Evaluating distributions of high-pressure rock recovery in subduction zones with large empirical datasets and numerical simulations

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Acknowledgements

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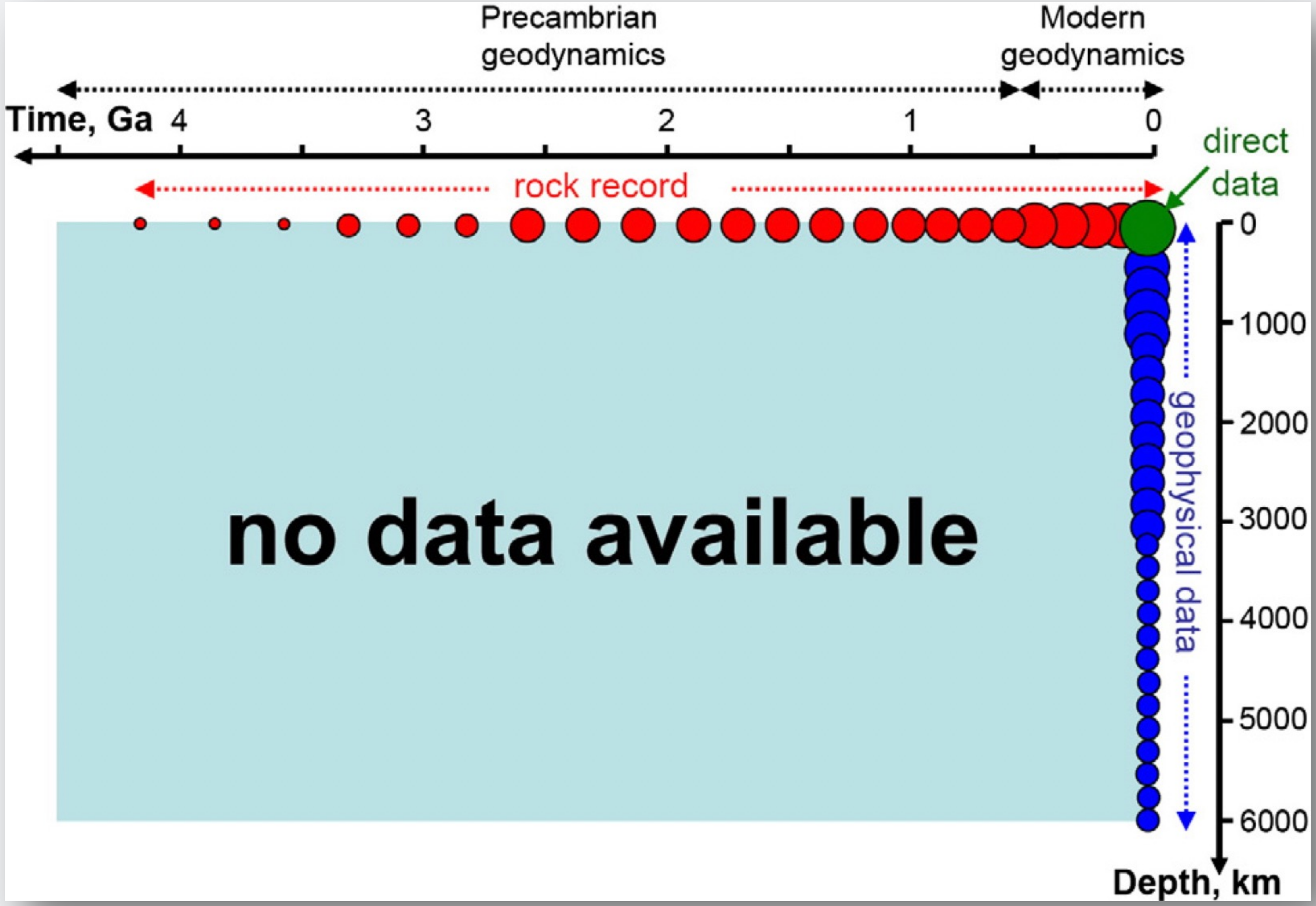
Preprint

The dilemma



Gerya (2014)

- The rock record provides information across deep time, but only near the surface, and is **incredibly sparse**
- Geophysical datasets probe Earth's interior, but only since the 20th century, and are **incredibly sparse**
- The deeper and farther back in time we try to observe geological processes, the more uncertainty grows **because of the sparseness** of geological data

A solution

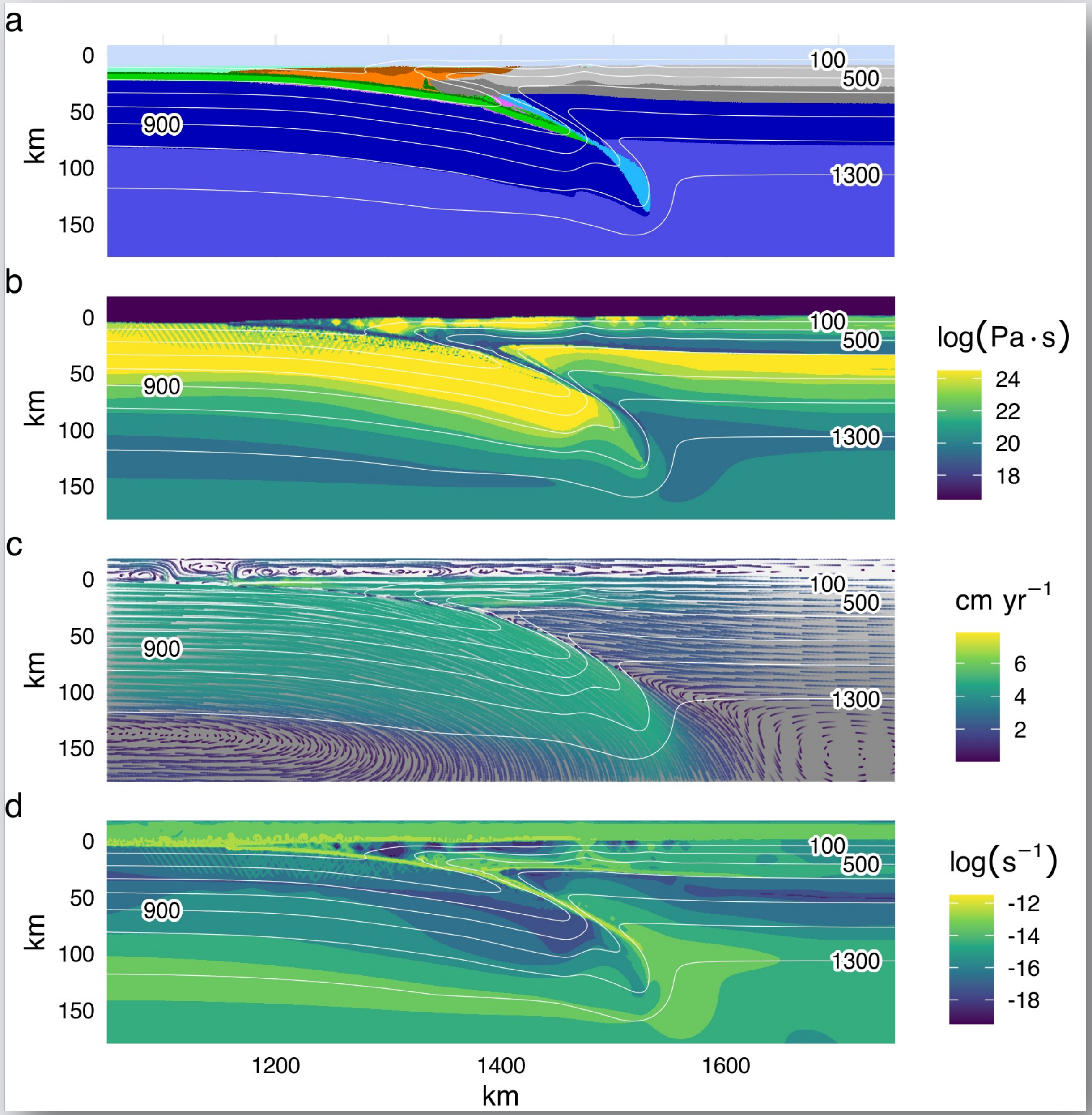
Numerical simulations allow geoscientists to:

