EGU 2022 — TS7.1
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Transformational Faulting in Metastable Olivine, From Lab to Slab

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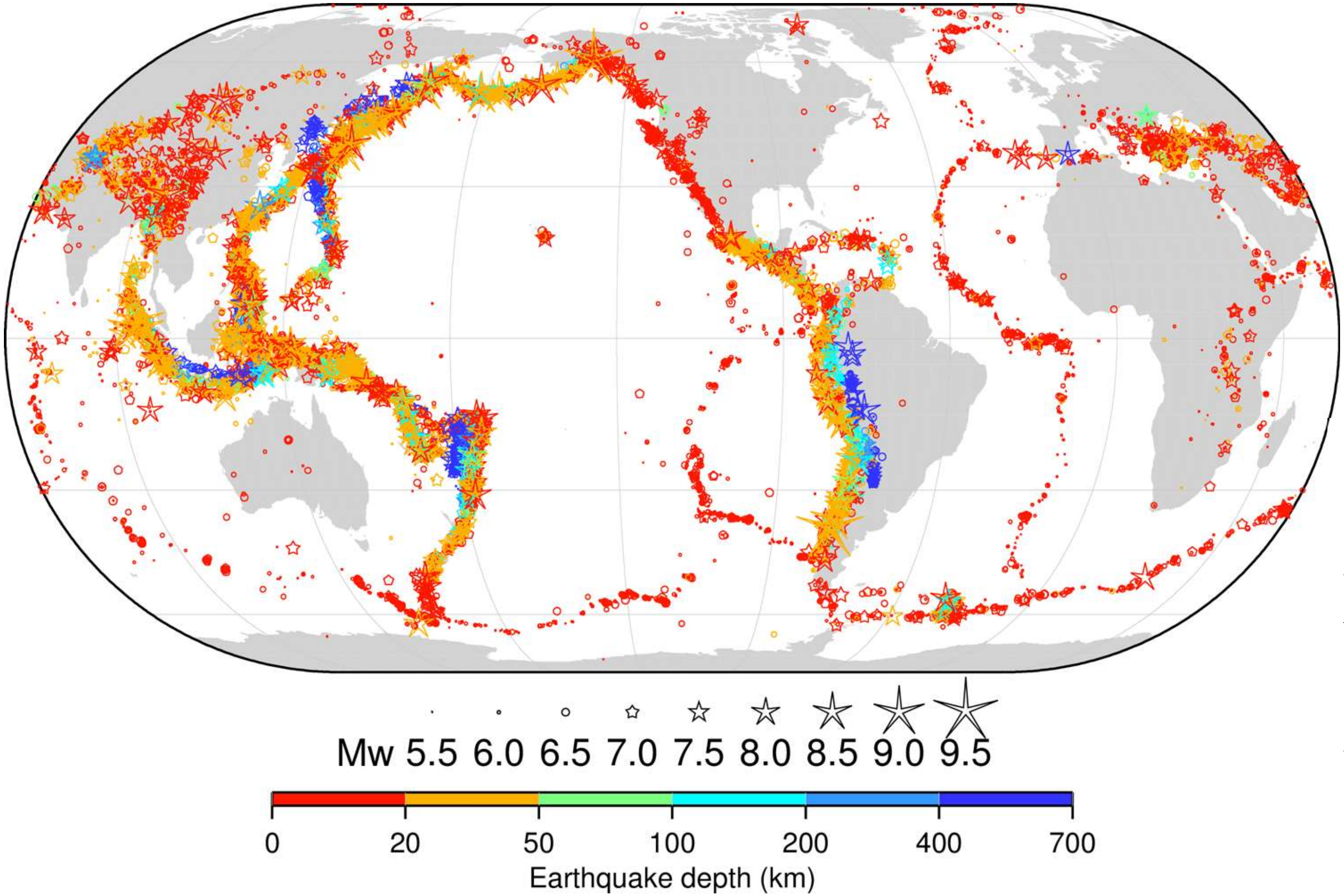
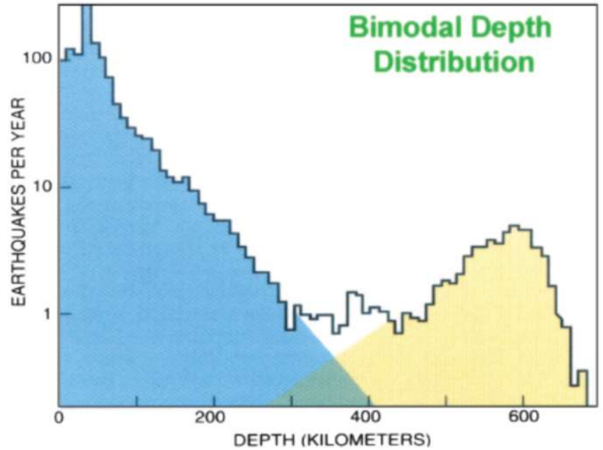
Depth-magnitude distribution of seismicity



