Intermediate-depth earthquakes in subduction zones: insights from high pressure experiments

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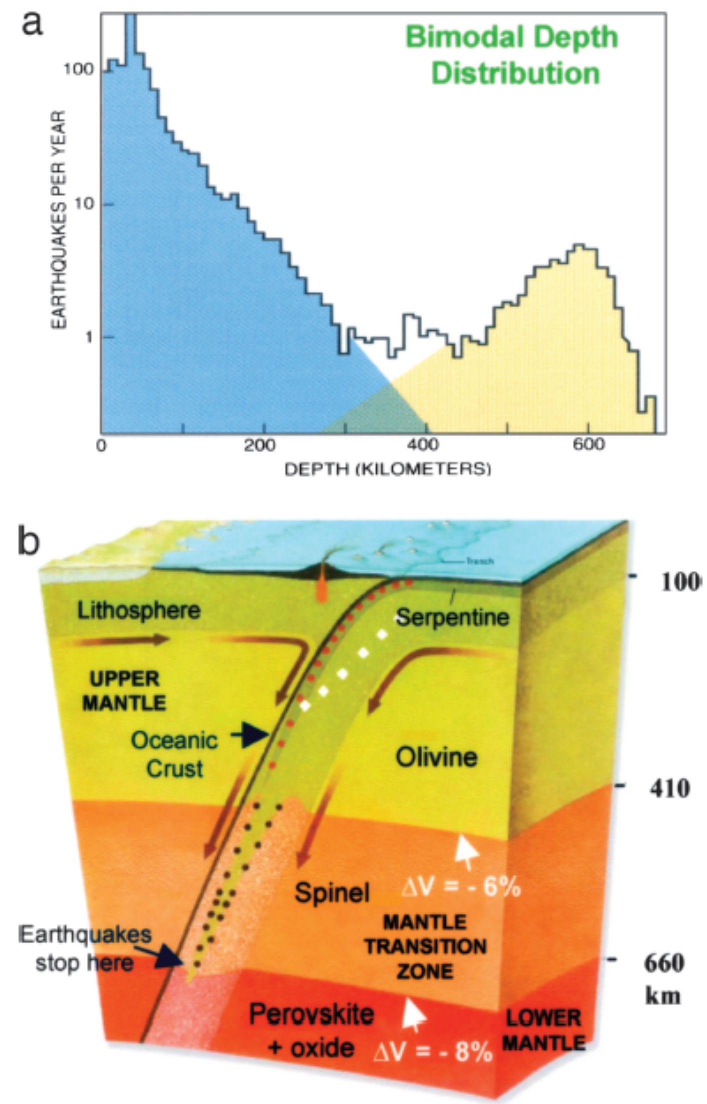
Earthquakes at depths

Earthquakes after ca. 50 km depth are not explained by friction theories.

… are these earthquakes induced *somehow* by mineralogical reactions ?

(and how do we test for this experimentally?)



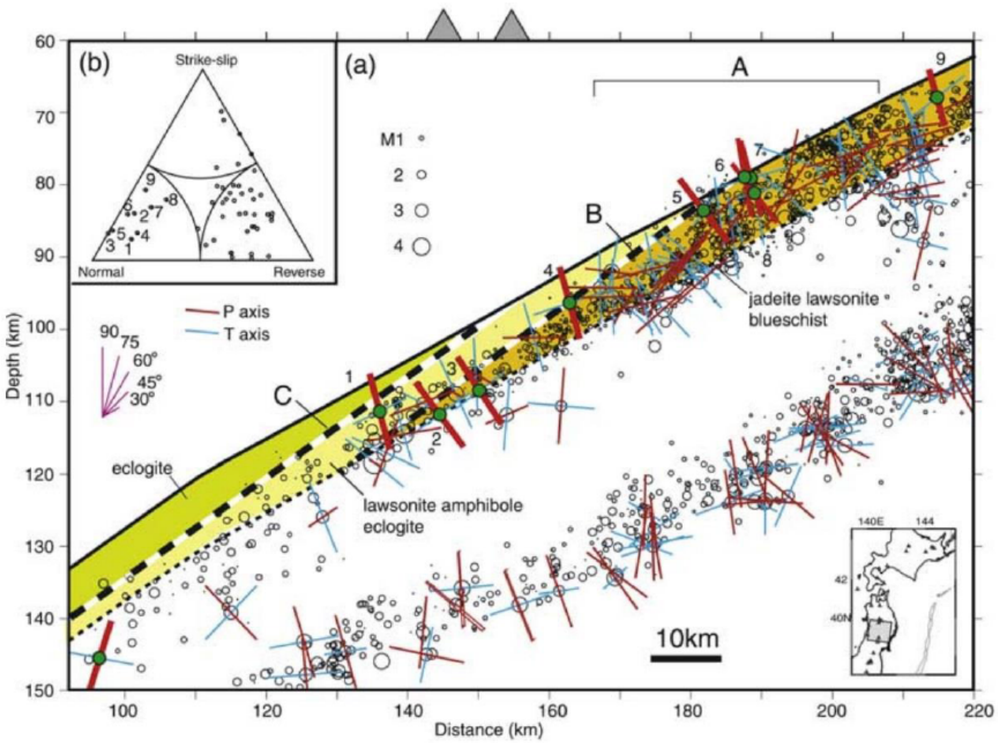
Green, PNAS 2007

Earthquakes
at intermediate depths and mineralogical reactions

Candidates:

- ❑ reactions in the oceanic crust (eclogitisation)
- ❑ dehydration reactions in the mantle

- o *Small grain sizes produced*
- o *Fluid release -> decrease in effective pressure*
- o *…??*

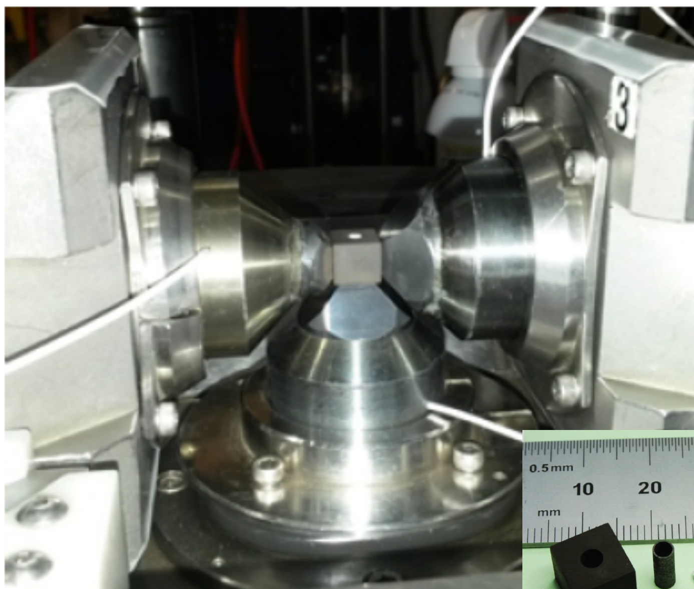


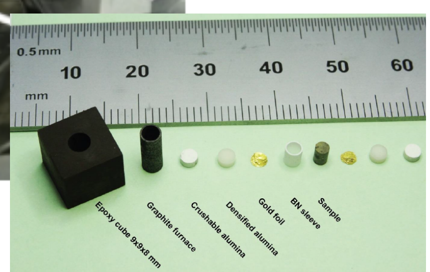
Kita et al, 2006

Investigate brittle-like behavior potential under high pressures

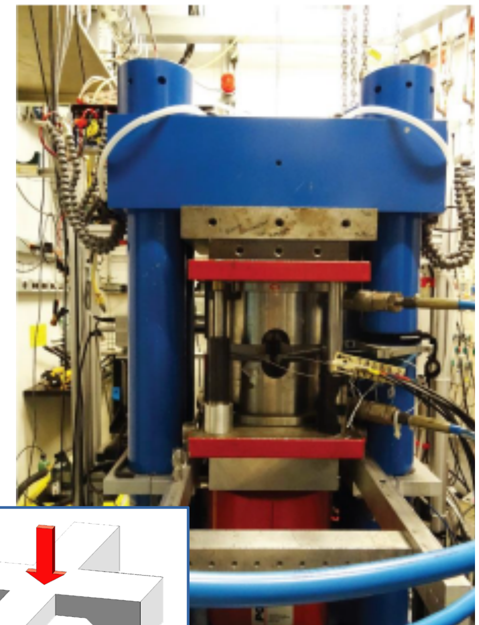
Generating large pressures (and deformation)

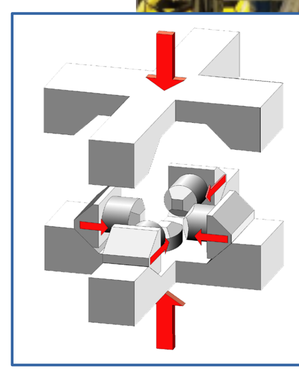
Experimental deformation under high pressures (> 2GPa):
Deformation-DIA multianvil press