- Explore parameter space
- Perform sensitivity tests
- Train our intuition
- Infer unknowns
- Generate new samples
- Discover new questions

Numerical simulations *do not* allow for:

- Distinguishing “correct” models
- Making precise predictions

Kerswell et al. (2021)



Previous work

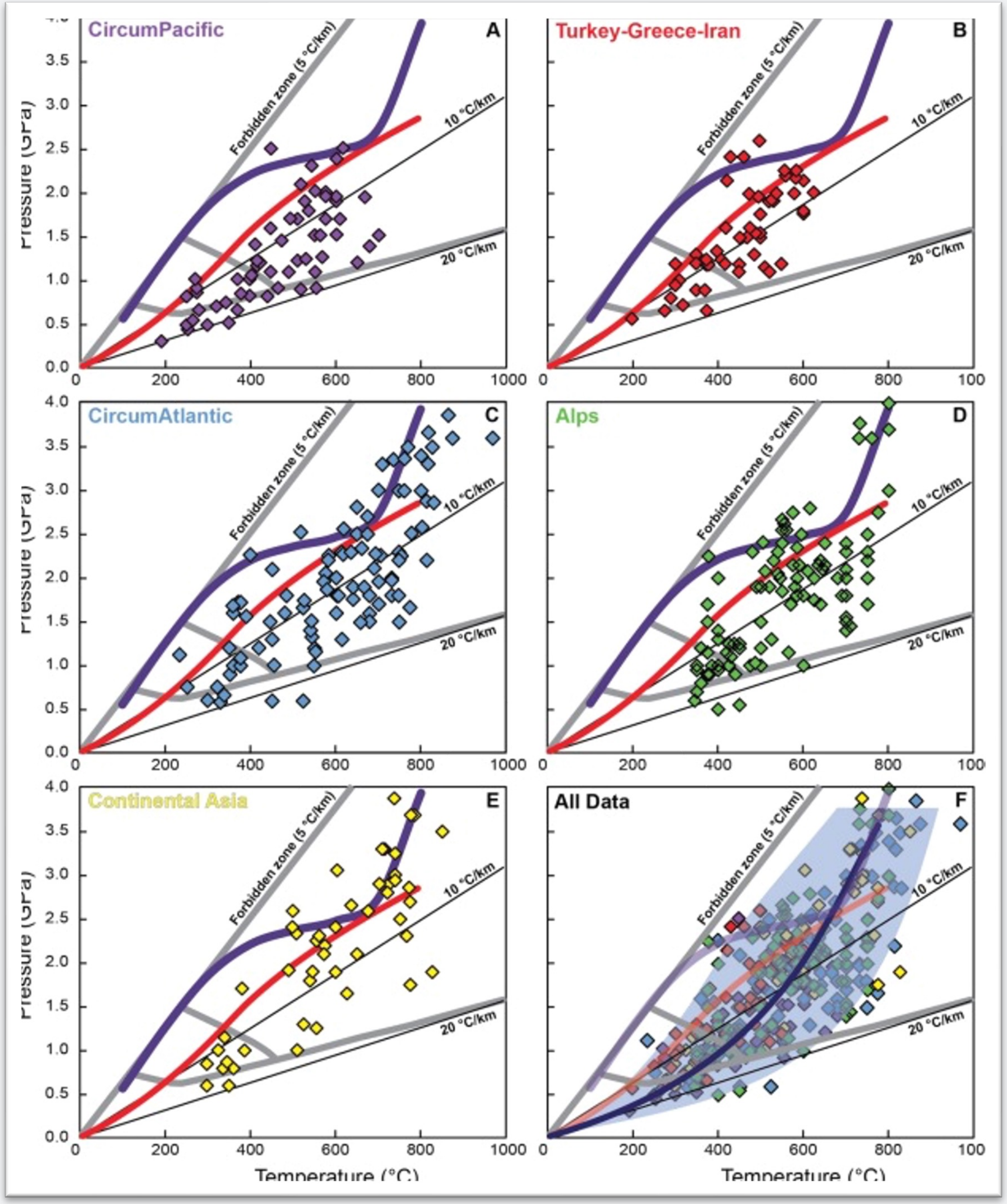
Comparing empirical and numerical datasets:

Penniston-Dorland et al. (2015)

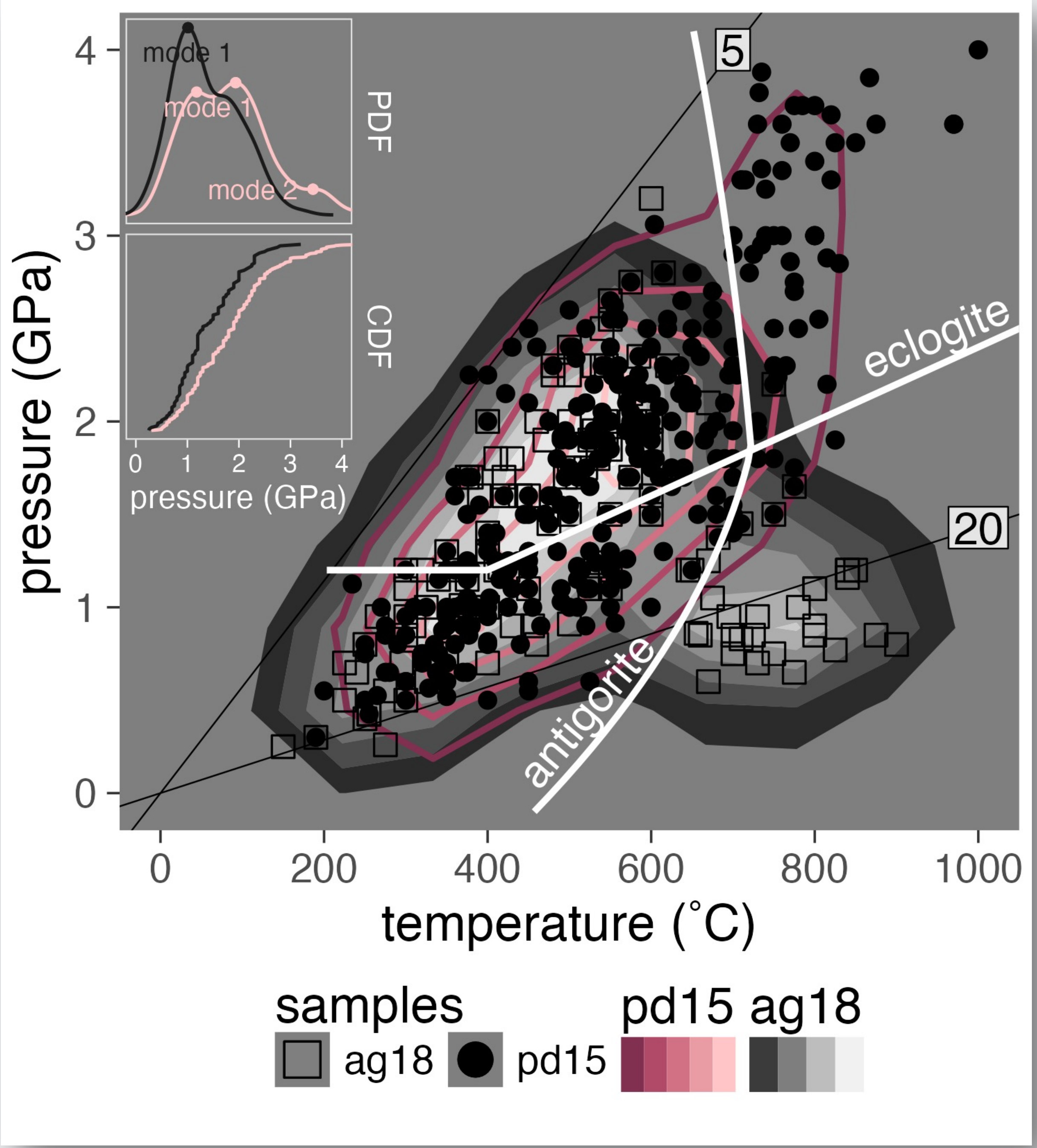
- Compiled a few hundred PT estimates of HP rocks from subduction zones
- Filter out estimates from studies before 1990
- Only include subduction systems from 750 Ma
- Carefully determine the P_{max}-T conditions

The challenge: at most, *only a few hundred PT data points are available* to discriminate accurate numerical geodynamic codes