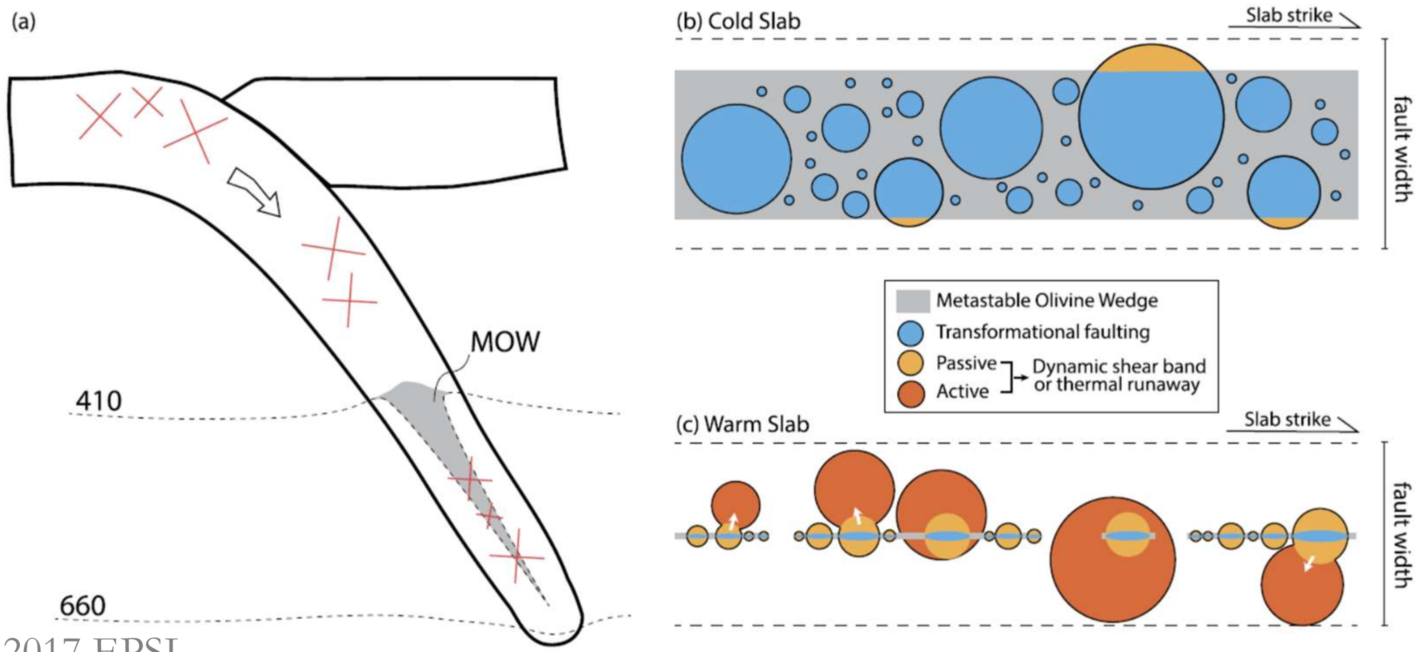


Deep-focus Earthquakes occur at depths >300 km.

They occur in some subduction zones where the lithosphere is old (i.e. cold) and/or descends rapidly in the mantle.

Their origin has been debated for a long time.

The dual-mechanism hypothesis

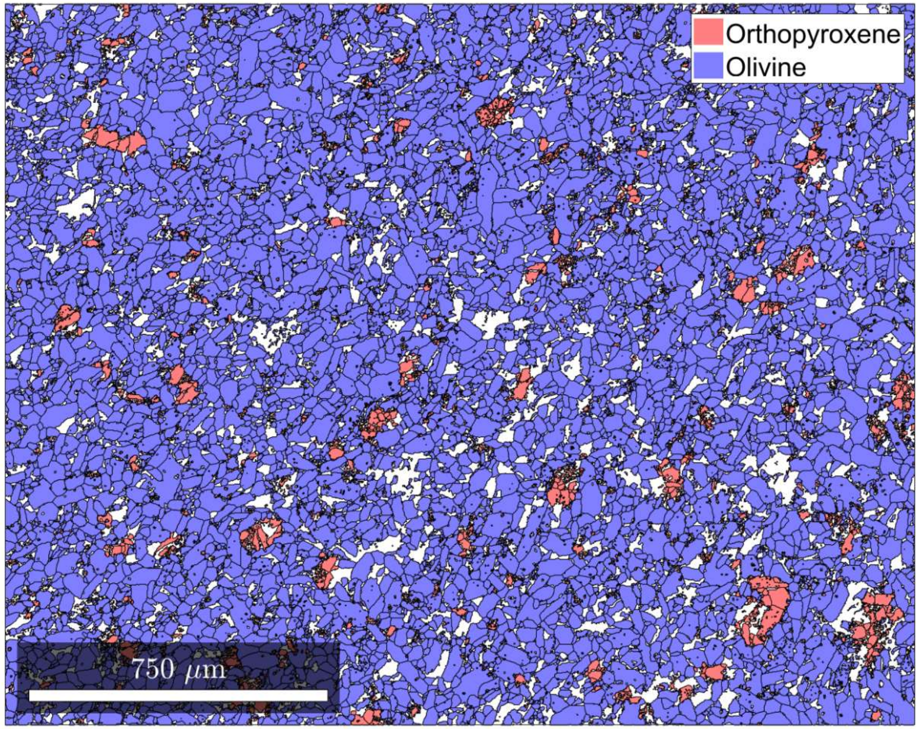


from Zhan 2017 EPSL

- Transformational faulting can explain the occurrence in DFEs where metastable olivine is present.
- But for some slabs (e.g. Chile) the metastable olivine wedge in the transition zone is too narrow to host the largest DFEs detected.
- It has therefore been suggested that shear heating instabilities, rather than transformational faulting, generate DFEs. However, it is likely that both mechanisms are both at play.

