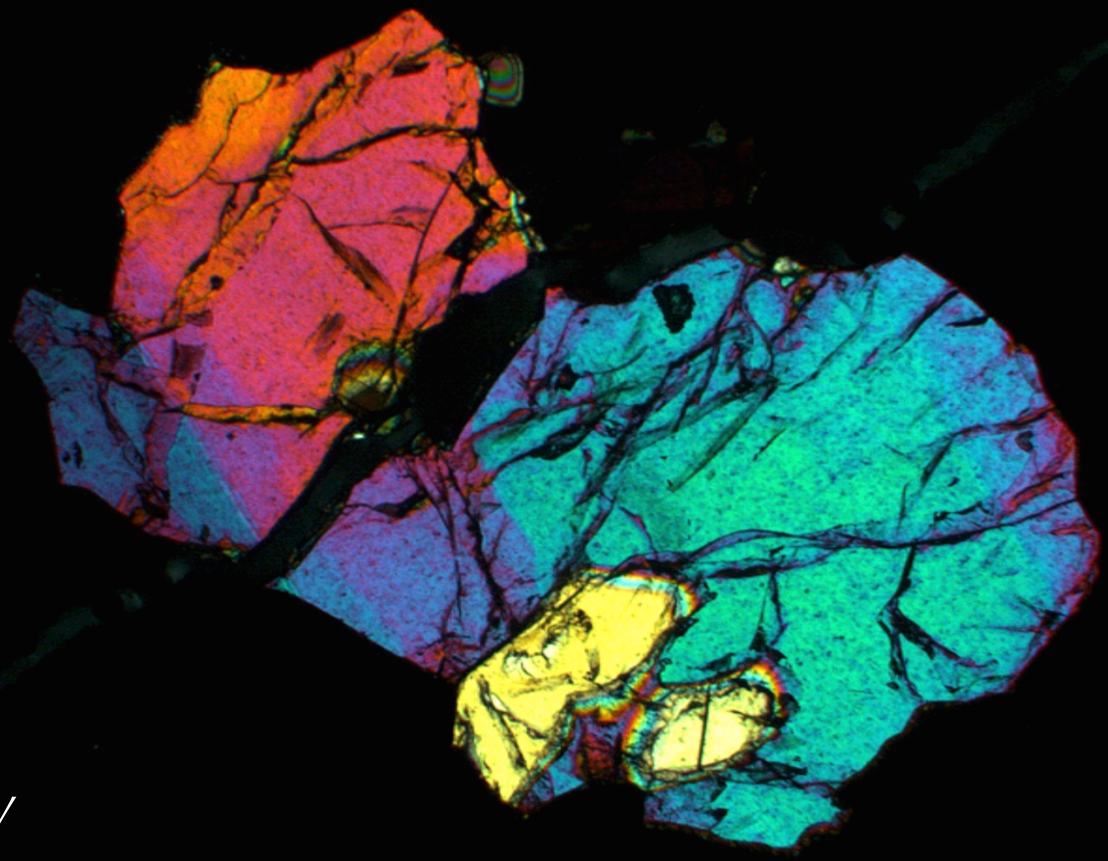
Everything flow, but how?

Meaningful tributs from natural samples

& laboratory experiments



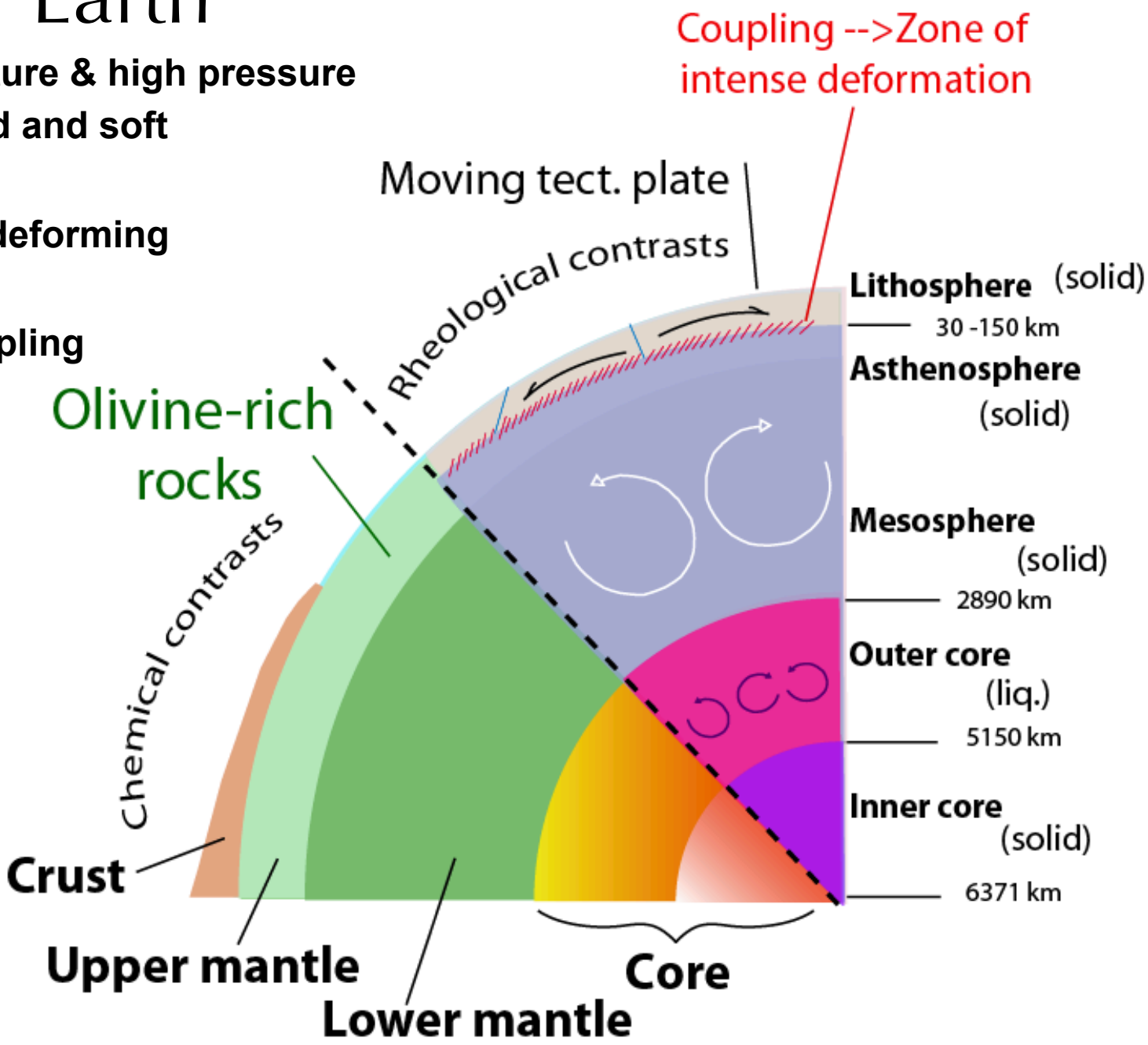
Sylvie Demouchy
CNRS - Géosciences Montpellier

A side of Earth

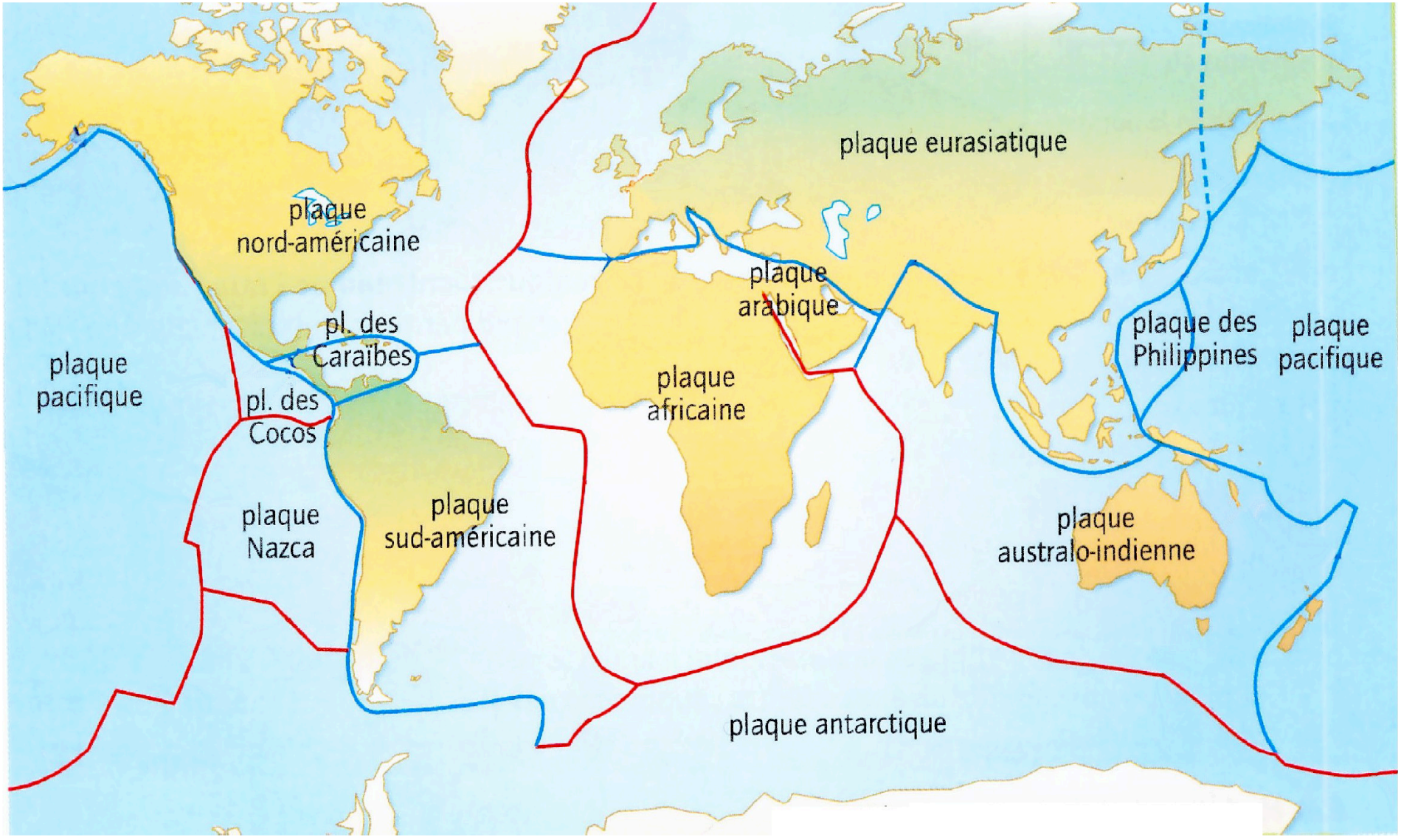
- **High temperature & high pressure**
- **Solid, silicated and soft**
- **Cooling**

→ convecting & deforming

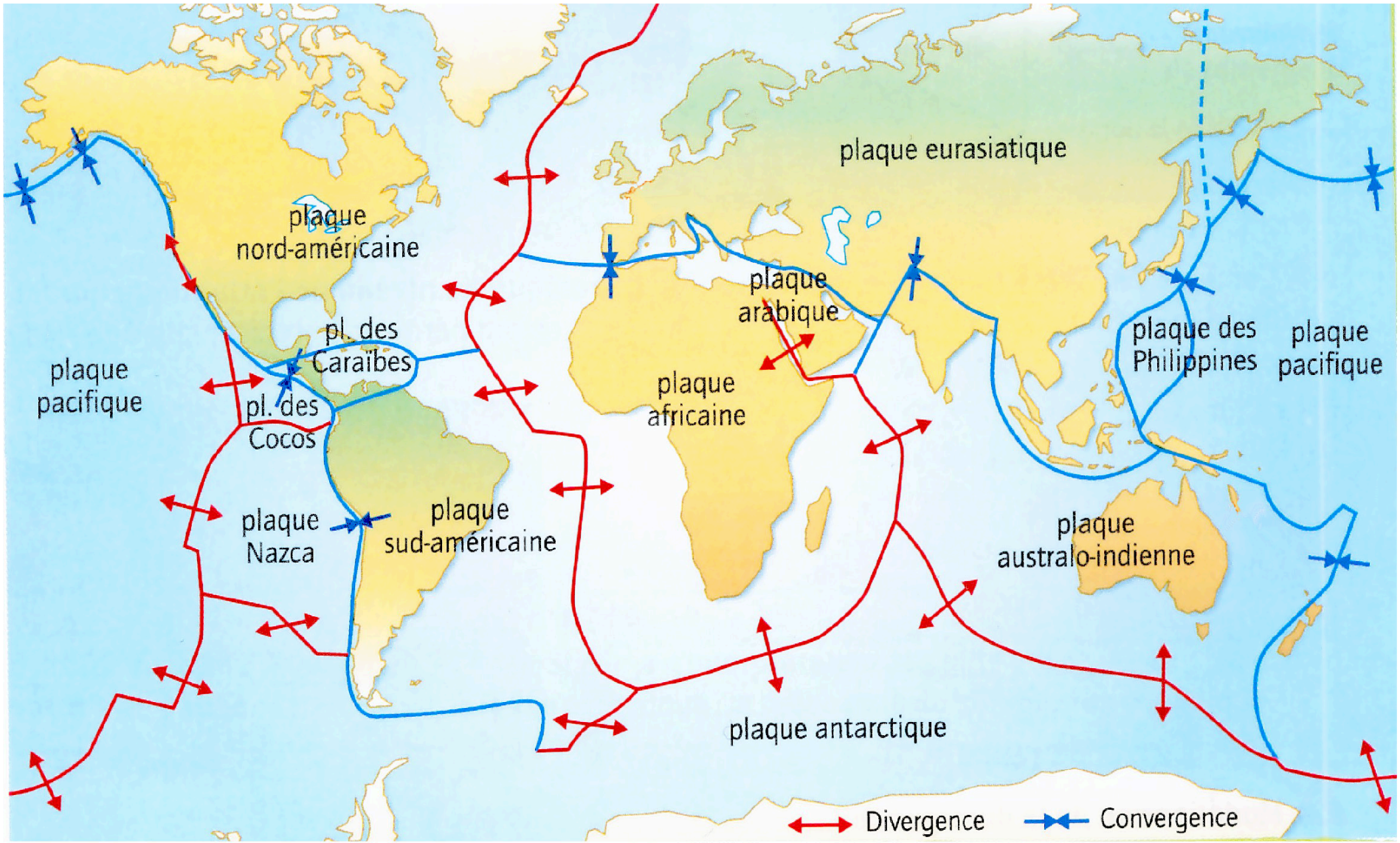
- **Layered !!!**
- **Imperfect coupling**