The solution: generate a PT dataset from geodynamic models so large that patterns will emerge out of the noise



Penniston-Dorland et al. (2015)



The basis for comparison

The metamorphic rock record:

P-D et al. (2015) & Agard et al. (2018)

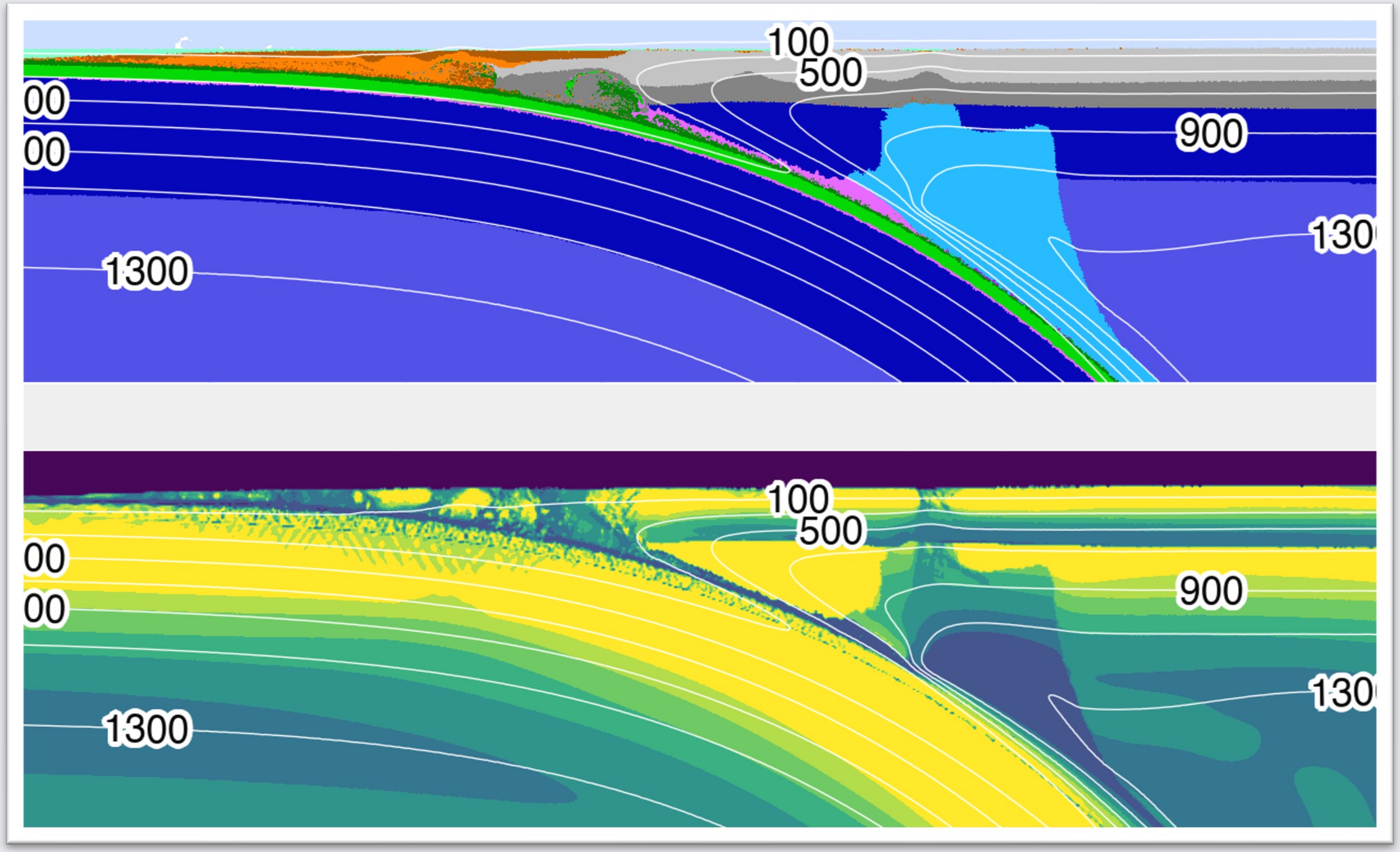
- Rocks appear to be sampled continuously across PT space
- Very few rocks are recovered from > 80km depth (~2-2.3 GPa)
- Some rocks are recovered shortly after initiation, while others are recovered during steady-state subduction or prior to collision

Kerswell et al. (in prep)

Research questions

Where are rocks recovered along subduction interface shear zones?	Continuously or at discrete depths? What do these data tell us about interface shear zone behavior?
How do recovery rates and distributions vary among subduction zones?	Are rocks preferentially recovered from some settings?
How do numerical and empirical PT distributions compare?	Are numerical models reliable indicators of PT conditions experienced by rocks?

Numerical setup



Kerswell et al. (2021)

Fixed parameters

- Rheologic model
- Hydrologic model
- Material properties
- Boundary conditions

Varied parameters

- Velocity (40-100 km/Ma)
- OP age (32-110 Ma)
- UP thickness (46-94 km)

Hydrologic model

- Continuous slab dehydration
- Atigorite forms weak interface

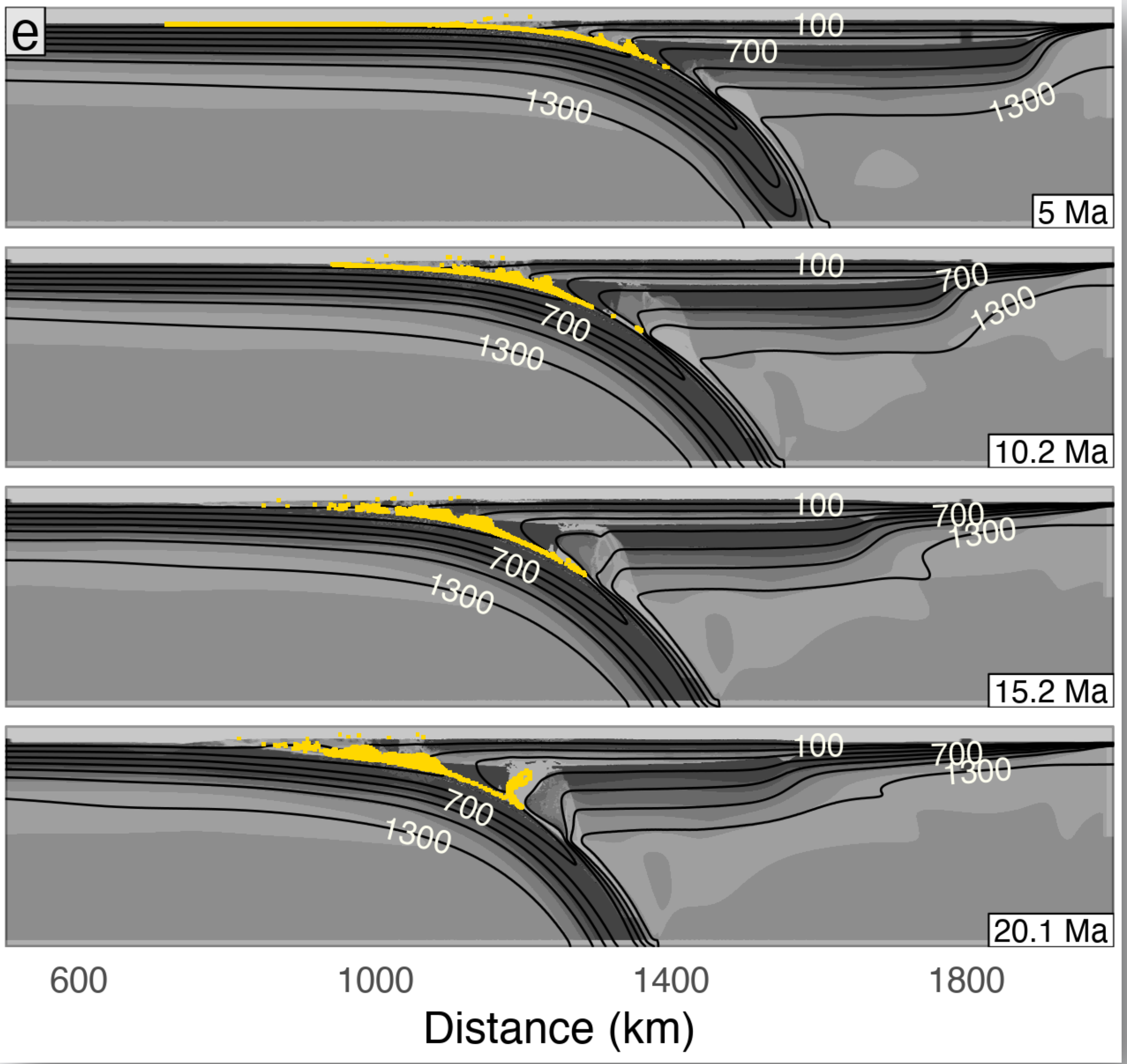
Kerswell et al. (in prep)