Materials and methods 1. Germanium olivine (Ge-olivine) starting material

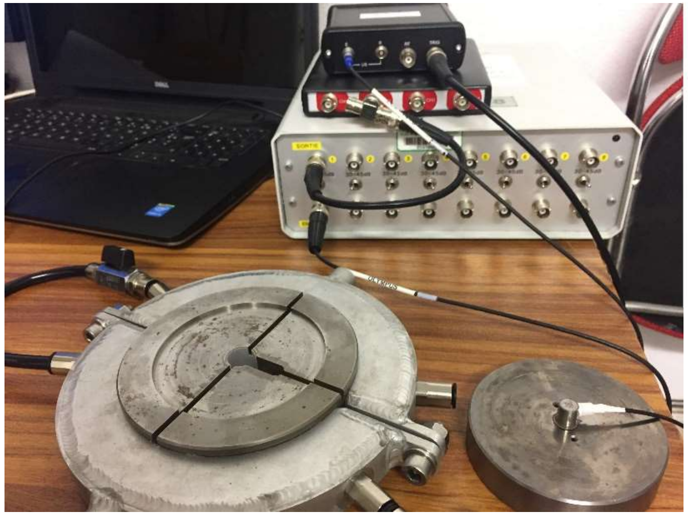
- Mg_2GeO_4 olivine + $MgGeO_3$ powders synthesized from oxides
- HIP sintering at 200 MPa and 1200°C for 9 hours
- Cored 5 mm Ø samples
- Ge-olivine ↔ Ge-spinel (ringwoodite) 14 GPa lower than the silicate



Materials and methods 2. Griggs experiments

Griggs rig deformation experiments with Acoustic Emission (AE) recording

- Confining pressure $P = 1.5$ GPa
- Temperatures $T = 500$-840°C
- Strain rates of $\dot{\varepsilon} \sim 10^{-6}$- 10^{-5} s^{-1}



- Ultrasonic transducer for AE detection (5 MHz)
- Amplified at 60 dB
- Sampling at 50 MHz

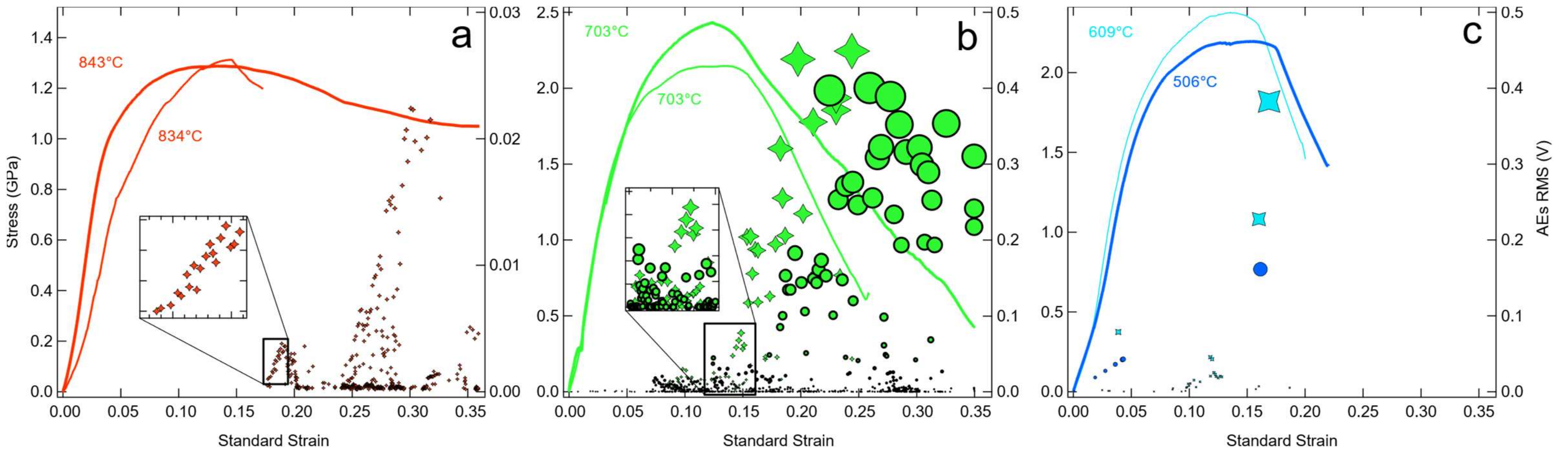
Results from high PT deformation

At > 800°C ductile behavior is observed. Small Aes are detected in one experiment.

At 700°C, samples fail in a brittle way. Many AEs, both small and large, are recorded.