T. Ferrand 2017





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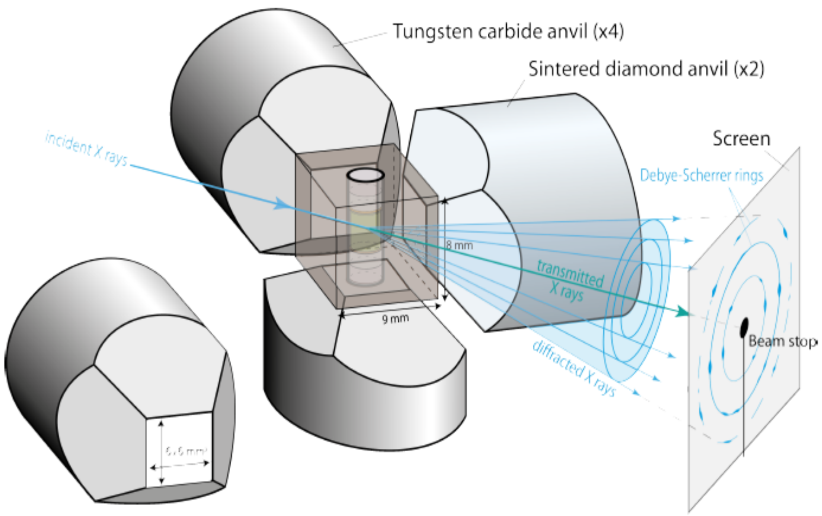
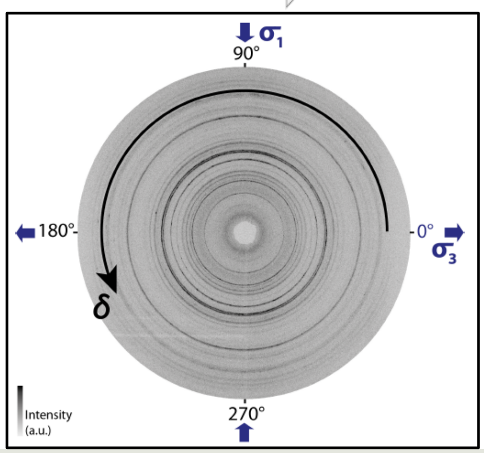
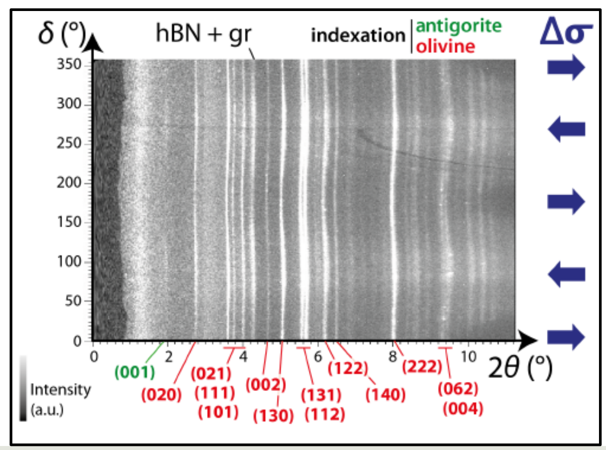
+ follow in-situ stress and mineralogical reaction progress :



Access to
- crystals and phases stresses rather than F/S
- phases proportions and reaction progress

In-situ monitoring using synchrotron X-rays diffraction (GSE-CARS, APS)





T. Ferrand, phD thesis.

… listening to rocks under high pressures?

= add acoustic emissions
monitoring

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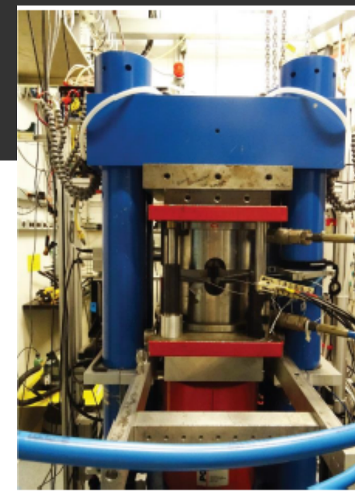
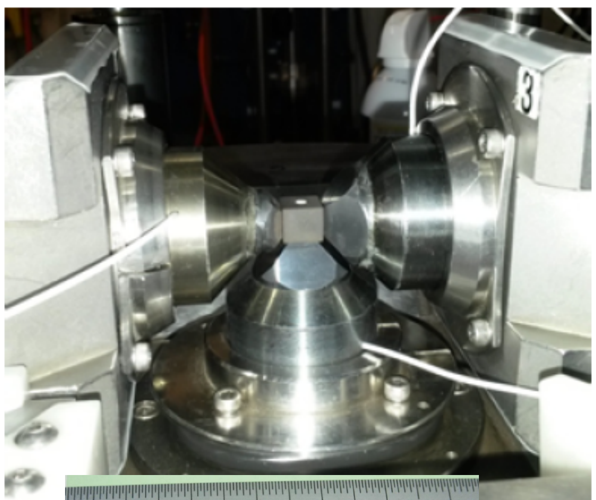
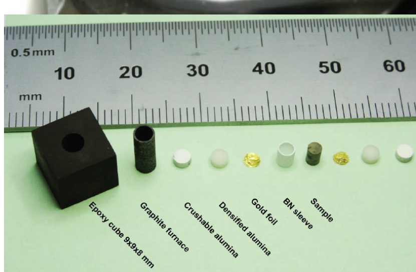
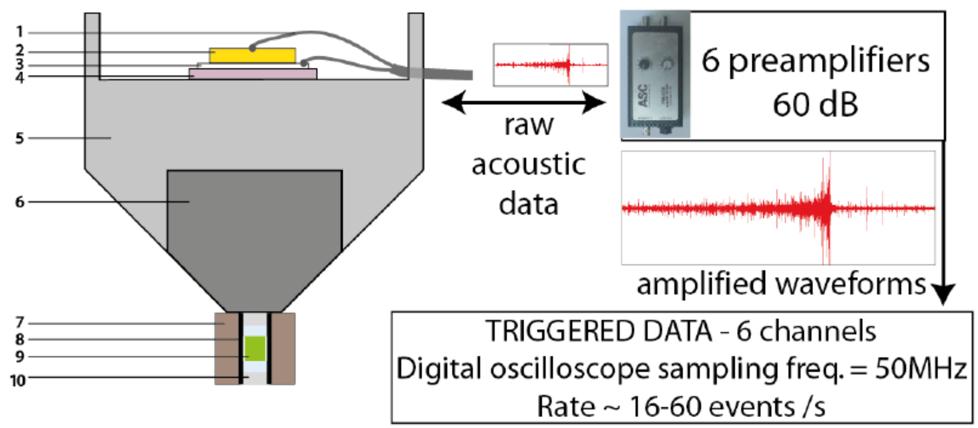
Listening to rocks under high pressures?



