Rheological heterogeneities on the deep subduction interface, and possible relationships to Episodic Tremor & Slow Slip (ETS)

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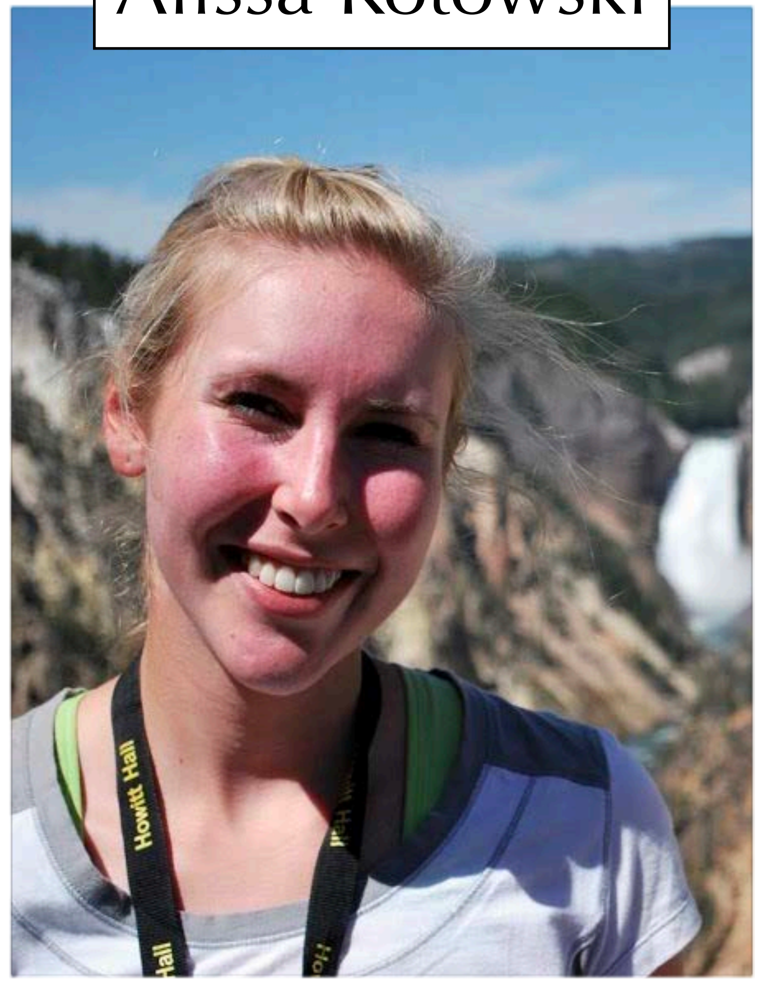

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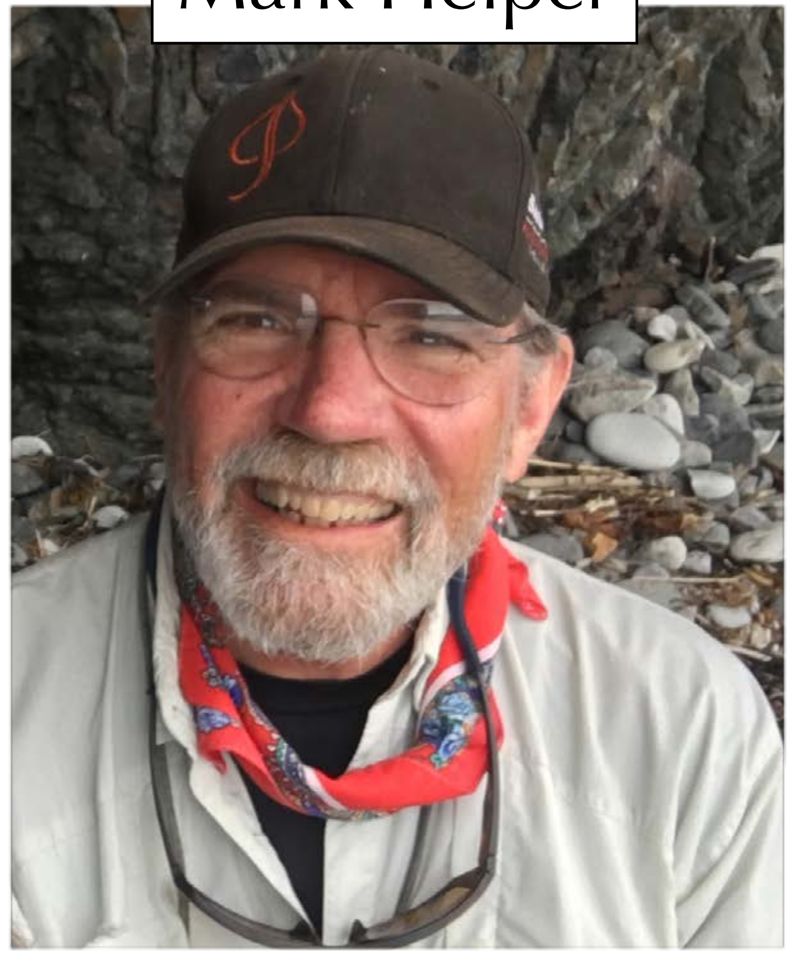

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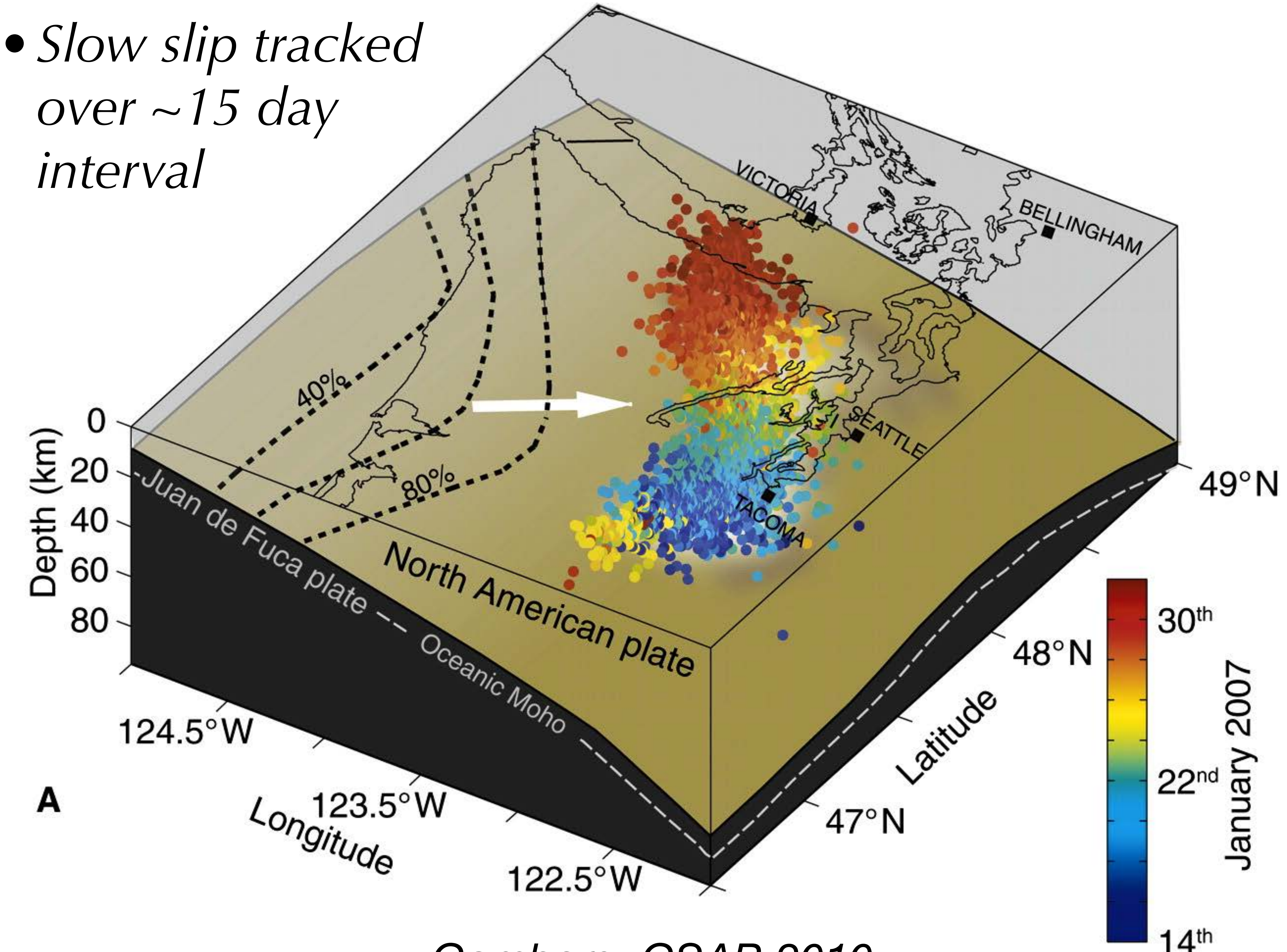
Quick Overview of ETS in Modern Subduction Zones

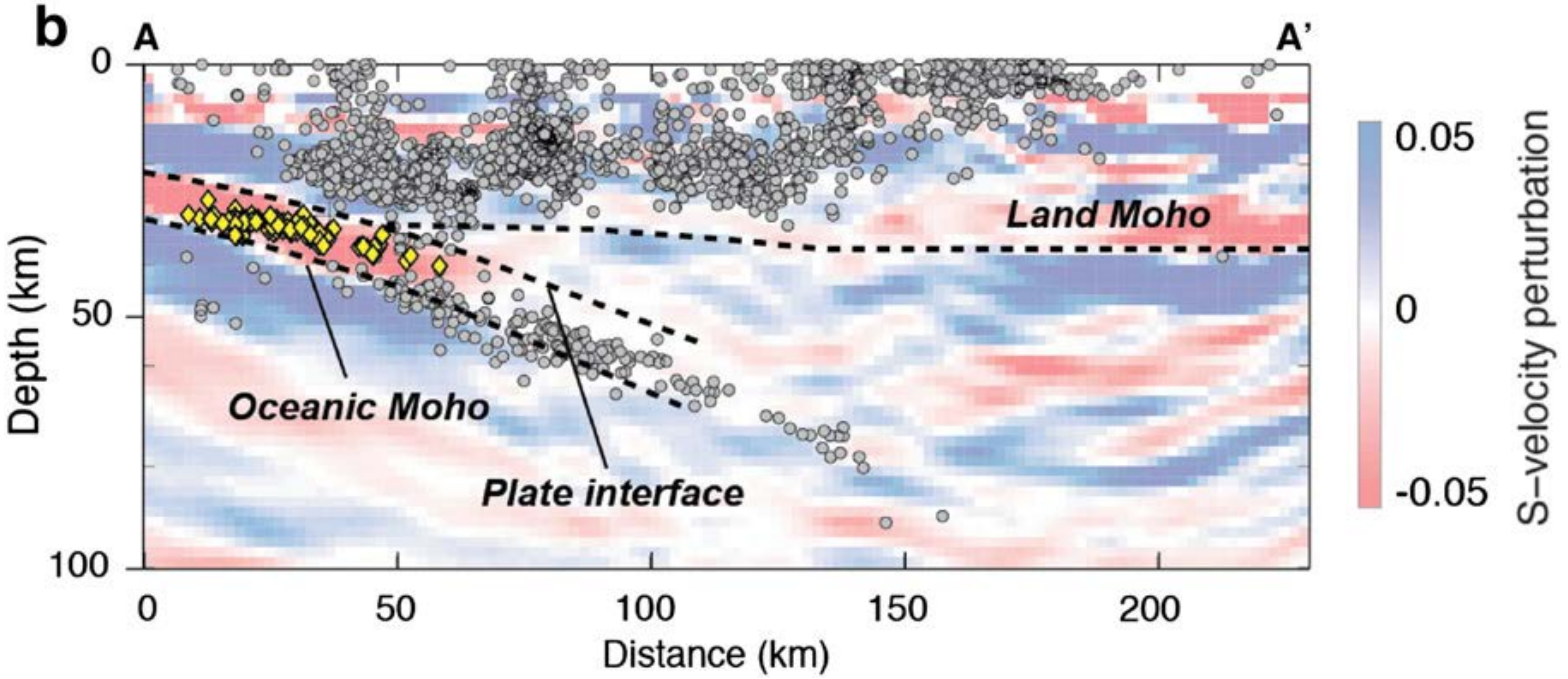
Example from Cascadia

- *Slow slip tracked over ~15 day interval*



Gomberg, GSAB 2010

- *Occurs at and around mantle wedge corner*
- *Correlates with seismic low velocity layer*



