Temporal evolution of fluid-driven processes along convergent margins:

Insights from petrologic and time dependent thermal models

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Cascadia & beyond!

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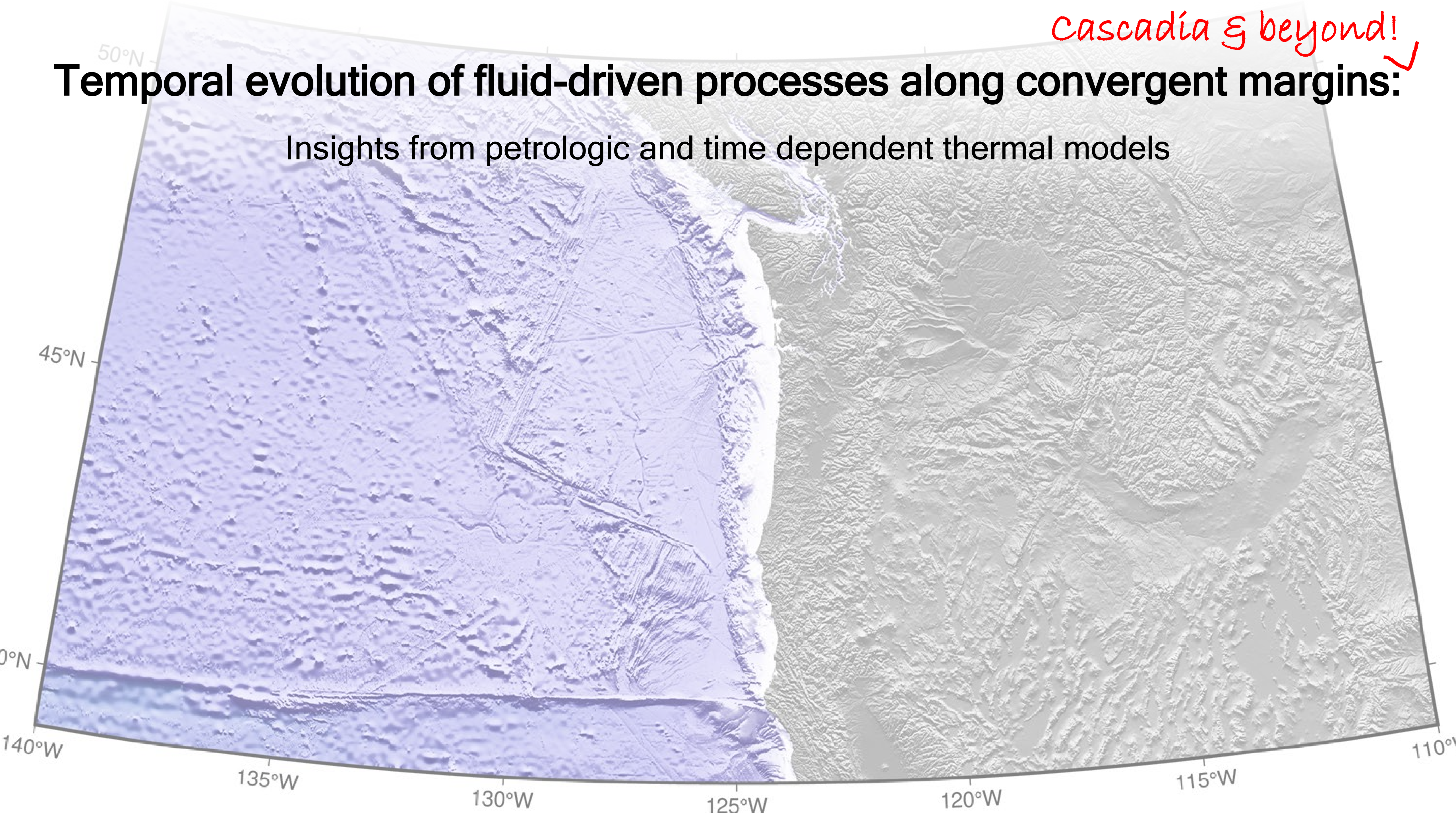
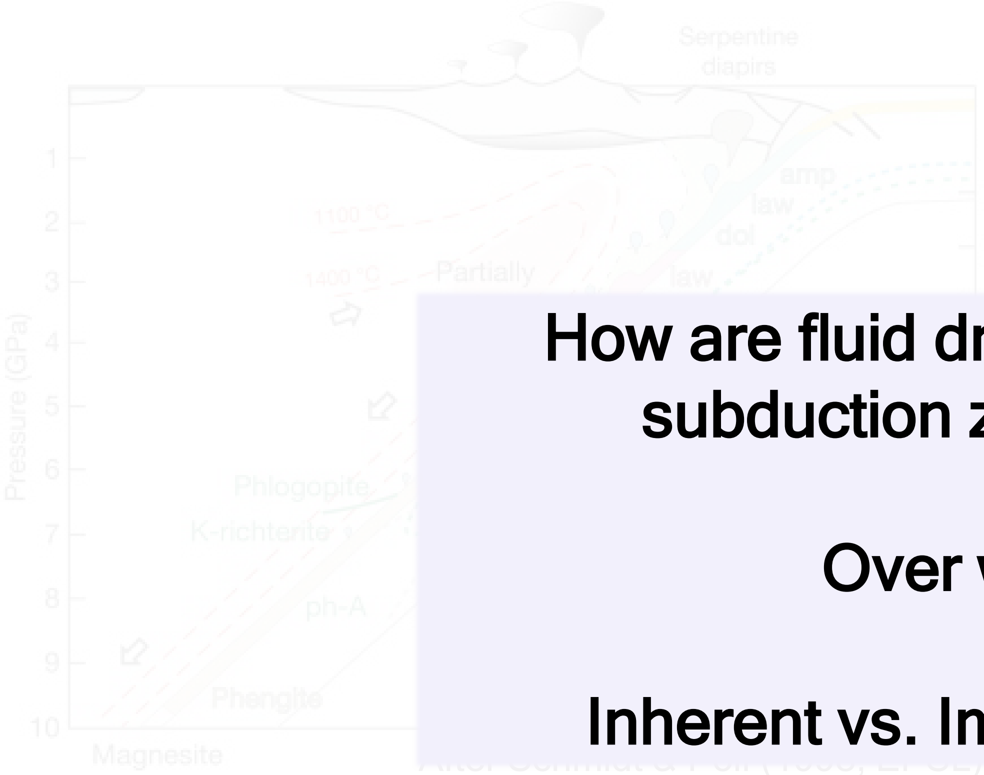
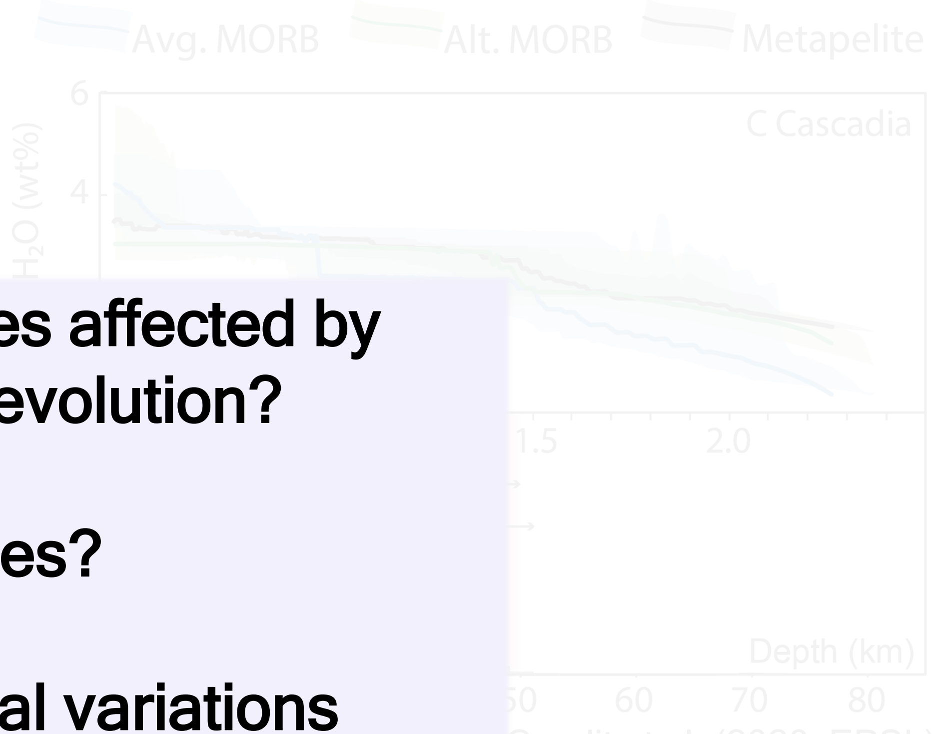
Insights from petrologic and time dependent thermal models



Fluids & Subduction





Condit et al. (2020, EPSL)

How are fluid driven processes affected by subduction zone thermal evolution?

Over what timescales?