Coupling Deformation-DIA (HP-HT) and acoustic emission (AE) recording



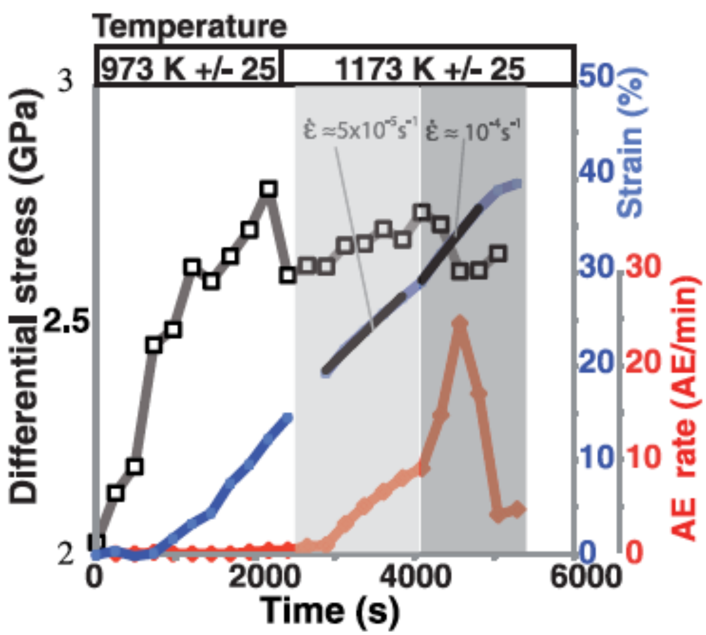




Gasc et al, 2011

« Proof of concept » study

Metastable olivine -> spinel in Mg_2GeO_4



Schubnel et al, Science 2013

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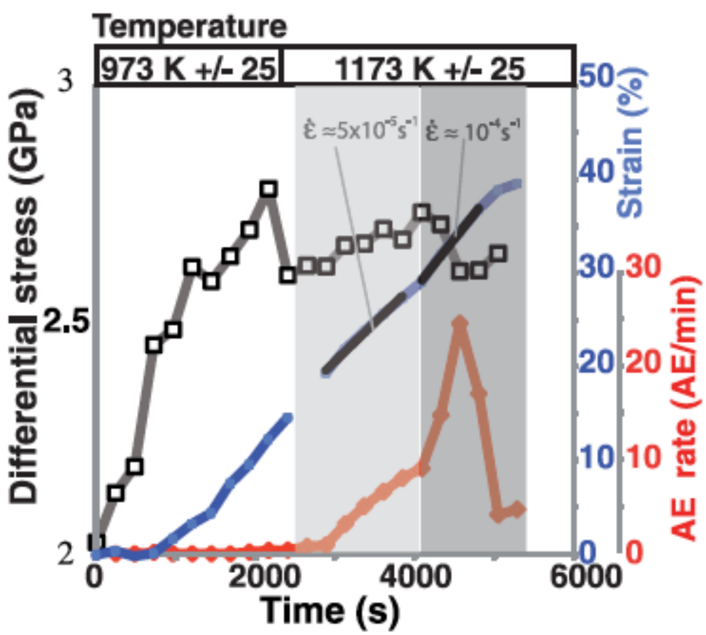
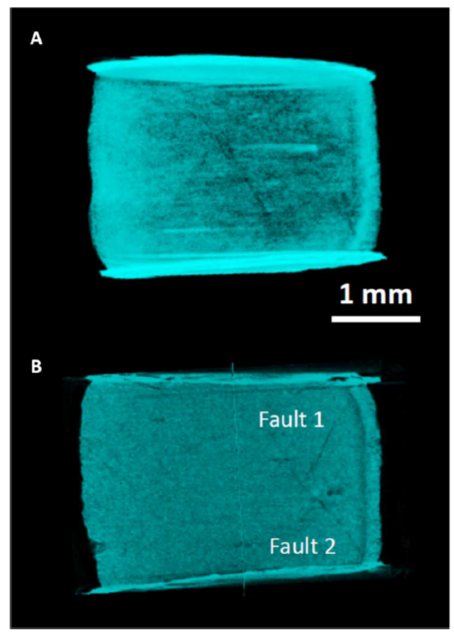
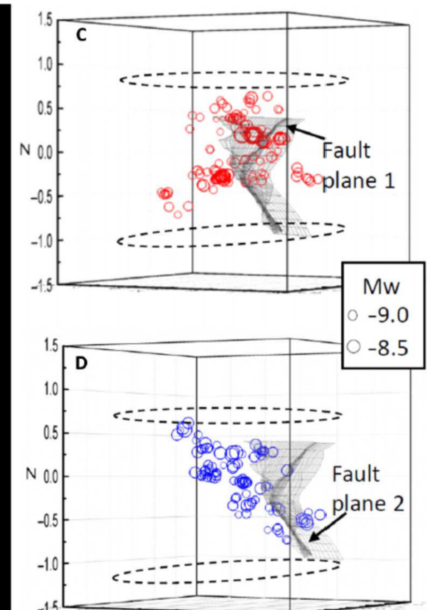


Schubnel et al, Science 2013

Post-experiment tomography



Relocated AEs



Wang et al, Sci. Adv. 2017

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« Proof of concept » study

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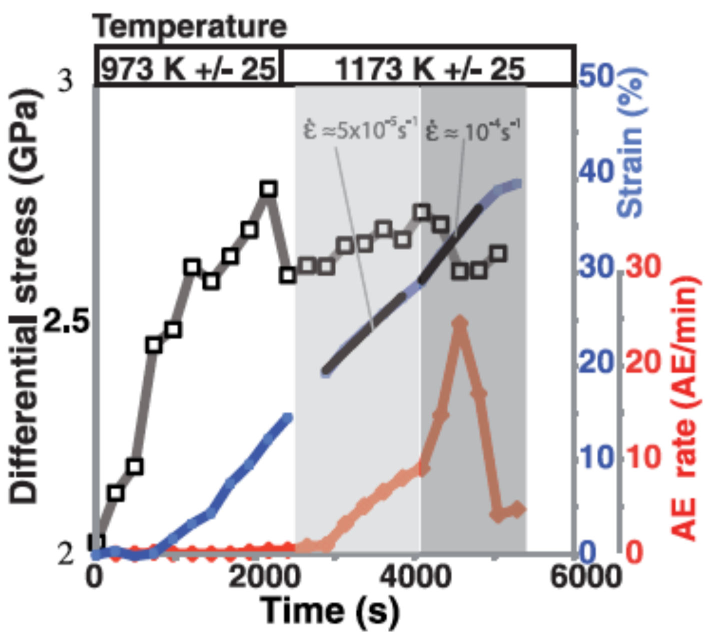
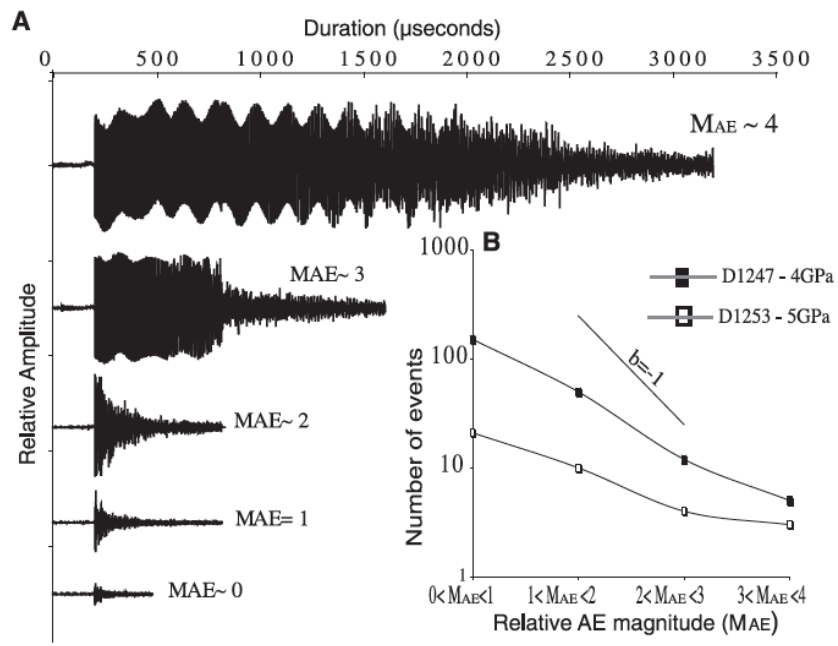
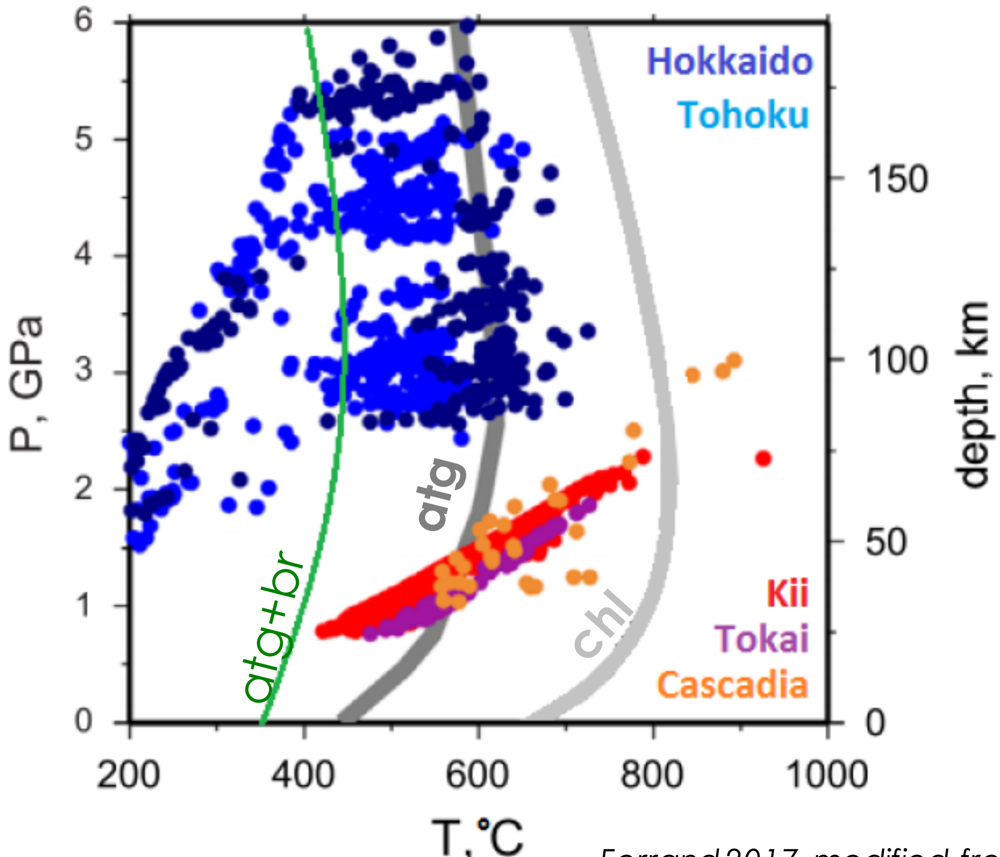