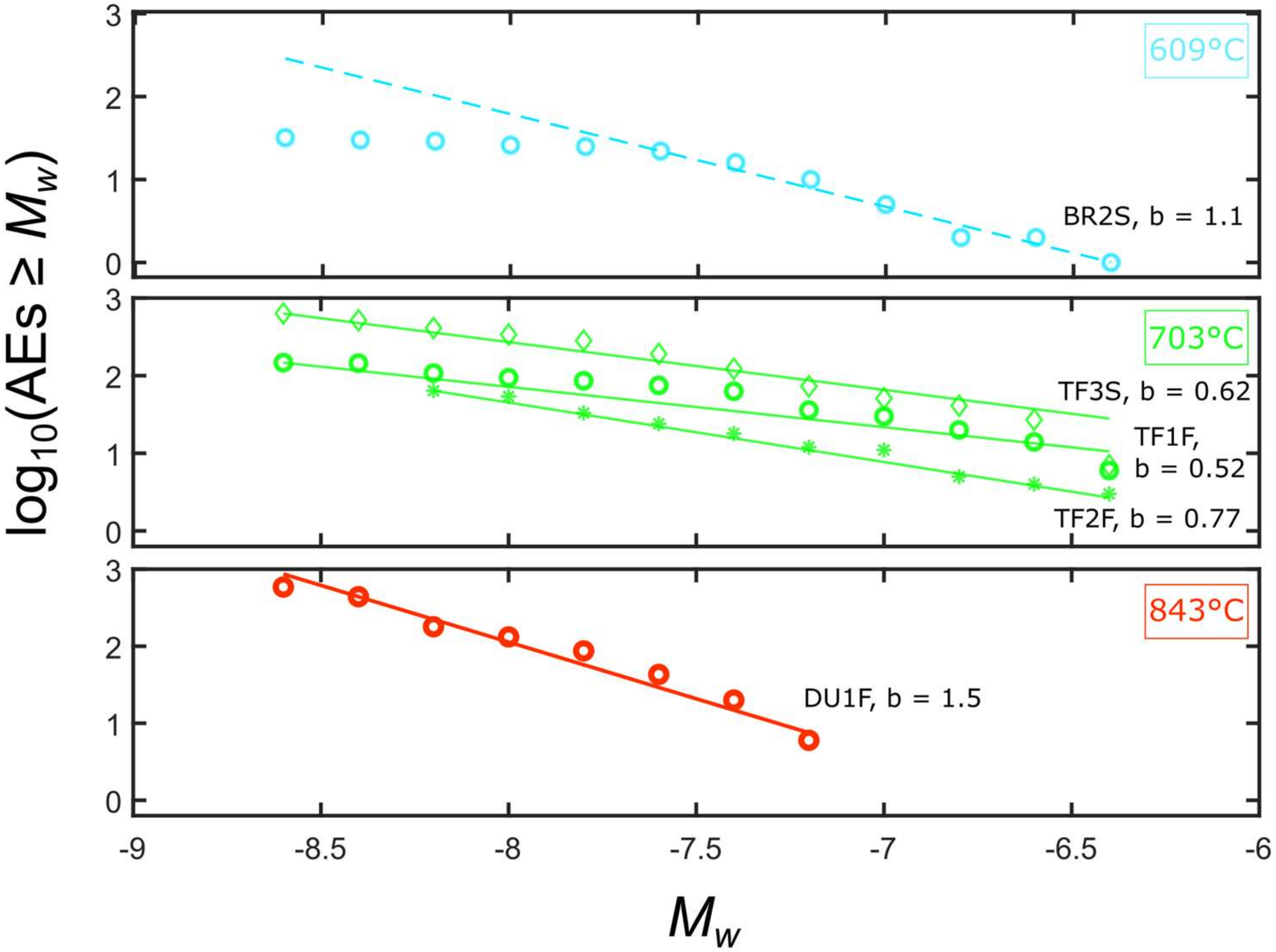
At < 600°C sample also eventually fails but a single AE is recorded.

Gasc et al., 2022 *Geology*



- Anomalous loss of ductility with increasing T and decreasing strain rate
- Predicted by previous studies that investigated transformational faulting