Inherent vs. Imposed thermal variations

Mantle Hydration vs. Magmatism
e.g. Wedge Serpentinization vs. Arc Volcanism

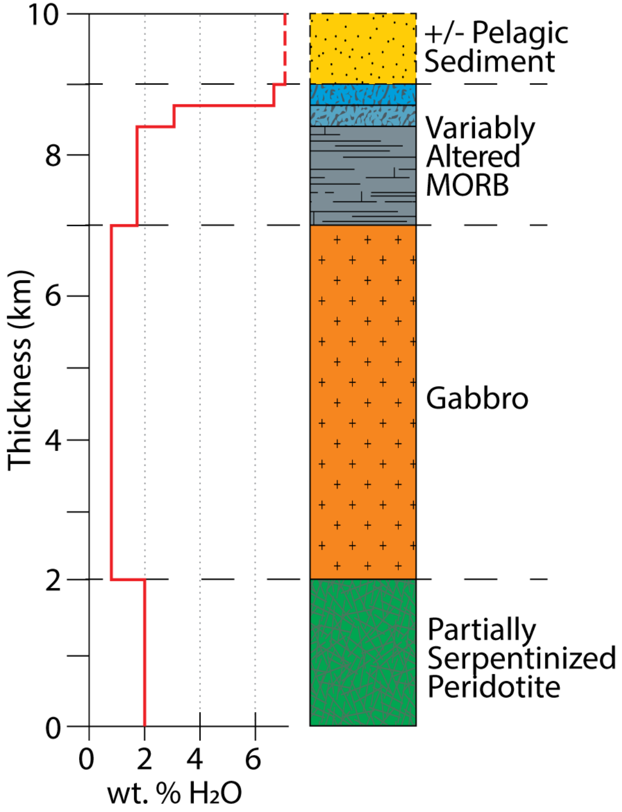
Seismicity
e.g. ETS

Slab Dehydration Parameterization

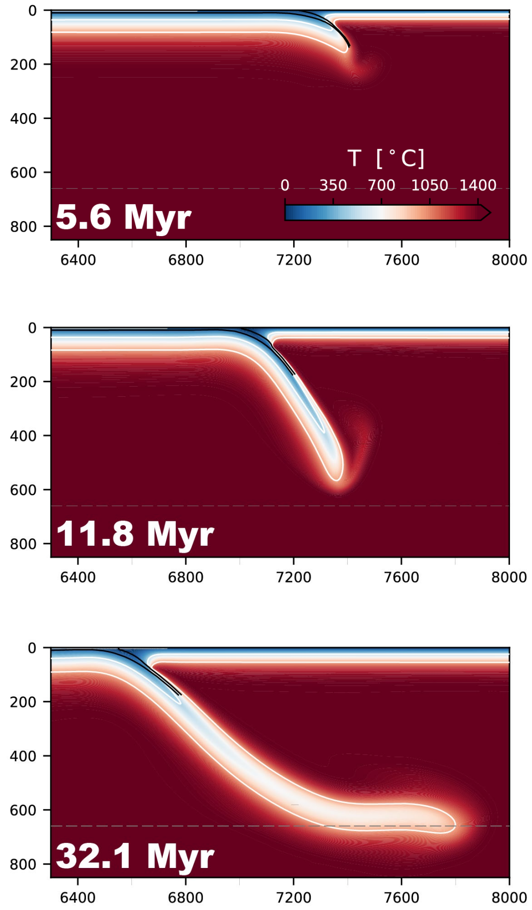
$$f(\; H_2O_{in}, \quad P-T, \quad \Delta G, \quad k \;)$$

Kinetics!?!

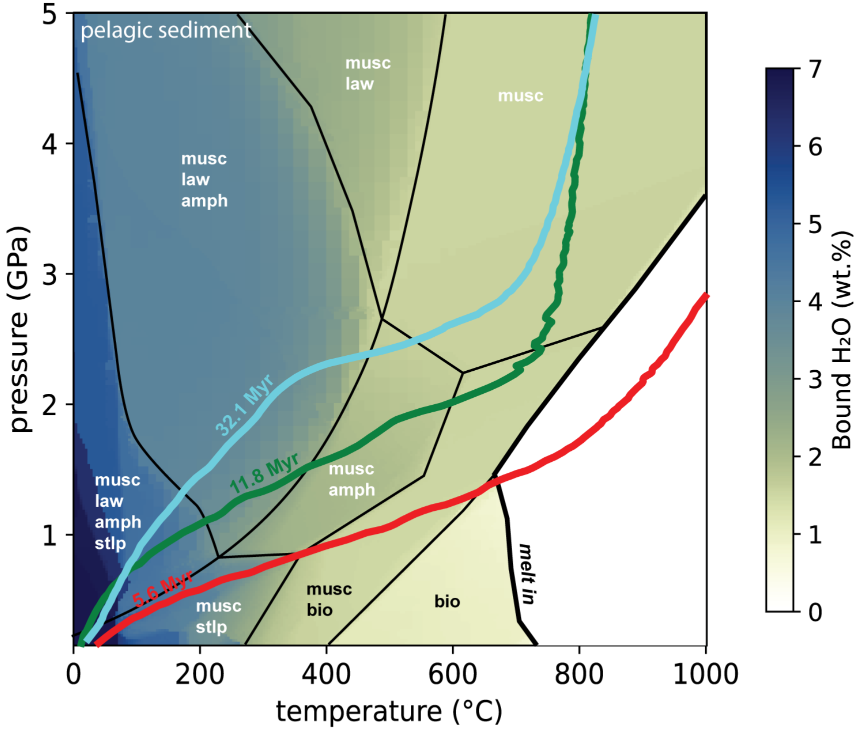
Lithostratigraphy
Bound Water
Plate Velocity



Thermal Model



Thermodynamics

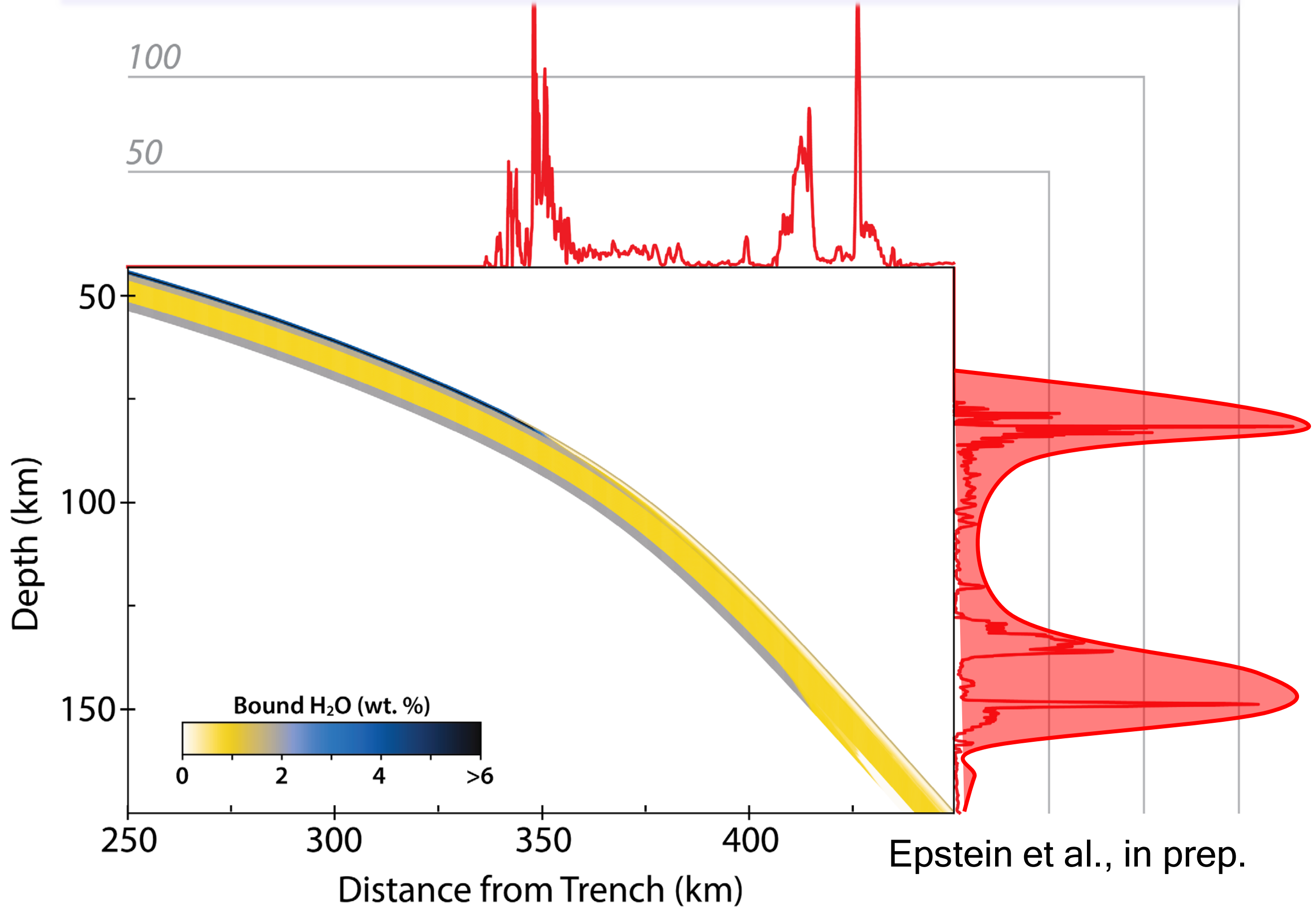


Epstein et al. (2024); Holt & Condit (2021)

Time Invariant Example

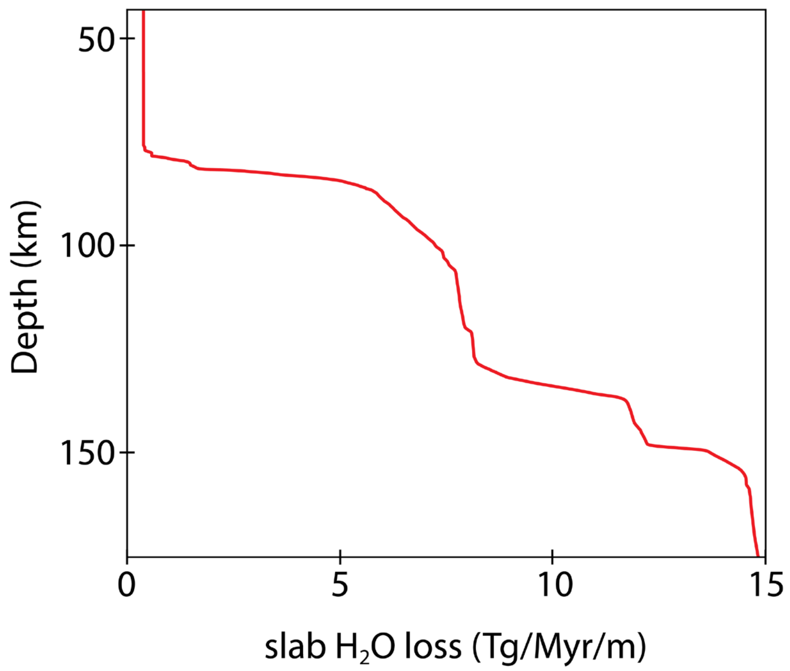
Slab geometry & convergence rate are fixed