Schubnel et al, Science 2013

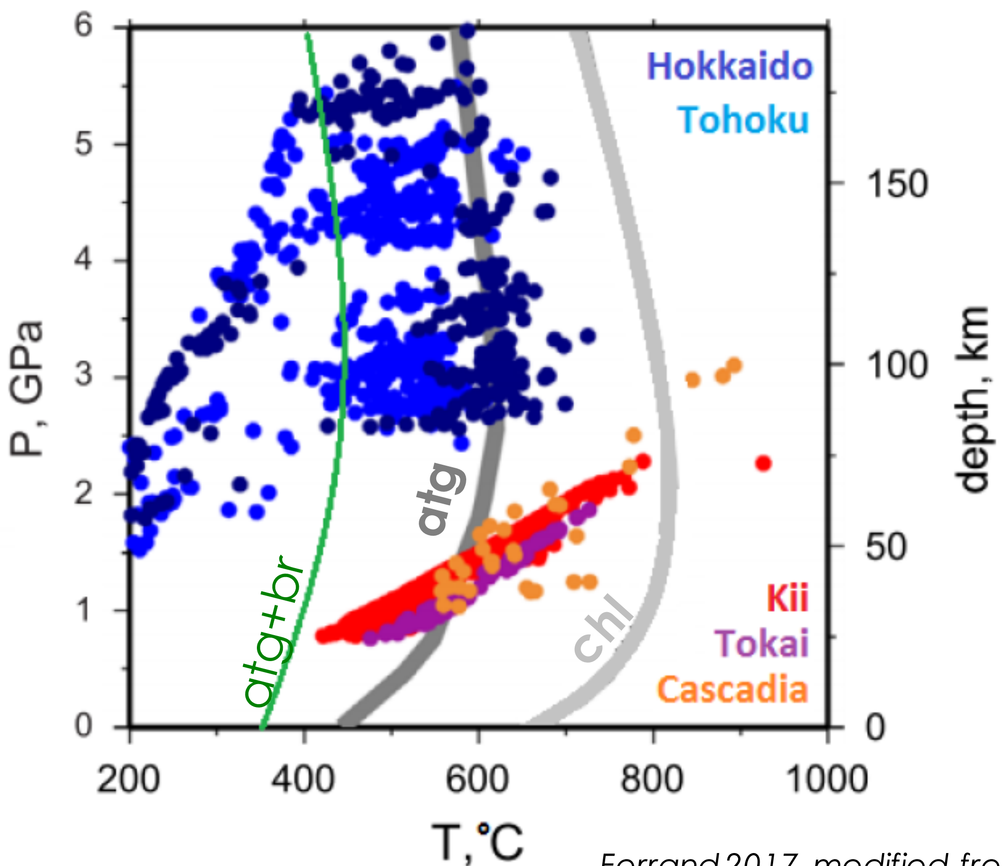


Lower Wadati-Benioff plane and dehydration reactions in the slab mantle



Ferrand 2017, modified from Abers et al, 2013

Lower Wadati-Benioff plane and dehydration reactions in the slab mantle



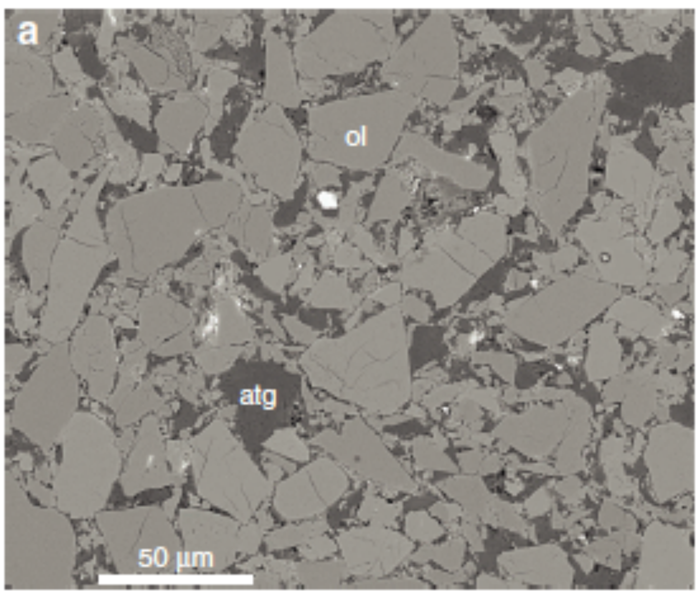
Mechanical stability of serpentinite upon dehydration and stress ?

- *Dobson et al 2002, Jung Green and Dobrzhinetskaya, 2004* fluid release causes « dehydration embrittlement »
- *Gasc et al. 2011, Hilairet and Reynard, unpub., Chernak and Hirth, 2011, Okazaki and Hirth 2016,* stable.

Ferrand 2017, modified from Abers et al, 2013

Experiments

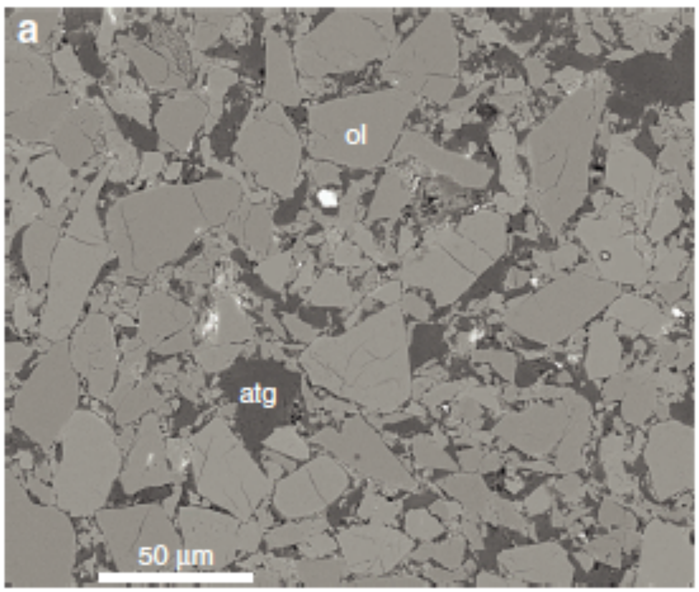
- Cold pressed antigorite + olivine aggregates (50:50, 20:80, 5:95, 0:100)



Starting material / T. Ferrand.

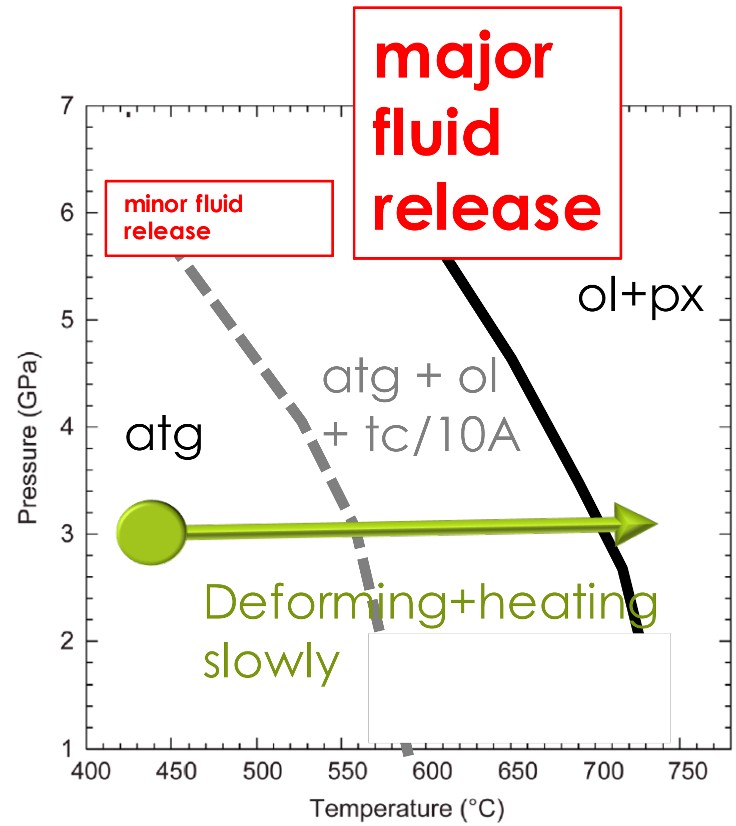
Experiments

- Cold pressed antigorite + olivine aggregates (50:50, 20:80, 5:95, 0:100)
- $\dot{T} / \dot{\varepsilon}$ is about 1200 K (below Okazaki and Hirth 2016, Chernak and Hirth 2011, and Gasc et al, 2017)



Starting material / T. Ferrand.