Numerical representation of rock detachment

- Over 1.3M markers are traced from 64 numerical experiments
- Each marker is classified as “recovered” or not depending on its PTt path
- **“Recovered” markers represent rocks that are detached from the subducting plate and are most comparable to natural data**

The challenge: don’t have *a priori* labels

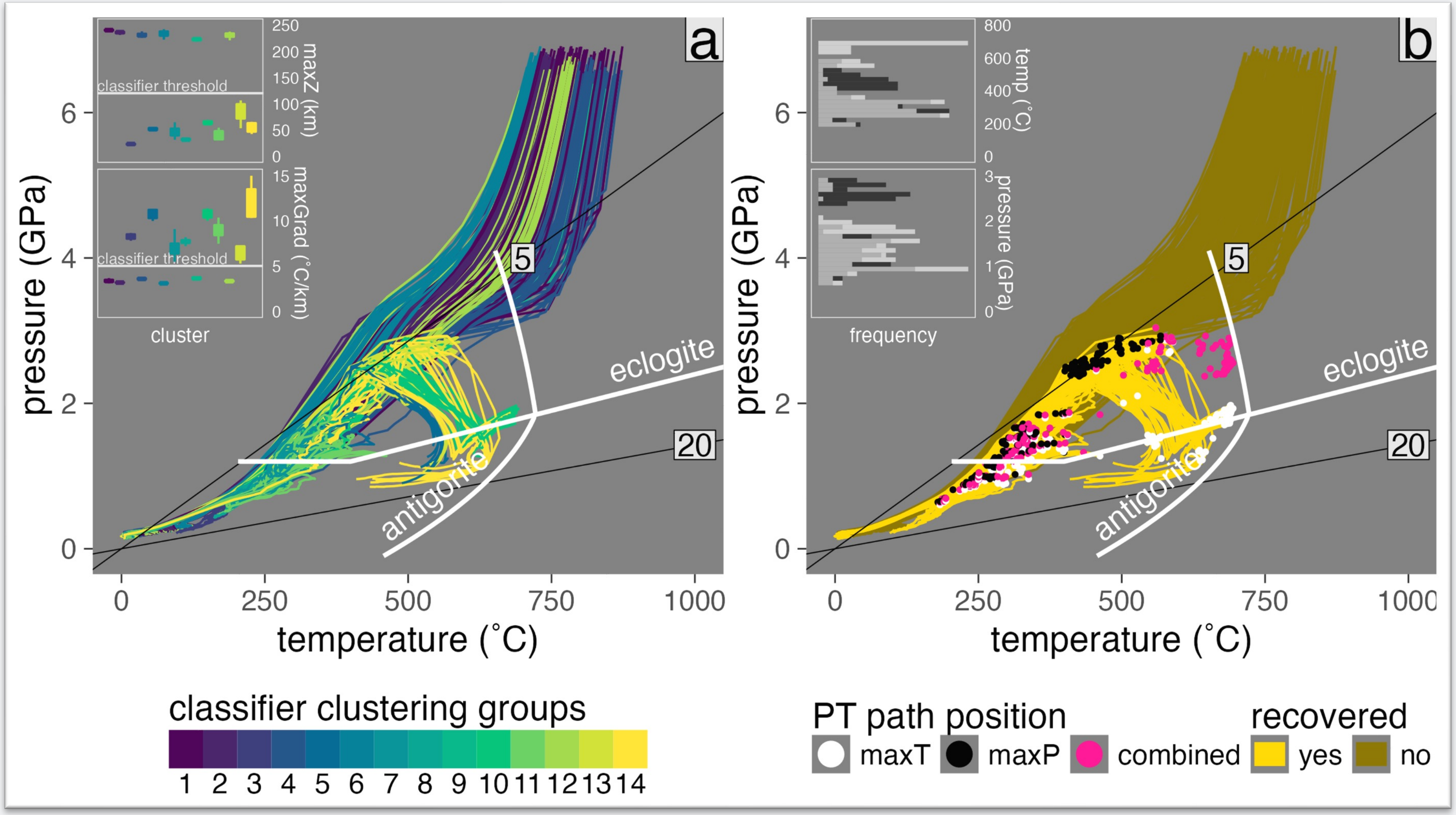
The solution: write an unsupervised classification algorithm to “recognize” recovery



Classifier algorithm

Kerswell et al. (in prep)

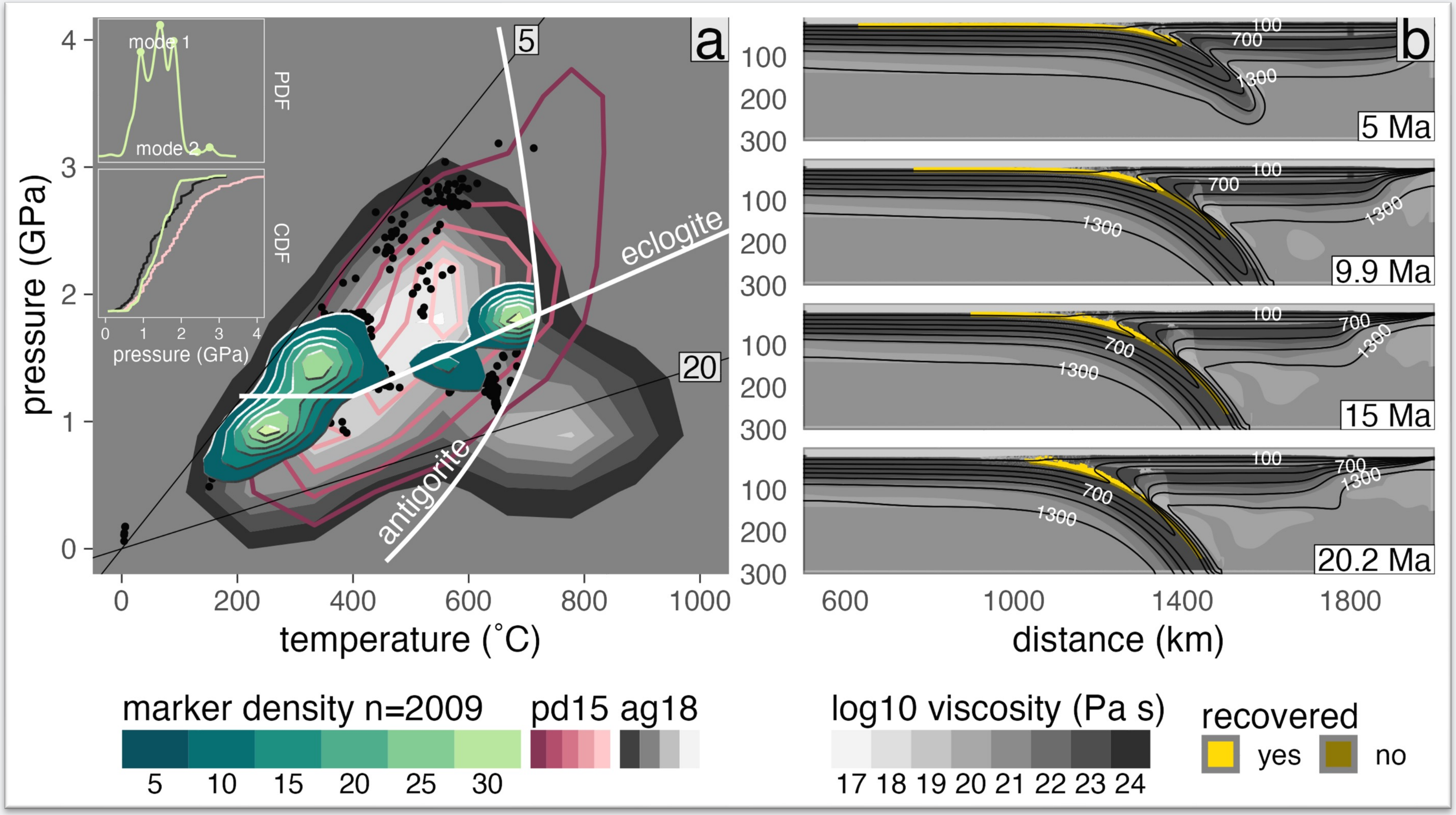
- *Apply Gaussian Mixture Modeling to clusters markers*
- *Apply rules to classify clusters as "recovered":*
    - Cluster > 3˚ C/km
    - Cluster < 120 km
    - Cluster < 1300 ˚C