Model run until steady state thermal structure is obtained

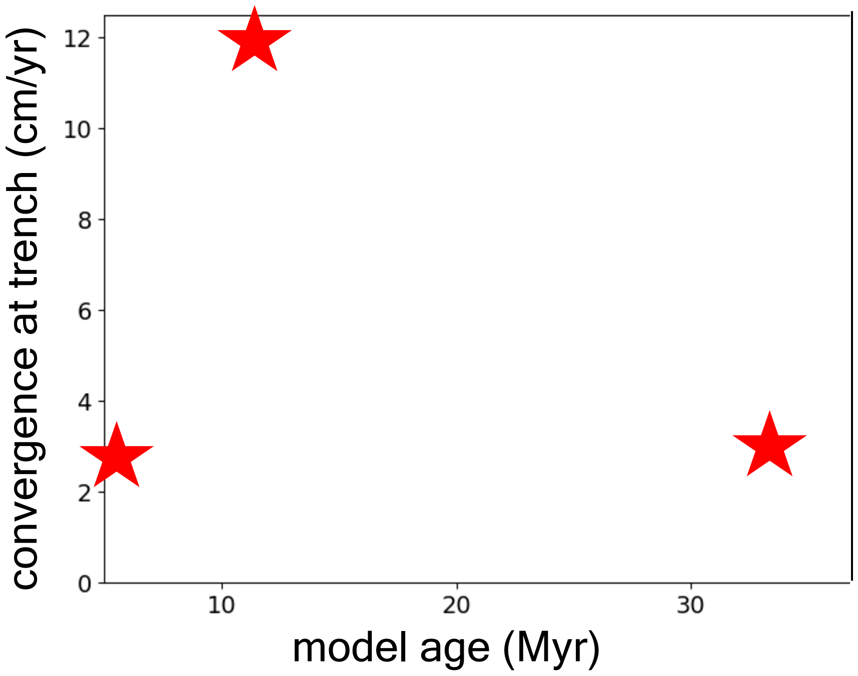


Epstein et al., in prep.

Cumulative fluid loss from slab



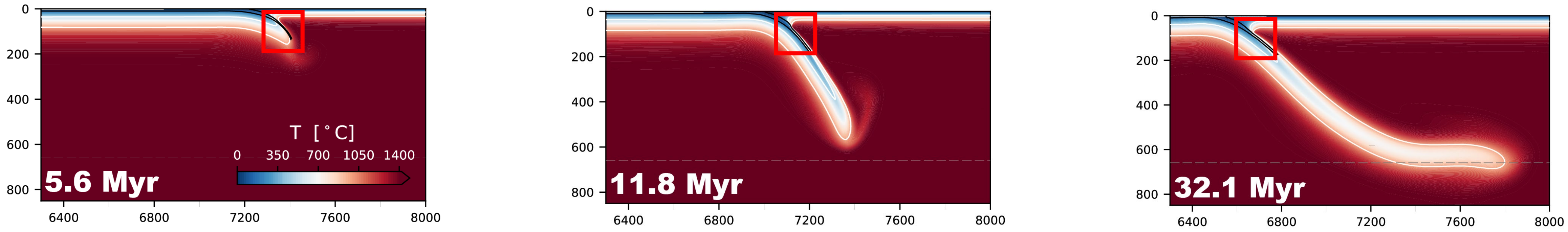
Dynamic Example



Spontaneous, buoyancy driven subduction model (Holt & Condit, 2021), using ASPECT*

Half space cooled slab & upper plate: **90 Myr** subducted beneath **10 Myr**

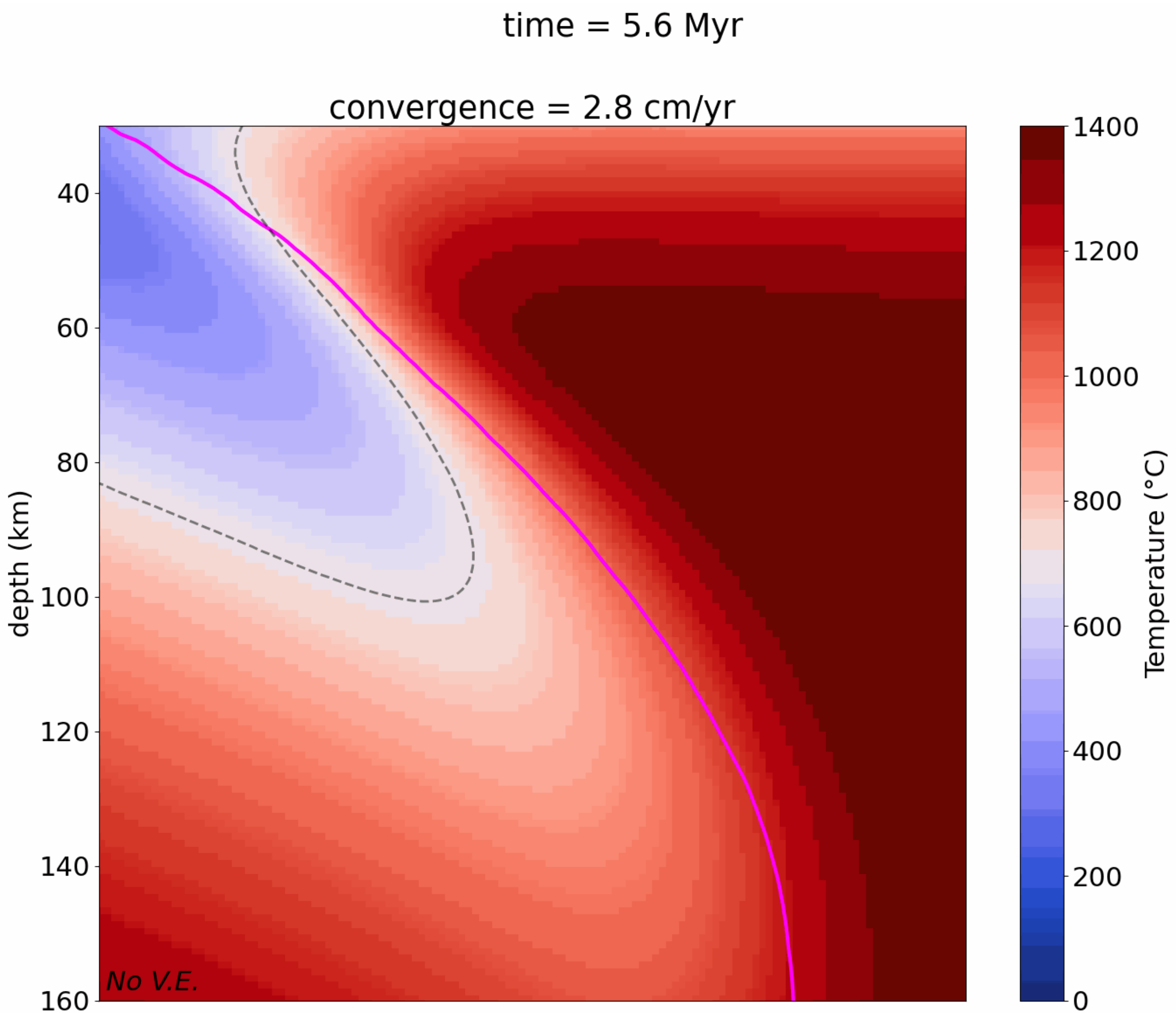
Temporal variation in slab dip, convergence rate, & thermal state



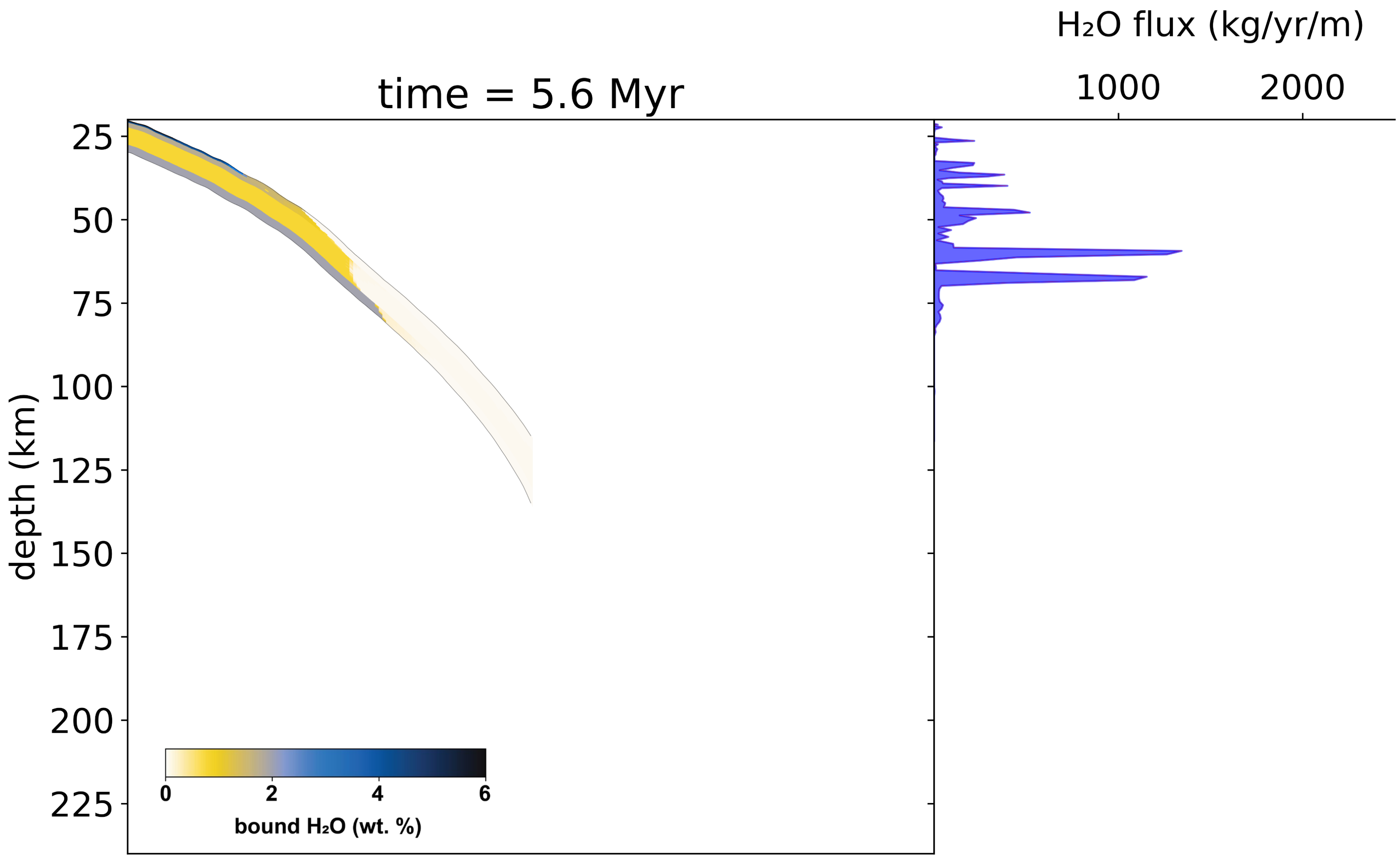
Holt & Condit (2021)