Audet & Kim, 2016;
modified from Bostock et al, 2012

Quick Overview of ETS in Modern Subduction Zones

Key characteristics & what they might mean…

Shear slip on plate interface **—> *Not just dilational cracking***

Highly sensitive to external stress perturbations (e.g. tides) **—> *Involves high fluid pressures***

Co-located with seismic low velocity/high Vp-Vs ratio layer in most subduction zones **—> *Involves high fluid contents & pressures***

Does not achieve dynamic rupture speeds **—> *Requires a mechanism for `damping' or seismic arrest***

Focus for Today

- We've thus far studied two rock record examples of deep subduction interface rheological heterogeneities in detail

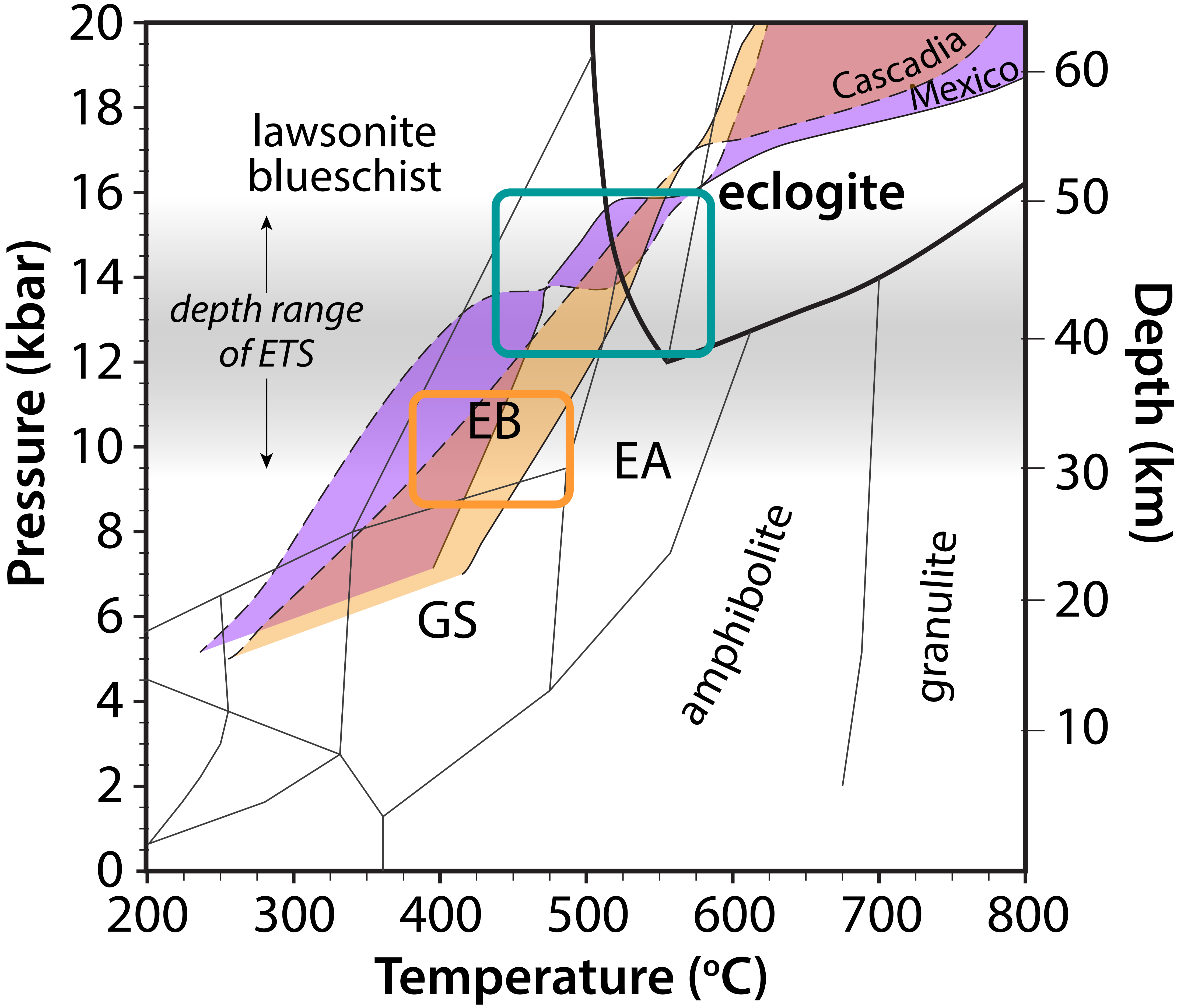
Key Messages from These Field Areas…

*Progressive **hydration** produces viscous matrix with relict embedded frictional blocks*

Condrey Mtn, n. CA

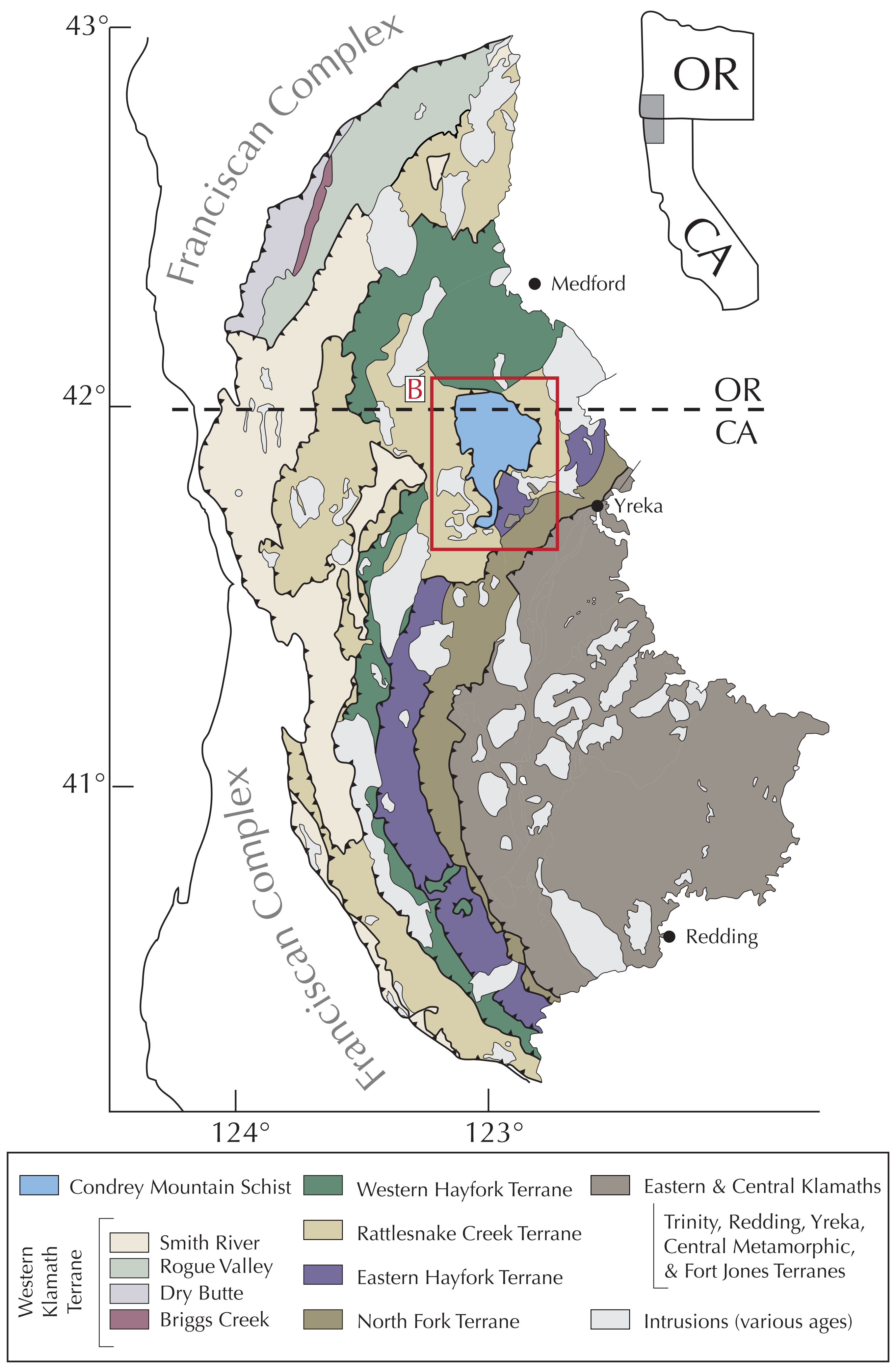
Syros Island, Greece

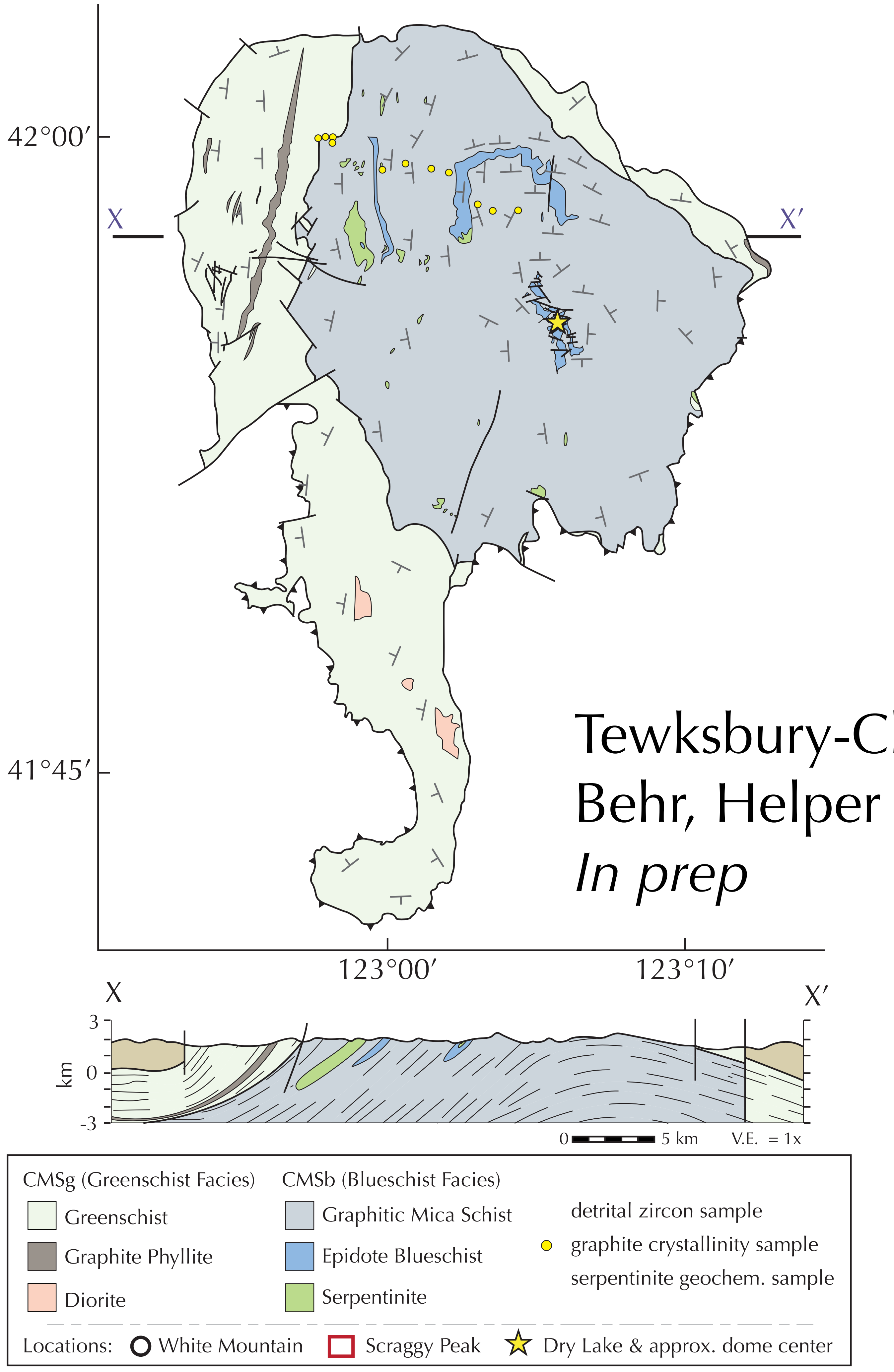
*Progressive **dehydration** produces frictional mafic blocks in a viscous matrix*