Marker distribution

Kerswell et al. (in prep)

- Markers are recovered from discrete depths (3-4 pressure modes)
- Markers are not recovered from high density areas of natural samples



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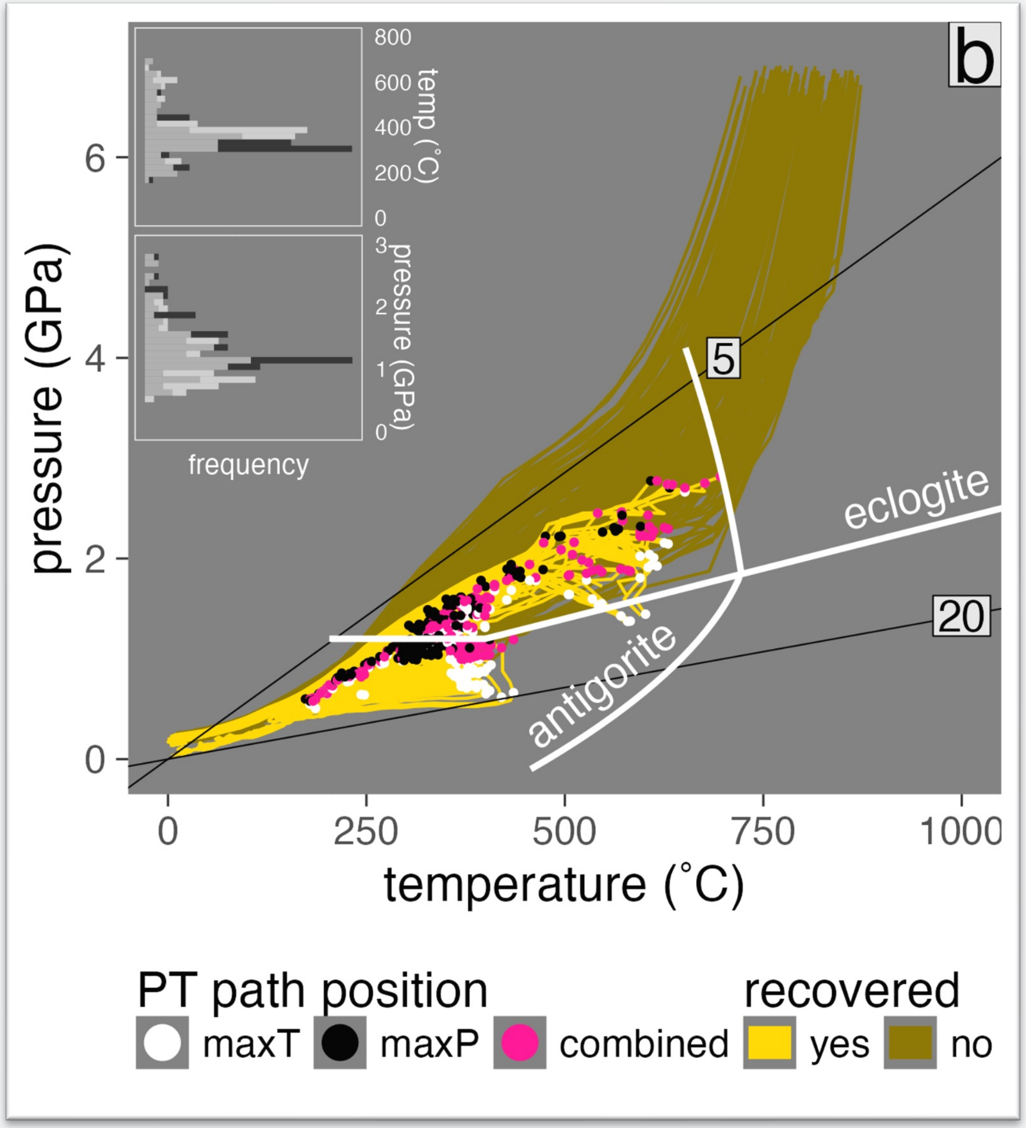
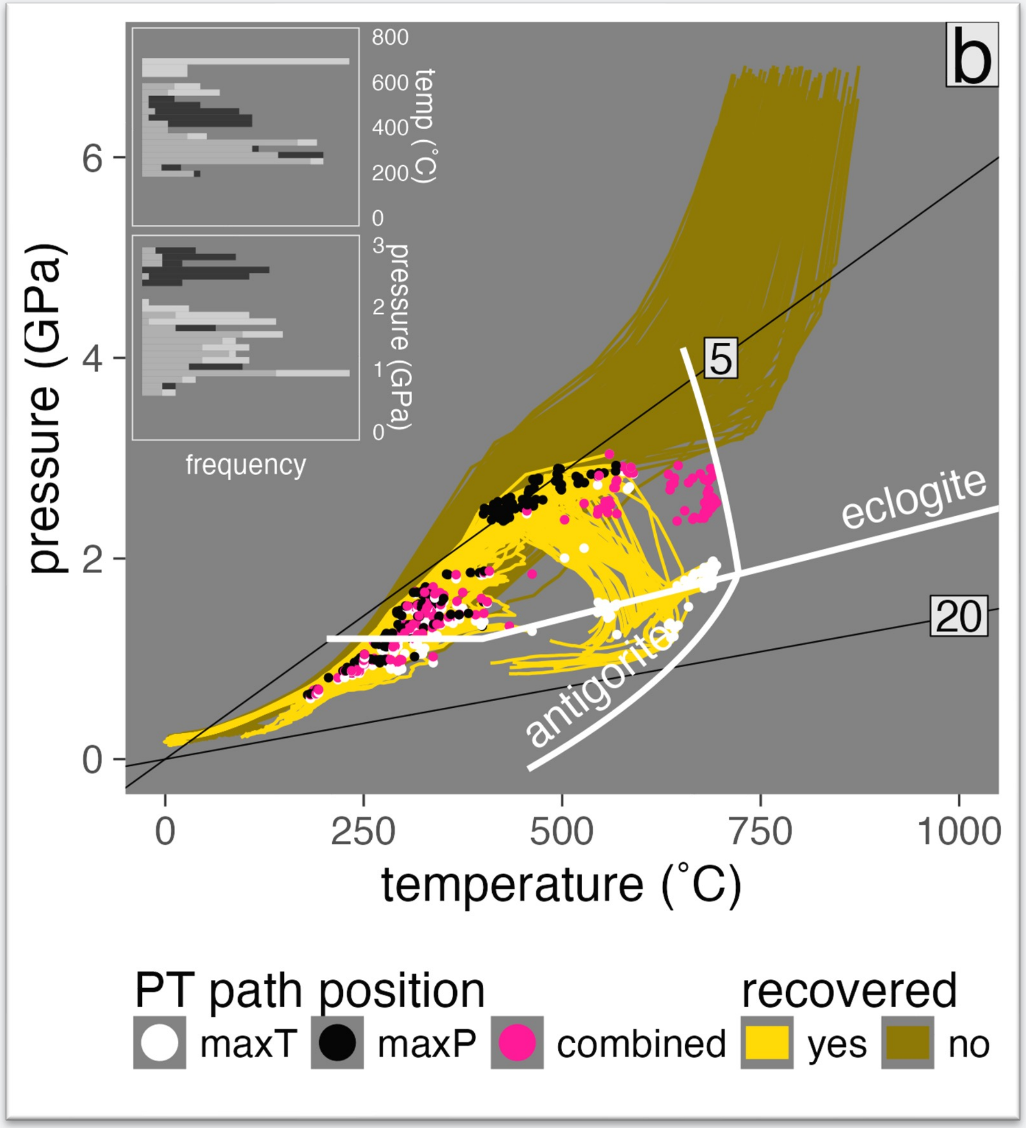