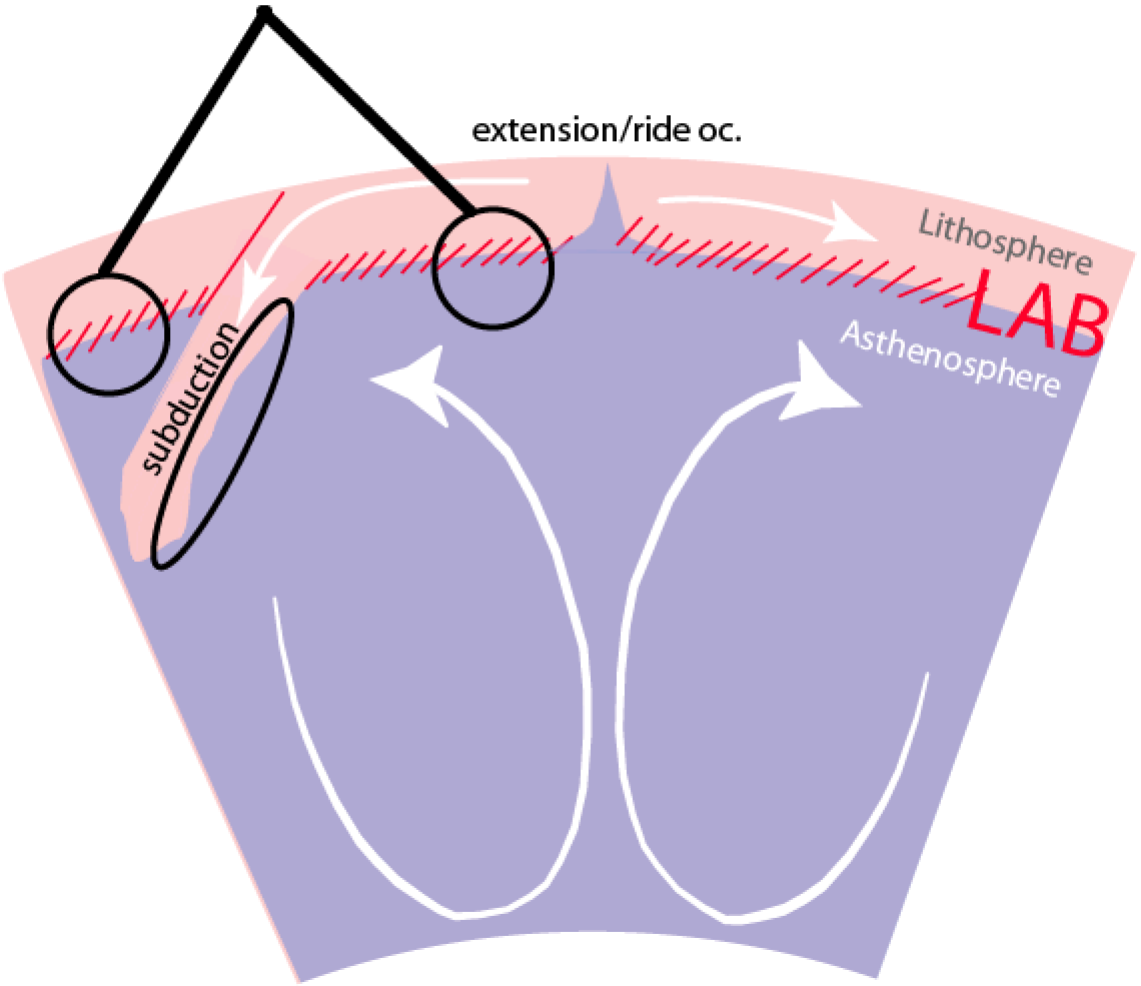
Earth from above



Earth from above

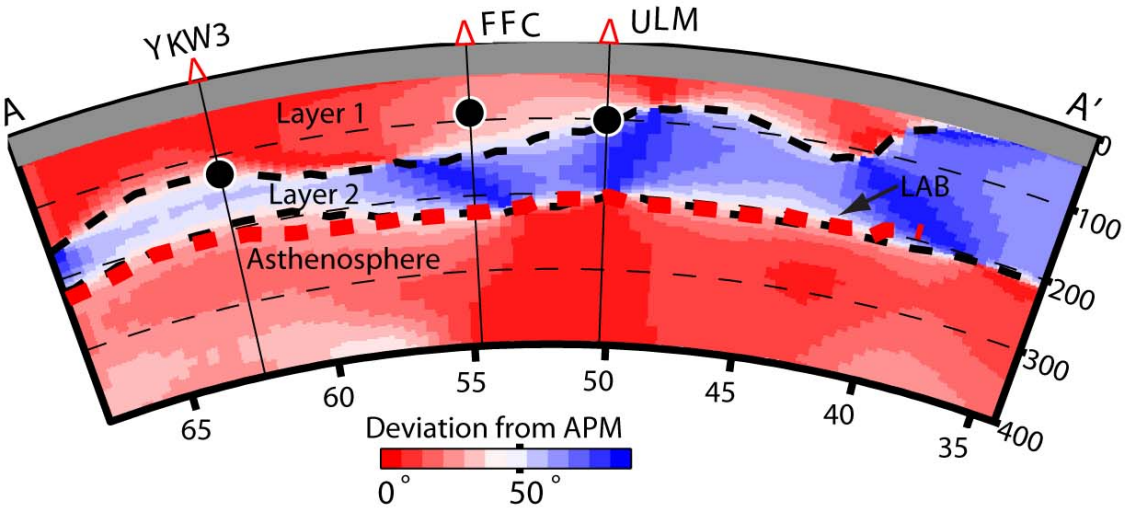


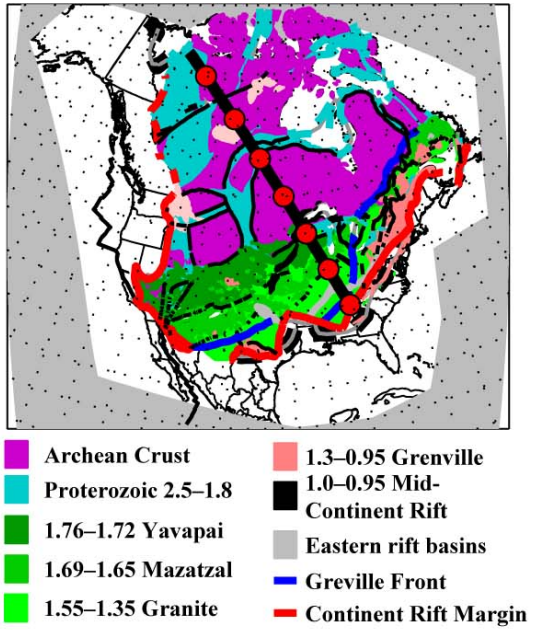
Olivine-rich rocks



A side of Earth…

…. with the help of seismology





Yuan et al., 2011

Obsessing questions since Wegener et al…

How does Earth create the vertical & horizontal boundaries of the plates ?

Obsessing questions since Wegener et al…

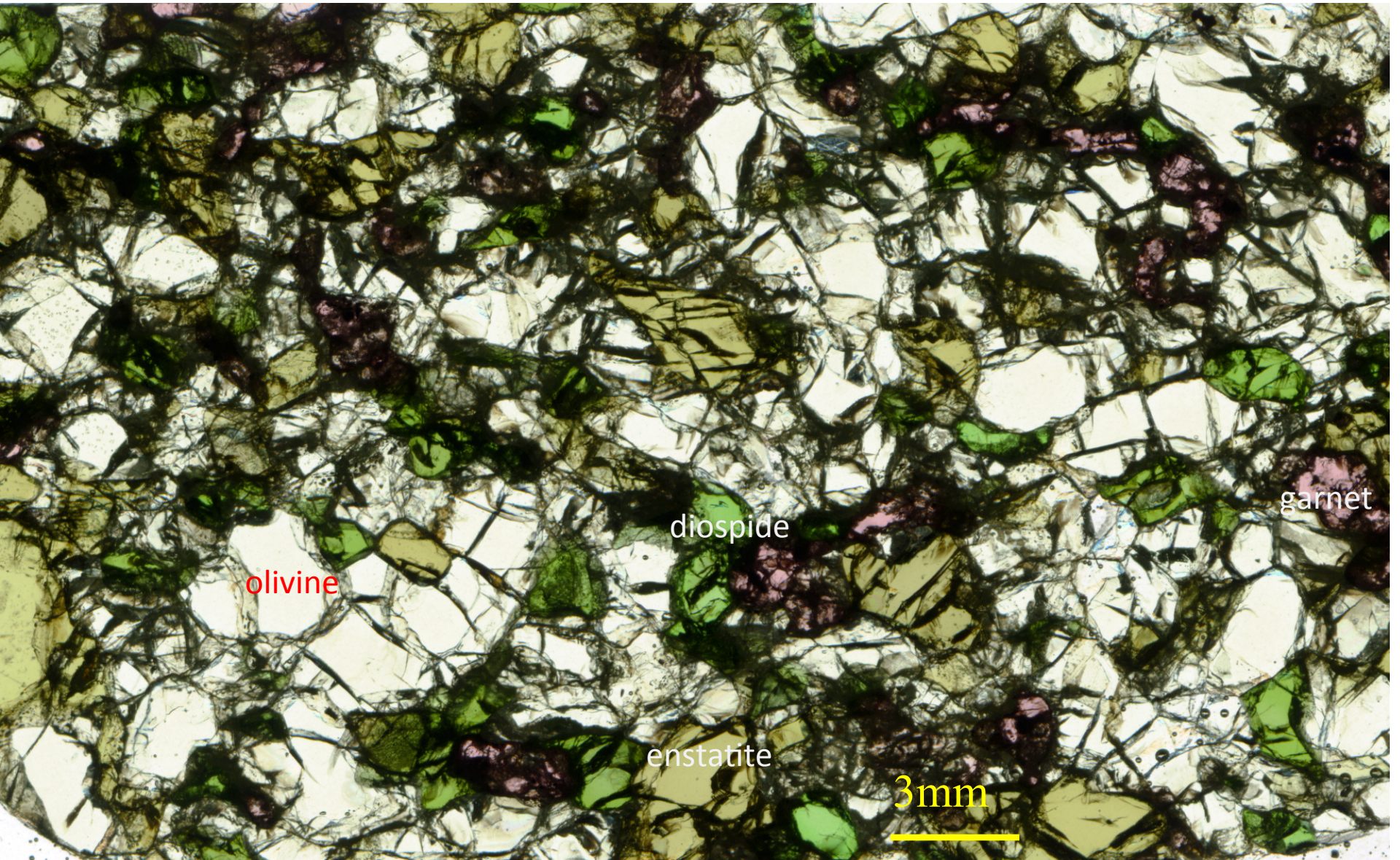
How does Earth create the vertical & horizontal boundaries of the plates ?

What do we know ?

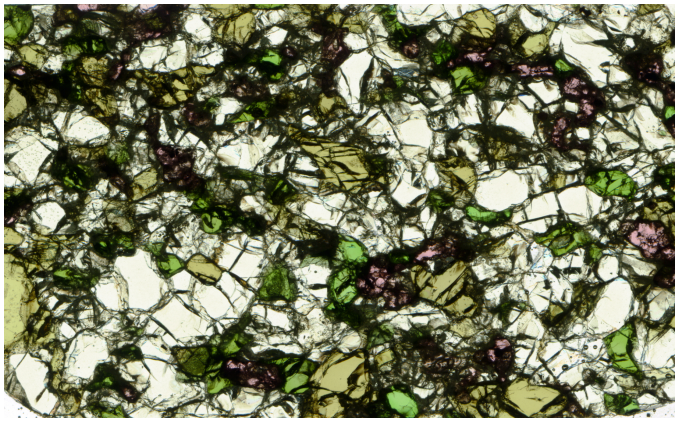
- The temperature and pressure conditions for the bottom boundary suggest visco-elasto-plastic deformation of mantle rocks.

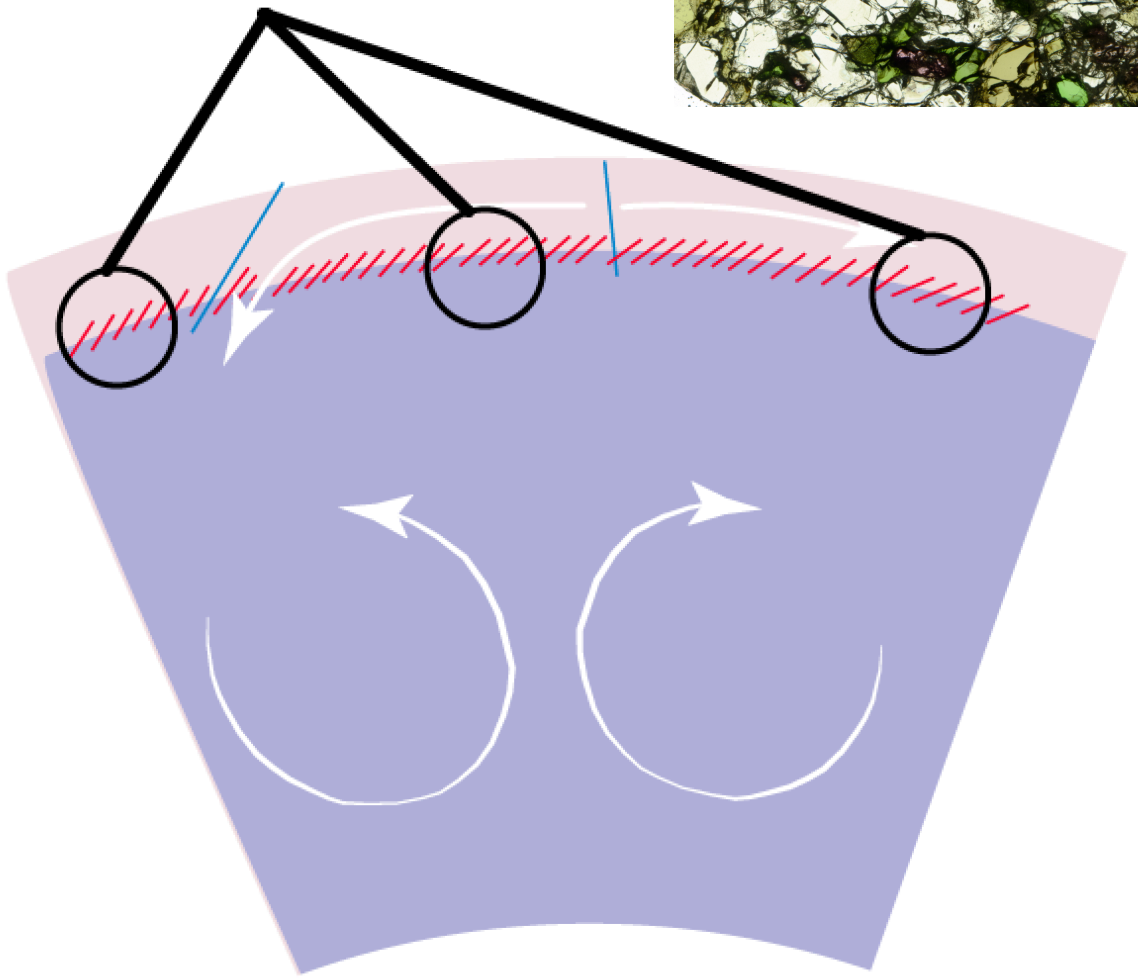
- These rocks are refractory material, Mg- and Si-rich silicates, polycristalline, mm-scale grains