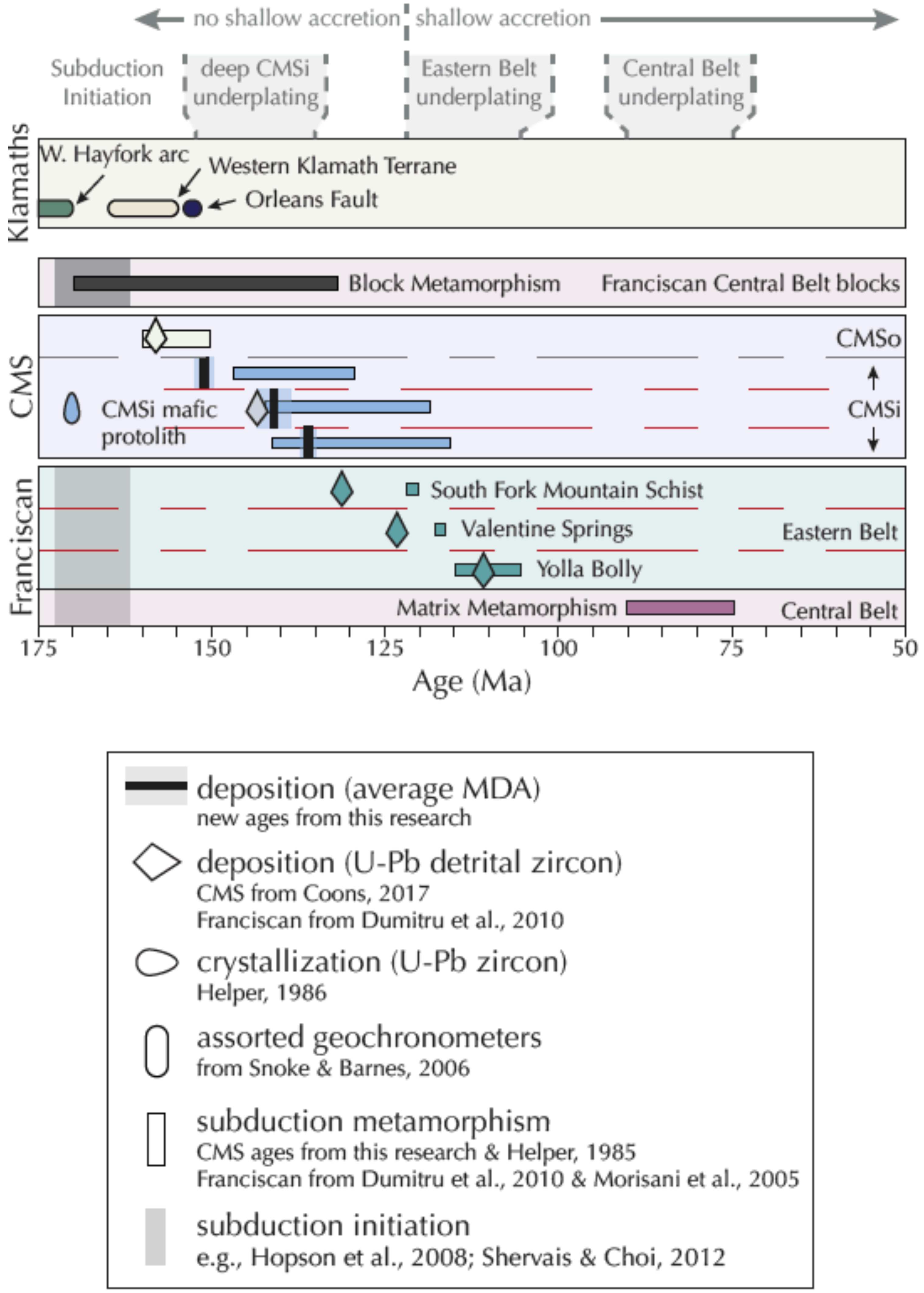
Observations from Two Exhumed Subduction Shear Zones /1

Condrey Mountain Window, southern Oregon/northern California





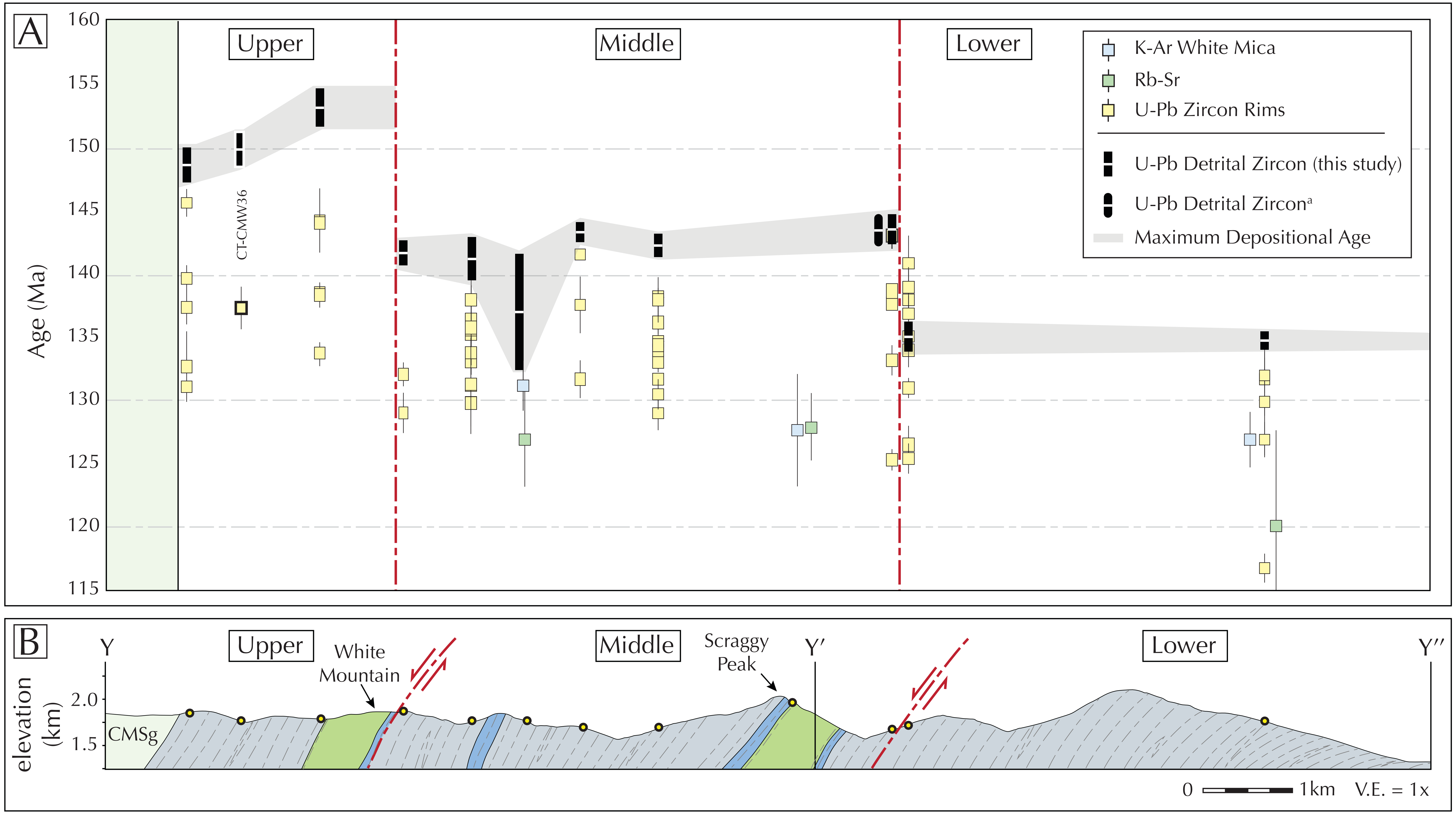
Tewksbury-Christle, Behr, Helper & Stockli, *In prep*



Observations from Two Exhumed Subduction Shear Zones /1

Geochronology + structural data resolve cryptic subduction interface thrusts

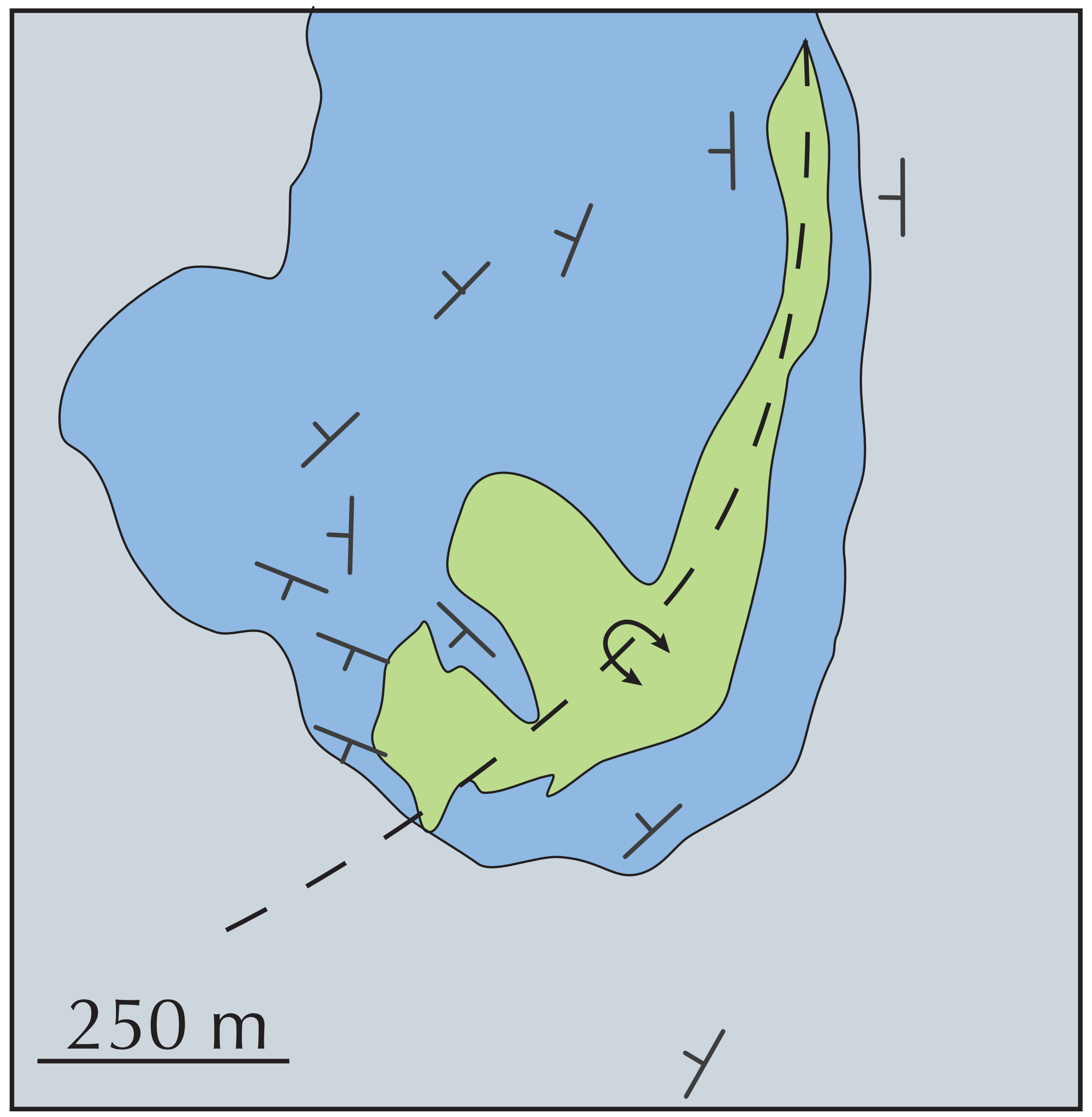
Tewksbury-Christle, Behr, Helper & Stockli, *in prep*