*Bangerth et al. (2023)

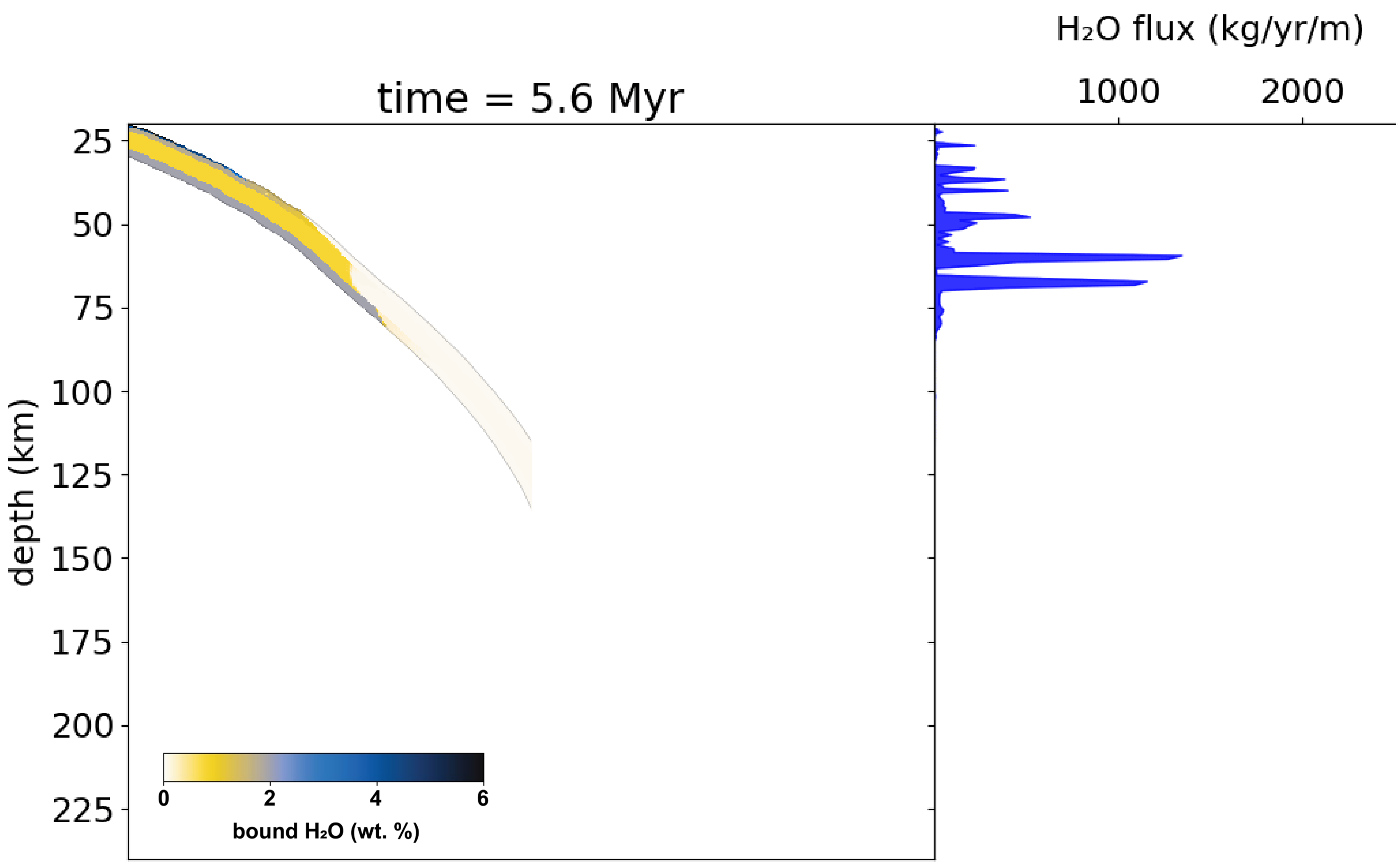
Inherent Thermal Evolution



Changing Dehydration Structure



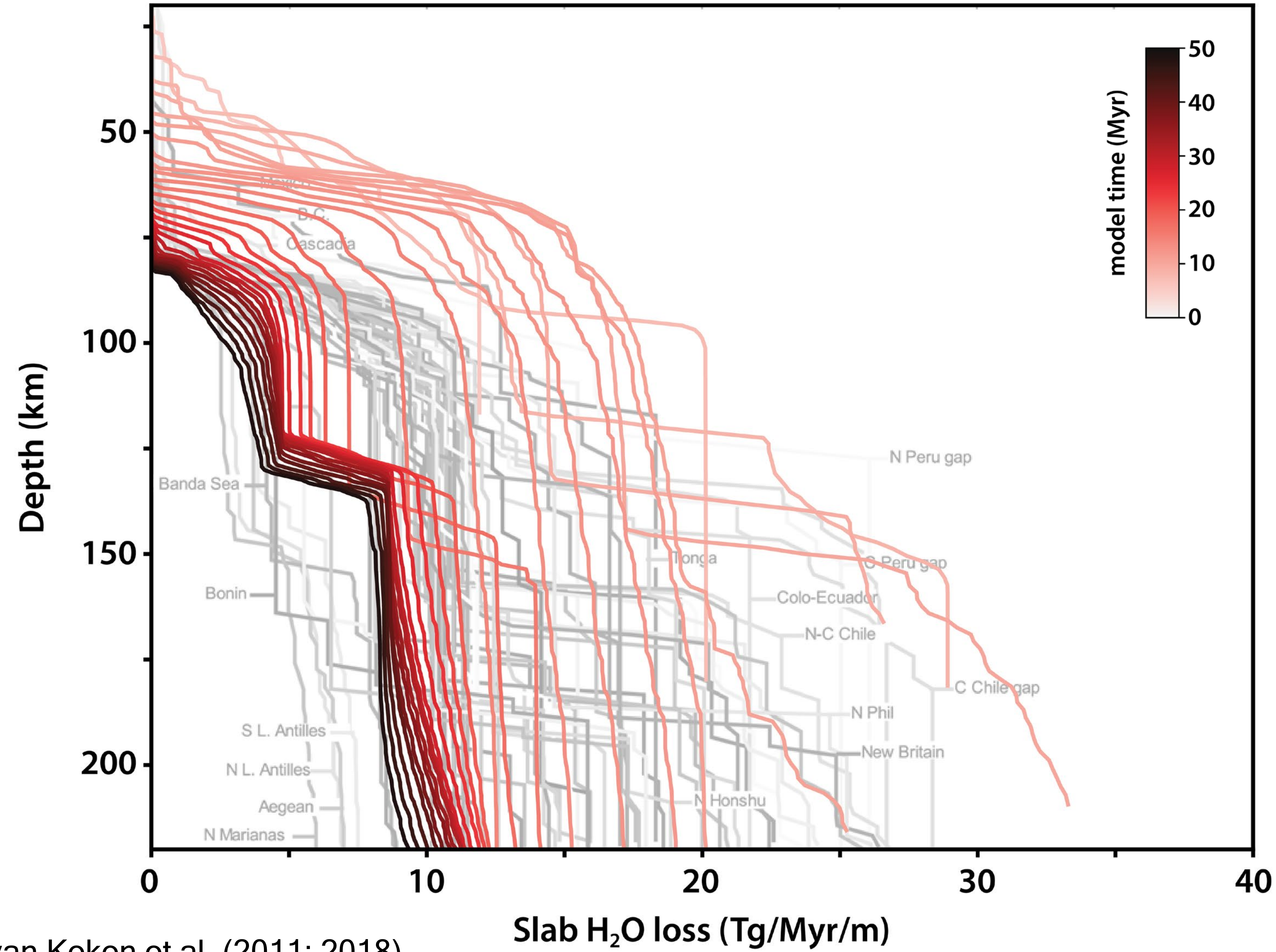
Changing Dehydration Structure



Early:
Shallow (forearc) dehydration

Mature:
Deeper (subarc) dehydration

Kinematic – Dynamic model comparison

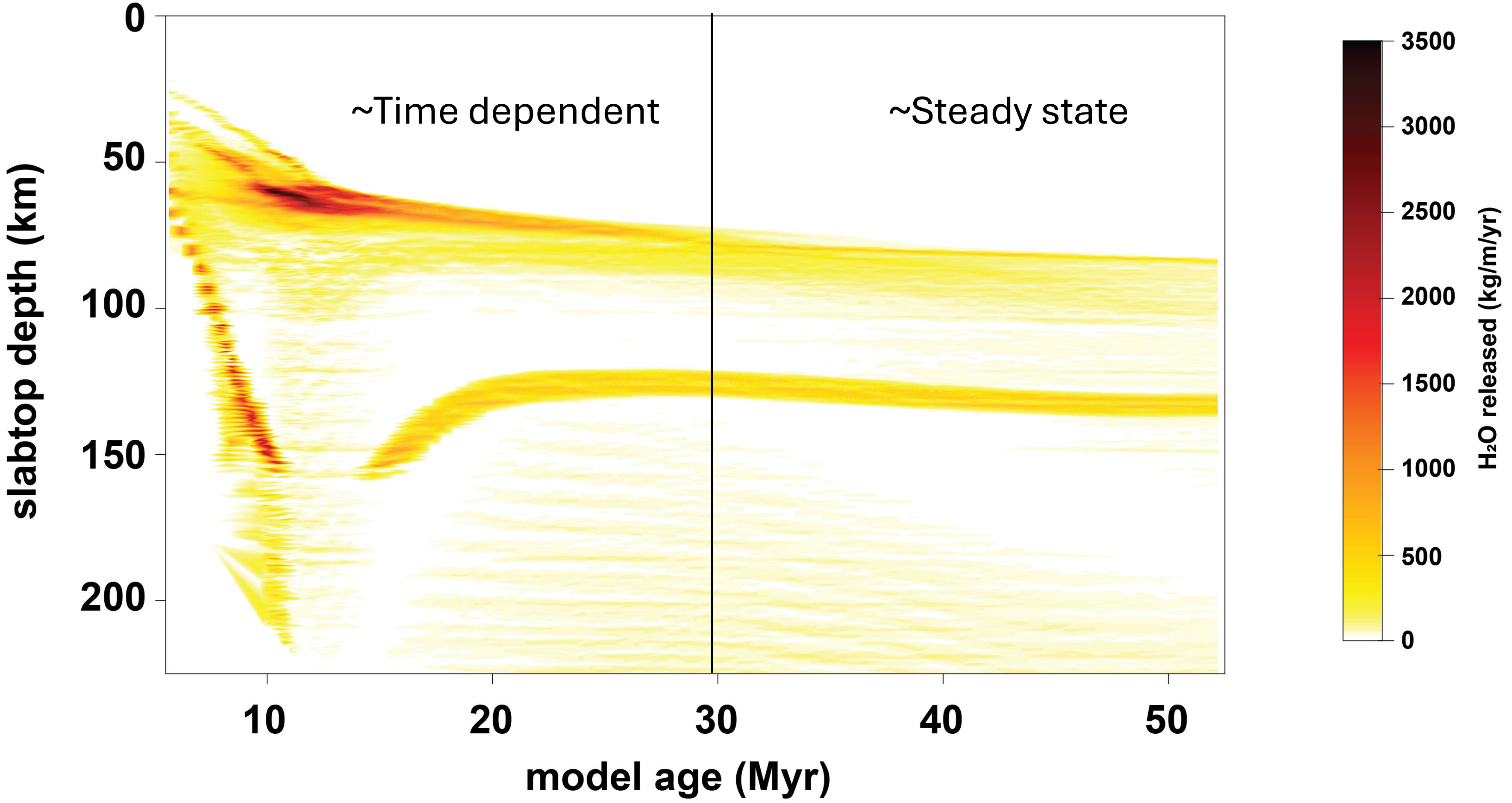