Magnitude - frequency distribution

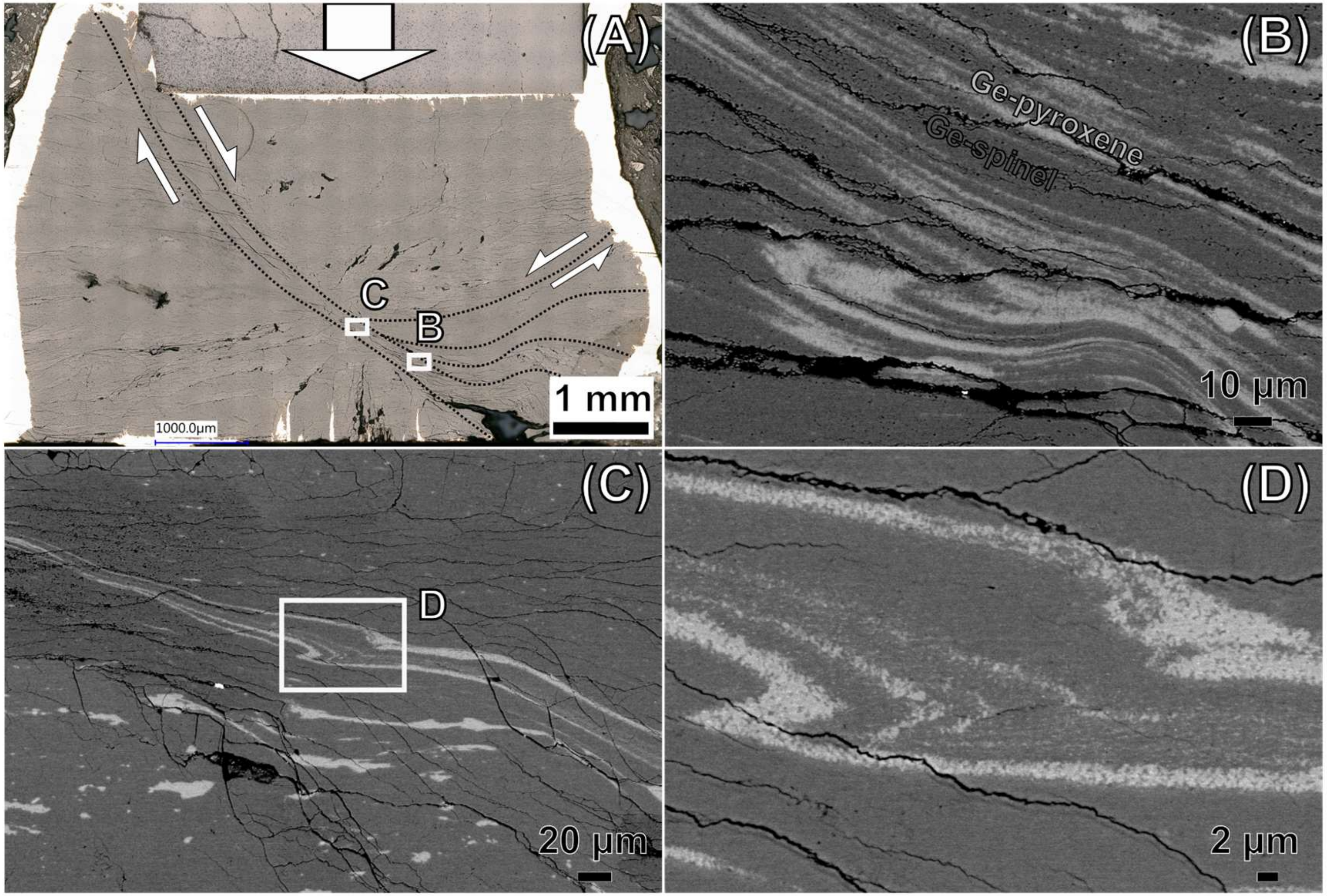


At 600°C, the *b*-value of 1 is consistent with standard brittle failure.

Experiments at 700°C show consistently low *b*-values.

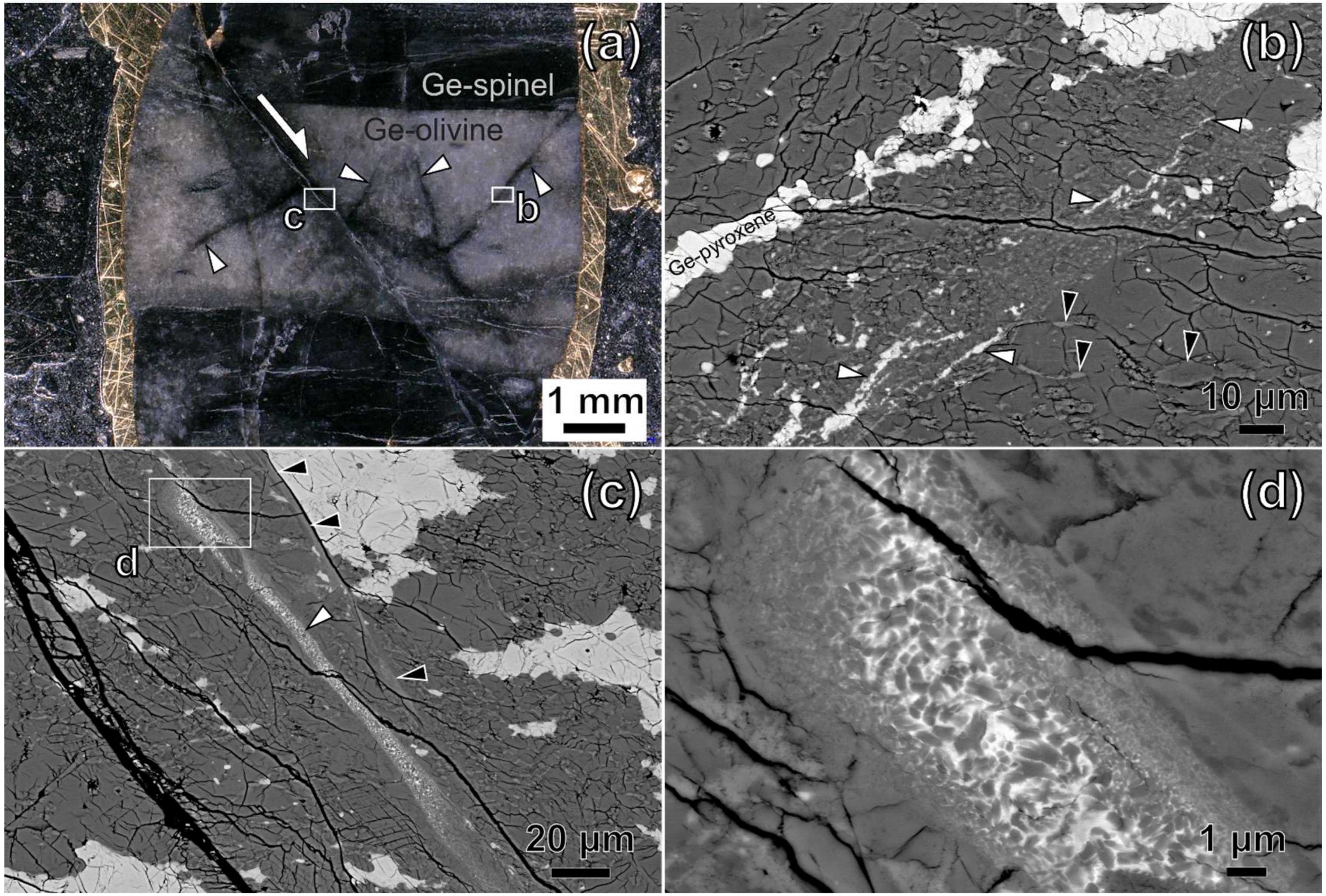
In the same magnitude range the high-T experiment has the same number of events but a very high *b*-value.