Observations from Two Exhumed Subduction Shear Zones /1

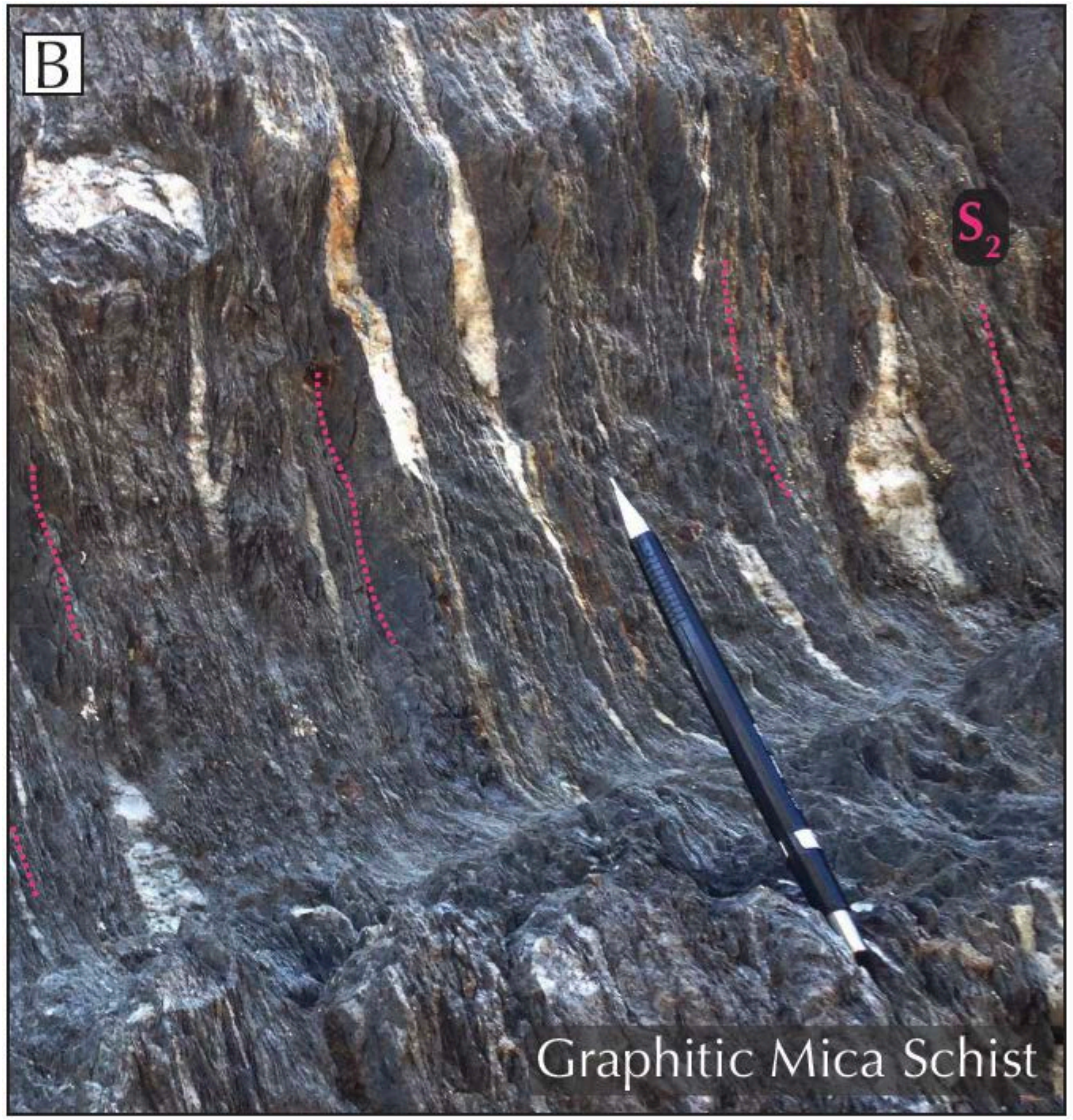
Interface thrust characteristics: highly attenuated and viscously sheared lower contact

Scraggy Mtn thrust nappe



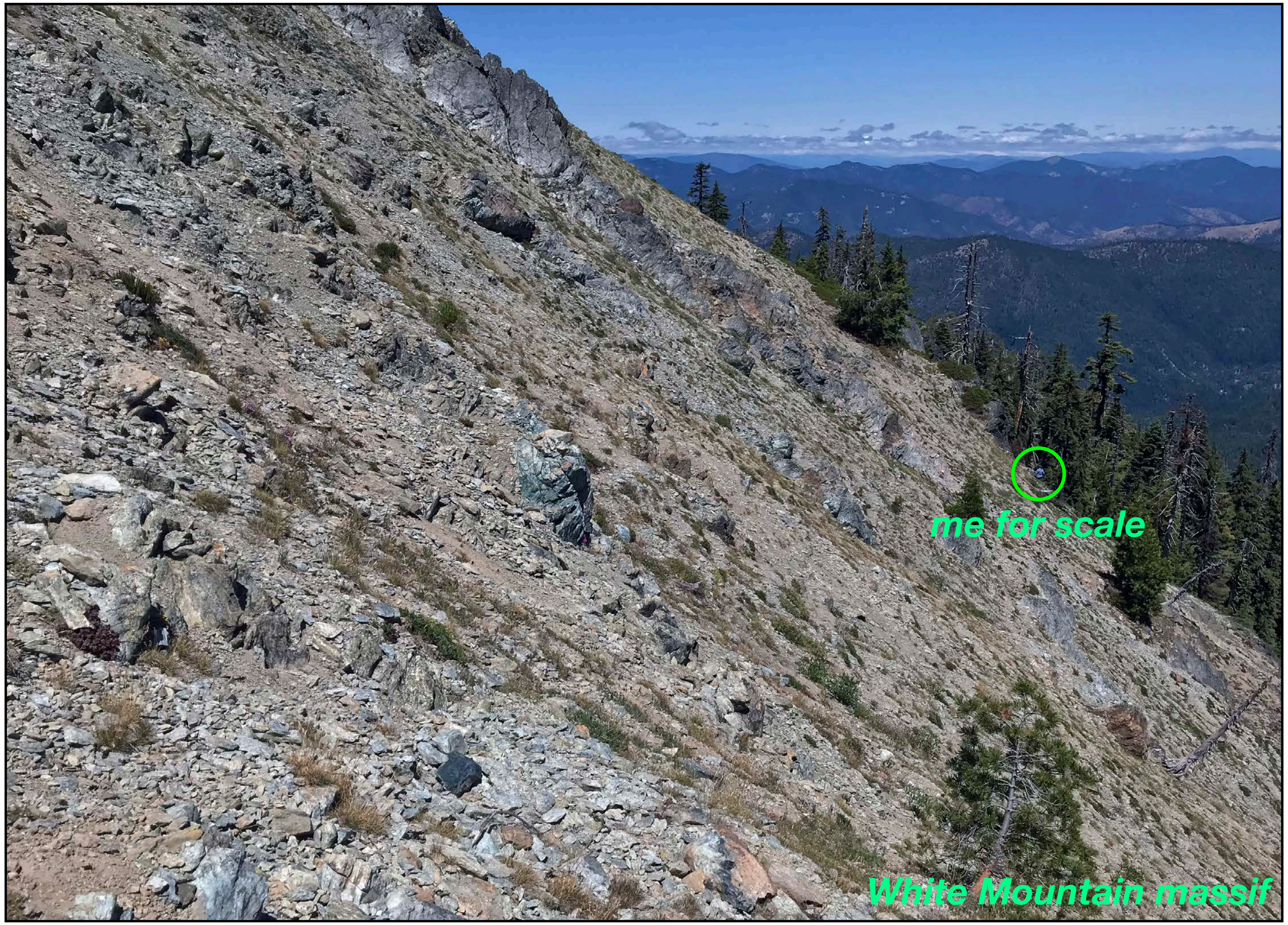
Dislocation glide in antigorite

Linear viscous pressure solution in GMS



Observations from Two Exhumed Subduction Shear Zones /1

Interface thrust characteristics: interior deformed primarily by brittle shear fracturing



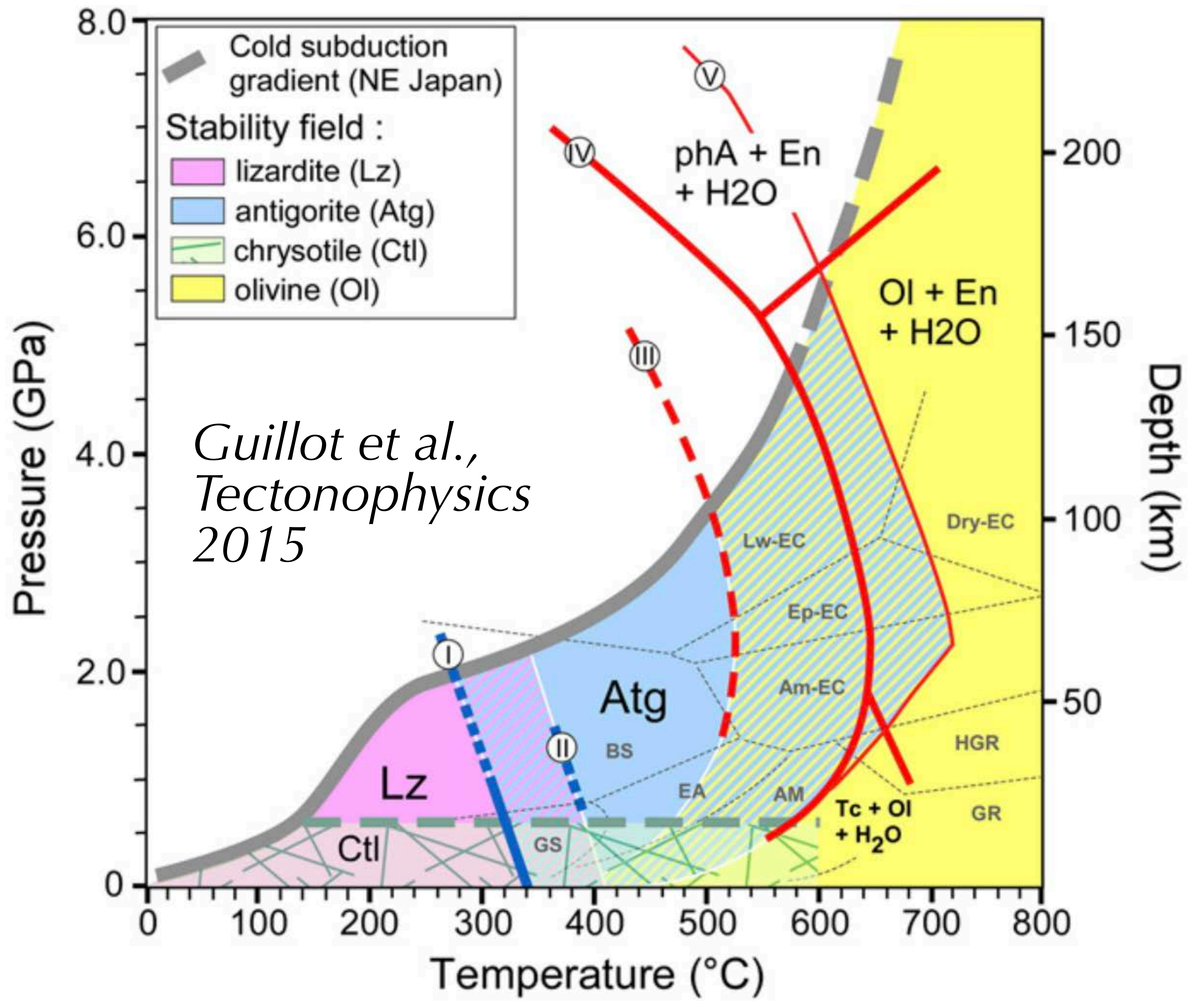
Observations from Two Exhumed Subduction Shear Zones /1

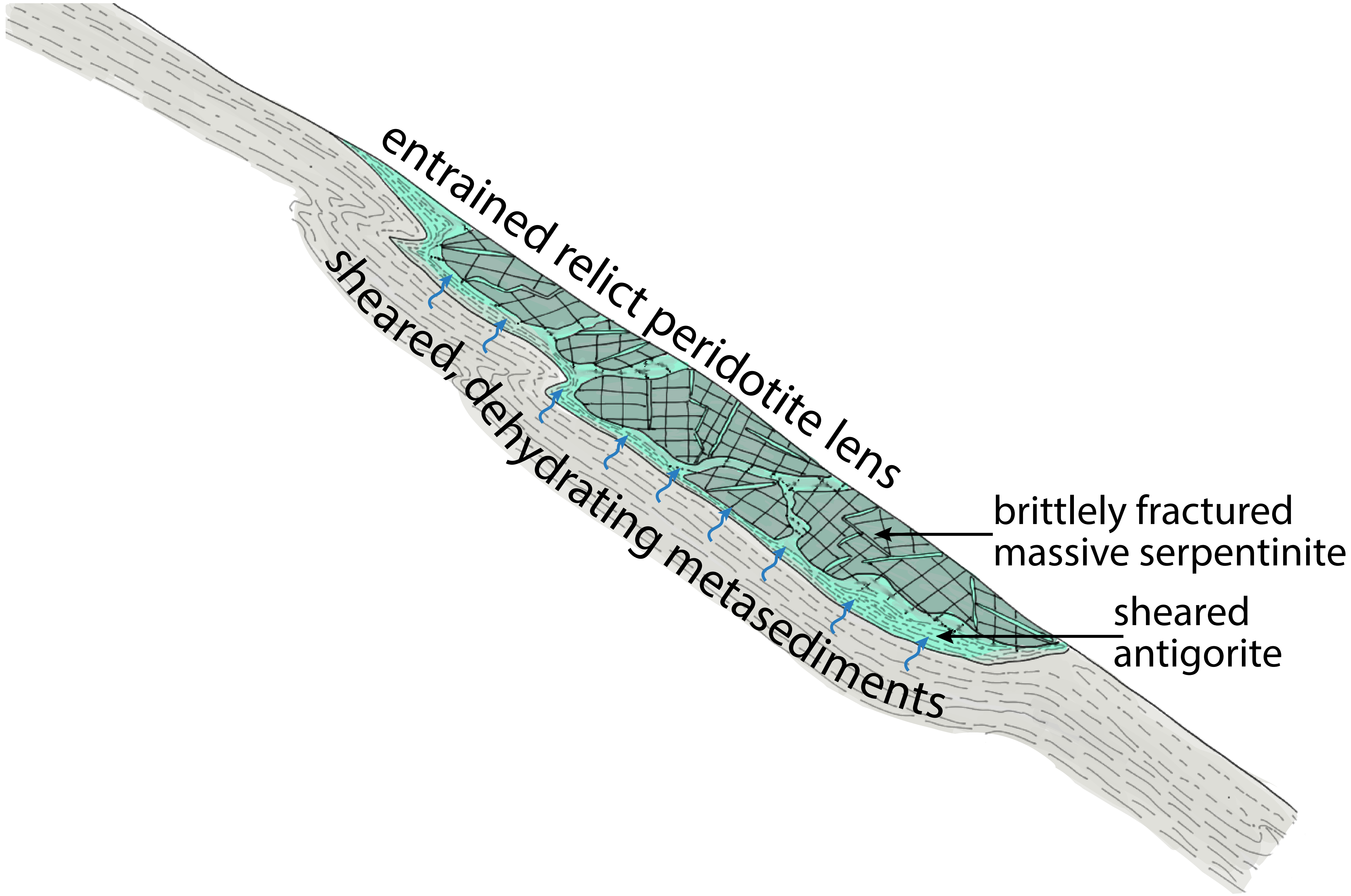
Interface thrust characteristics: interior deformed primarily by brittle shear fracturing