Thermal evolution within a single model overlaps the global range of modern day dehydration patterns

van Keken et al. (2011; 2018)

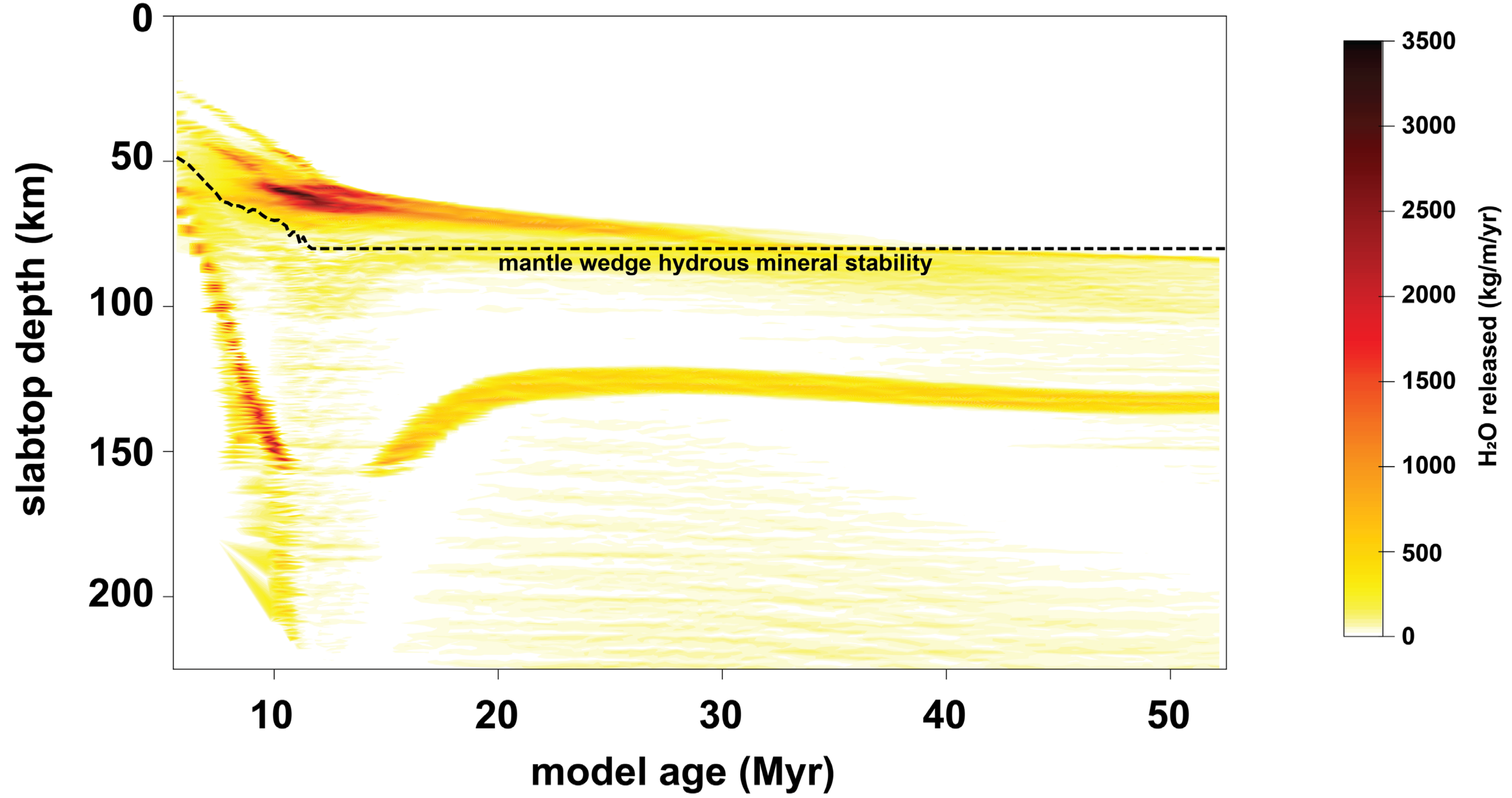
Dehydration Timeseries

Thermal evolution leads to dramatic variations in dehydration



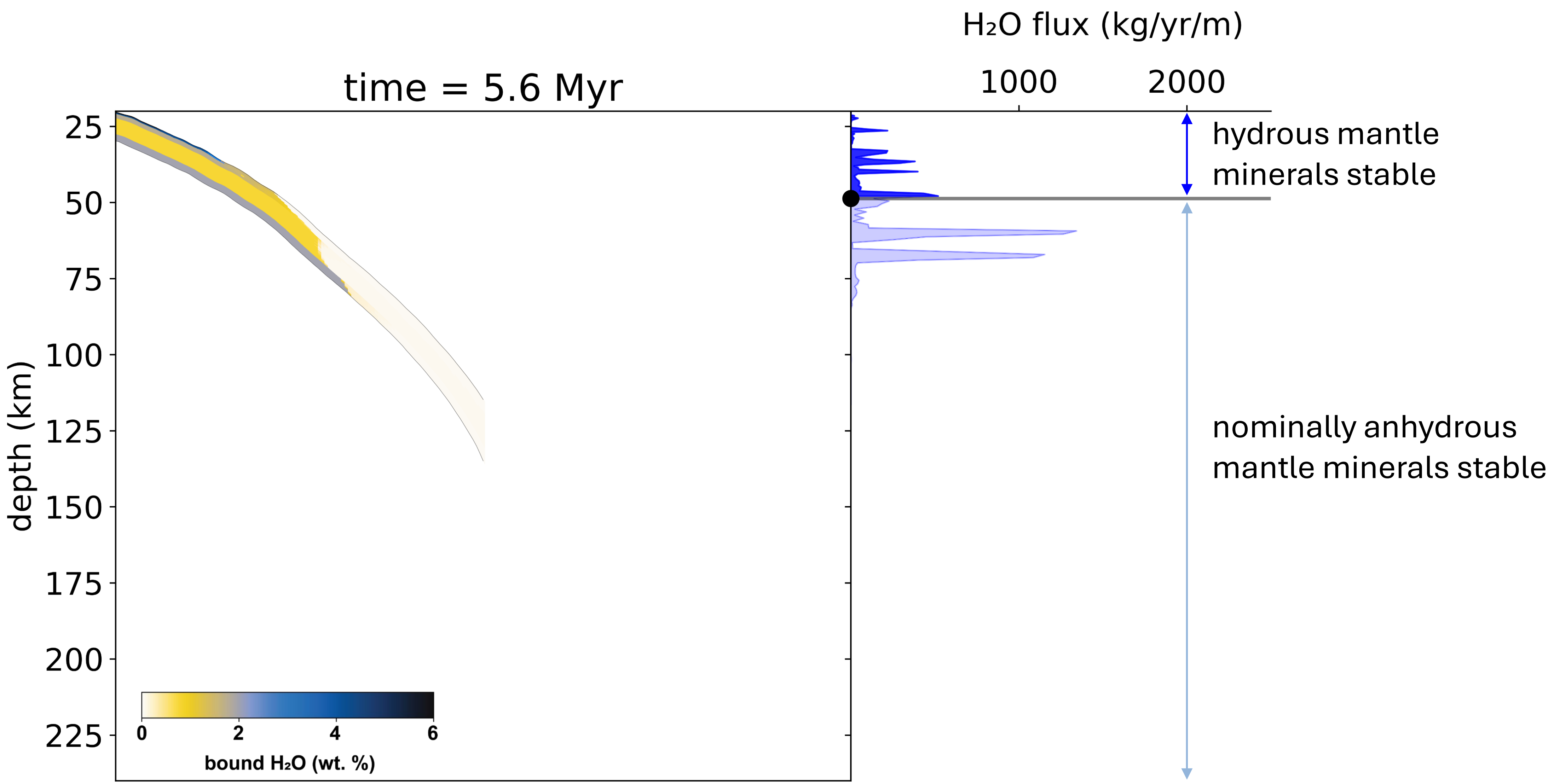
Epstein et al. (2024; AGU Advances)