Experiments (vs. nature)…



modified from Chollet et al., JGR 2011

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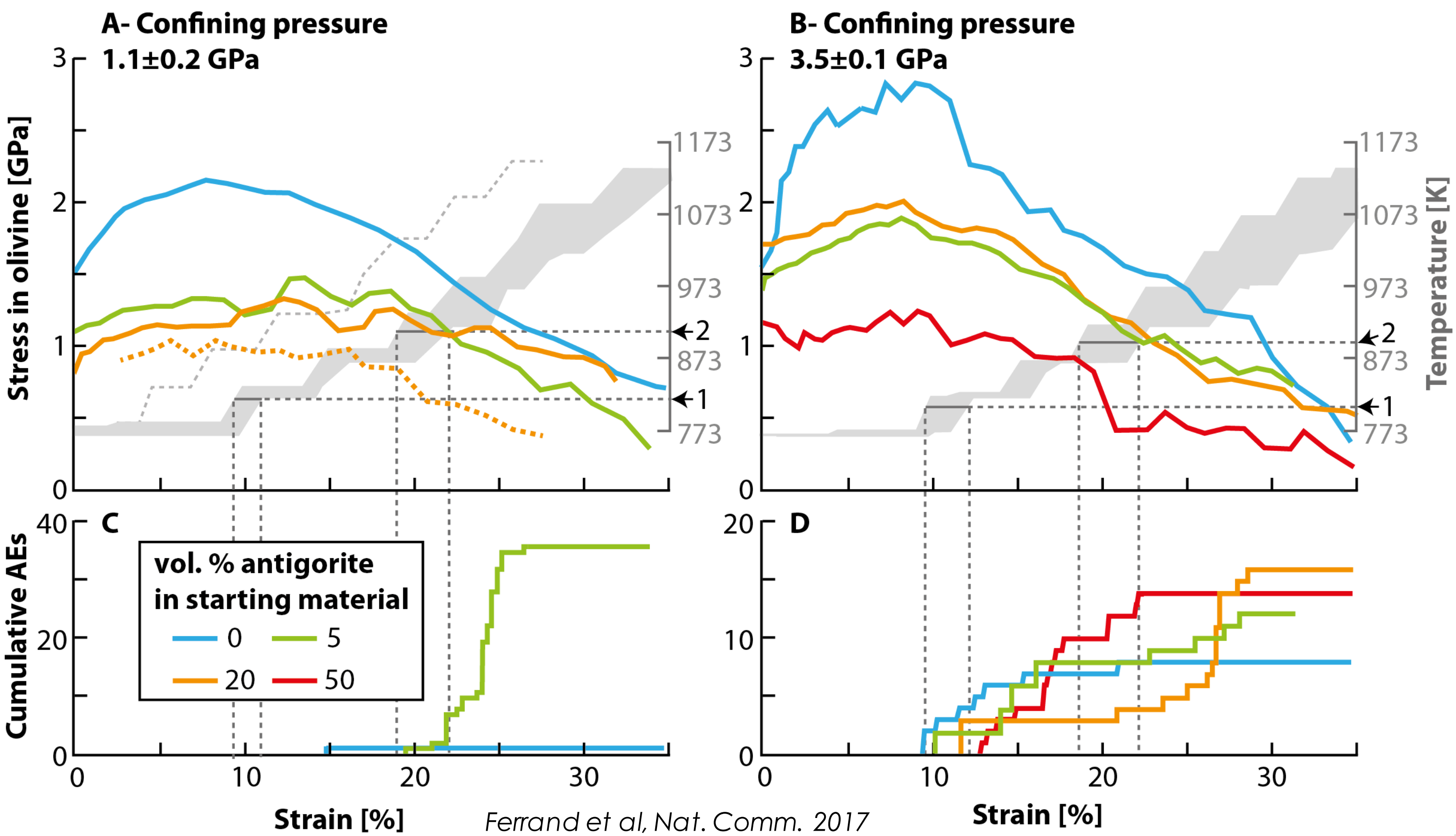
Ol + atg aggregates and 100% olivine: Stresses and AE records



Ferrand et al, Nat. Comm. 2017

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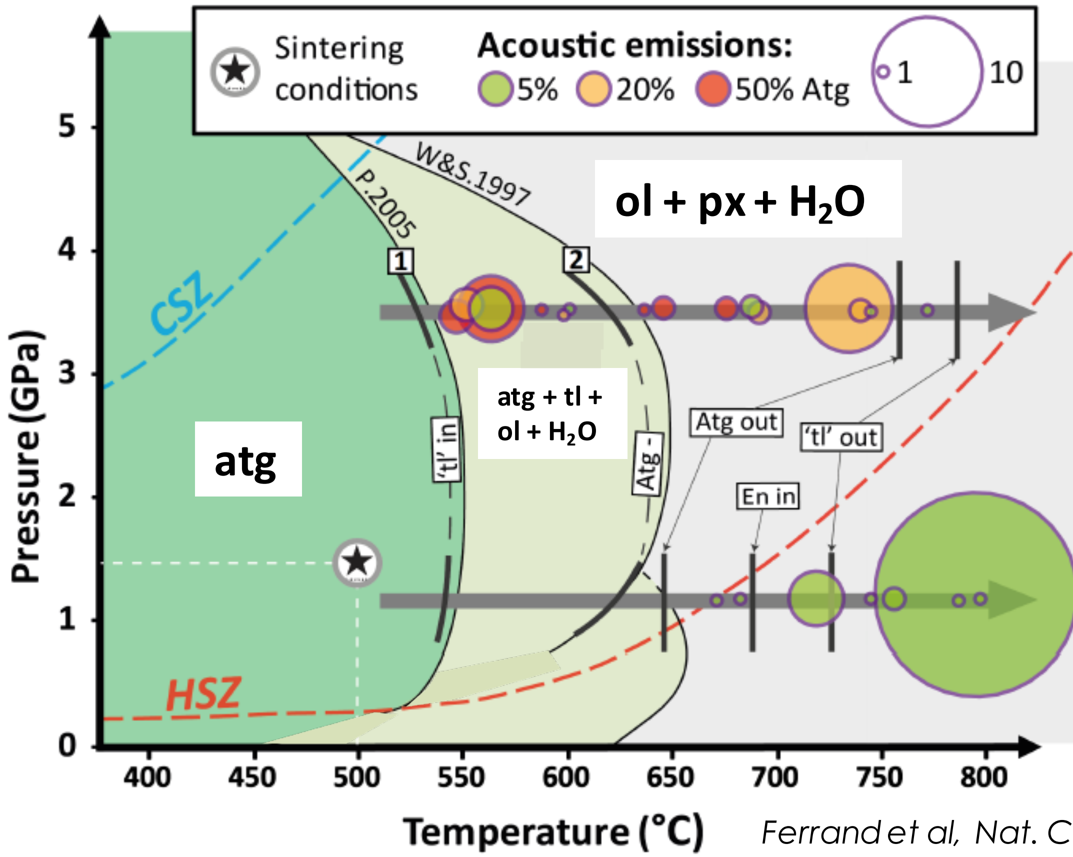
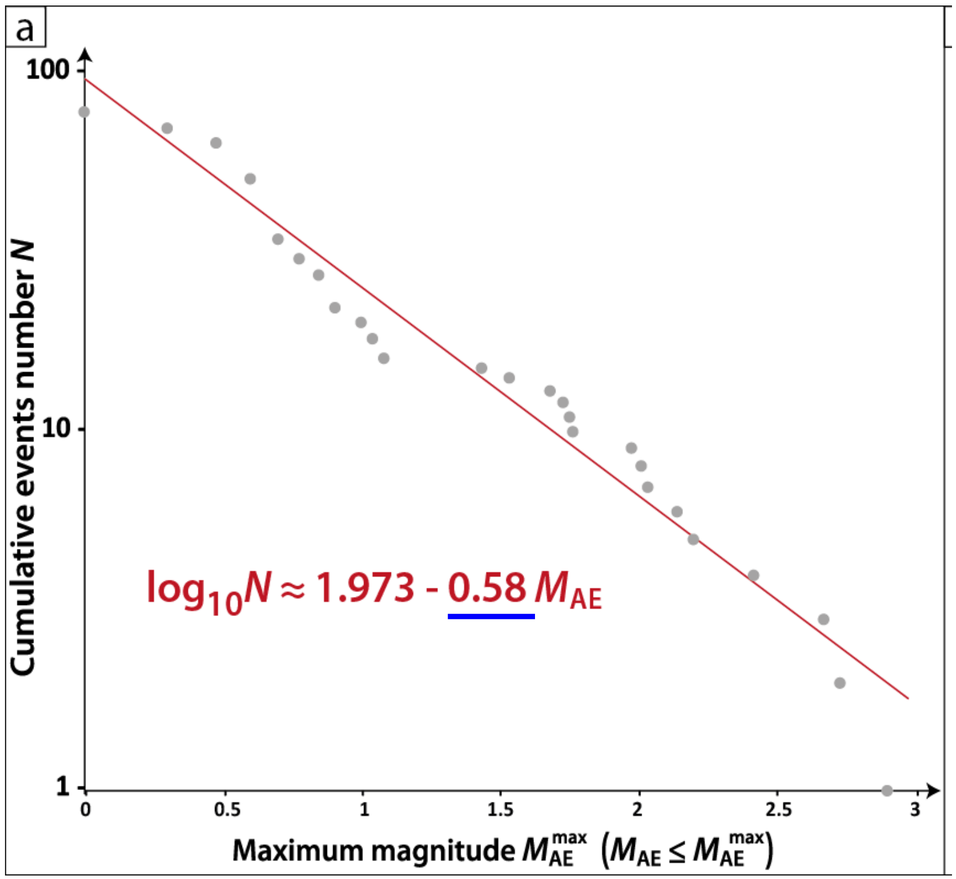
… vs. phase P-T fields