Observations from Two Exhumed Subduction Shear Zones /1

Interpretation of CMW ductile thrusts

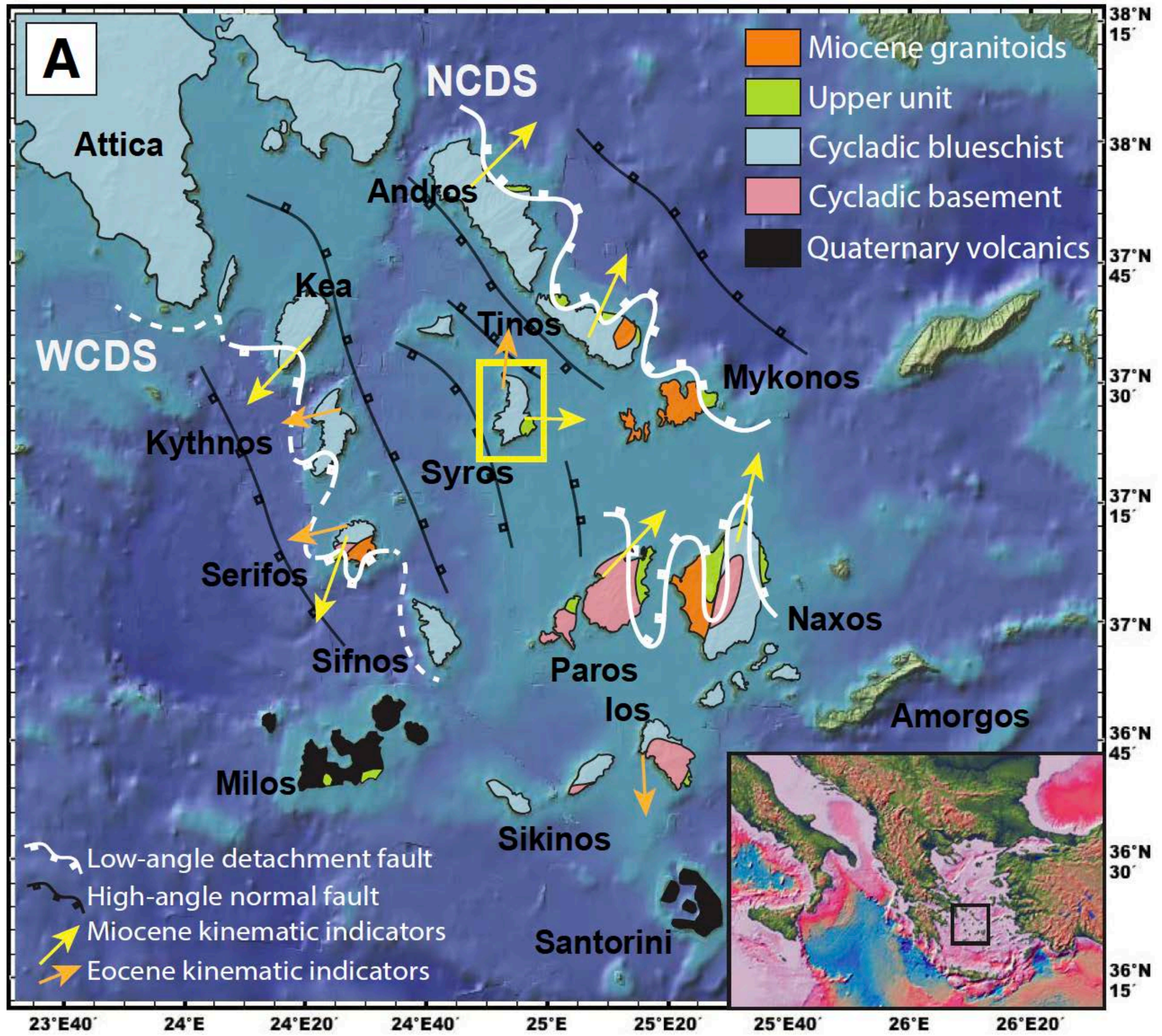
*Progressive **hydration** produces viscous antigorite serpentine matrix surrounding brittle relict ultramafic blocks*