Thin upper plate lithosphere



Thick upper plate lithosphere

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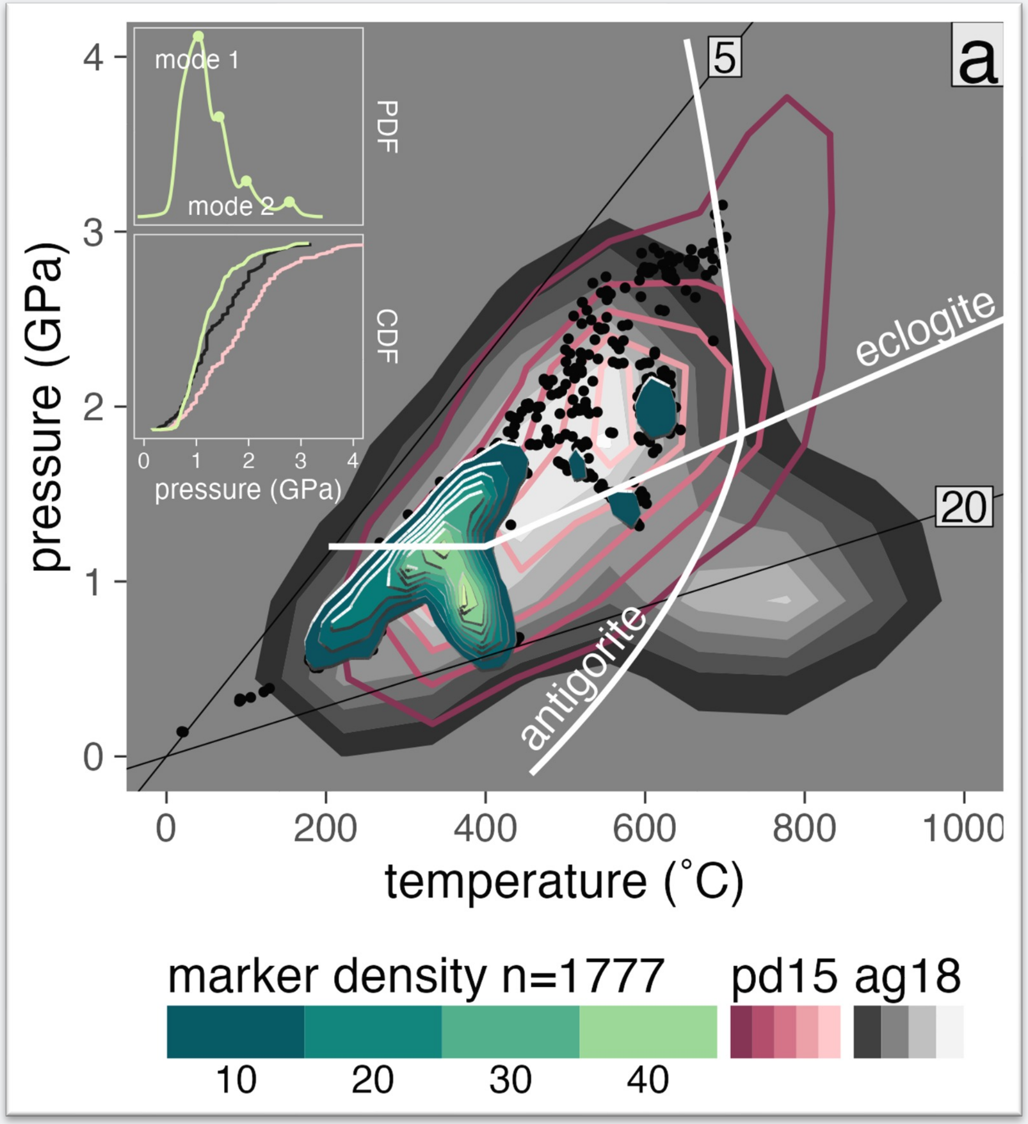
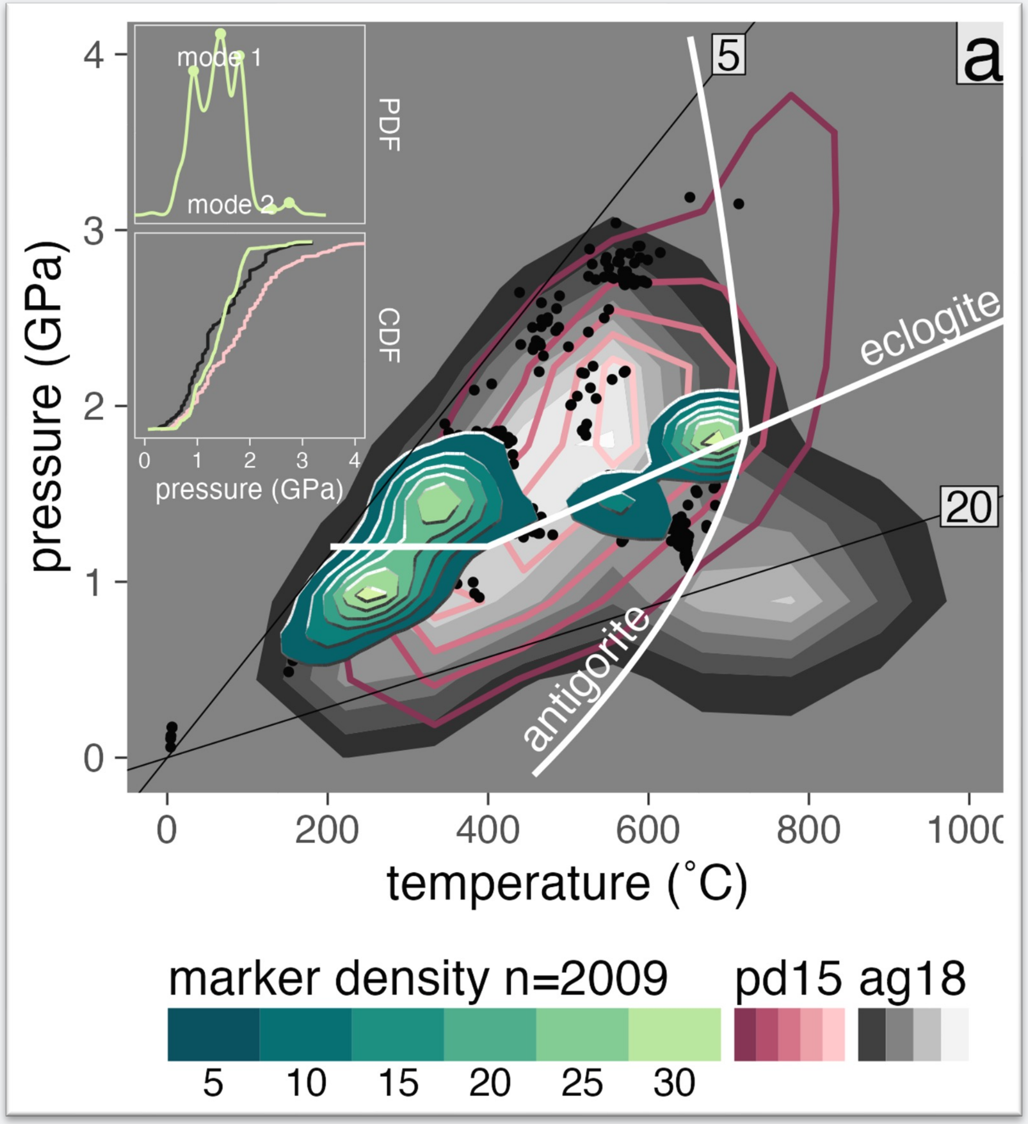