Peridotite: olivine + enstatite + diopside + garnet
Origine: Patagonia



Olivine-rich rocks



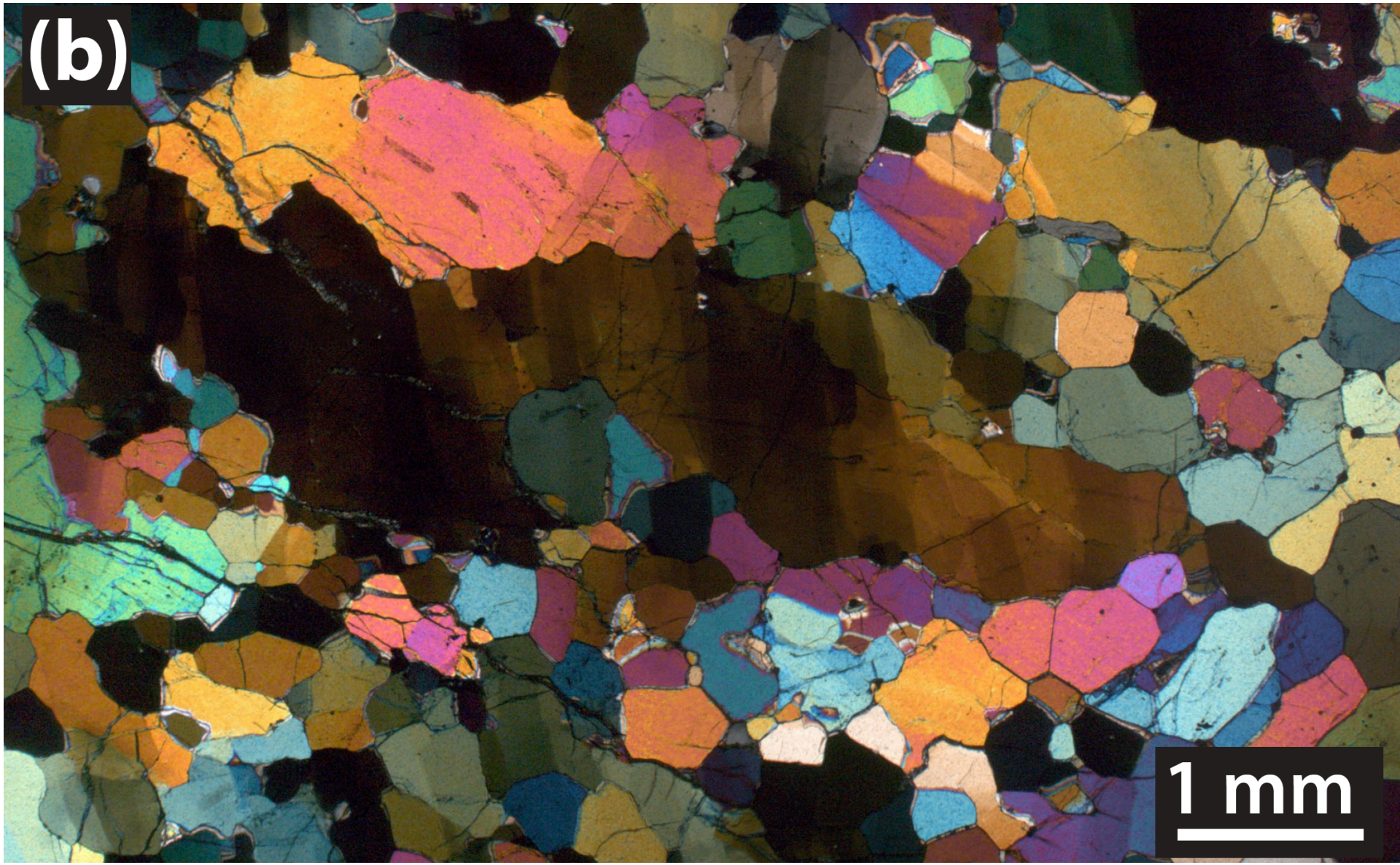


What do we know from nature ?

- Easy evidence of internal plastic deformation:
  - ✓*Subgrain boundaries,*
  - ✓*Grain size reduction by dynamic recrystallisation*

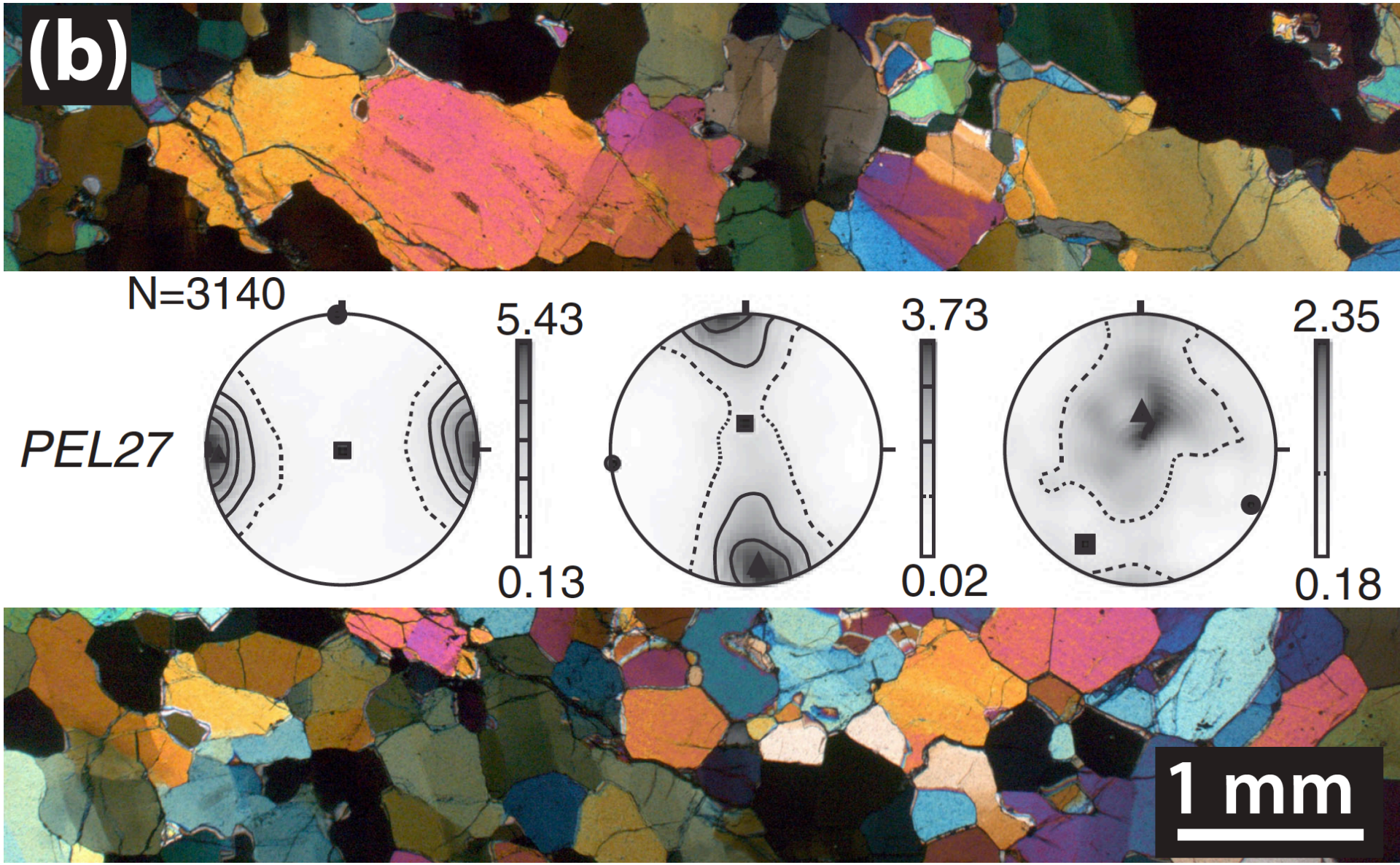
  And also
  - ✓*Annealing and equilibrated microstructures*
  - ✓*Grain boundary migration*

✓ Subgrain boundaries



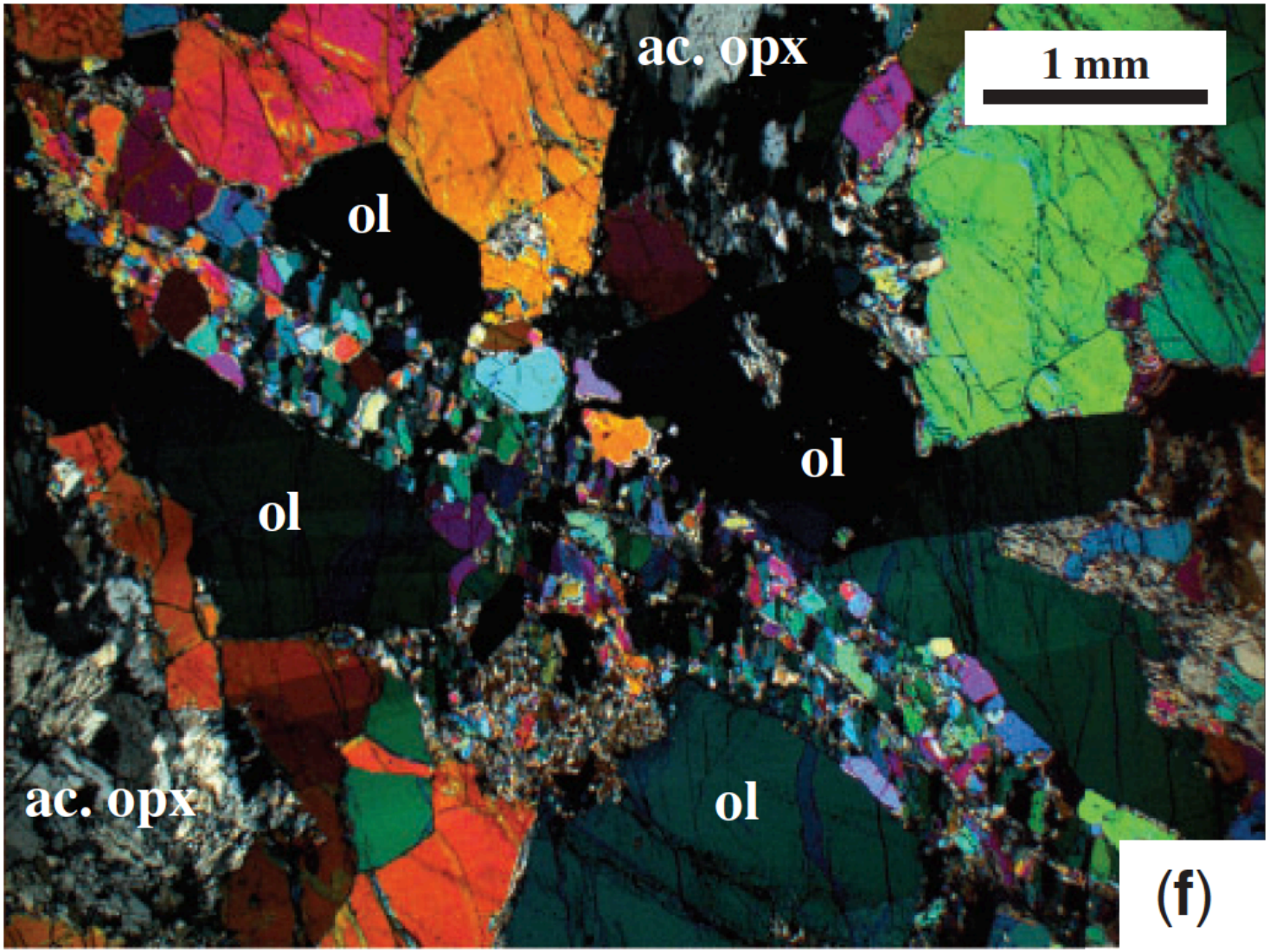
Peridotite from Tanzania, from Baptiste al., 2015

✓ Subgrain boundaries



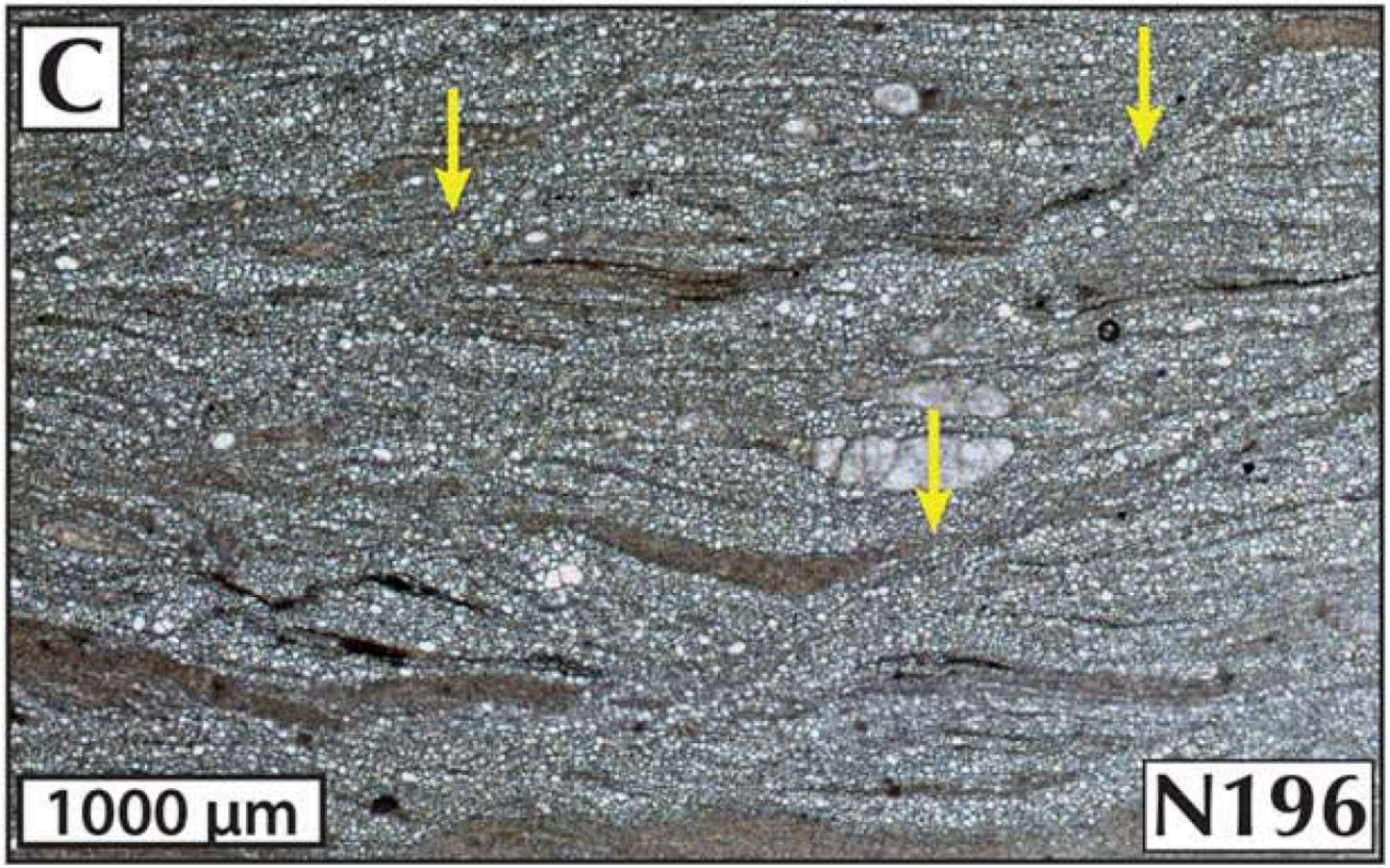
Peridotite from Tanzania, from Baptiste al., 2015