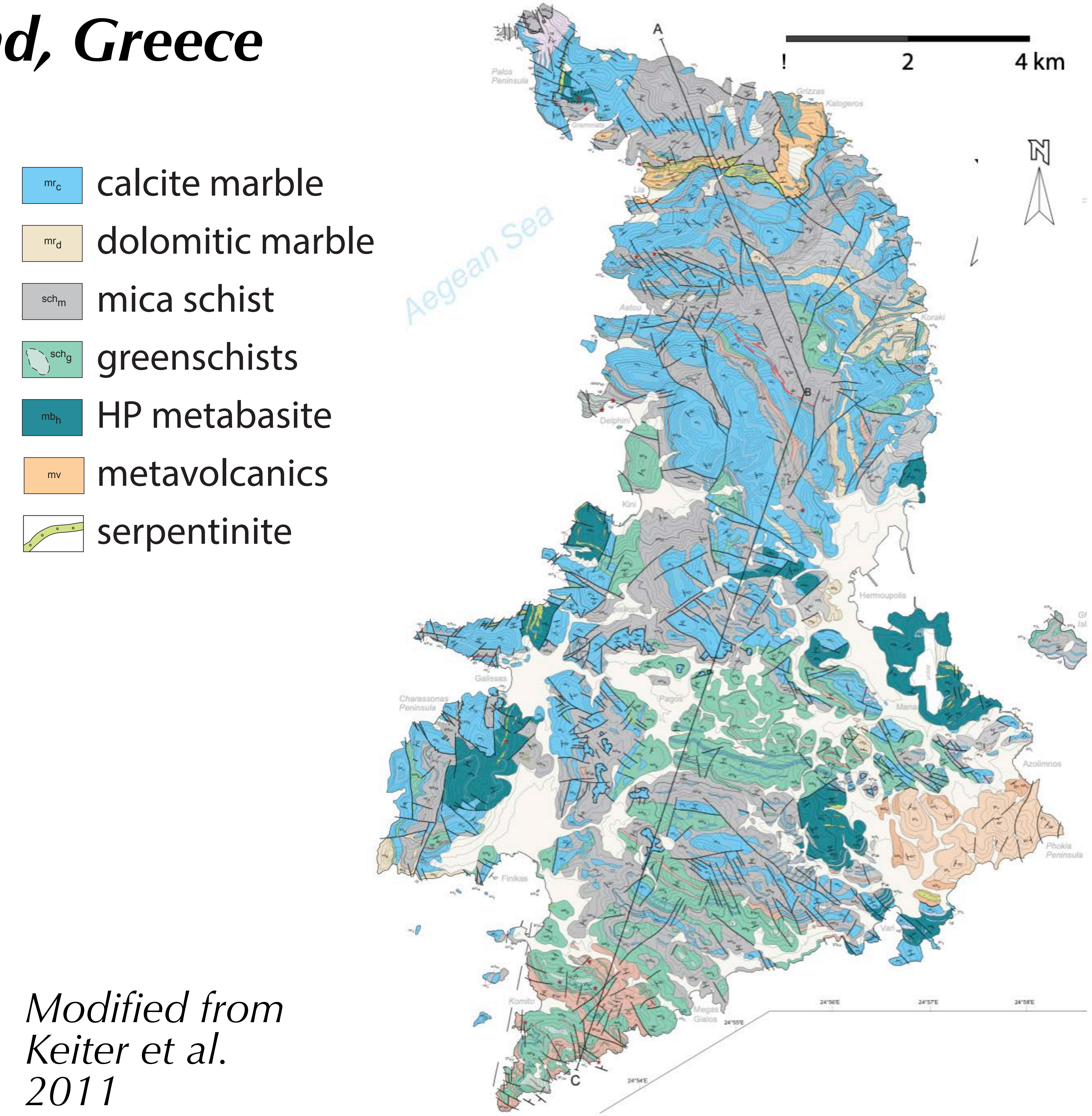


Observations from Two Exhumed Subduction Shear Zones /2

Cycladic Blueschist Unit, Syros Island, Greece



Kotowski & Behr, Geosphere 2019

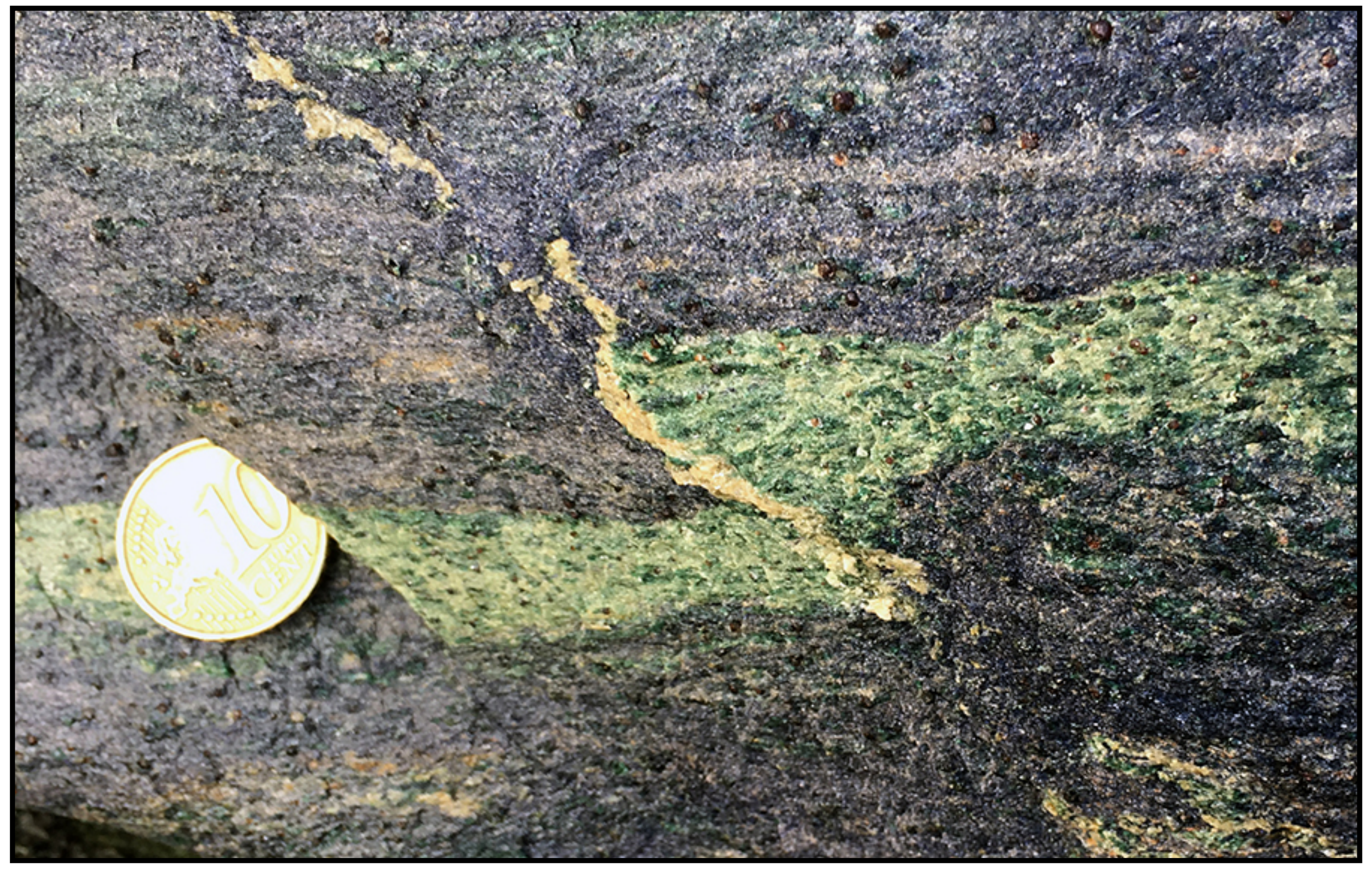


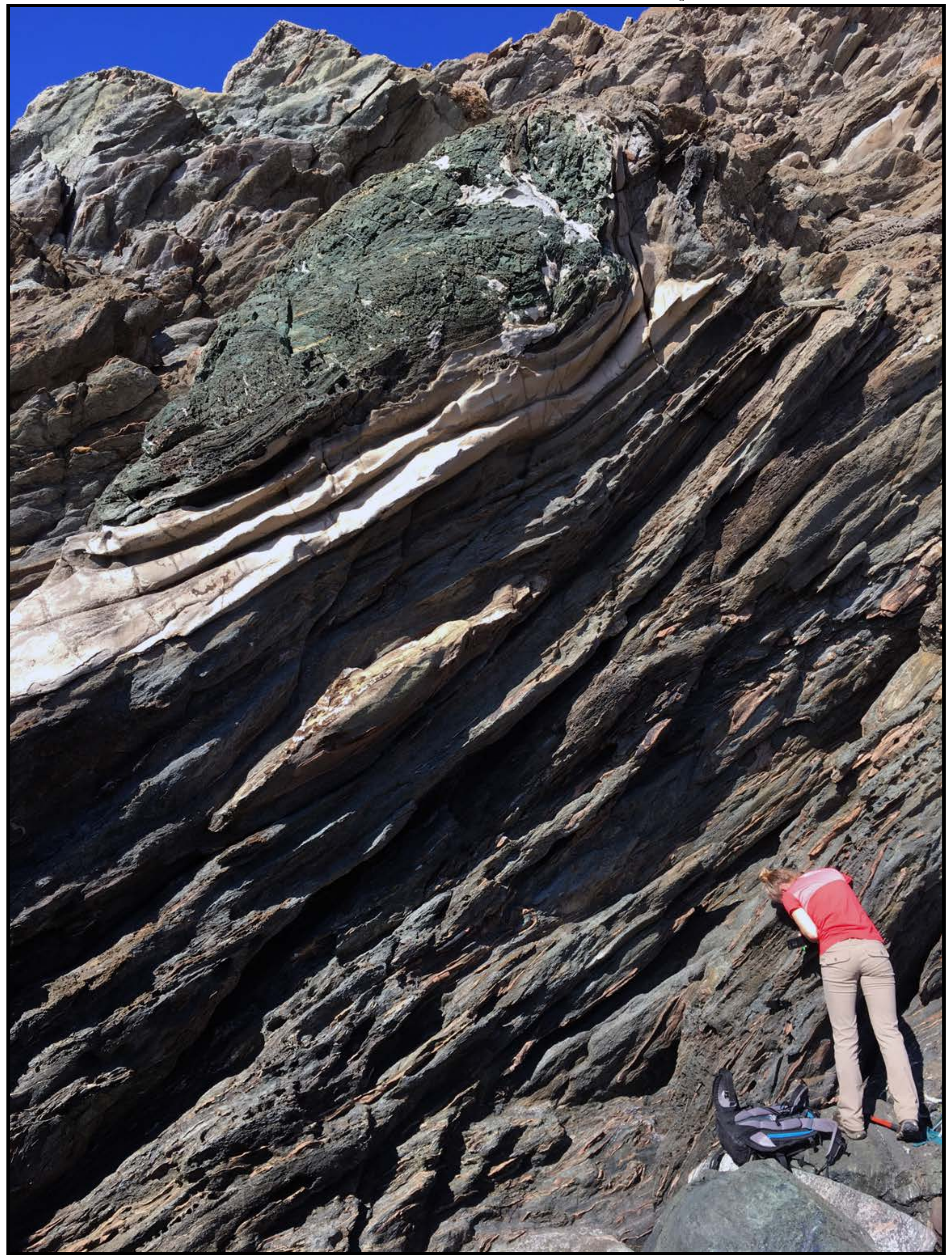
Modified from Keiter et al. 2011

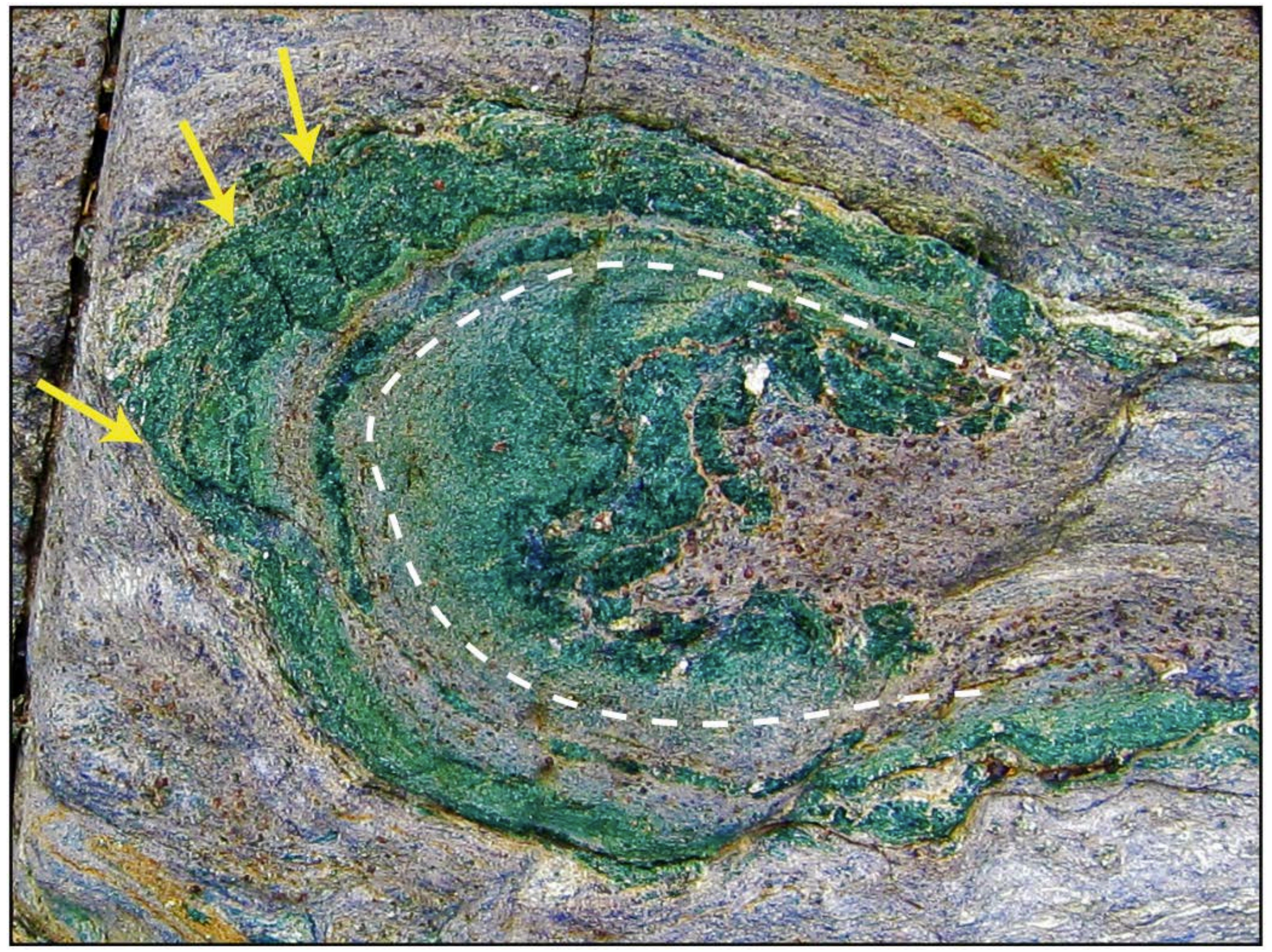
Observations from Two Exhumed Subduction Shear Zones /2

Evidence for frictional-viscous deformation associated with eclogite formation

Behr et al, Geology 2018 & Kotowski and Behr, Geosphere 2019

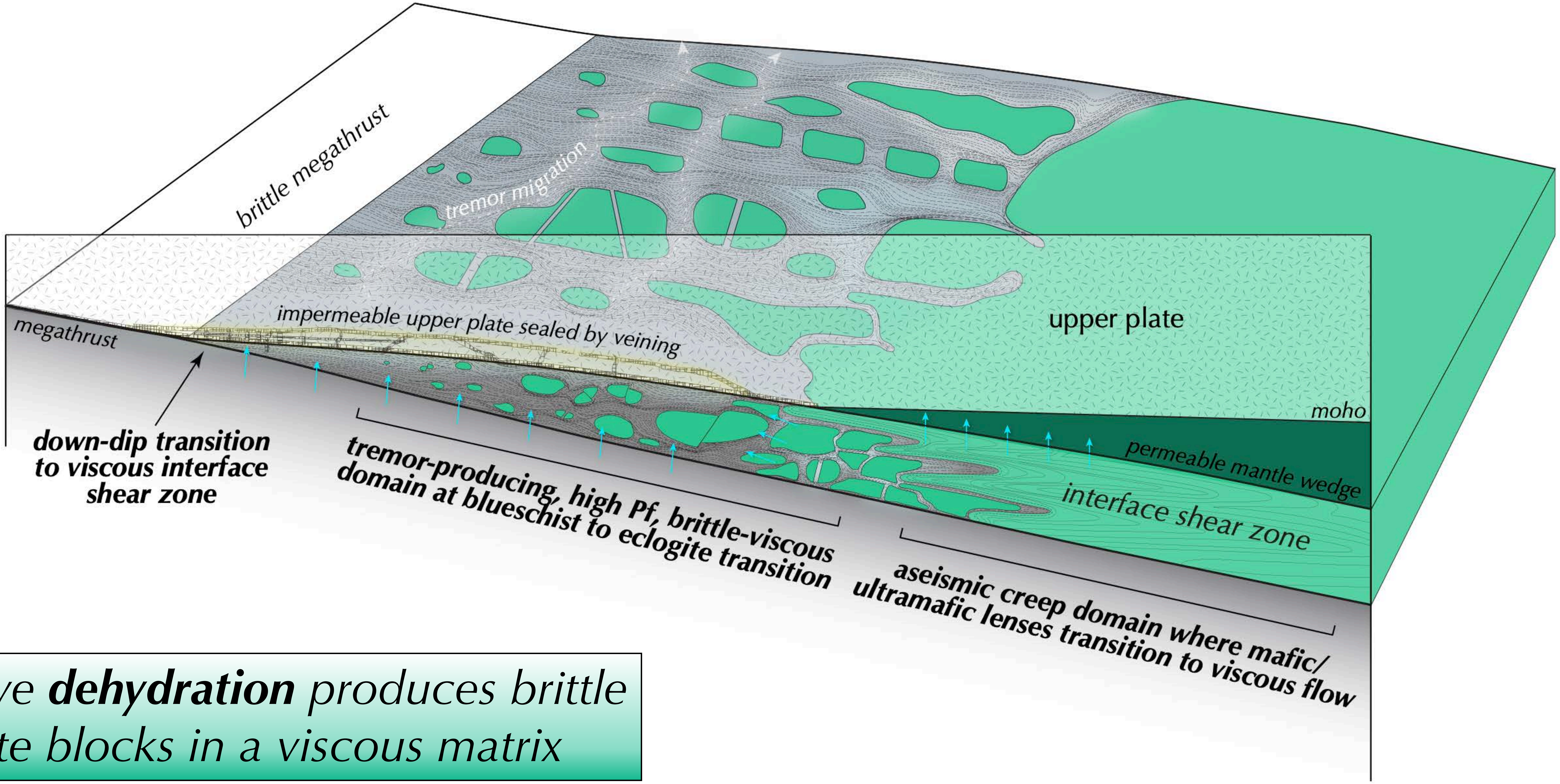






Observations from Two Exhumed Subduction Shear Zones /2

Interpretation of Syros mafic lenses



*Progressive **dehydration** produces brittle eclogite blocks in a viscous matrix*

Compatibility of Observed Heterogeneities with ETS Events…?