Implications for Dynamic Processes



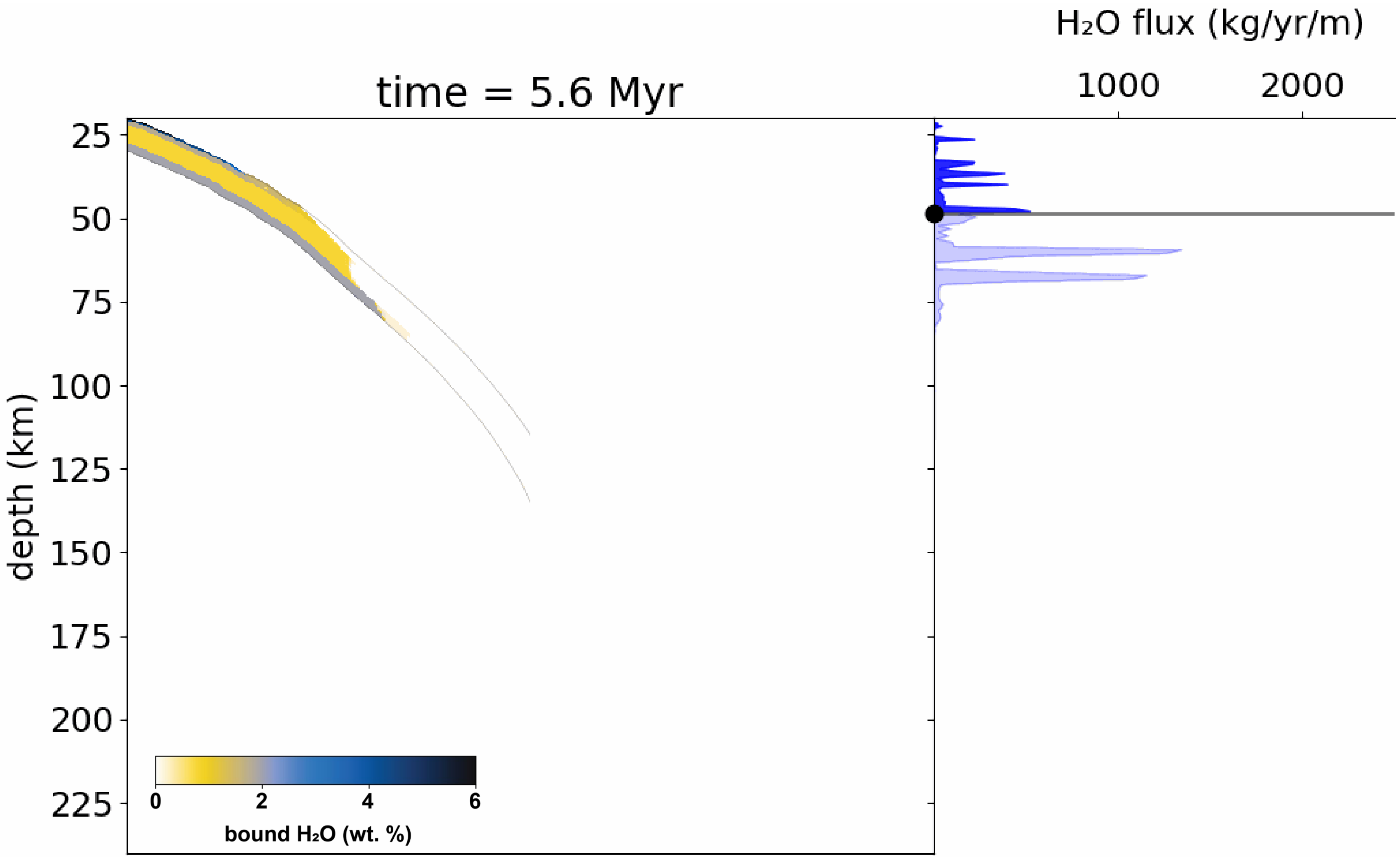
Epstein et al. (2024; AGU Advances)

Forearc Mantle Wedge Hydration



No vertical exaggeration

Forearc Mantle Wedge Hydration



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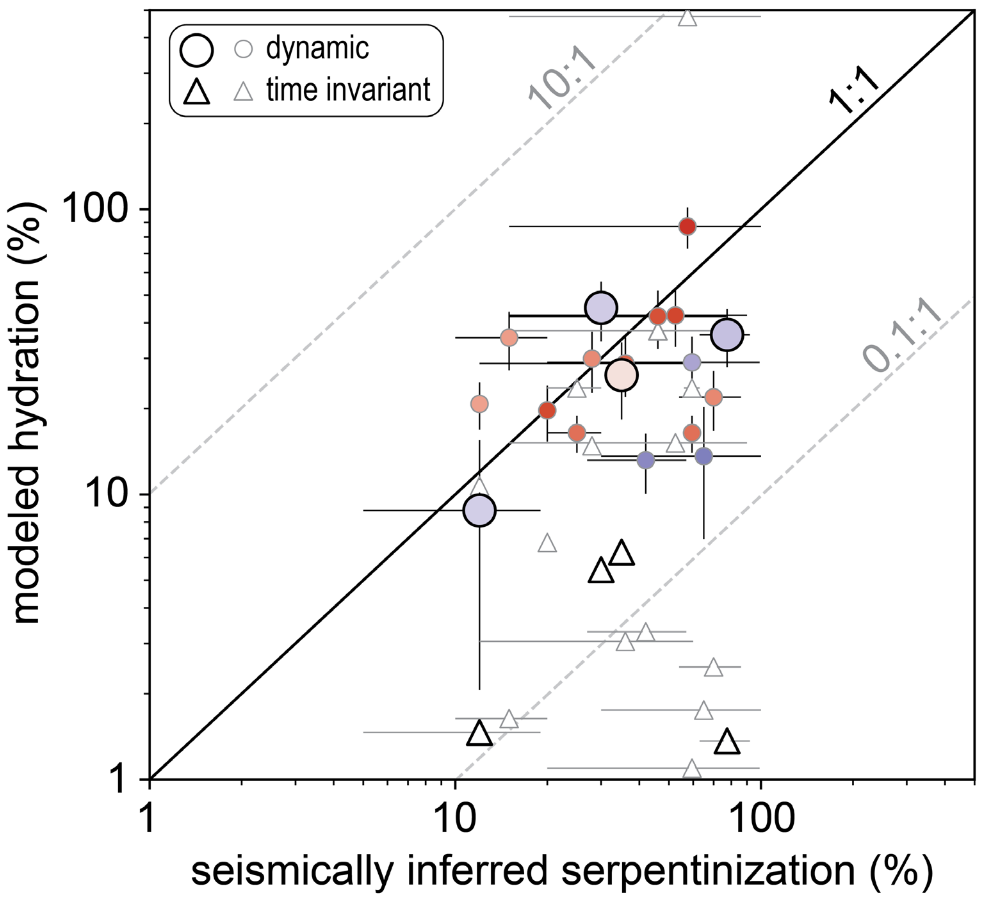
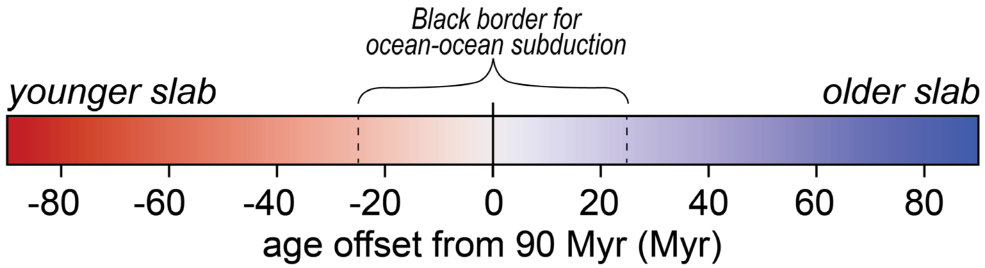
Forearc Mantle Wedge Hydration





Time invariant thermal models underpredict forearc hydration

Dehydration during thermal evolution may account for discrepancies between models and observation

Time invariant data: Abers et al., 2017; Dynamic data: Epstein et al., 2024
Sediment thickness & Composition: van Keken et al., 2011;
Inferred subduction zone ages: Schellart, 2010