Thin upper plate lithosphere

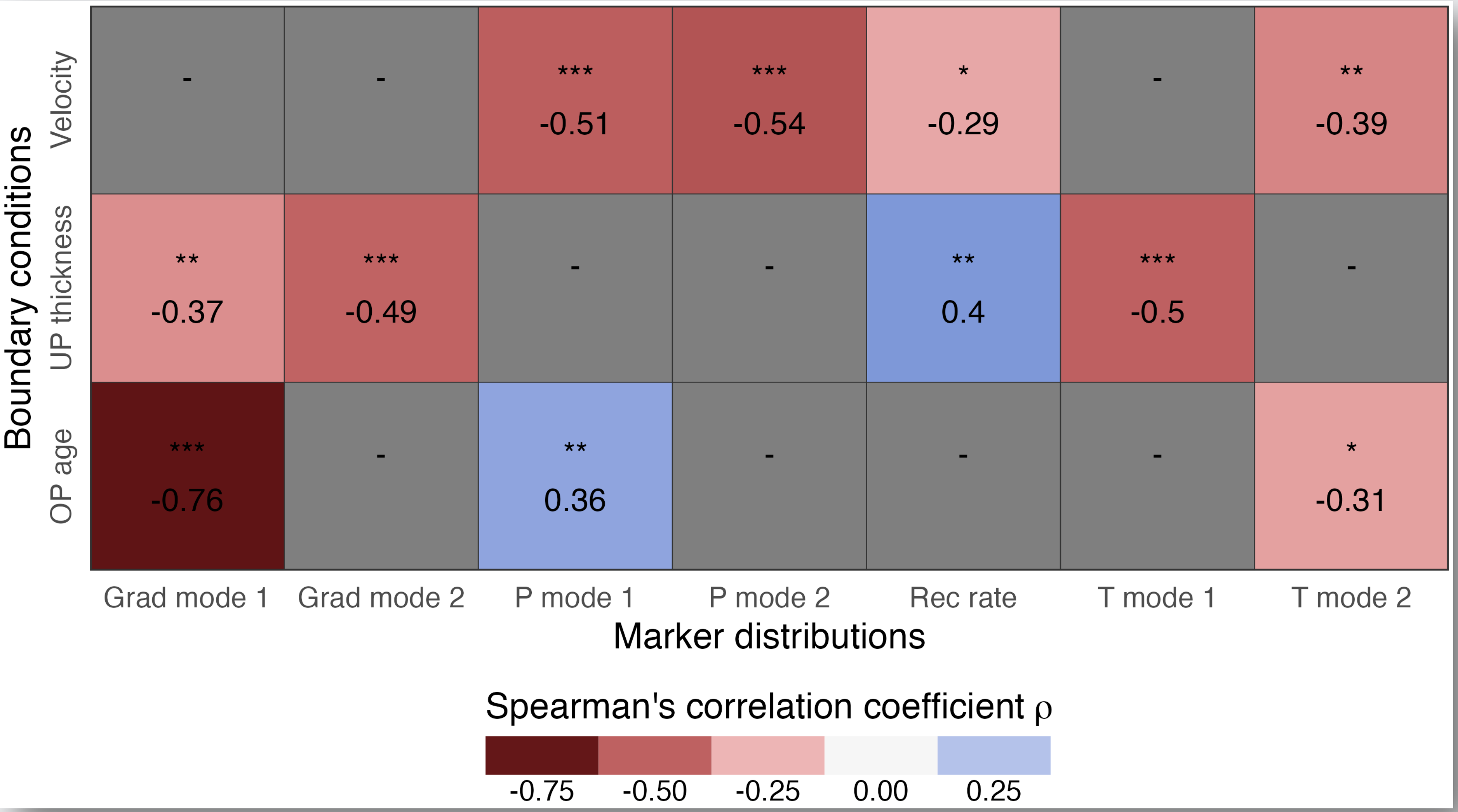


Thick upper plate lithosphere

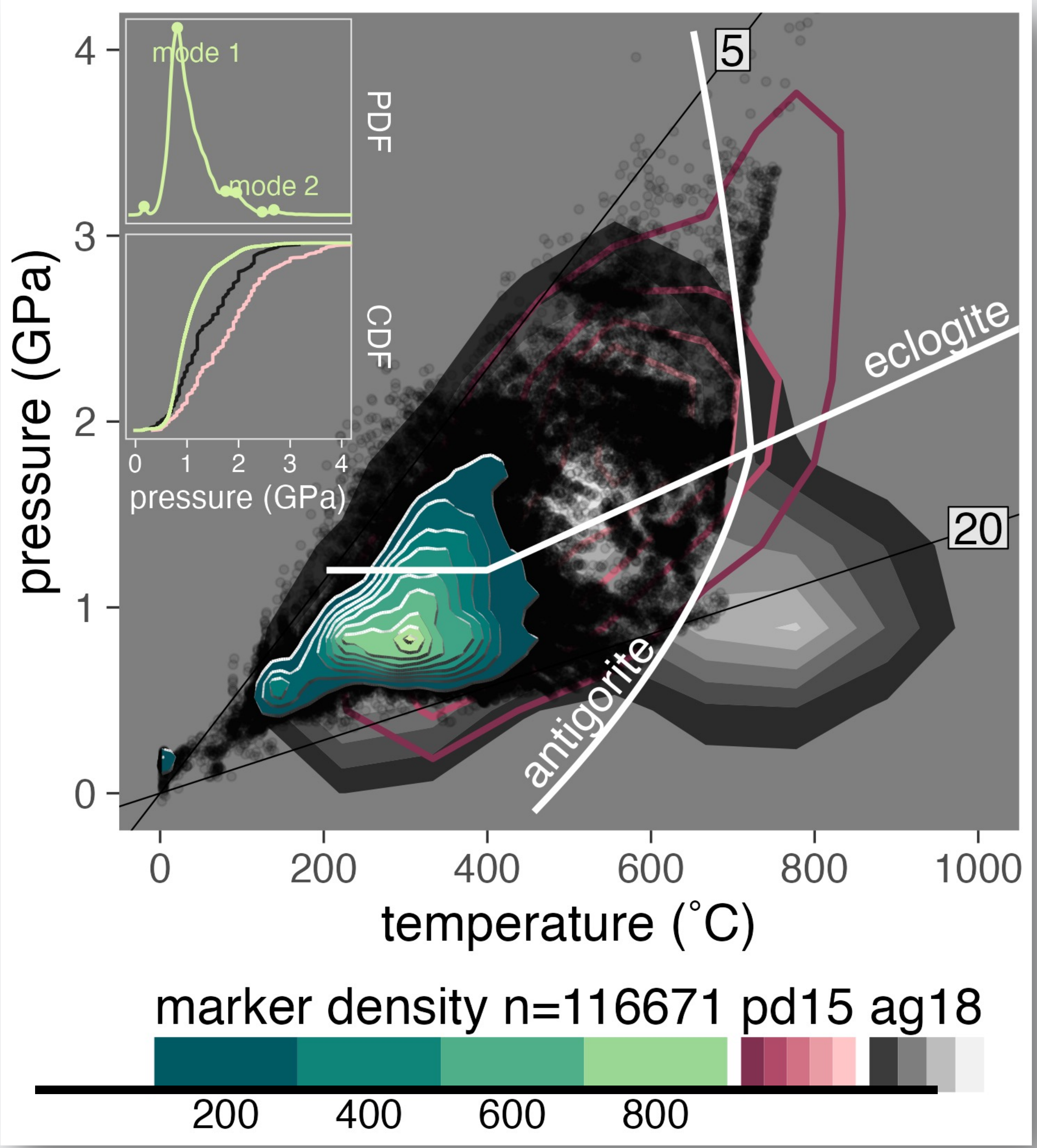
Correlations with boundary cond's

1. **Gradient**: OP age & UPT
2. **Depth**: OP age & velocity
3. **Temp**: UPT
4. **Recovery %**: UPT

- Marker recovery correlates strongly and weakly with initial conditions
- Recovery expected to vary among subduction zone settings



Kerswell et al. (in prep)