Ferrand et al, Nat. Comm. 2017

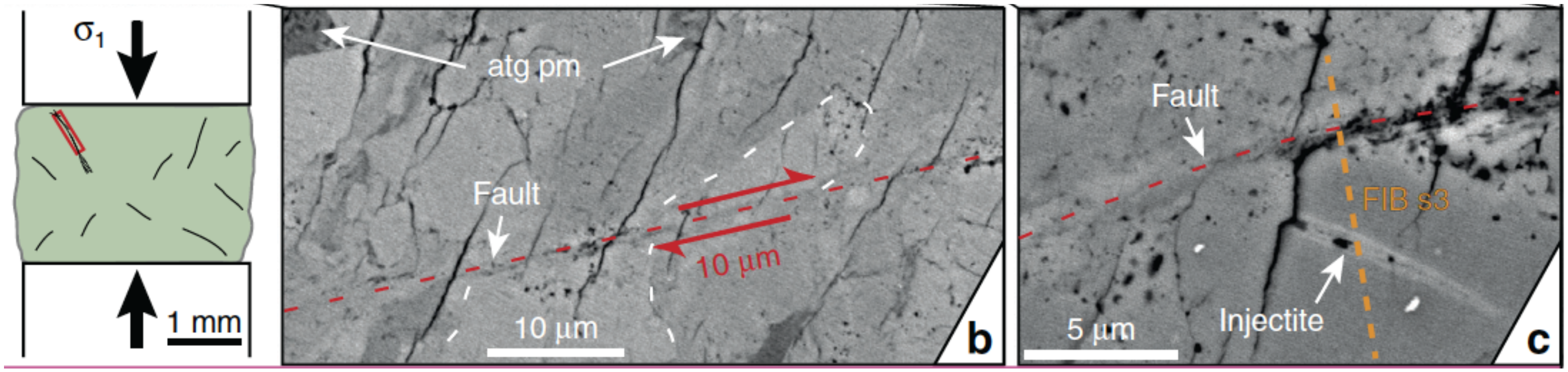
AE statistics

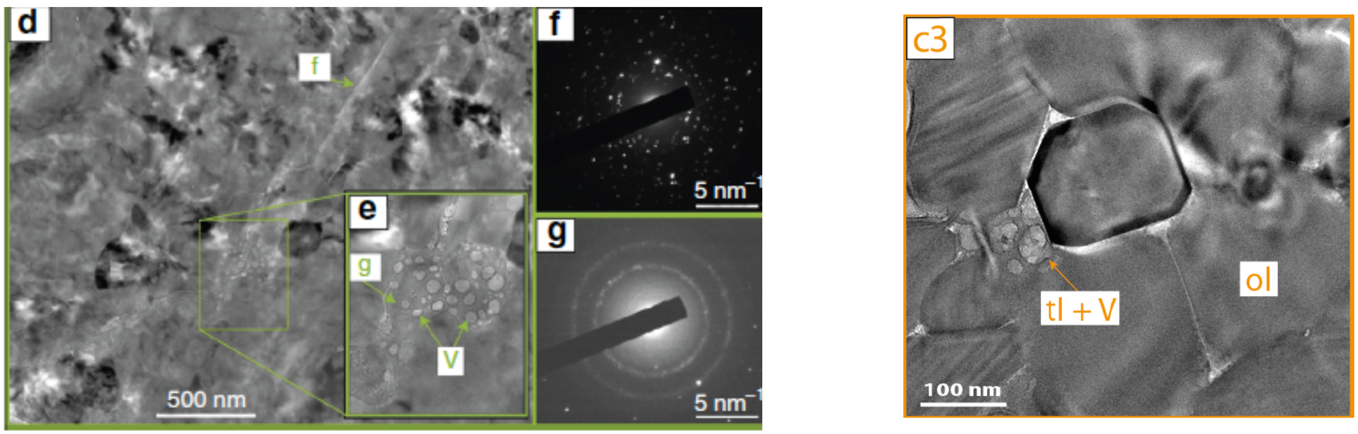


Ferrand et al, Nat. Comm. 2017

microstructures

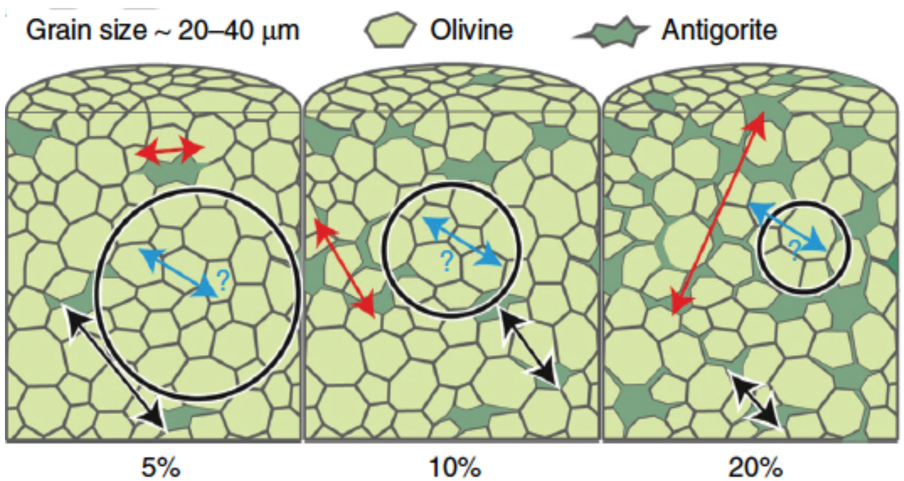
5% antigorite 1.1GPa





Ferrand et al, Nat. Comm. 2017

A dehydration-driven stress transfer model based on percolation theory



Antigorite stress goes to zero close to dehydration

Connectivity length for antigorite
Maximum olivine asperity size
Critical nucleation length

Ferrand et al, Nat. Comm. 2017

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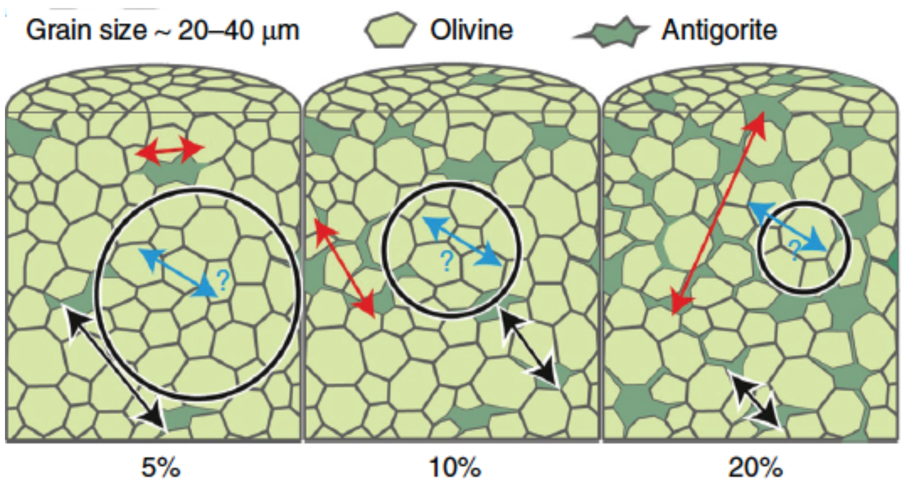
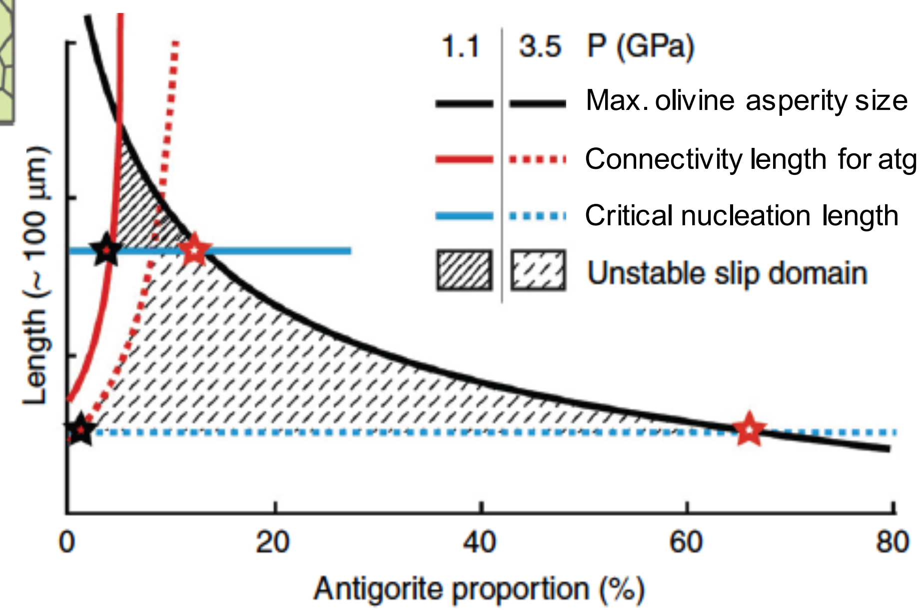
A dehydration-driven stress transfer model based on percolation theory