Imposed Thermal Variations

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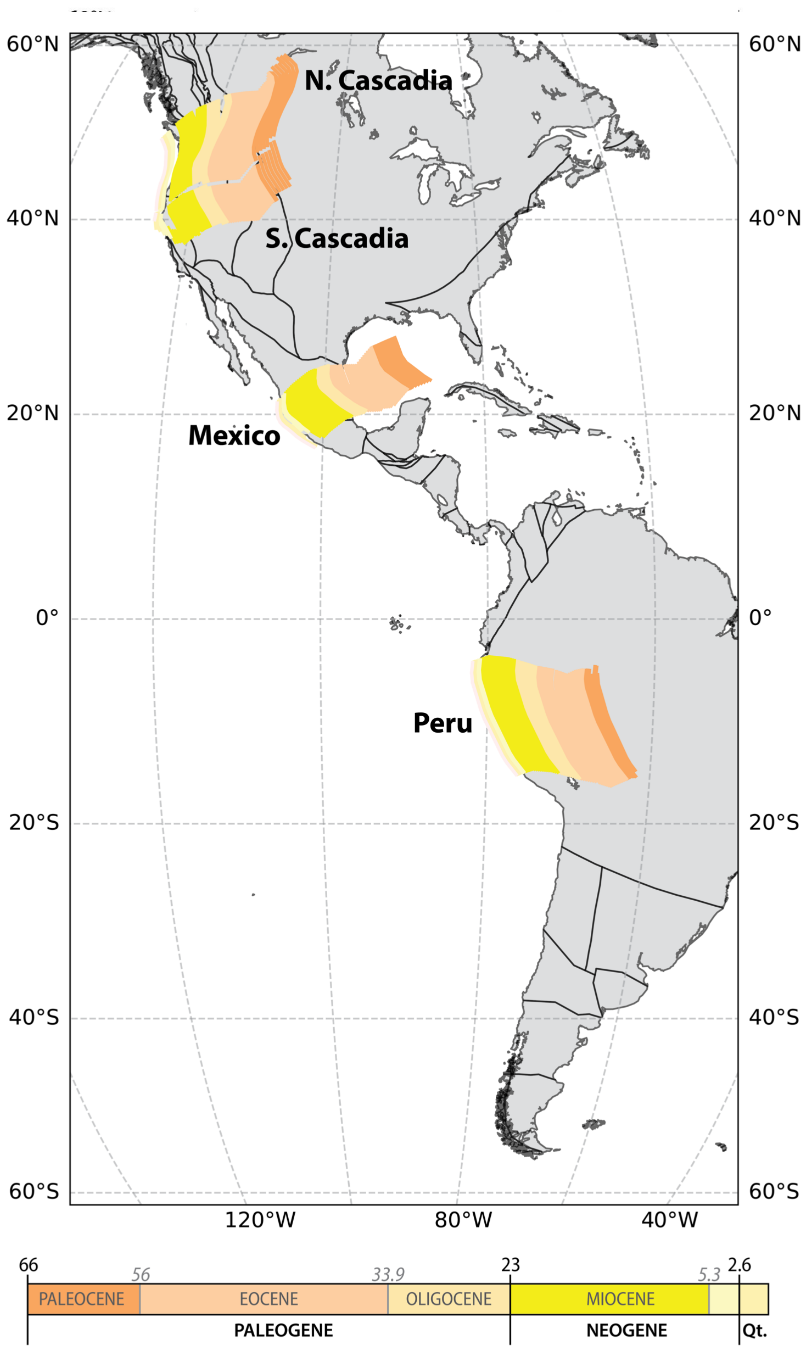
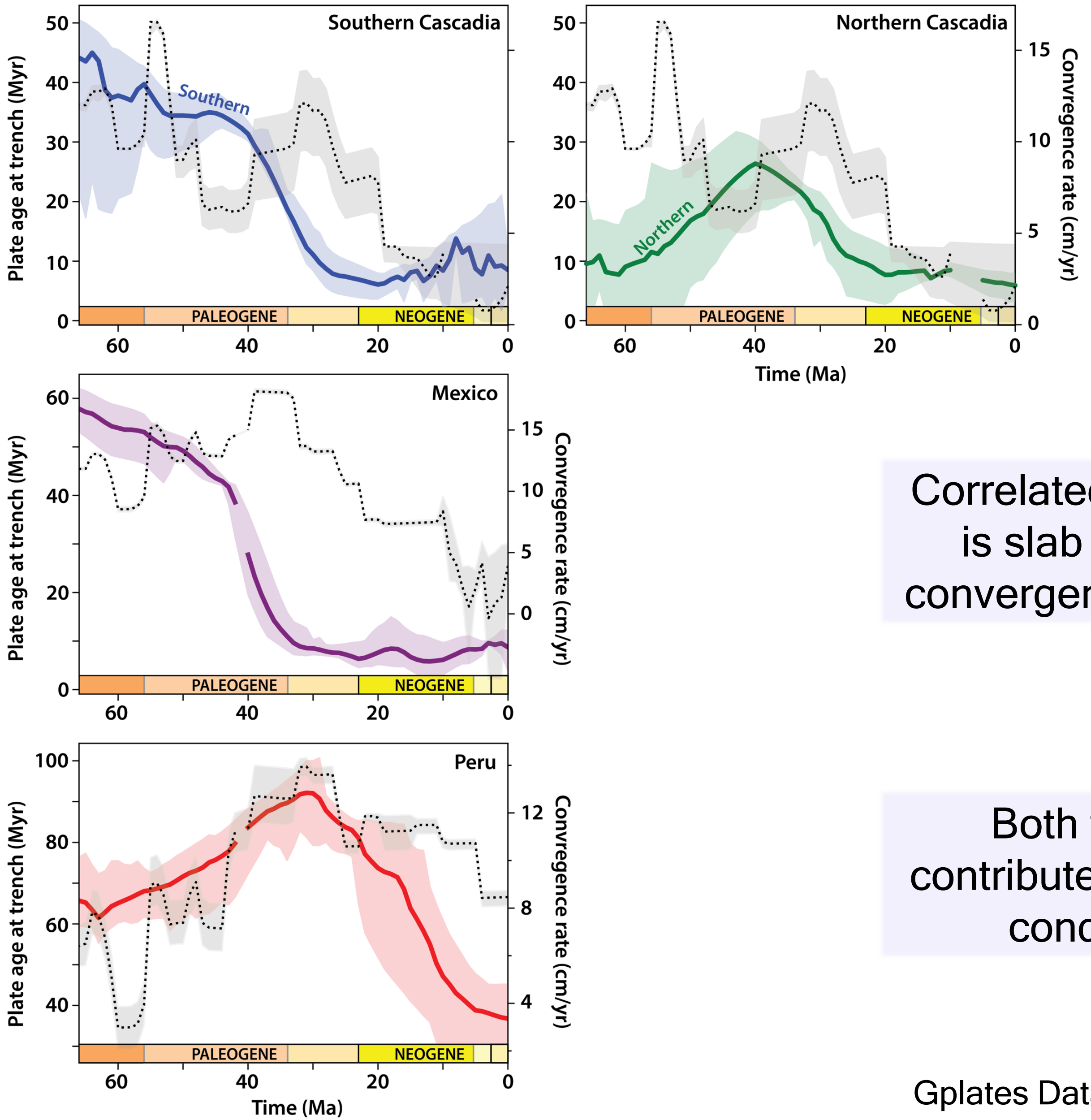




Correlated decrease is slab age and convergence velocity

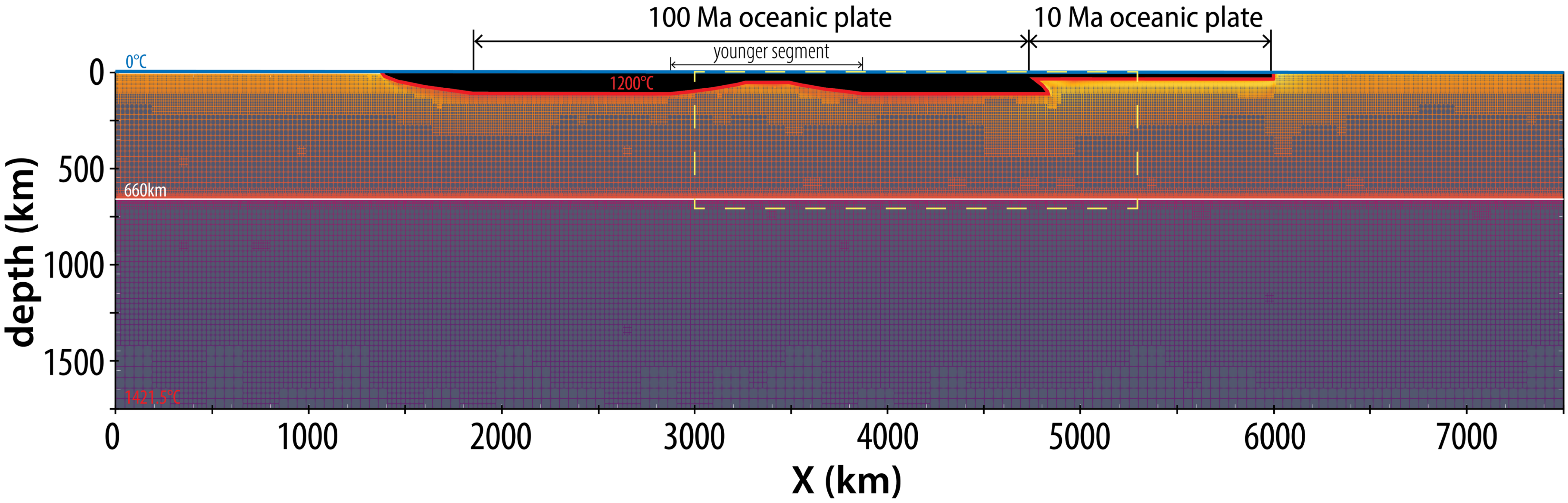
Both factors contribute to warmer conditions

Epstein et al., in prep.

Gplates Data: Muller et al. (2016; 2019)

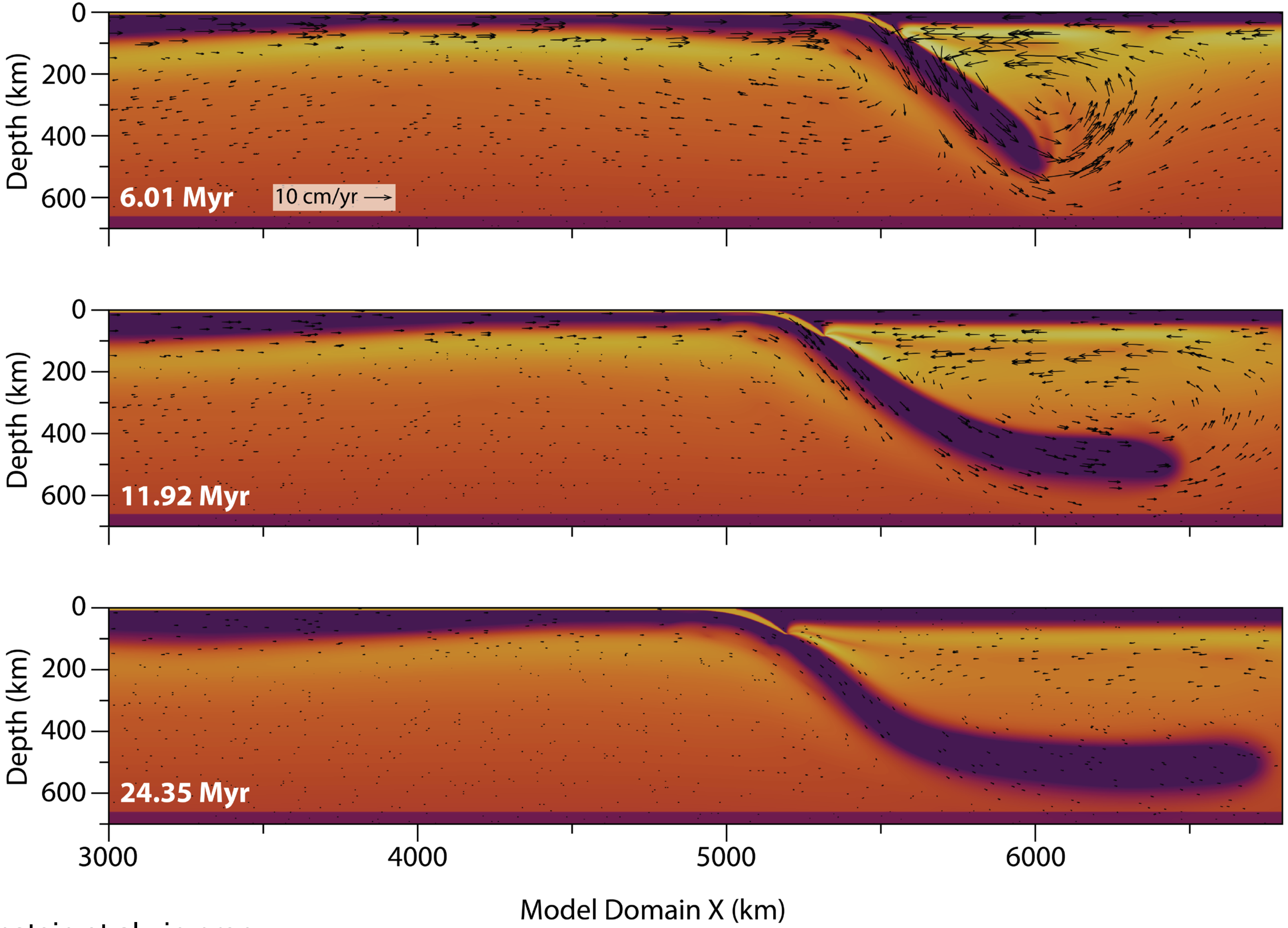
Imposed Plate Younging

Dynamic model with imposed initial plate age variation

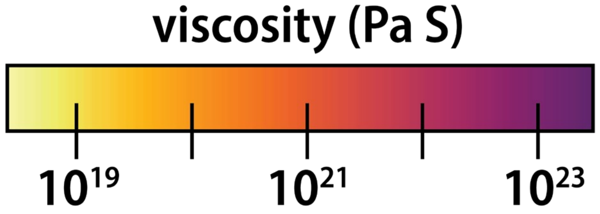


Epstein et al., in prep.