Microstructures 1. fast transformation rates



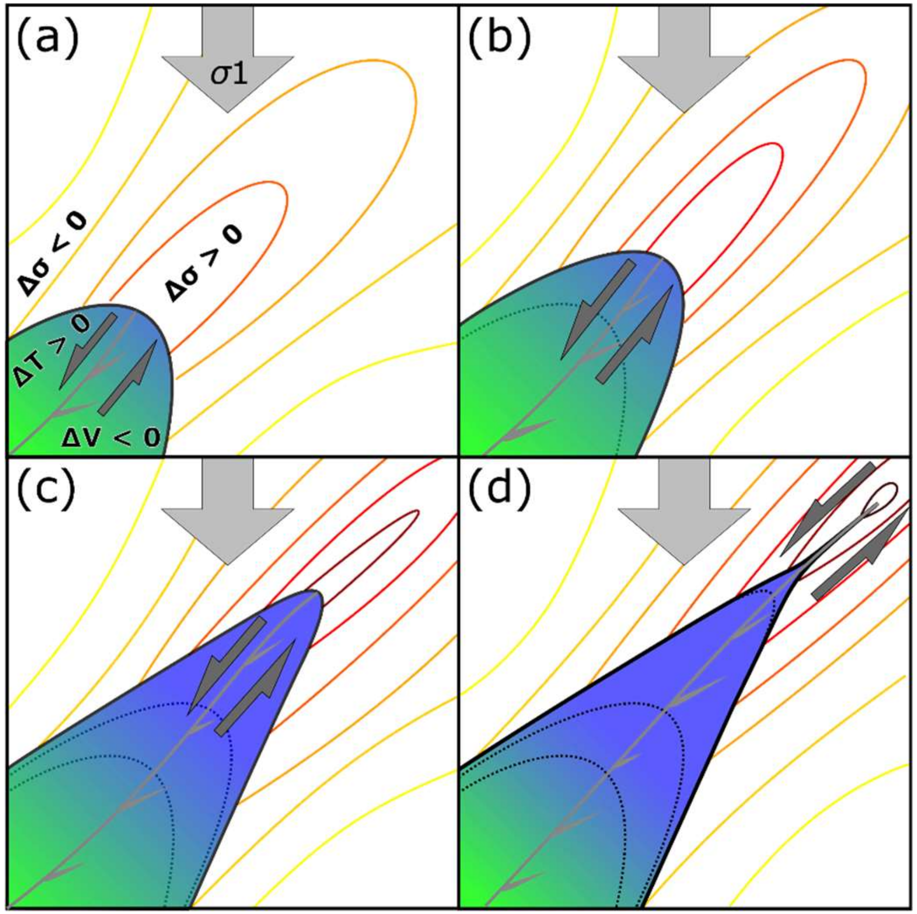
- Samples are fully transformed
- Large shear bands accommodate strain
- Dramatic shearing is revealed by the brighter Ge-pyroxene phase

Microstructures 2. sluggish transformation rates



- Samples are partly transformed.
- Narrow shear bands accommodate all of the strain.
- Transformation is much more important inside the shear bands.
- This shear localization leads to faulting.
- Melt is present along the fault.