✓ Grain size reduction / dynamics Rx



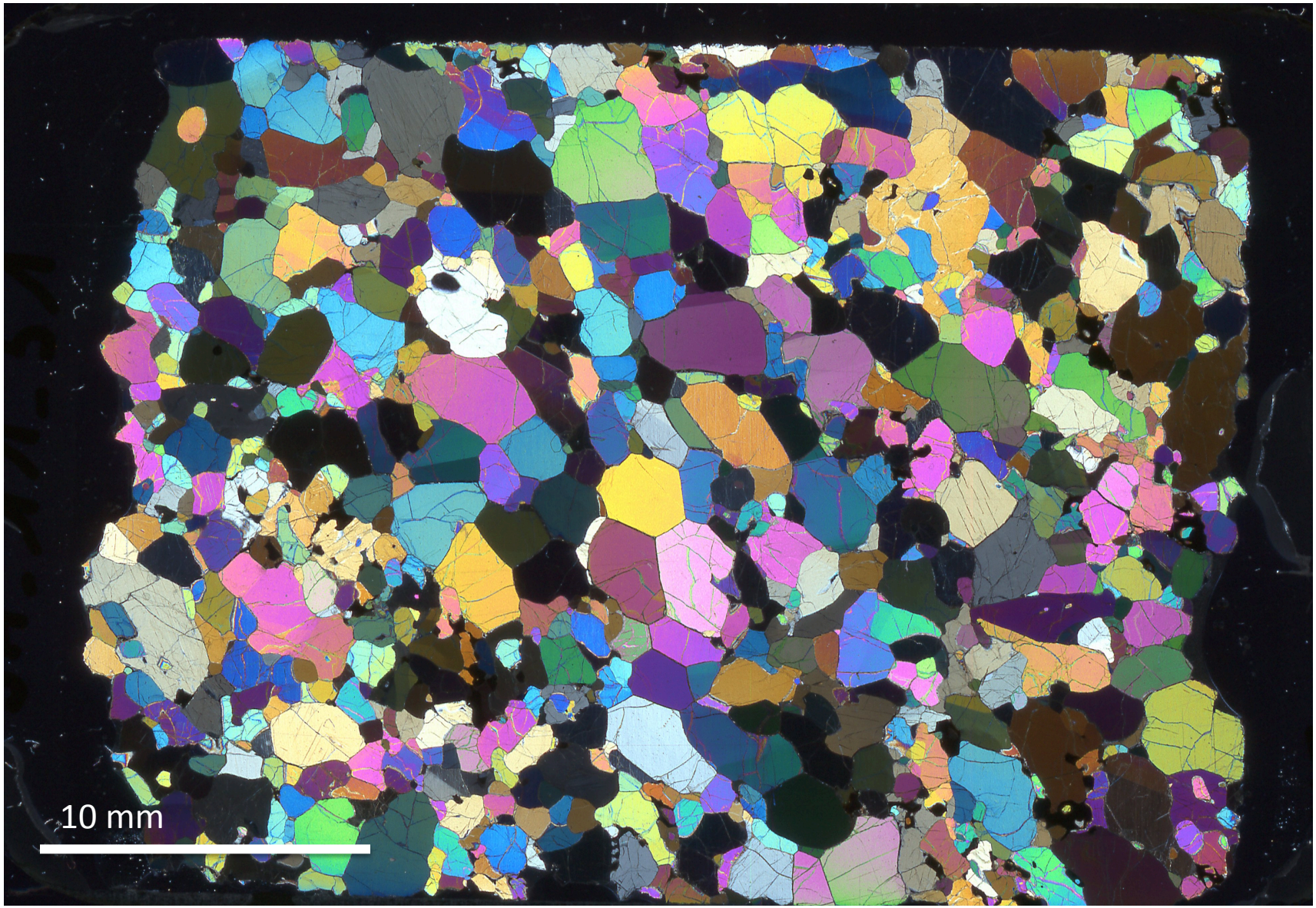
Soustelle et al., 2010

Dynamic recrystallization can lead to very fine-grained mantle rocks (mytlonitic texture)



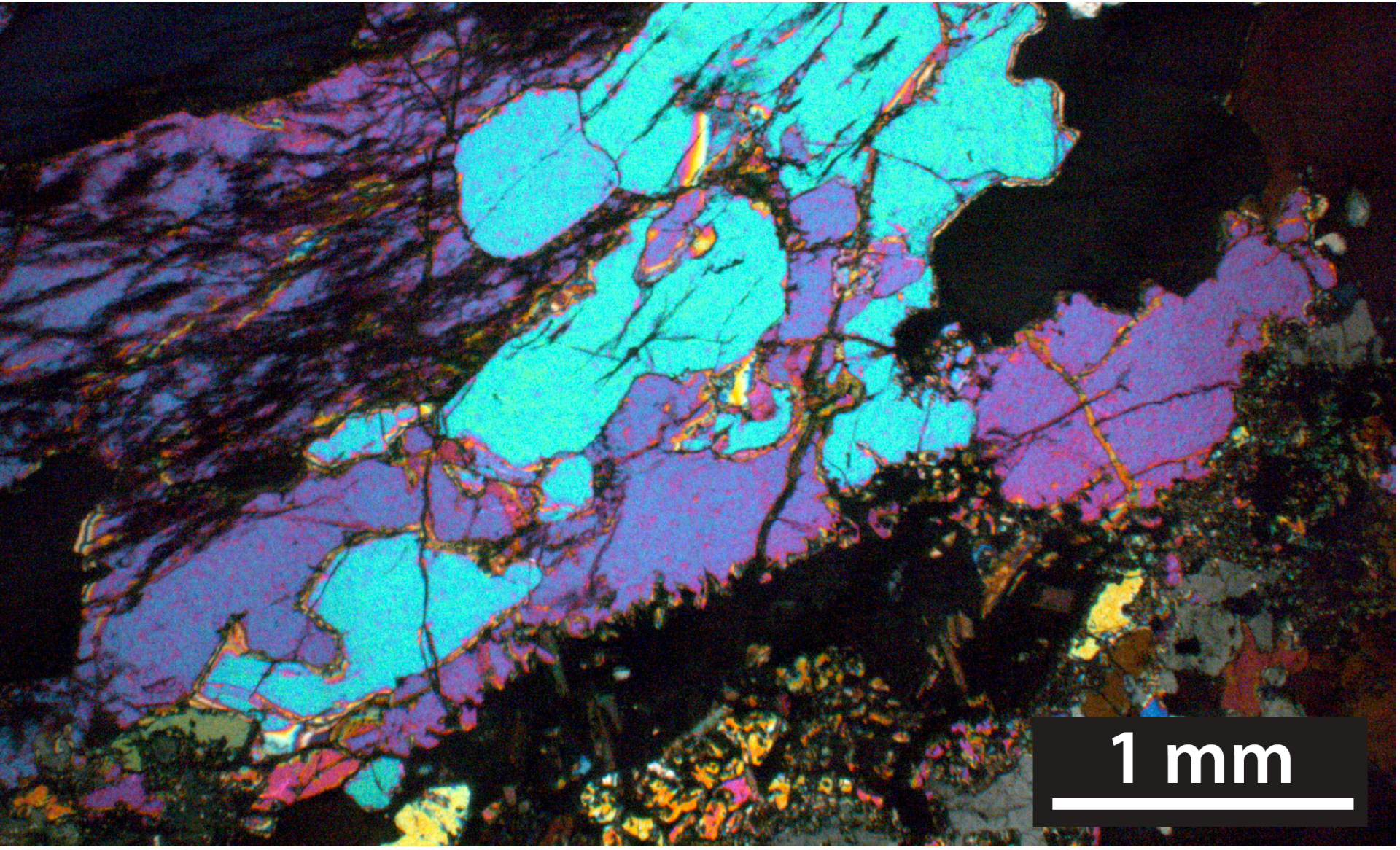
Behr and Smith
G3, 2016

✓ Annealing / eq. structures



Demouchy et al., G3, 2019

✓ Grain boundary migration



Peridotite from Tanzania, from Baptiste al., 2015

What do we know from the lab?

- Old approach of the « rock-squeezers »
  - ✓*To reproduce temperature and somehow pressure.*
  - ✓*To deform in axial compression and torsion.*
  - ✓*To establish empirical flow laws (at best semin-empirical) at lab strain rates.*
  - ✓*To create a weak zone by dynamic recrystalization.*
  - ✓*To deform single crystal and polycrystal @ HT.*
  - ✓*To identify CPO & dislocation slip systems.*

Tools ?

- ✓ Vickers Indentations.
- ✓ Griggs press – too much friction, not good for low differential stresses.
- ✓ Paterson press – crustal pressure only 0.3 Gpa.
- ✓ Griggs new model (ENS Paris and ISTO @ Orleans).
- ✓ Framed Paterson press (ENS Paris and EPF@Lausanne).
- ✓ Micro-plasticity: e.g., micro pilar and push-to-pull in situ TEM → ERC TimeMan.


New generation Griggs Press
ISTO - ERC L. Jolivet


New generation
(Framed) Paterson instrument
ENS Paris - ERC A. Schubnel

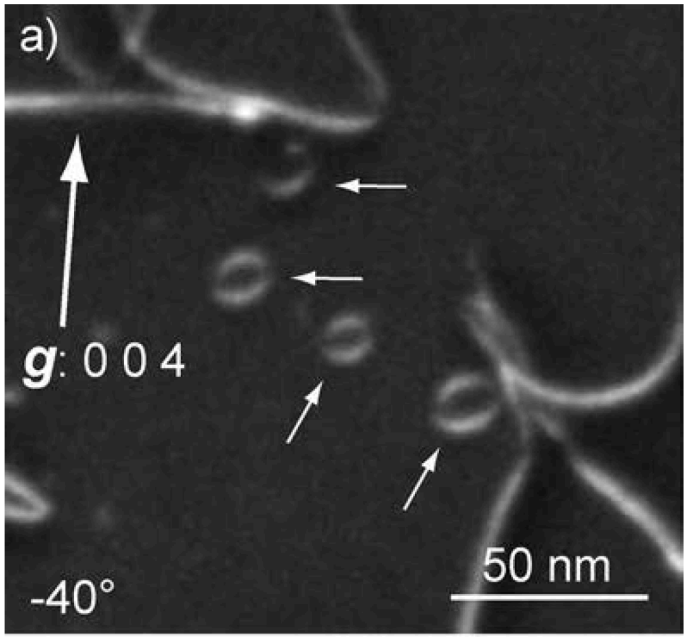
What does limit us in the lab?

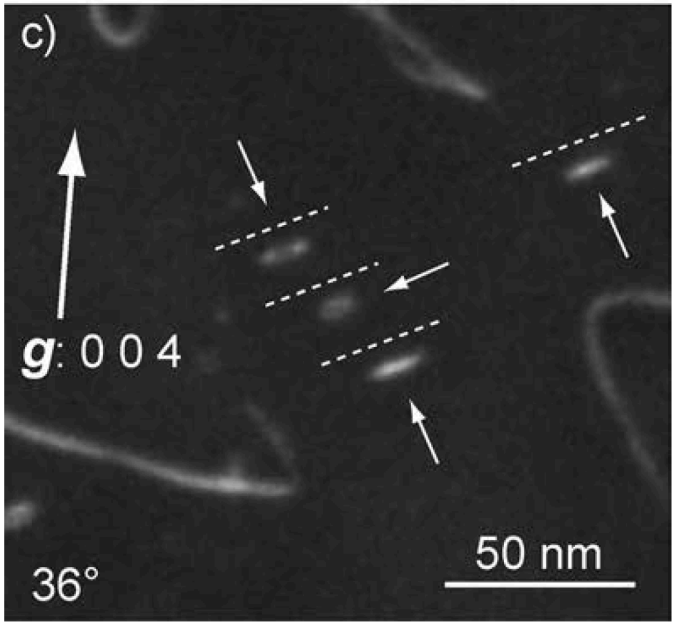
- ✓ *T up to 1300 °C, but below 800 °C ☹*
- ✓ *Pressure 5 GPa, (up to 15 in D-Dia)*
  - → *Stress with HR for uppermost mantle only ☹*
- ✓ *Strain rate very fast compare to the deep Earth*
  - → $10^{-5}\ s^{-1}$ *and not* $10^{-15}\ s^{-1}$
  - → *require extrapolation ☹*

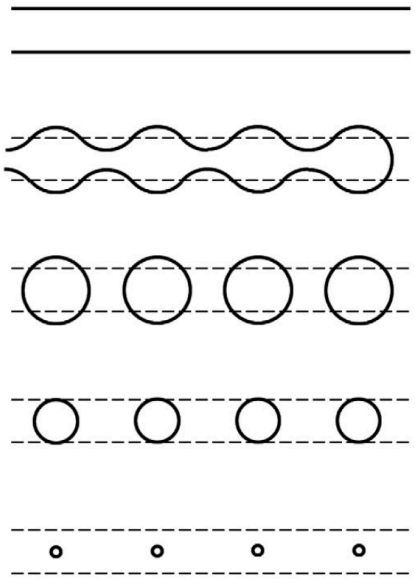
Solutions ?

- ✓ Learnings from the deformation experiments to nourrish numerical approach/models
- ✓ Alreayd started during ERC-*Rheoman*
- ✓ *E.g., sessile loops in experimentallly deformed olivine*

Mussi et al., 2015b; Boioli et al., 2015b







BEFORE

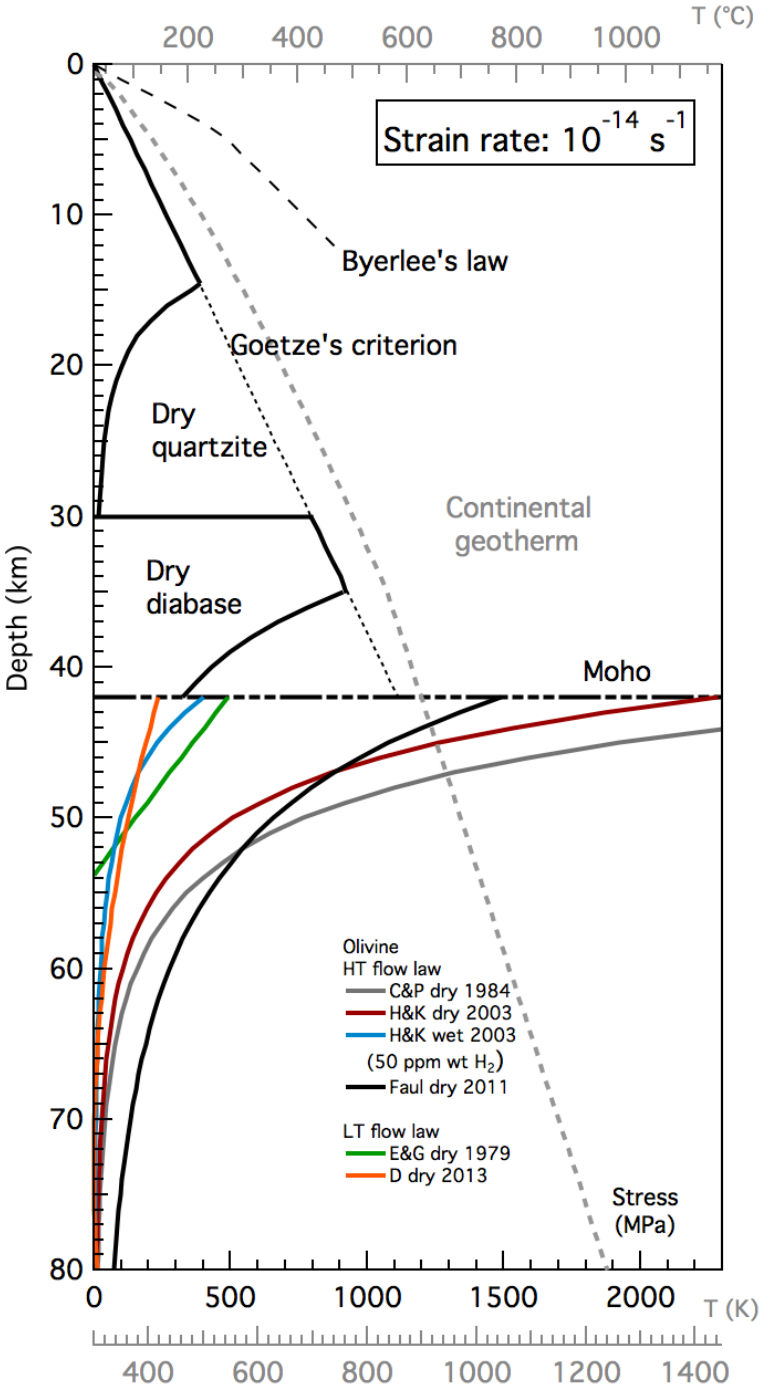
Vertical cut of the LAB

=

Strength envelop model

=

Xmas tree



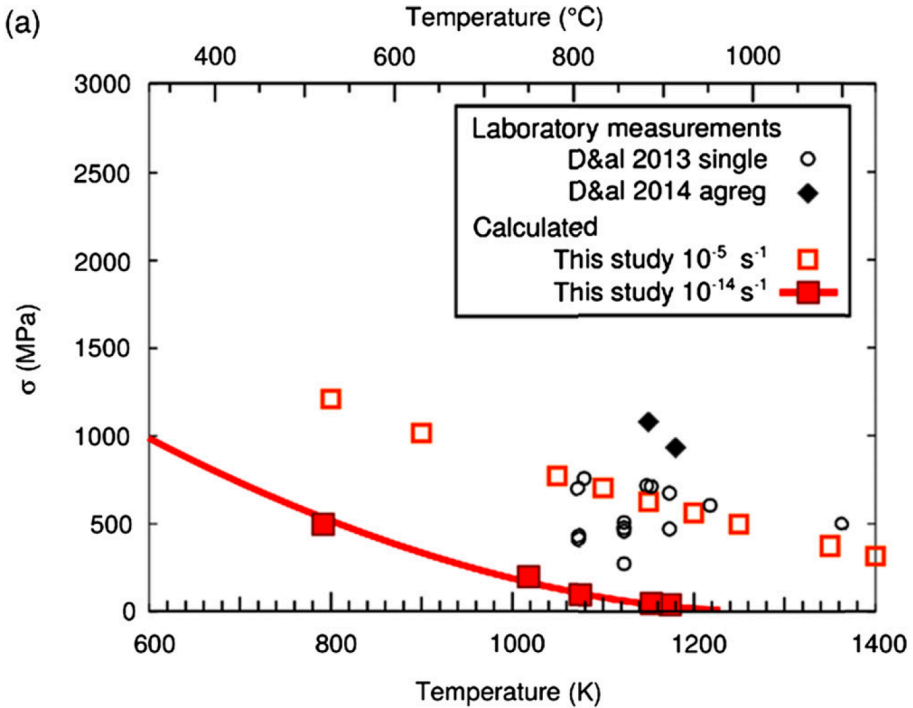
Demouchy et al., 2013

AFTER

We use samples from rock squeezers (e.g., Demouchy et al., 2013, 2014) to pin point dislocation interactions and to fine tune dislocation dynamics models