Two rock record examples of deep subduction interface rheological heterogeneities

Shear slip on plate interface —> ***Not just dilational cracking*** ✓

Highly sensitive to external stress perturbations (e.g. tides) —> ***Involves high fluid pressures*** ✓

Co-located with seismic low velocity/high Vp-Vs ratio layer in most subduction zones —> ***Involves high fluid contents & pressures*** ✓

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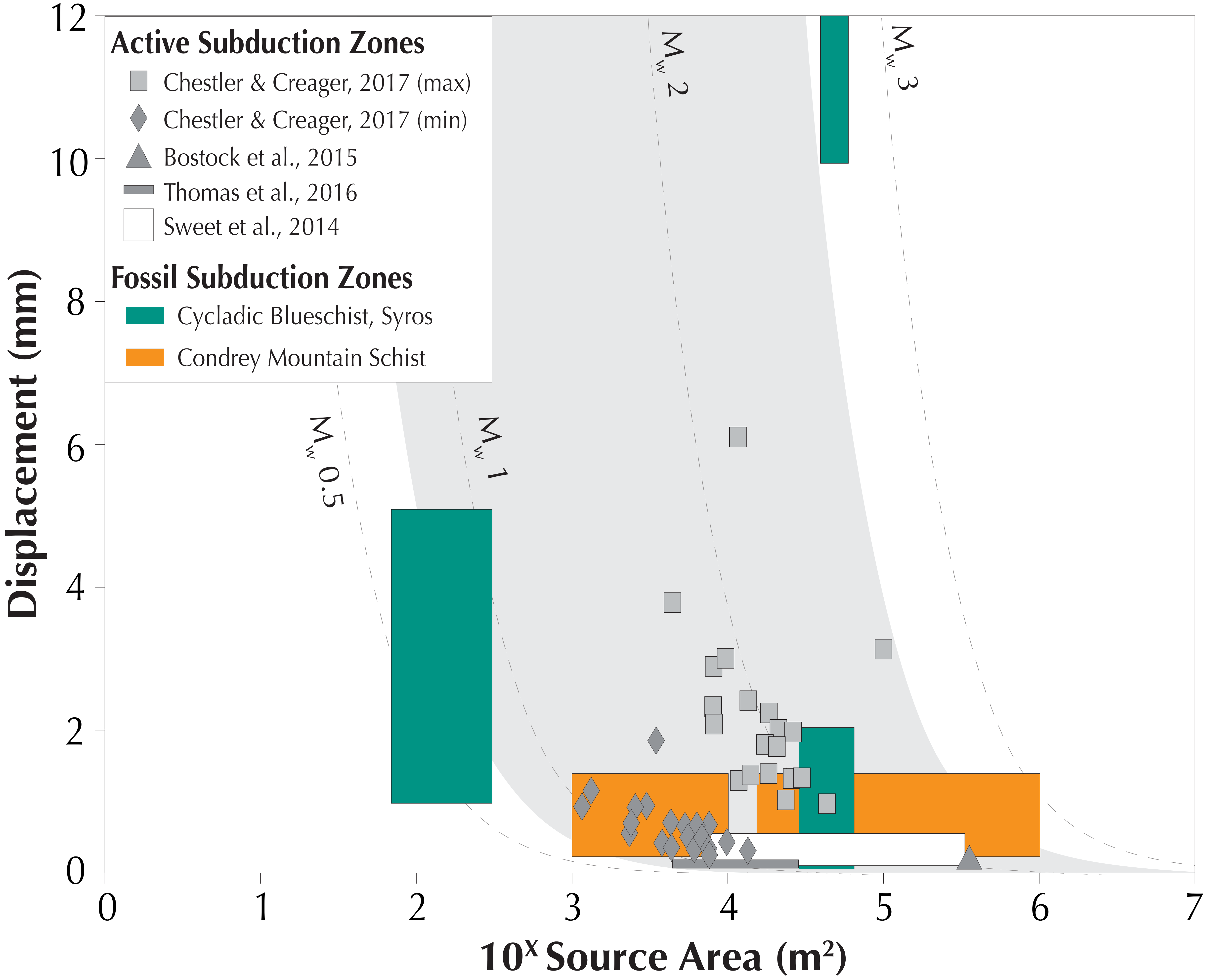
But how do we assess compatibility with slow slip events in terms of **sizes** and **rates**?

- *Estimating displacement-area relationships (i.e. seismic moment)*
- *Numerical modeling of frictional-viscous systems*

Compatibility of Observed Heterogeneities with ETS Events /1

Estimating maximum seismic moment from displacement-area calculations

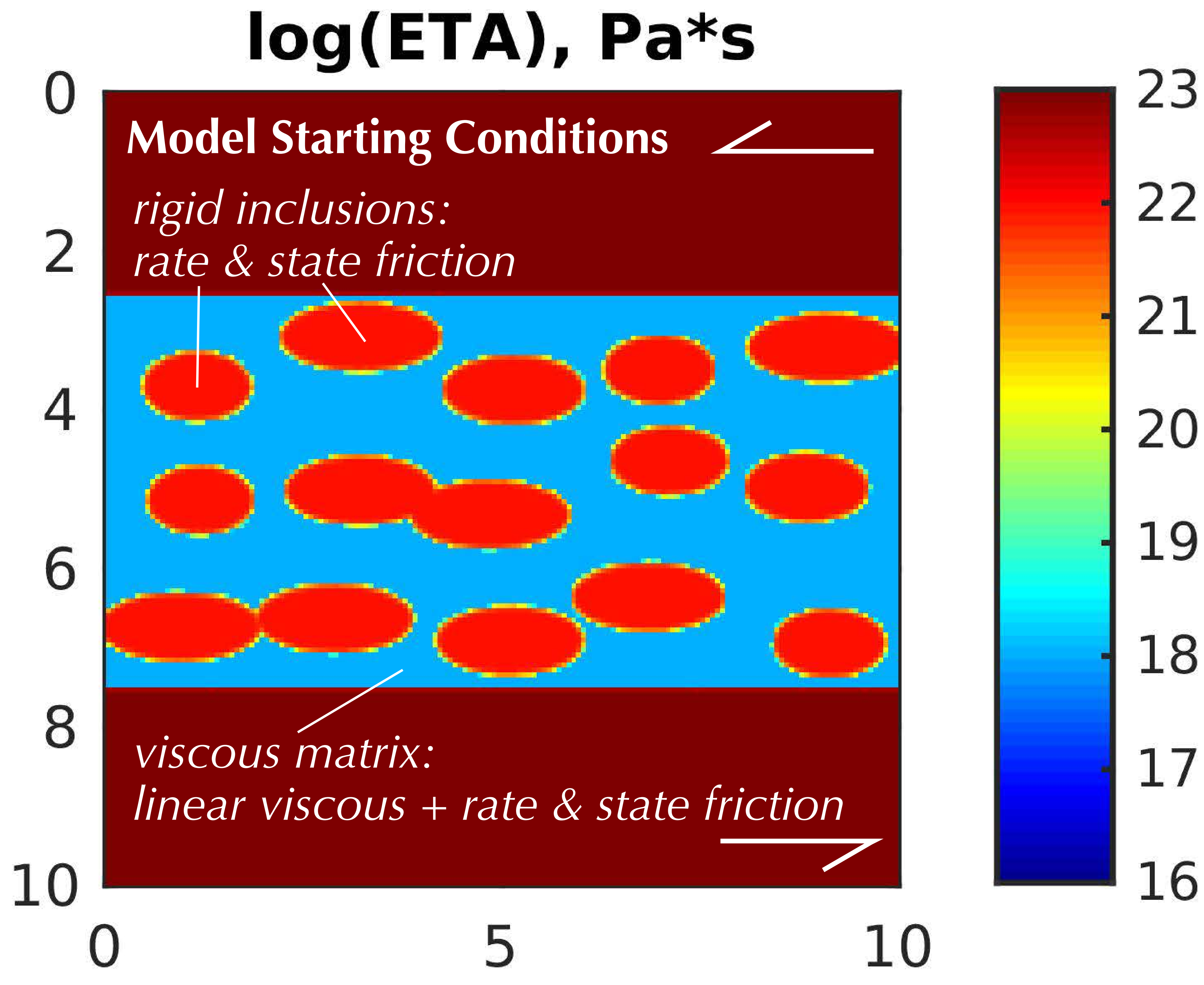


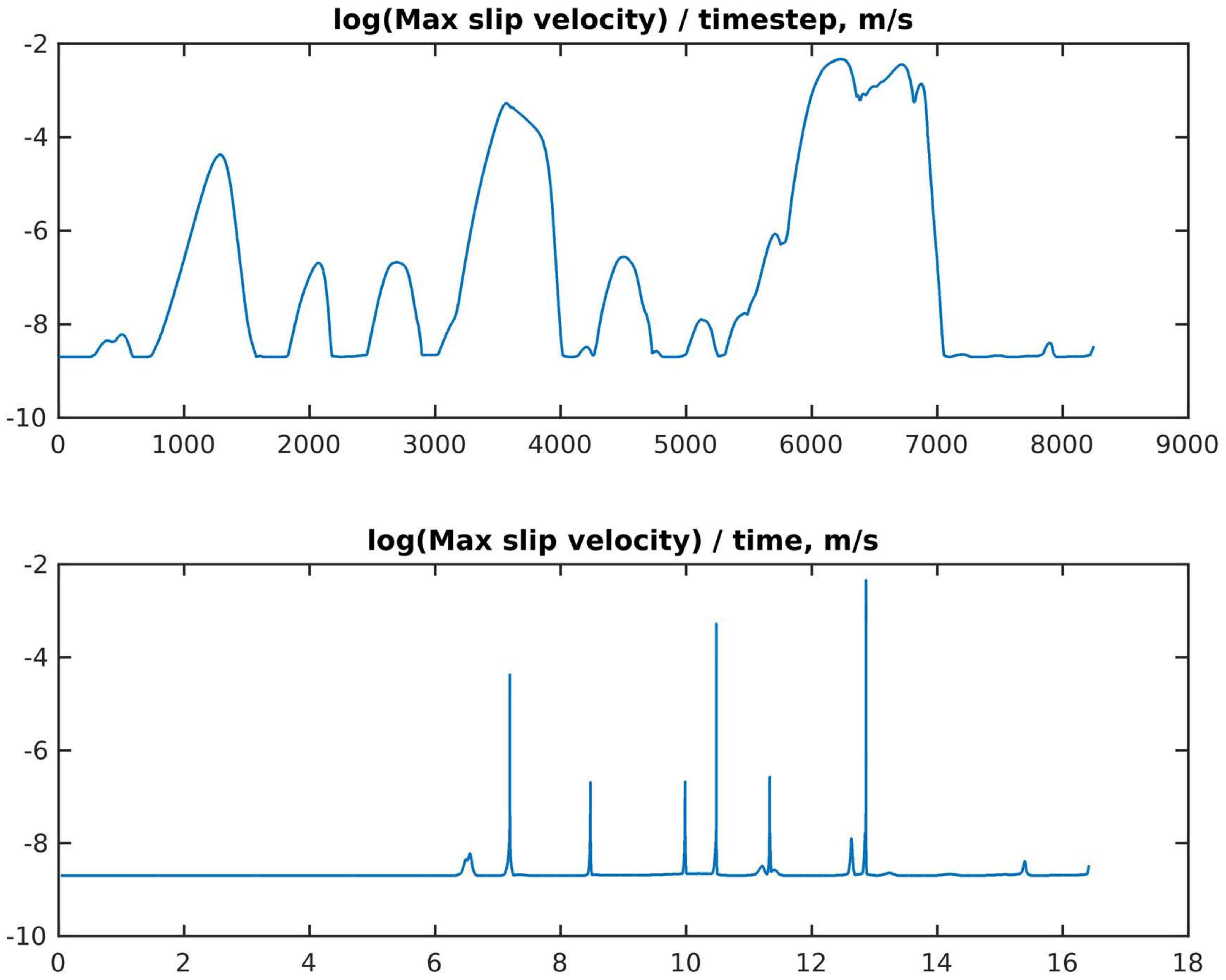
cf. Kotowski & Behr, Geosphere 2019 for more information