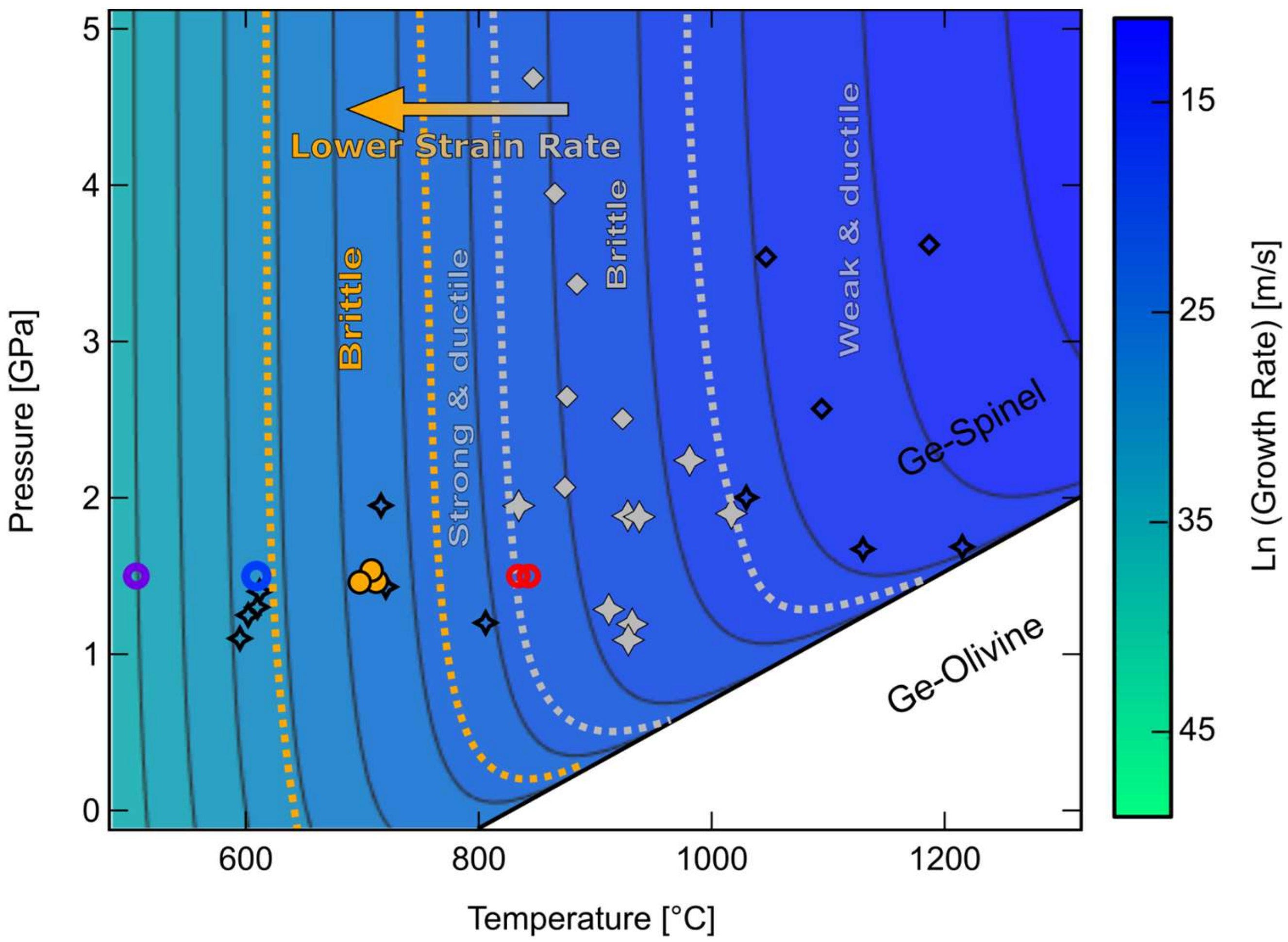
The role of thermodynamics



Gasc et al., 2022 *Minerals*

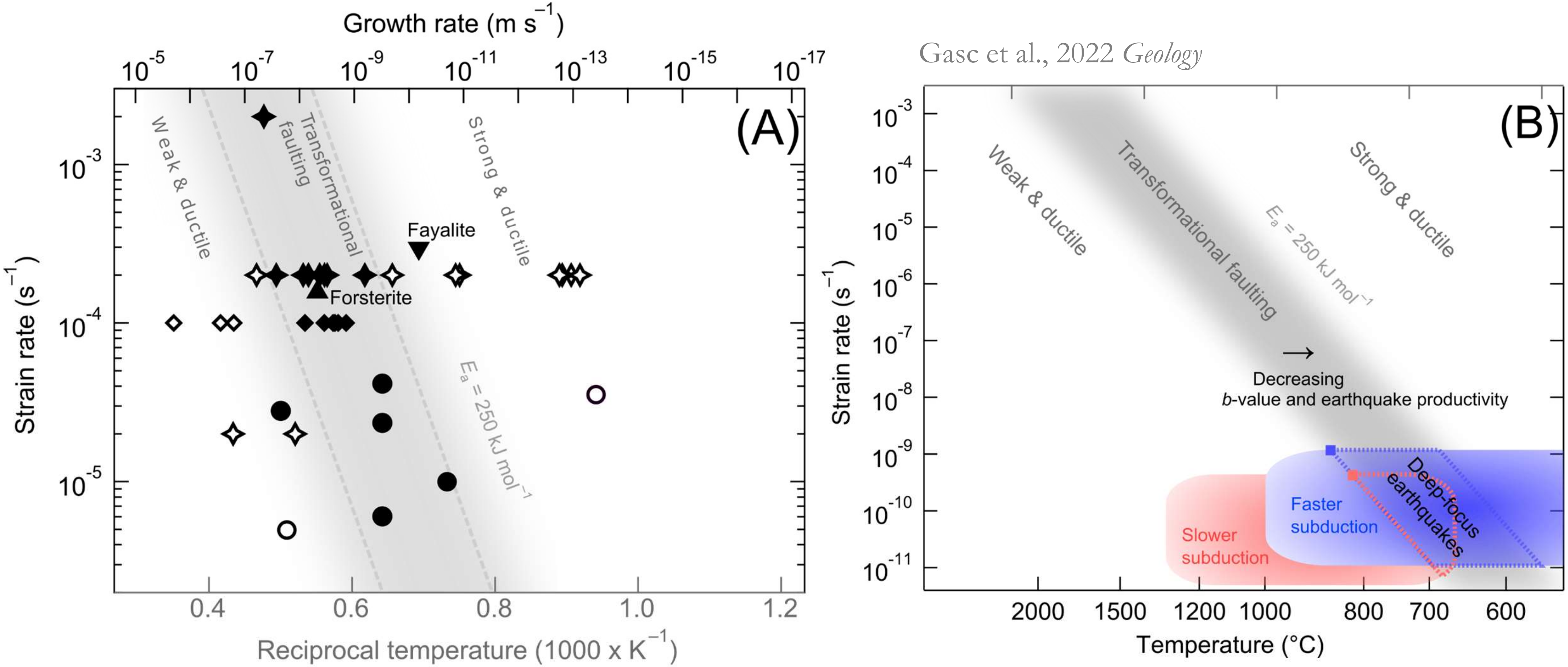
- Volume reduction generates stress concentrations that locally boost the transformation. Kinetics are then further enhanced by latent heat release.
- Strain localizes in these weaker transformed regions.
- Their growth is unstable and self sustained. Microstructres and AE records evidence that they lead to seismogenic, dynamic rupture.