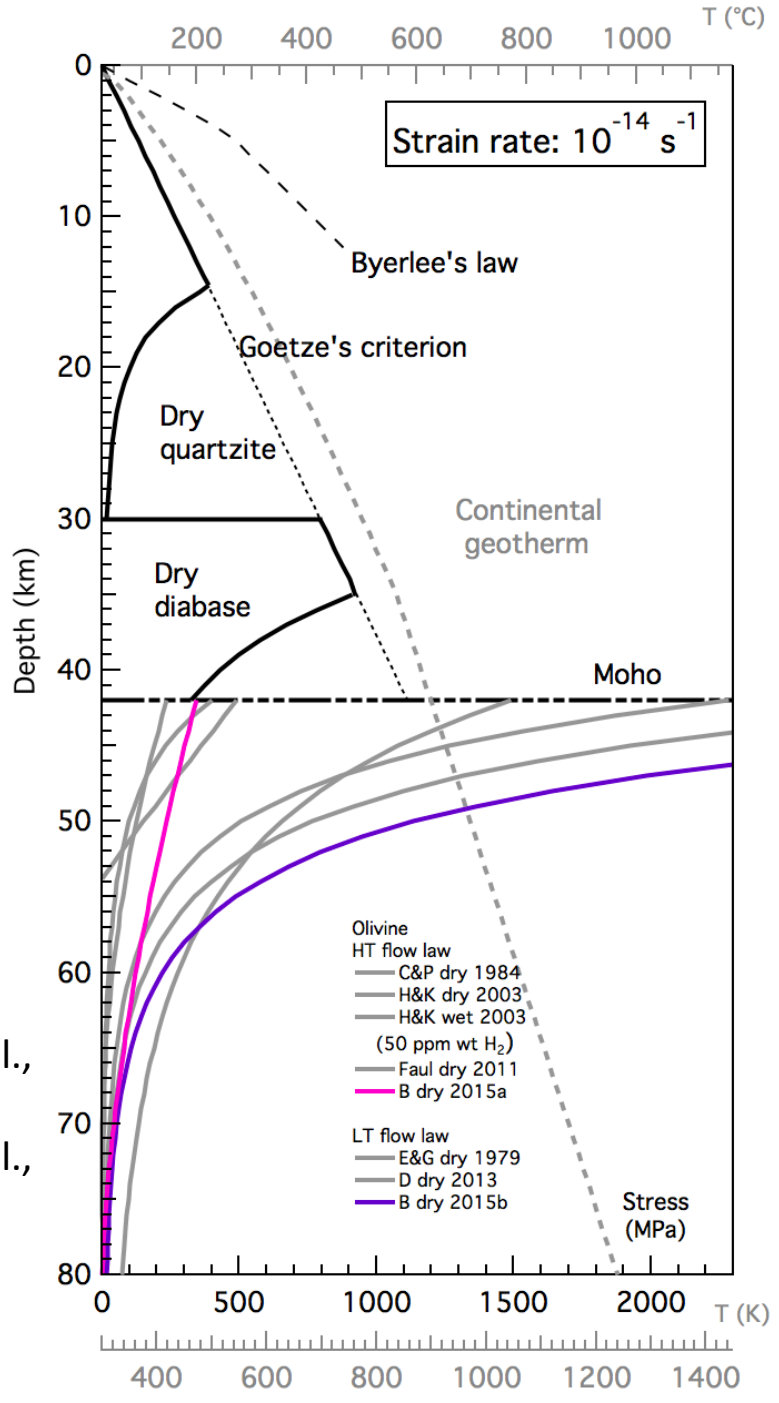
→ New flow law, for single crystal of olivine