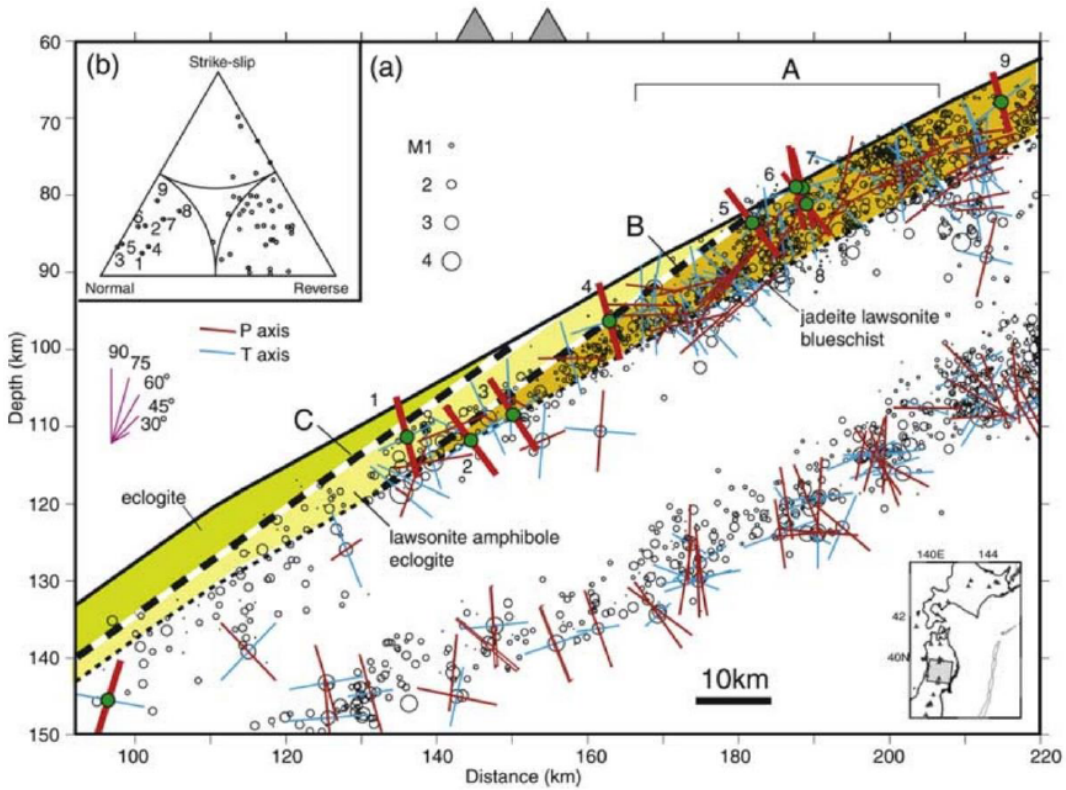


- ❑ Olivine ‘asperities’ need to be larger than the critical fracture nucleation length
- ❑ Atg clusters need to be large enough to transfer a significant amount of stress
- ❑ trigger ≠ failing material



Ferrand et al, Nat. Comm. 2017

What about oceanic crust eclogitisation ?



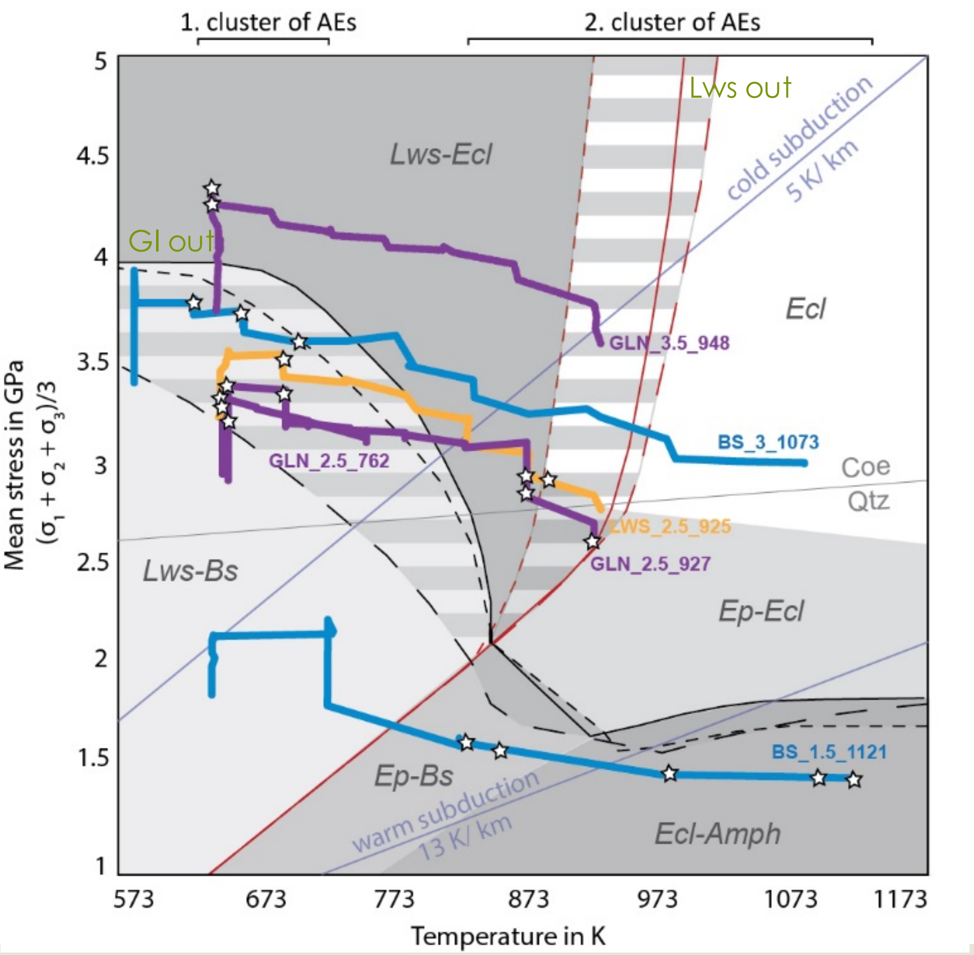
Kita et al, GRL 2006

What about oceanic crust eclogitisation ?

Incel et al, EPSL 2017

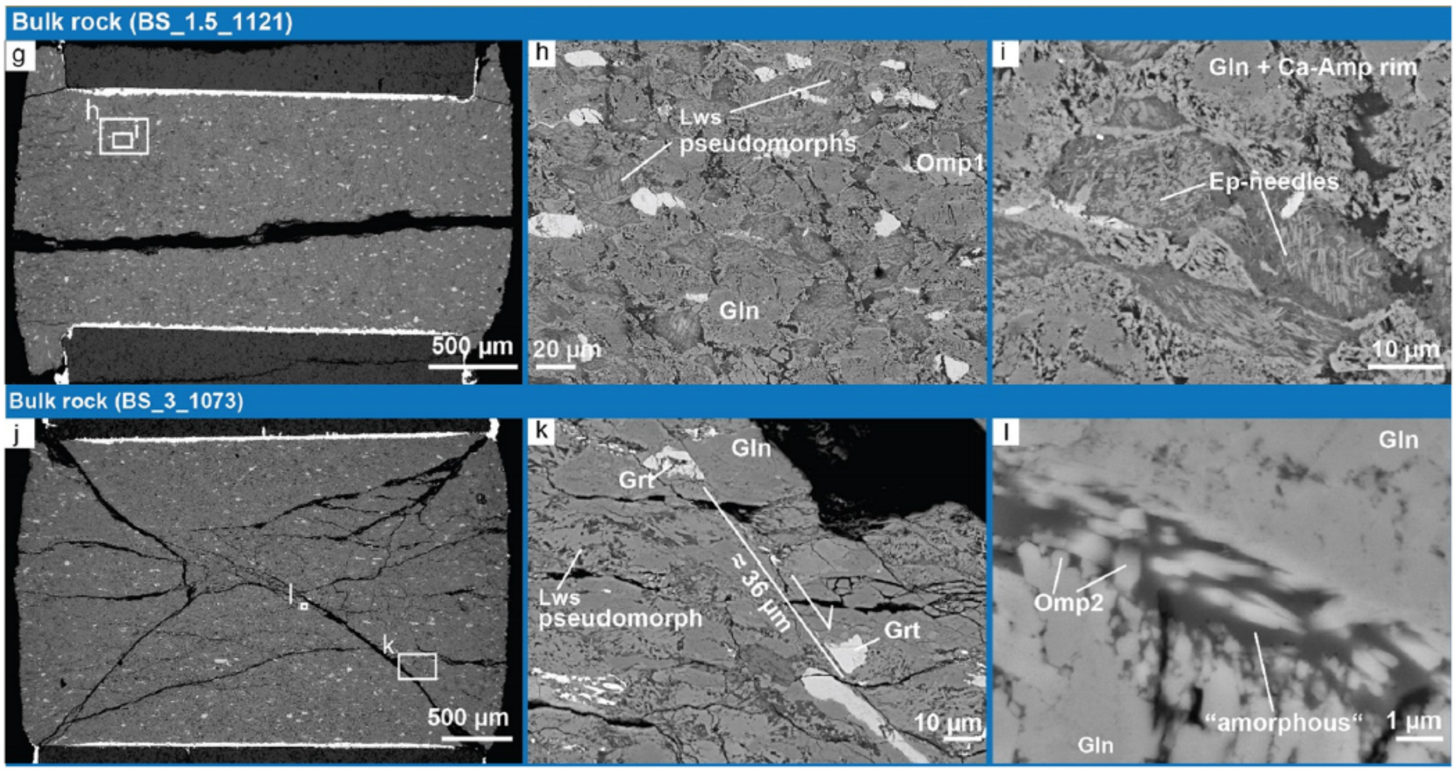
- ❑ lawsonite + glaucophane in various proportions
- ❑ natural blueschist

- ❑ AE are not specifically associated with a major fluid release (ie. lws breakdown).