Global marker distributions

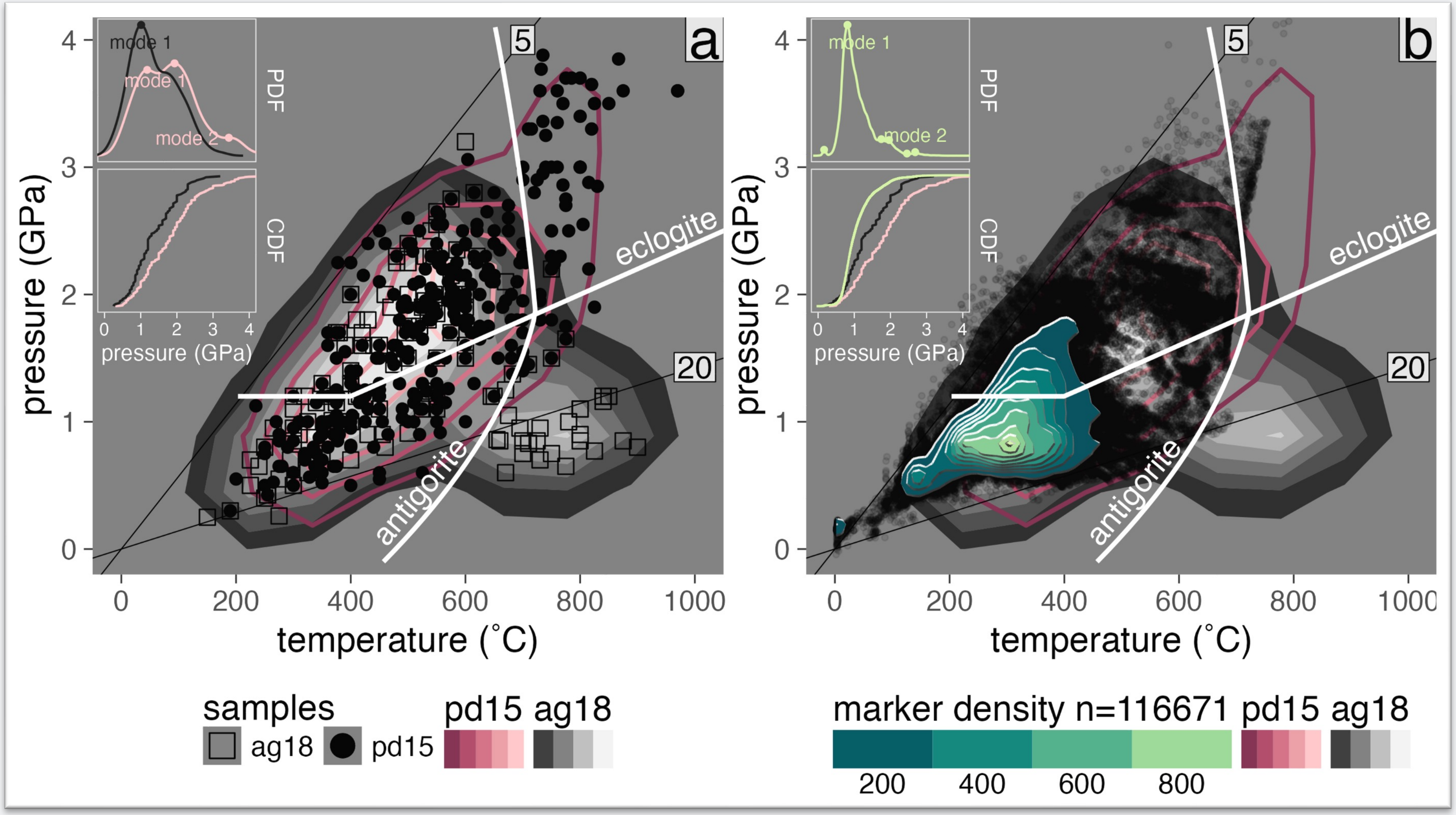
- Markers are recovered from discrete depths from individual subduction zones
- Most markers are globally recovered from near the Moho @ 1 Gpa (consistent with low-velocity layers)
- Very few markers recovered from beyond 2-2.3 Gpa (consistent with the onset of mechanical coupling)

Kerswell et al. (in prep)

Comparing datasets

Kerswell et al. (in prep)

Few markers are recovered from the highest density region of natural samples (why?)



Conclusions

Marker recovery modes correspond with mechanical transitions

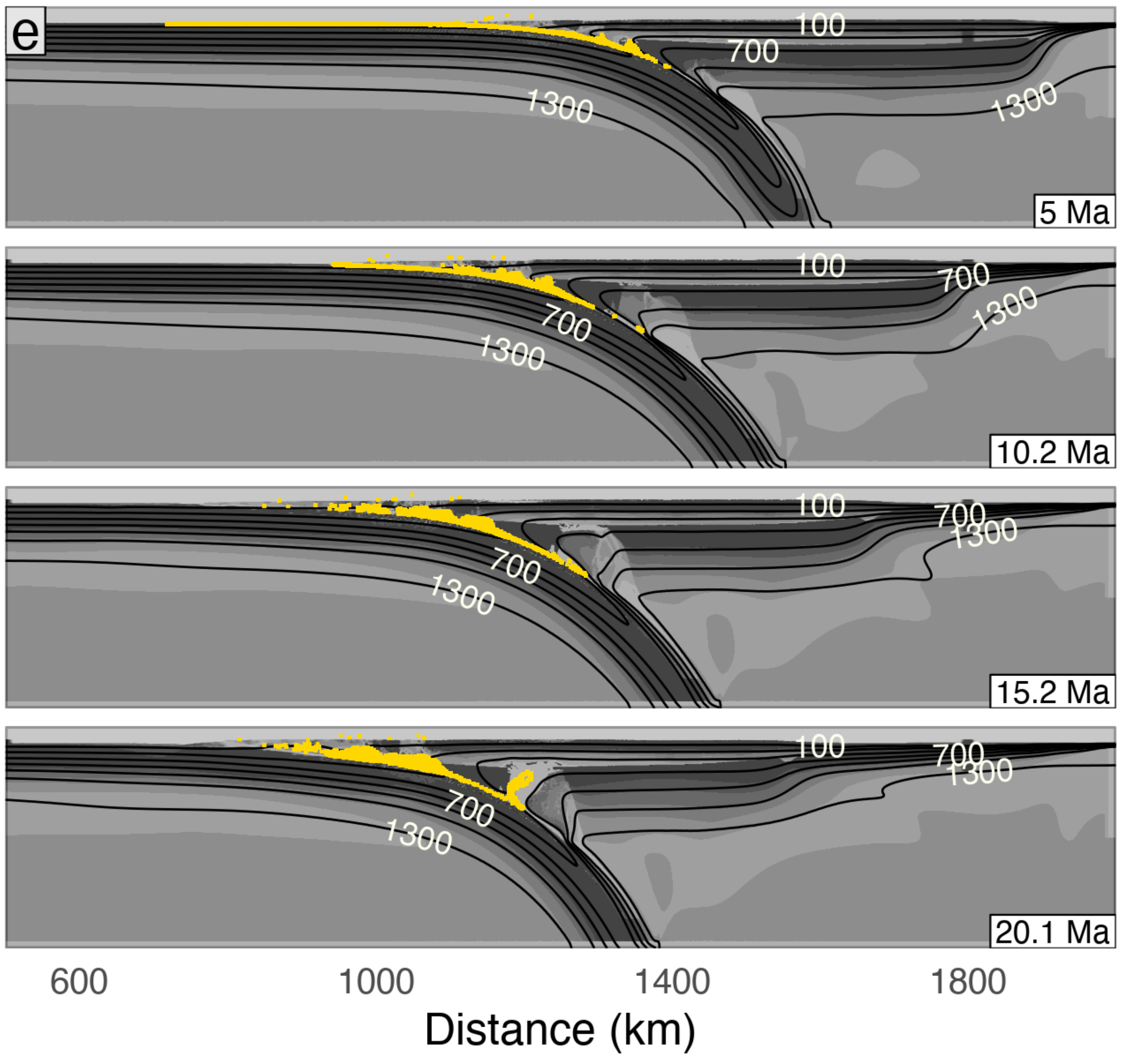
- Underplating/mélange at 1 GPa
- Minor recovery near viscous coupling depth at ~2.3 Gpa

Markers show appreciable deviations from the rock record

- Increasing average T does not fill in the marker recovery gap
- Recovery rates are not correlated with OP age or velocity
- Recovery rates are poor for thin UP lithospheres

Less than 1% of markers detach from 1.8-2.2 GPa and 500-625 ˚C

- Poor implementation of detachment mechanisms (modeling bias)
- Rock PTs are systematically misinterpreted (petrologic bias)
- Rocks are (re)sampled from the same conditions (scientific bias)
- Rocks are recovered early and/or during short-lived events (tectonic bias)



Questions?

Thanks for the attention