→ but not easy to implement in models at large-scale → Gouriet et al., 2019

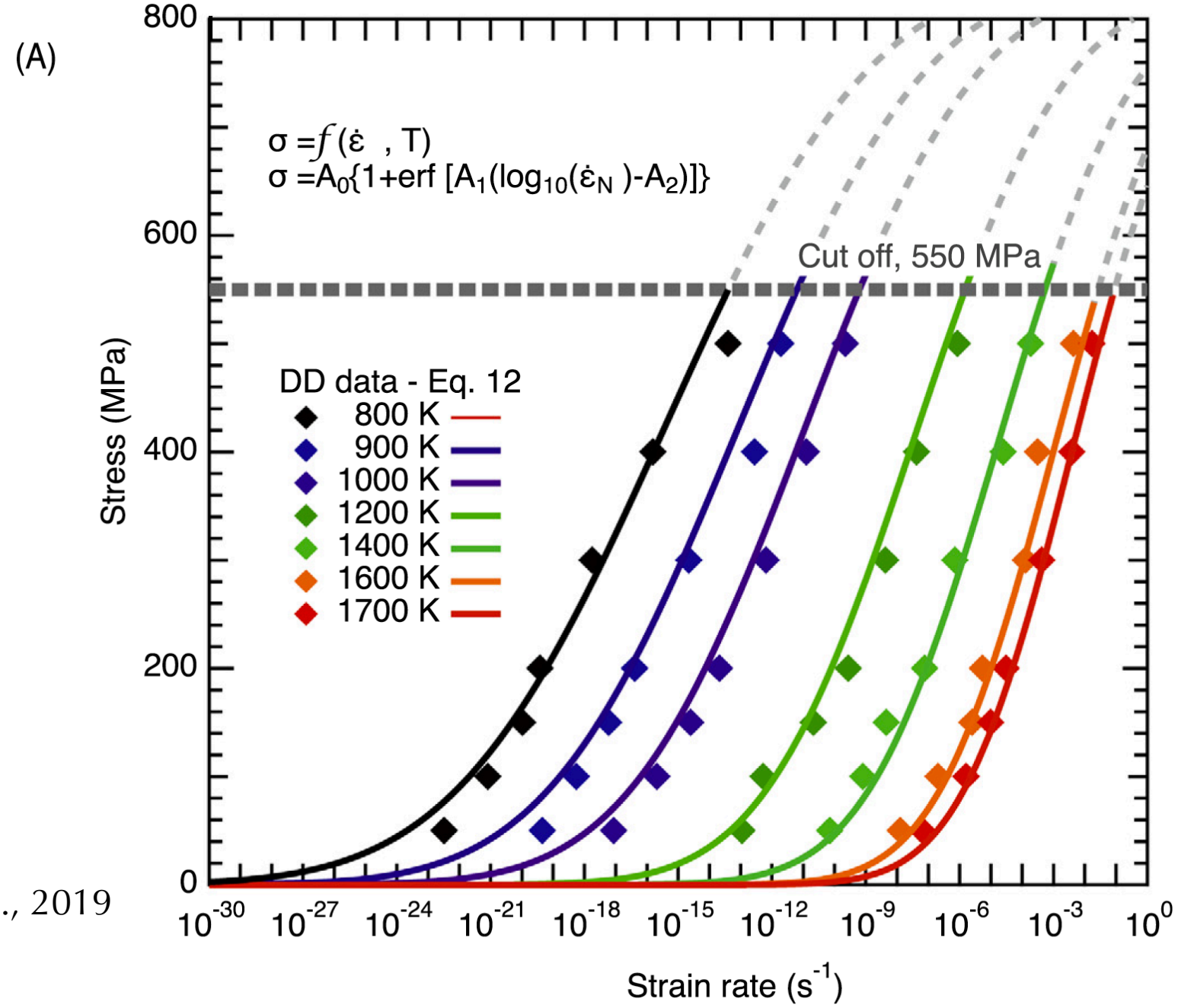


Boioli et al., 2015a

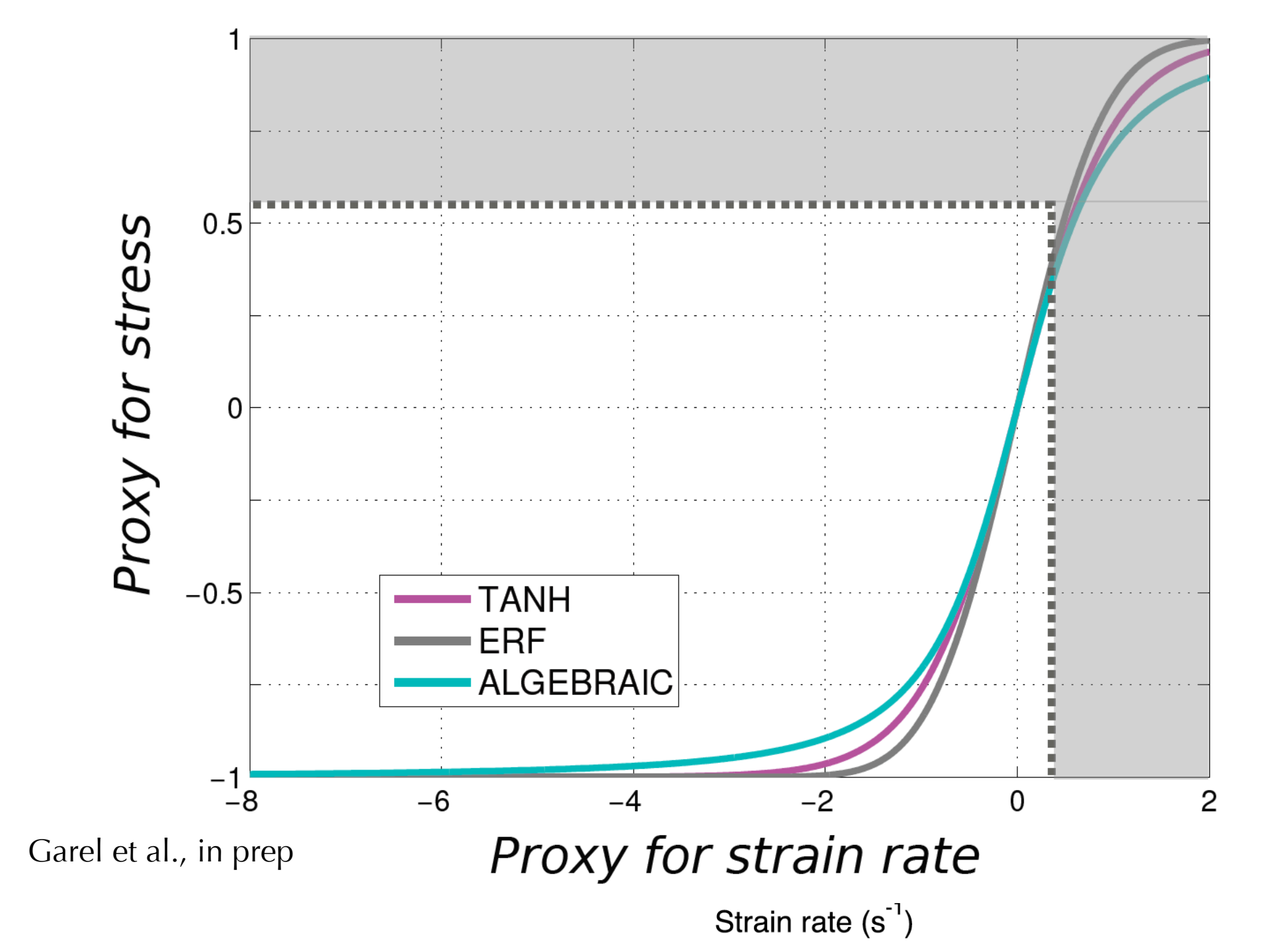
Boioli et al., 2015b



BETTER

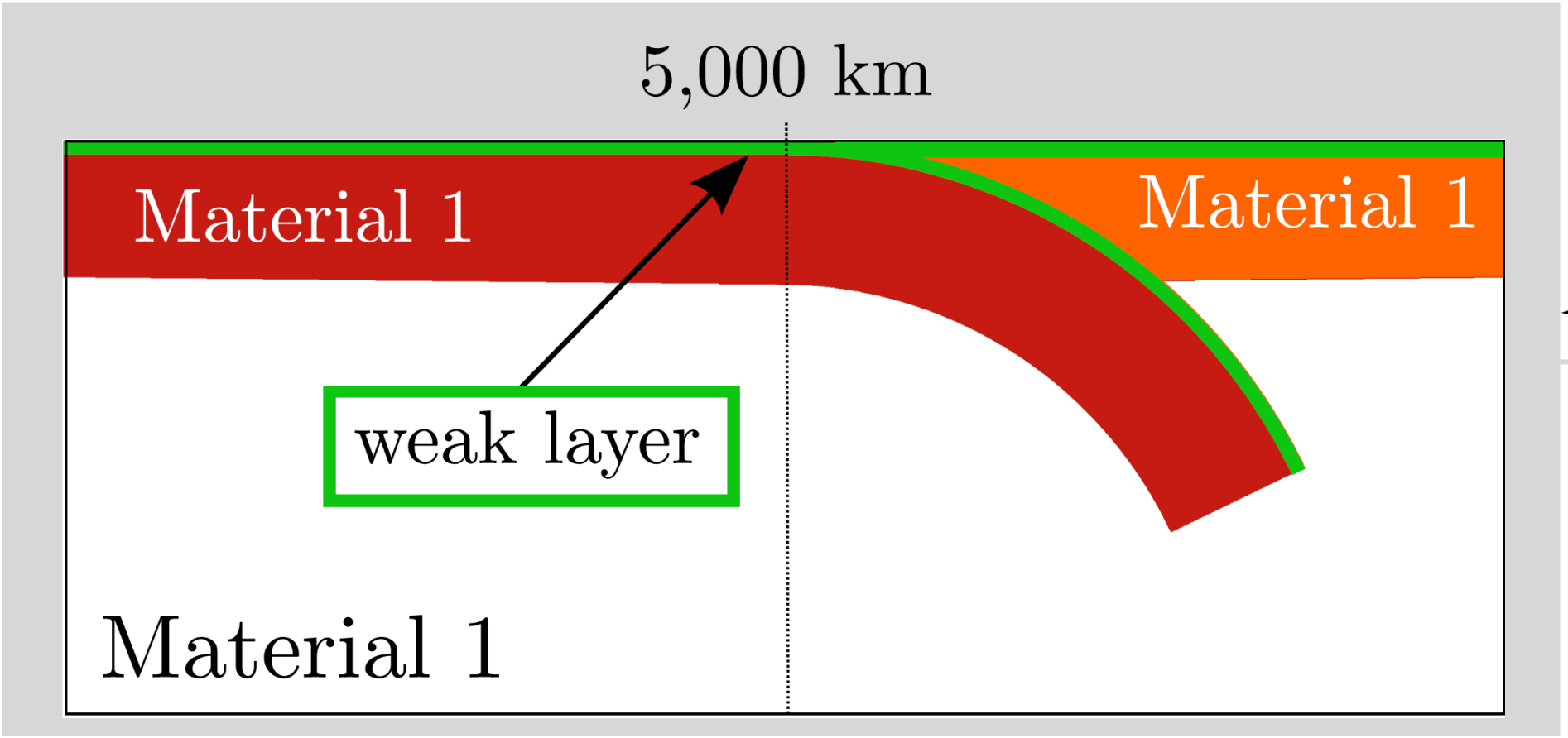


Gouriet et al., 2019

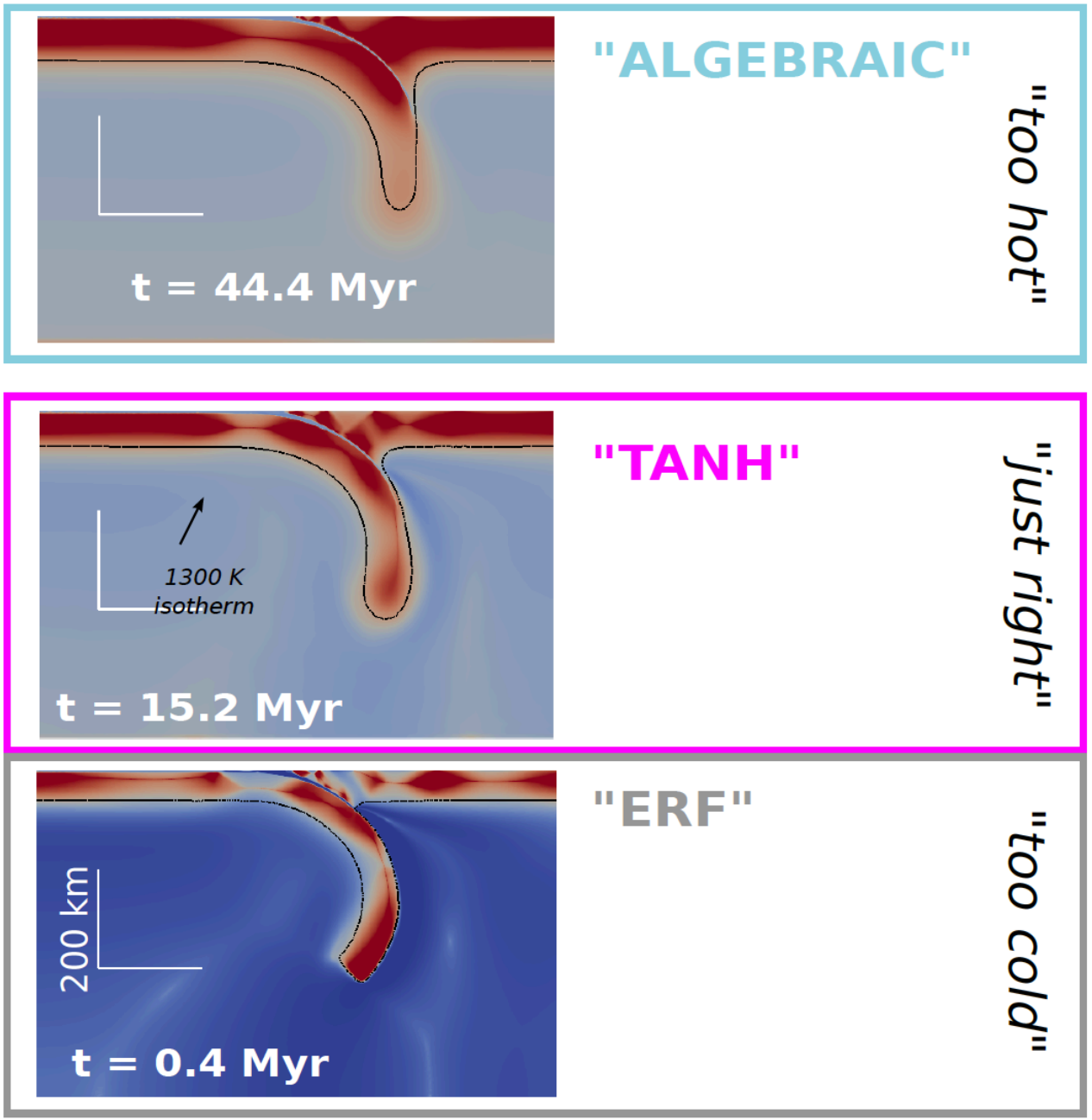


Garel et al., in prep

Numerical modeling of onverging plates



Garel et al., in prep



Garel et al., in prep

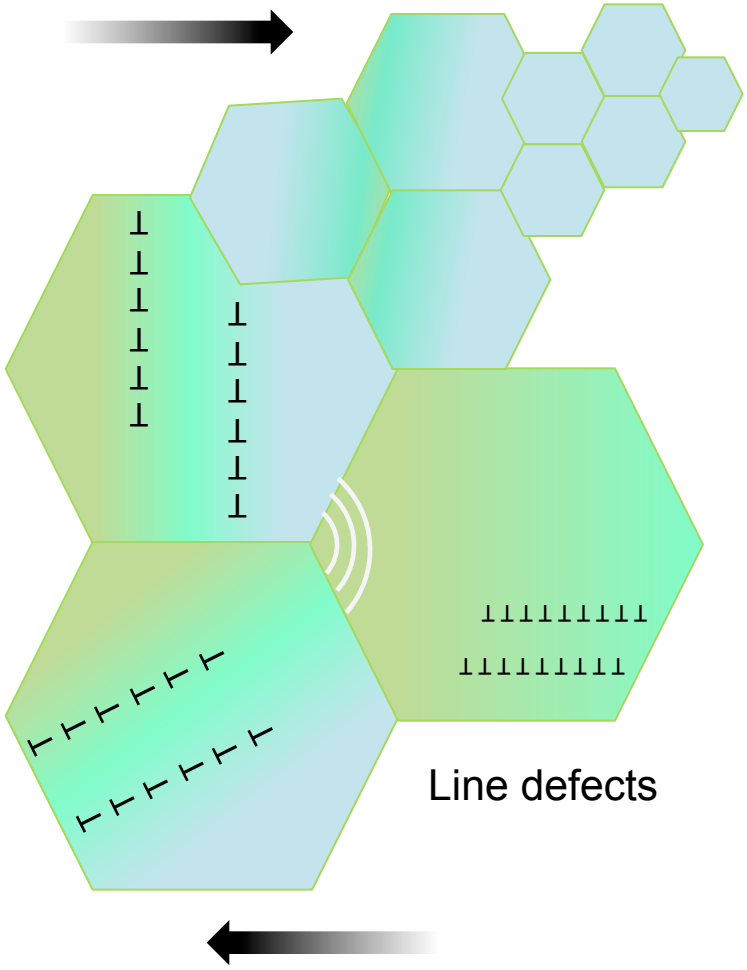
Moving forward with ERC-TimeMan and beyond

- ✓ Vacancies and Si diffusivity are more important than previously thought.
- ✓ Velocity of dislocation motion.
- ✓ Grain boundary mechanisms cannot be negleted anymore
- ✓ Plastic deformation of olivine is not limited to a bimodal world (diffusion creep vs dislocation creep)
- ✓ Defects of various dimension must interact !

Up to now (recently)