Compatibility of Observed Heterogeneities with ETS Events /2

Numerical modeling of frictional-viscous heterogeneity & earthquake slip

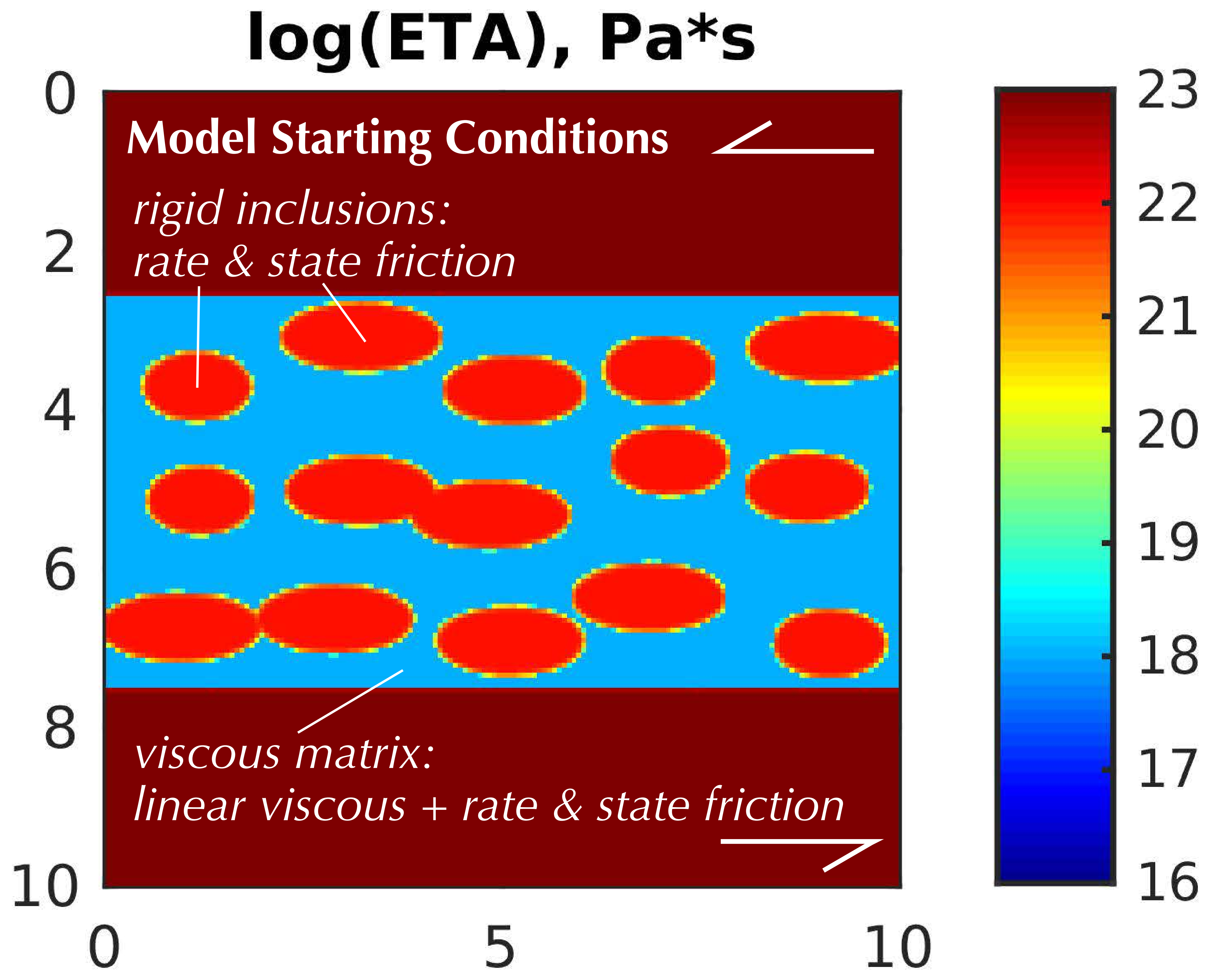
Seismo-thermo-mechanical modeling, with adaptable time-stepping (cf. Herrendörfer et al., 2018)





Compatibility of Observed Heterogeneities with ETS Events /2

Numerical modeling of frictional-viscous heterogeneity & earthquake slip



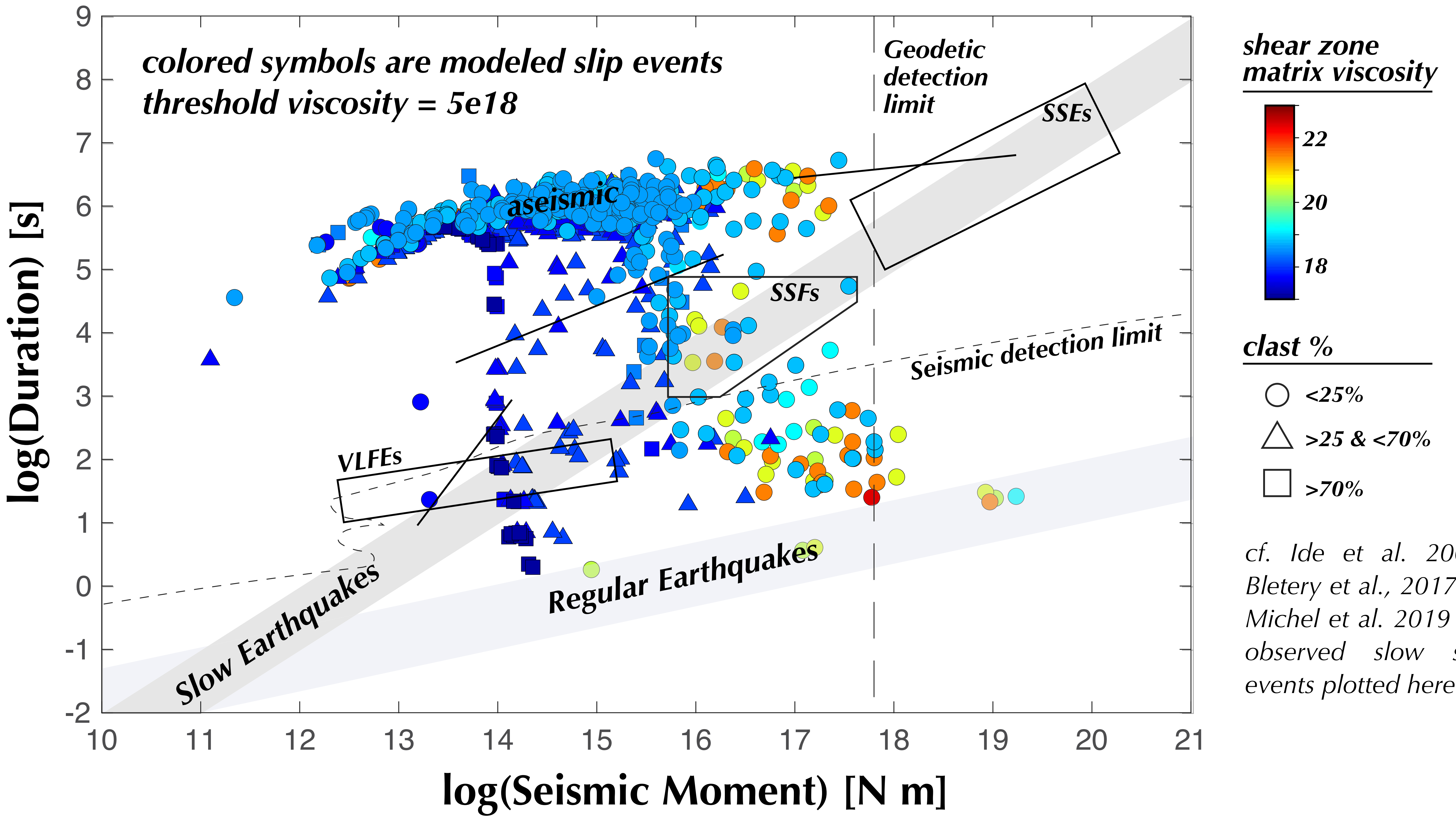
- *Over what viscosities, sizes, and spacings can the inclusions be loaded to failure?*
- *If a failure event nucleates within/around the inclusions, can they propagate through the matrix and load nearby inclusions?*
- *If ruptures propagate through the model, what are the rates, and which conditions produce slow slip vs. 'regular earthquakes' vs. aseismic creep?*

Compatibility of Observed Heterogeneities with ETS Events /2

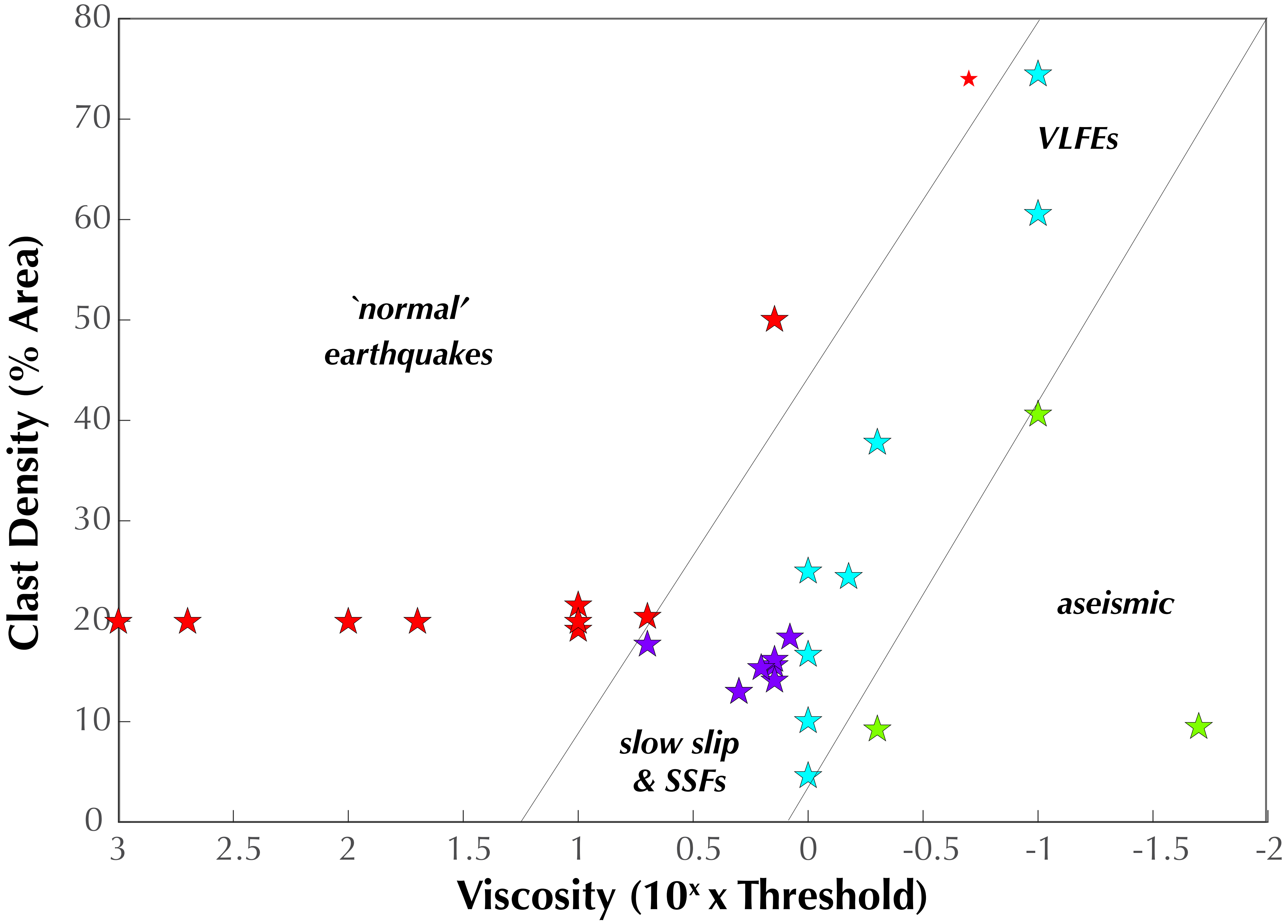
Numerical modeling of frictional-viscous heterogeneity & earthquake slip

Key Results: models run around a threshold viscosity (i.e. the frictional-viscous transition) yield a wide range of seismic slip behaviours that span much of the slow slip spectrum

Behr, Gerya, Cannizzaro & Blass, in prep



cf. Ide et al. 2003, Bletery et al., 2017, & Michel et al. 2019 for observed slow slip events plotted here



Conclusions

- In the CMW, **hydration** reactions led to progressive serpentinization and generated frictional-viscous deformation of peridotite bodies entrained in the subduction shear zone
- In the CBU on Syros Island, **dehydration** reactions in MORB-affinity basalts led to progressive development of strong brittlely deformed eclogitic lenses within a weaker viscous matrix.
- The sizes and displacement magnitudes of these frictional-viscous heterogeneities observed in the field are compatible with estimates of seismic moment from modern ETS events
- Adaptive time-stepping numerical modeling of rigid clasts within a viscous matrix suggests that frictional-viscous heterogeneities can produce a wide spectrum of slow transient slip events
- **General conclusion:** distributed viscous deformation with embedded frictional lenses is ubiquitous in the rock record, can exhibit mixed velocity-weakening and -strengthening behavior, and is thus a promising explanation for unconventional seismicity

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