Transformation-induced faulting



The transformational faulting temperature window previously described for strain rates of $\sim 10^{-4}$ s^{-1} is found here at lower temperatures for lower strain rates of $\sim 10^{-5}$ s^{-1}.
This illustrates the control of both strain rate and transformation kinetics on faulting.

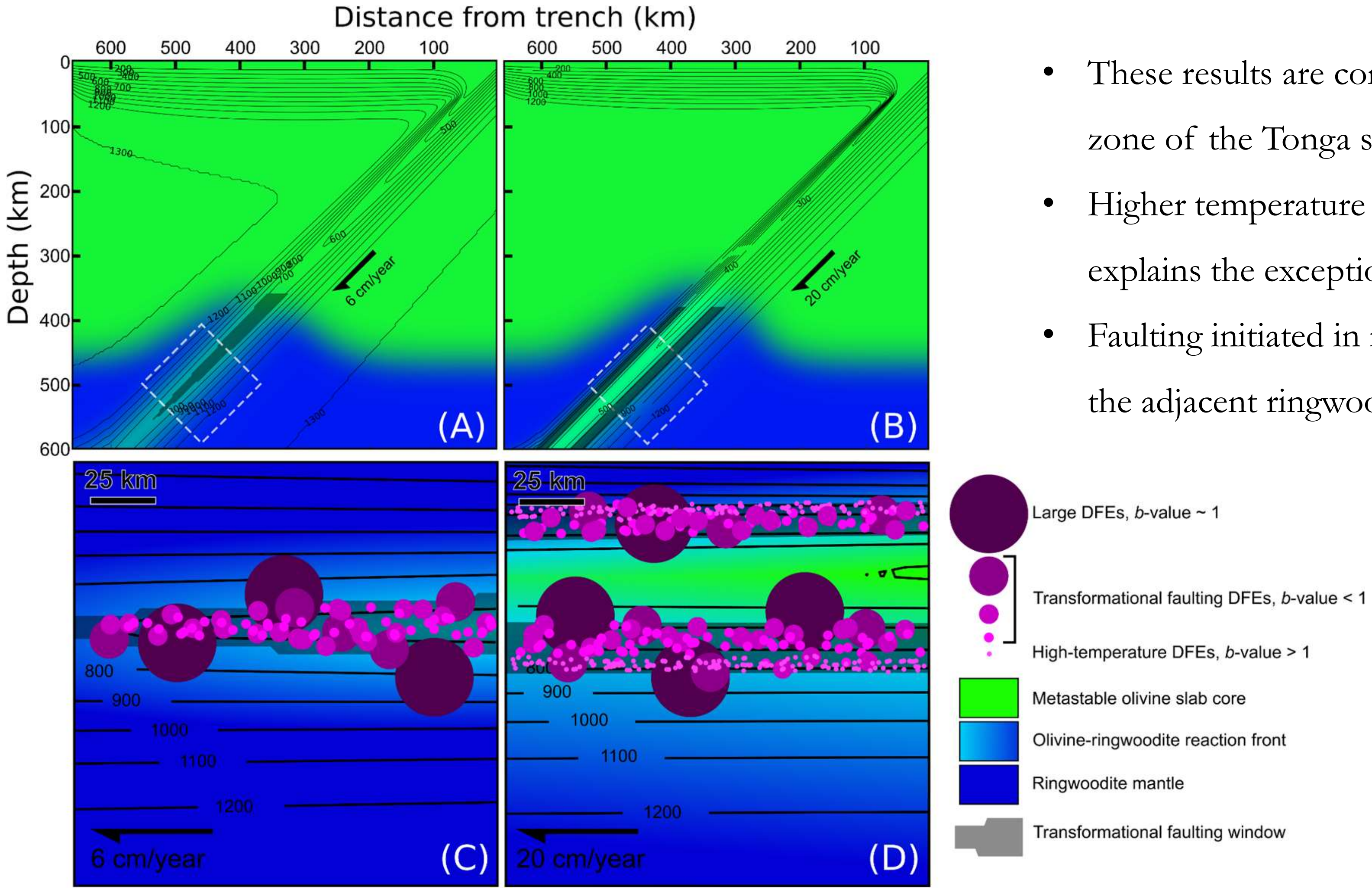
Transformation-induced faulting



The transformational faulting window has a slope of 1 in a log-log plot

Faster subduction, i.e., colder, allows transformational fauting at higher temperature

Deep-focus Earthquakes – Warm vs Cold Subducting Slabs



- These results are consistent with the double seismic zone of the Tonga slab in the transition zone
- Higher temperature of transformational faulting explains the exceptionnaly high *b*-value in Tonga
- Faulting initiated in metastable olivine can propagate in the adjacent ringwoodite mantle.