Dislocation creep and Dx

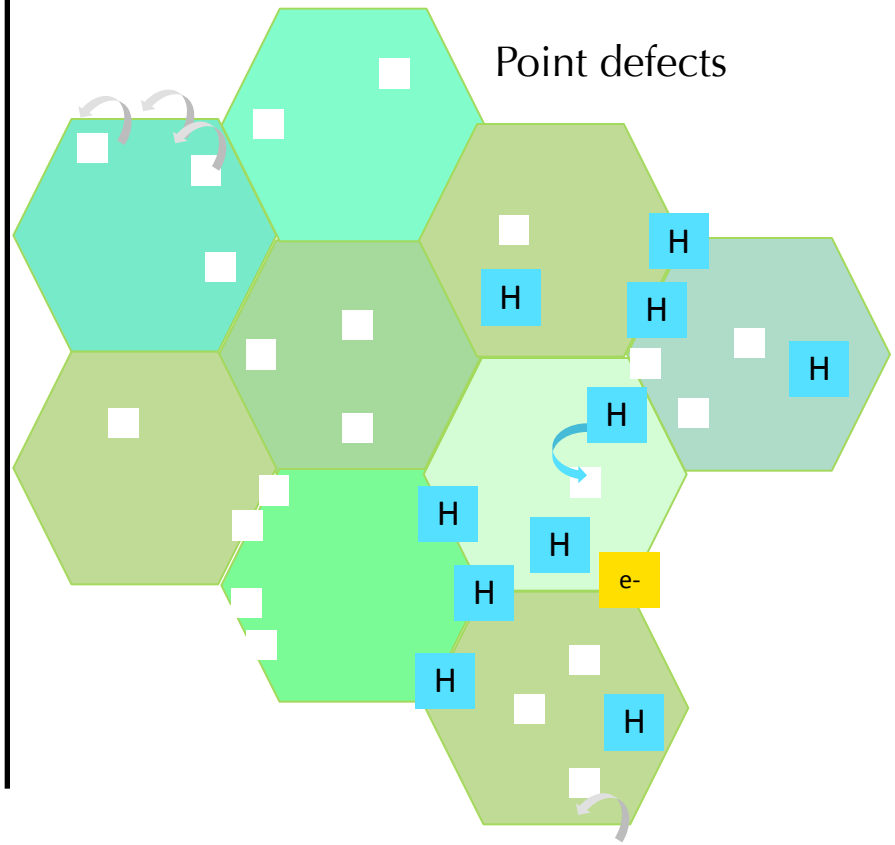
Olivine, mostly



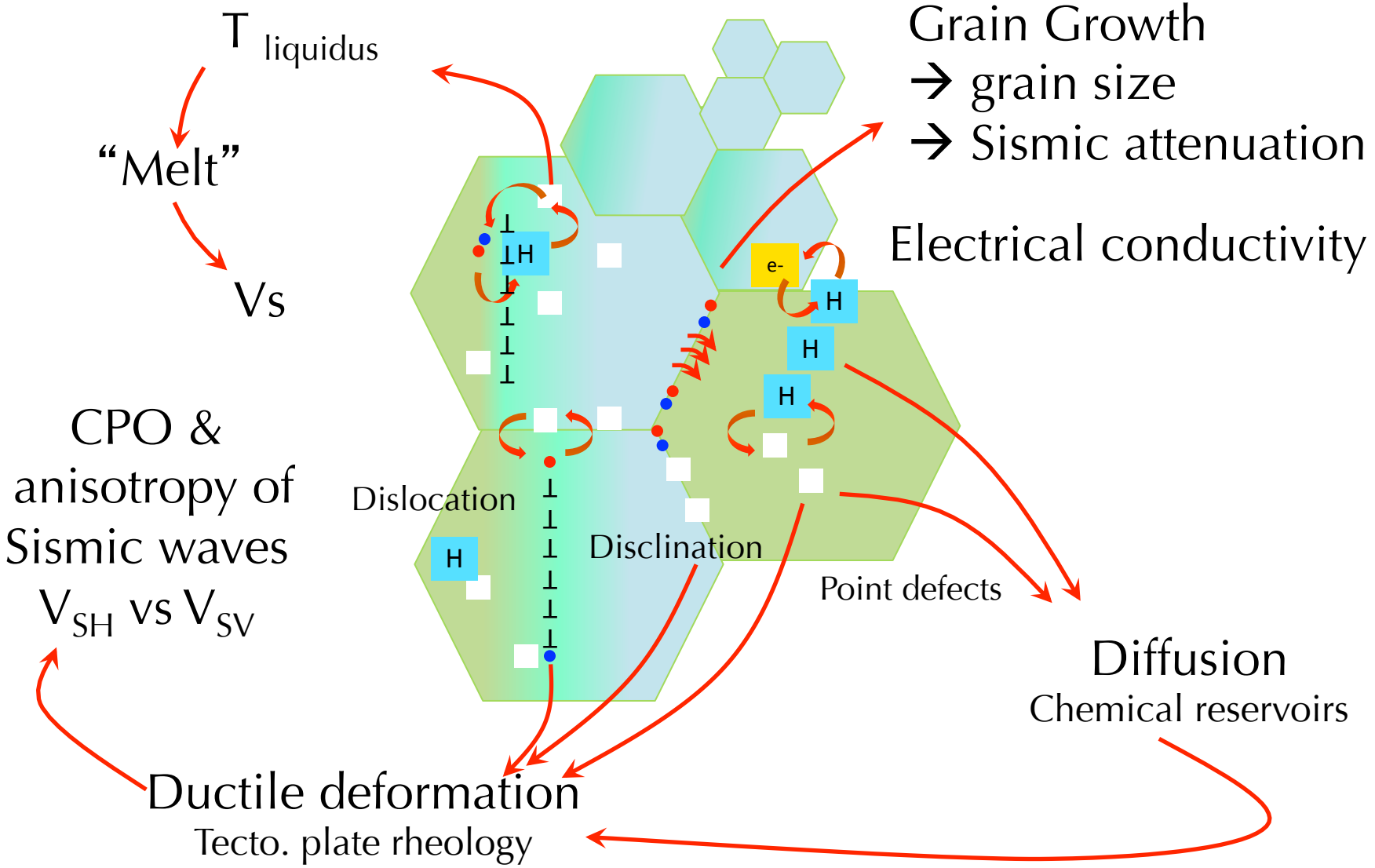
Diffusion creep

Vacancies and impurities

Grain size sensitive



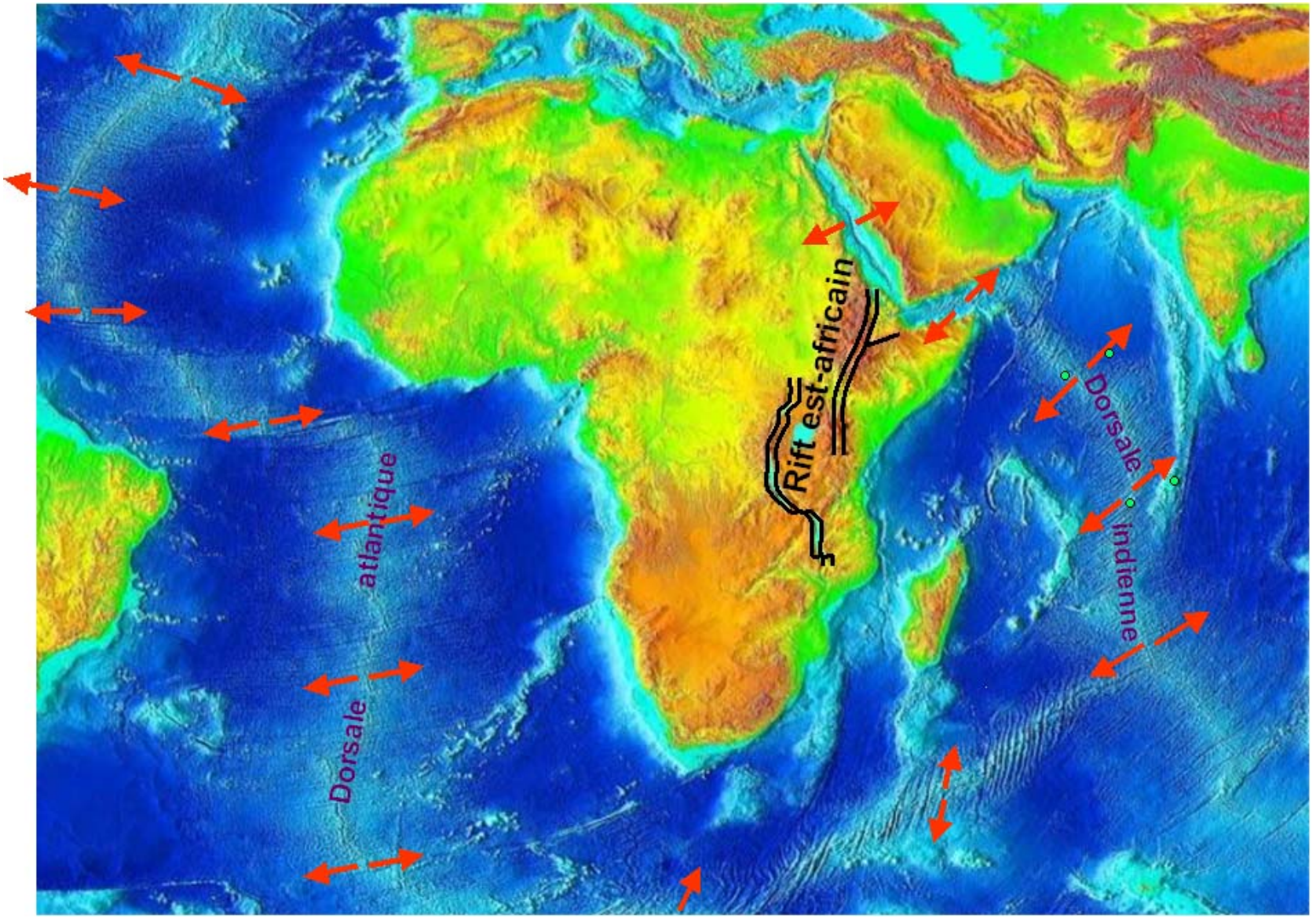
Tomorrow: *the players of mantle rheology*