Microstructures and AEs

1.5 GPa: only lws breakdown AEs, no visible failure



3 GPa: omphacite grain growth (in situ + post- microstr) correlated with AEs, failure

Incel et al, EPSL 2017

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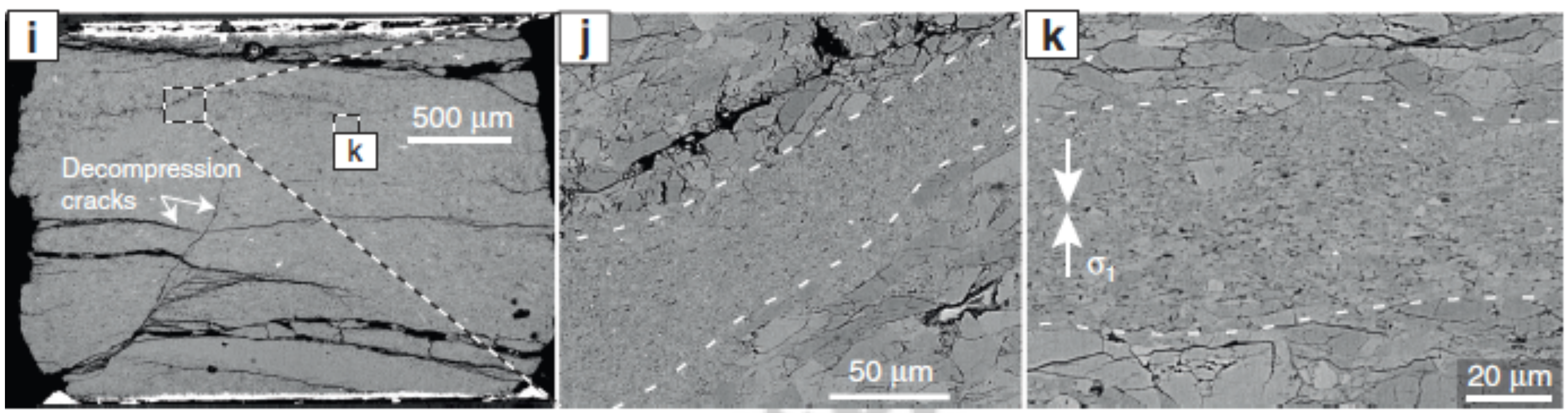
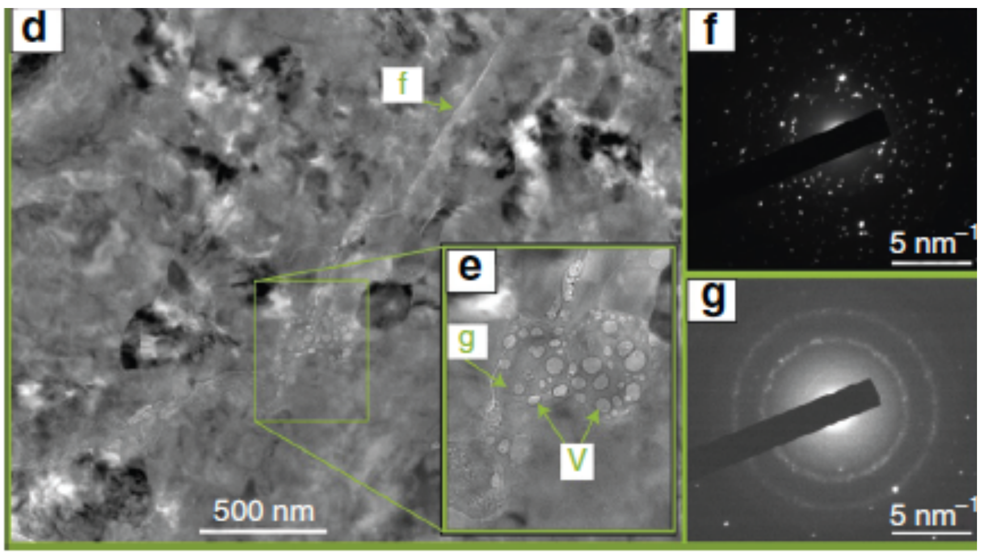
Summary and open questions

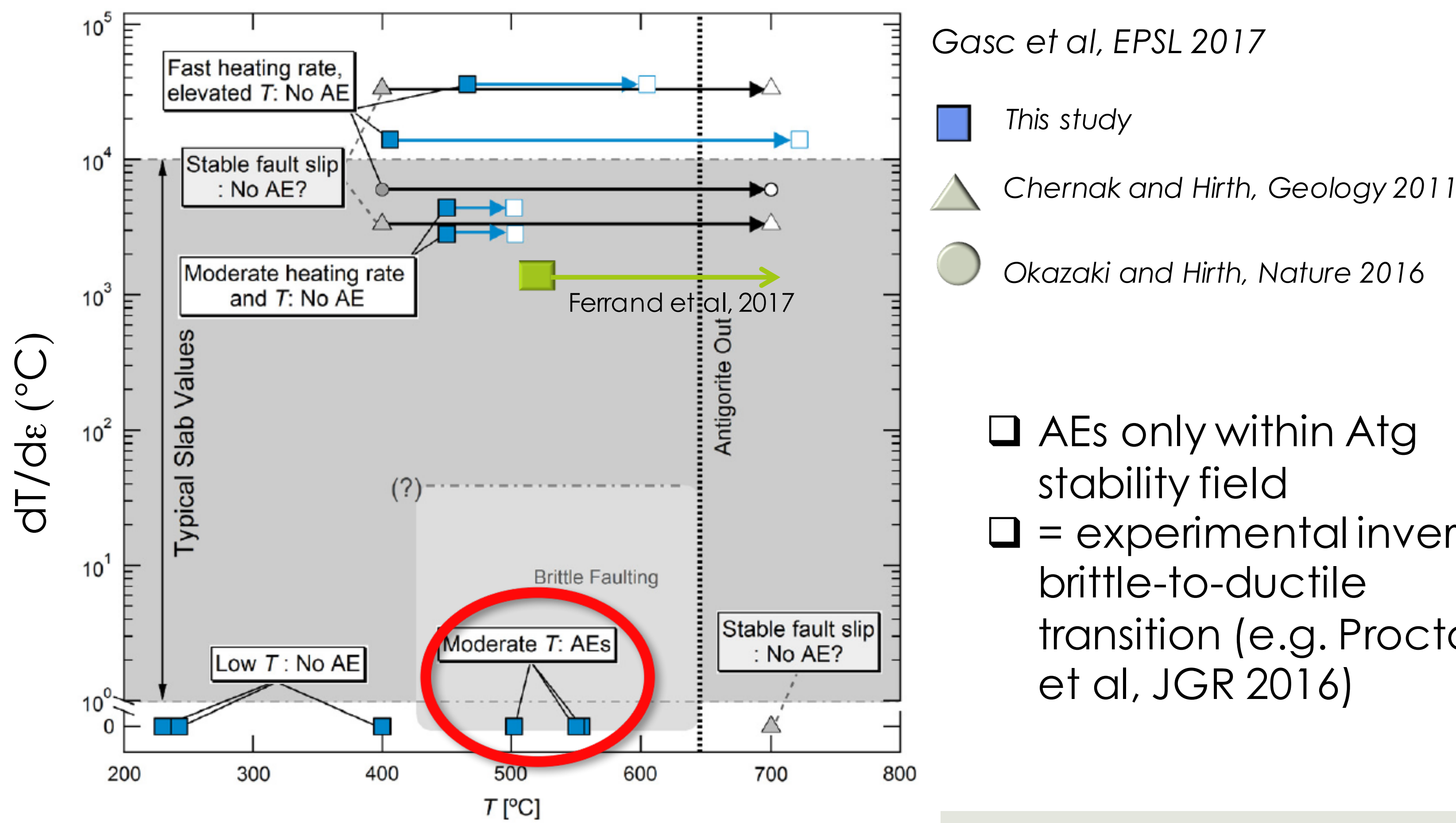
- Coupling of in-situ reaction, stresses and AE monitoring was crucial in this work
- Dehydration with large water releases (serpentine, lawsonite) do not (necessarily) induce sample failures
- Rather, distribution of stresses within heterogeneous aggregates may be one important key (grains sizes, minerals with different mechanical properties).
- Some mineralogical reactions may be privileged as a trigger for dynamic sample failure, not the ones previously thought of.

Olivine 100%, 3.5 GPa




d
f
e
g
V
500 nm
f
5 nm⁻¹
g
5 nm⁻¹

The scaling problem



- AEs only within Atg stability field
- = experimental inverse brittle-to-ductile transition (e.g. Proctor et al, JGR 2016)