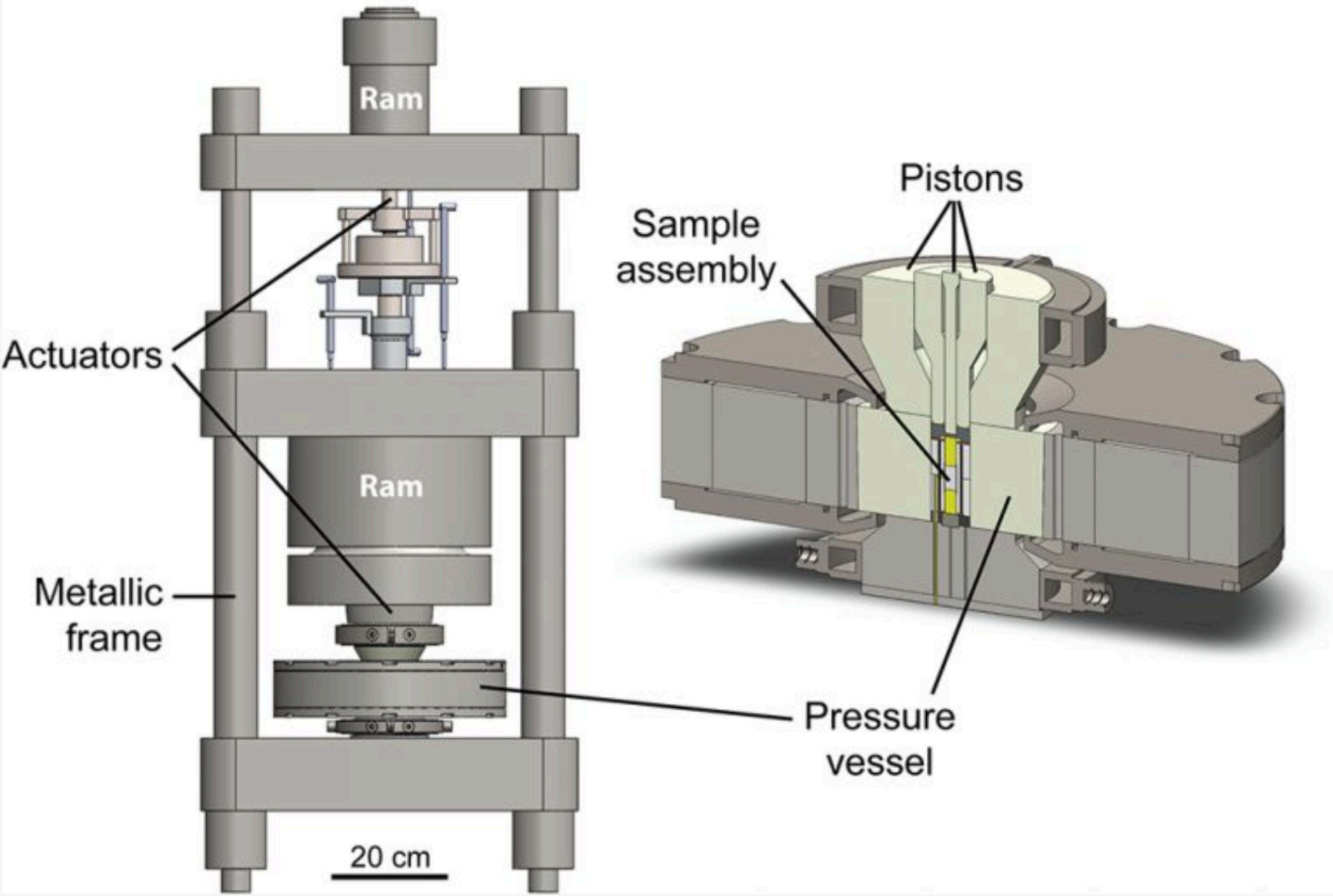
Thank you

Olivine

Earth from above



The "New generation" Griggs-type apparatus

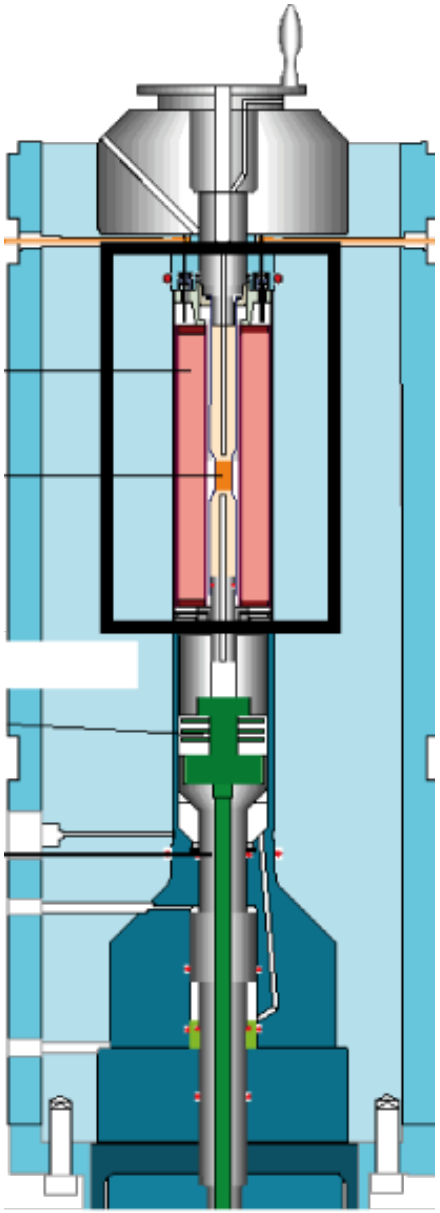


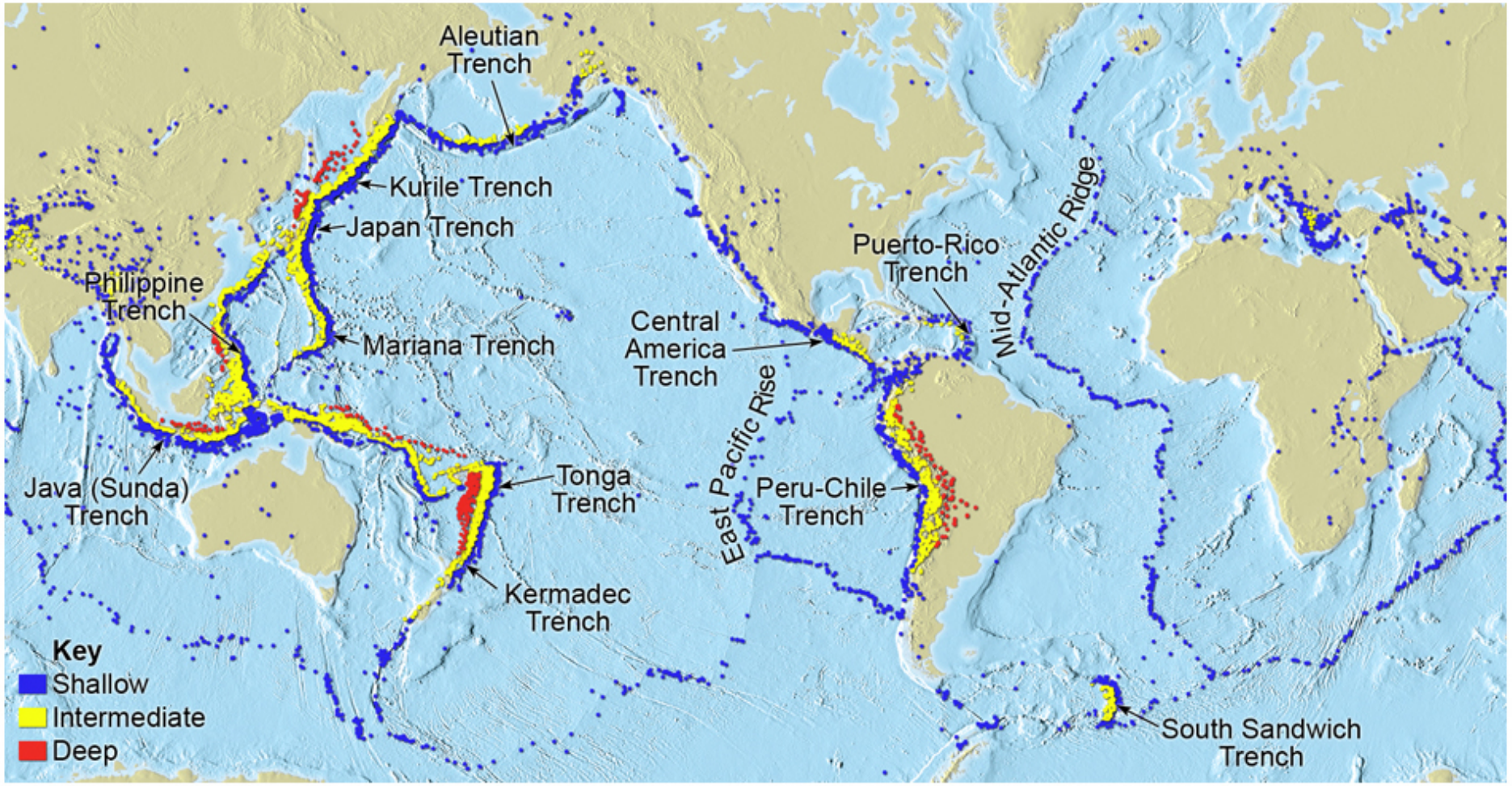
Paterson press principle

Internal furnace

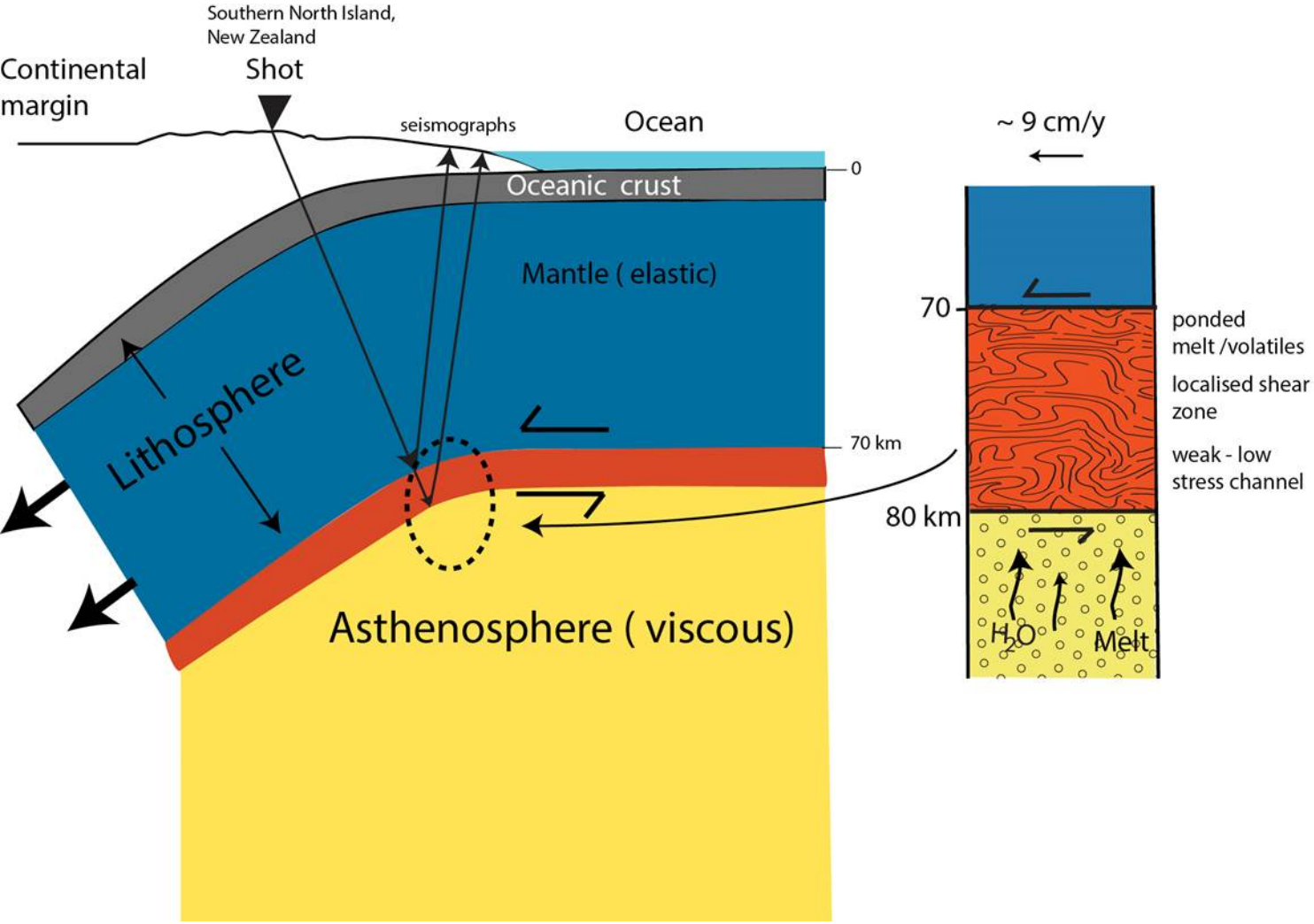
Sample 1 cm x 2 cm

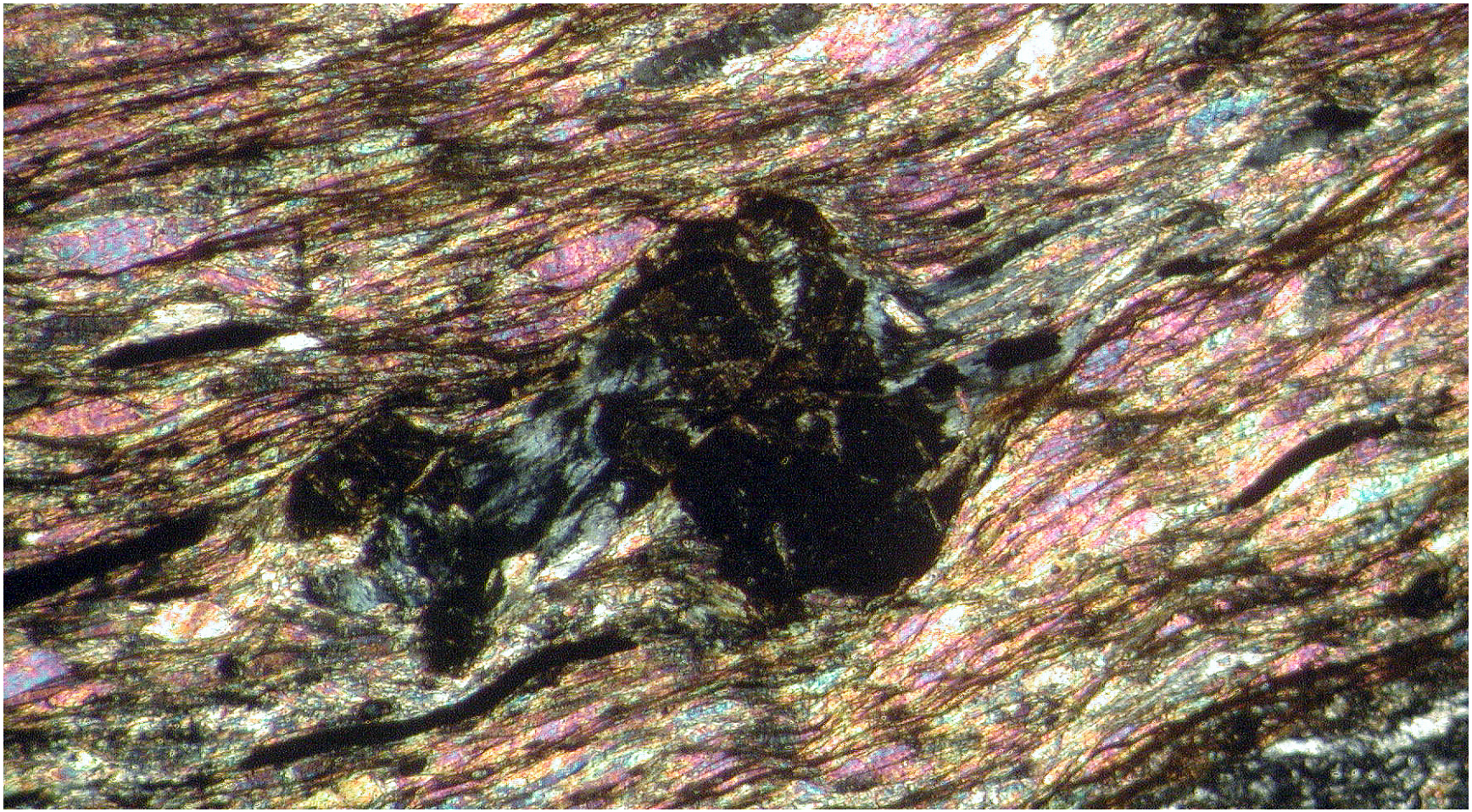
Internal load cell

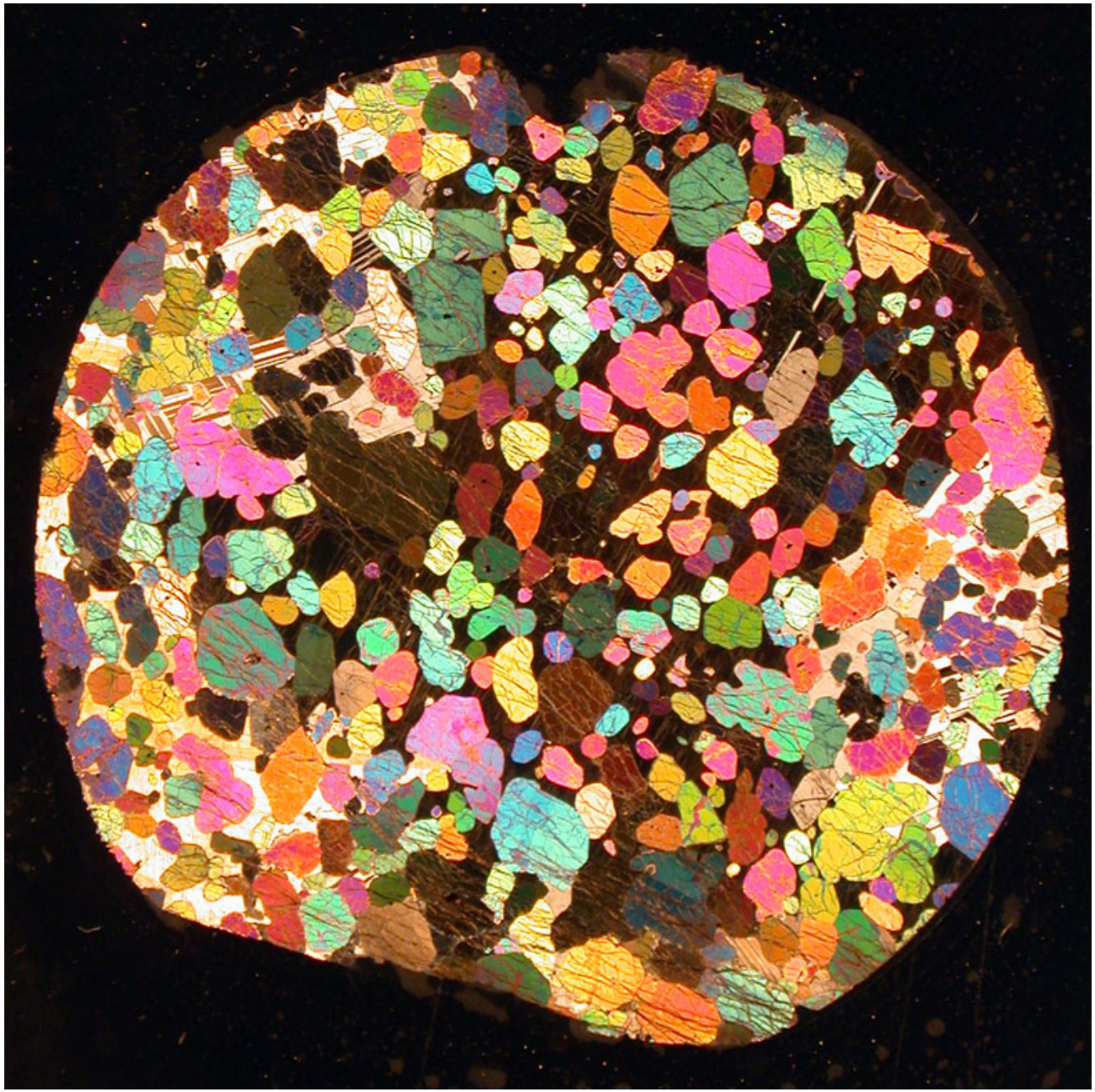


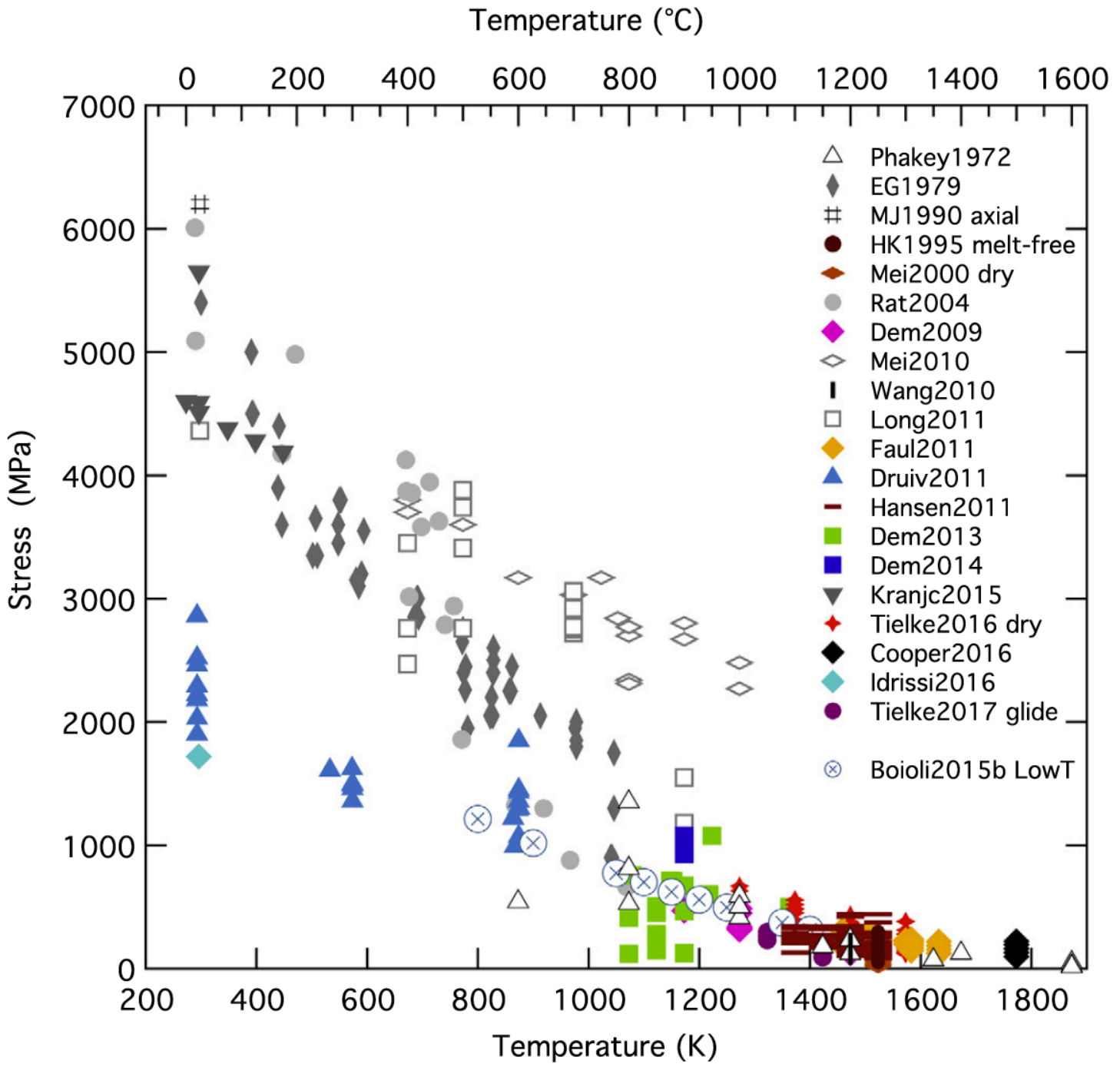


Distribution of shallow-, intermediate-, and deep-focus earthquakes. (Data from NOAA)

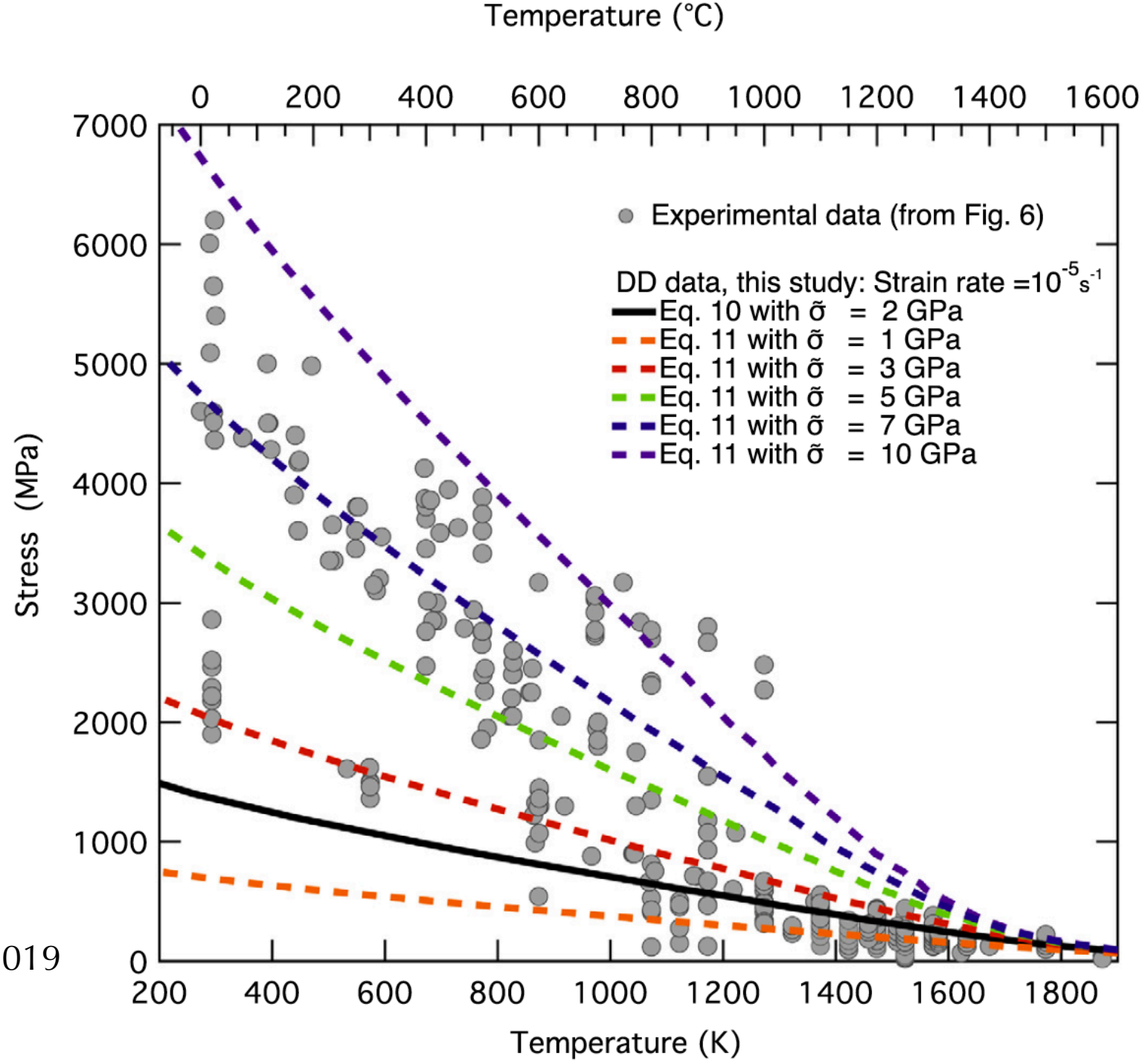

Southern North Island,
New Zealand
Continental
margin
Shot
seismographs
Ocean
Oceanic crust
Mantle (elastic)
Lithosphere
0
70 km
Asthenosphere (viscous)
~ 9 cm/y
70
80 km
ponded
melt /volatiles
localised shear
zone
weak - low
stress channel
H2O
Melt







Gouriet et al., 2019



Gouriet et al., 2019