Imposed Plate Younging

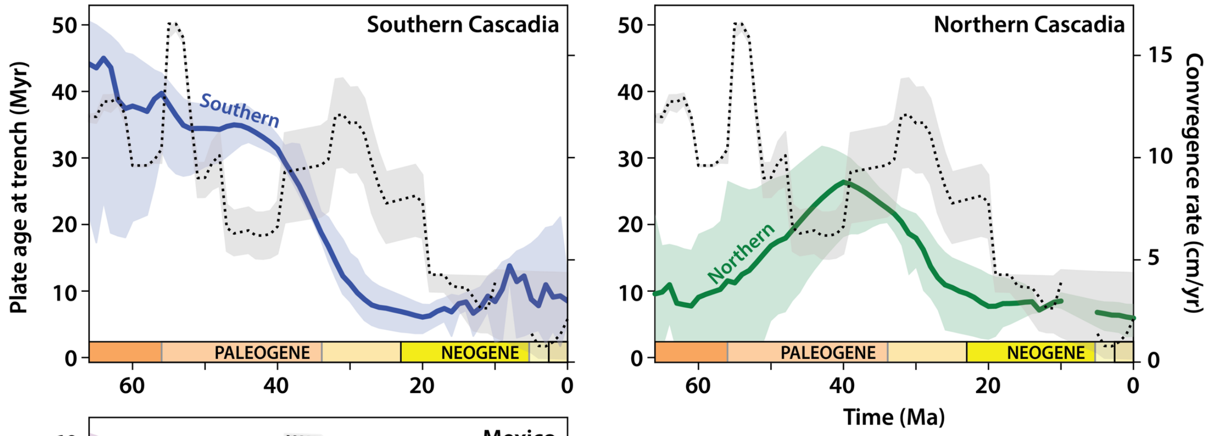


progressively decrease in plate age as model evolves



Epstein et al., in prep.

Imposed Plate Younging



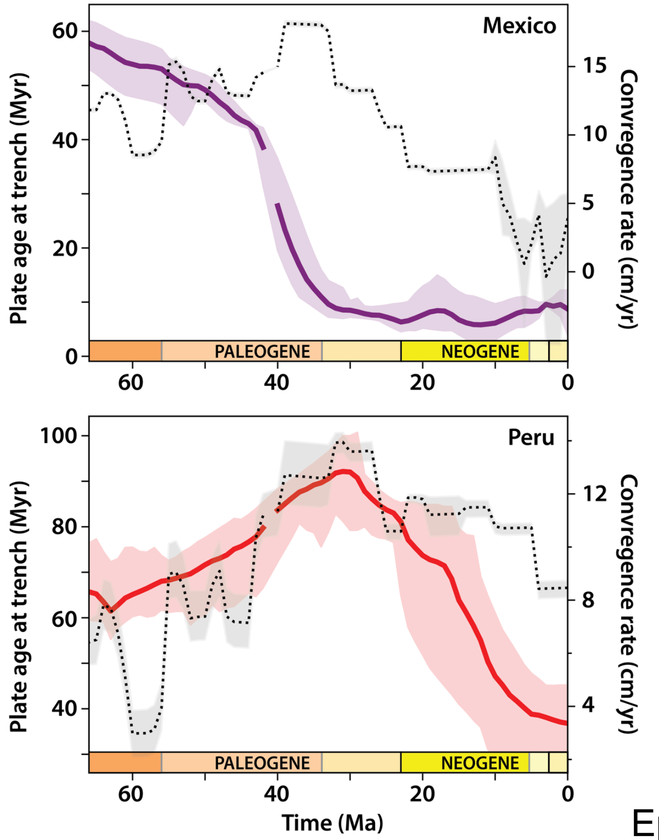
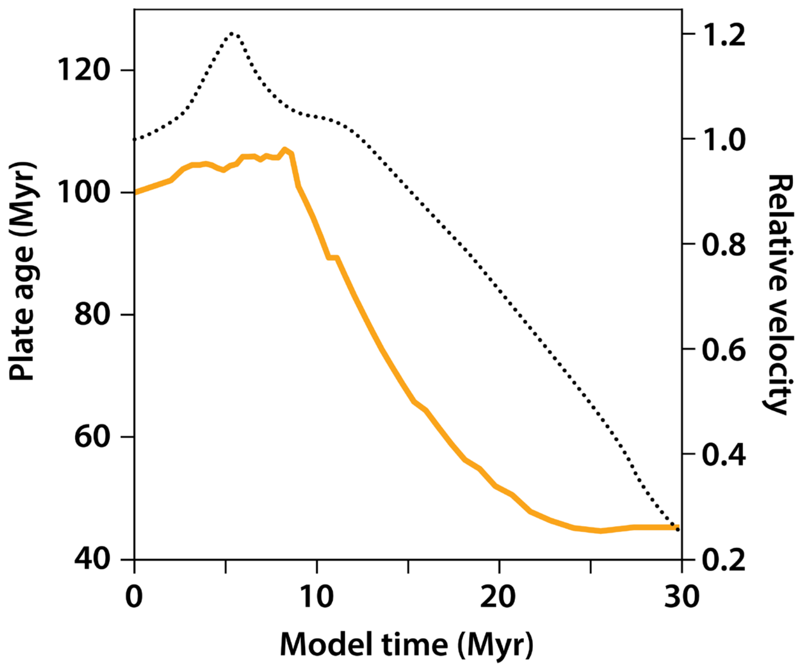


plate age and convergence rate evolution similar to margin reconstructions

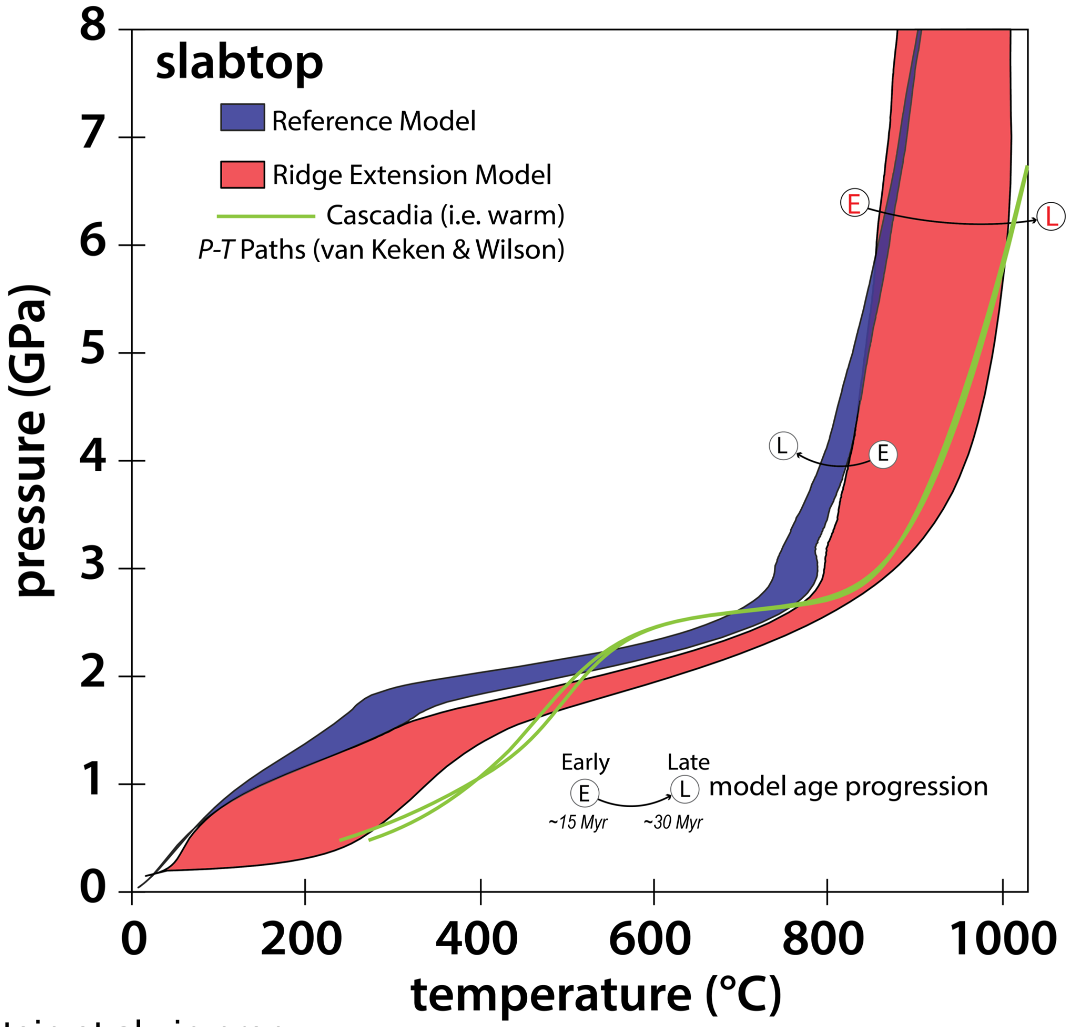


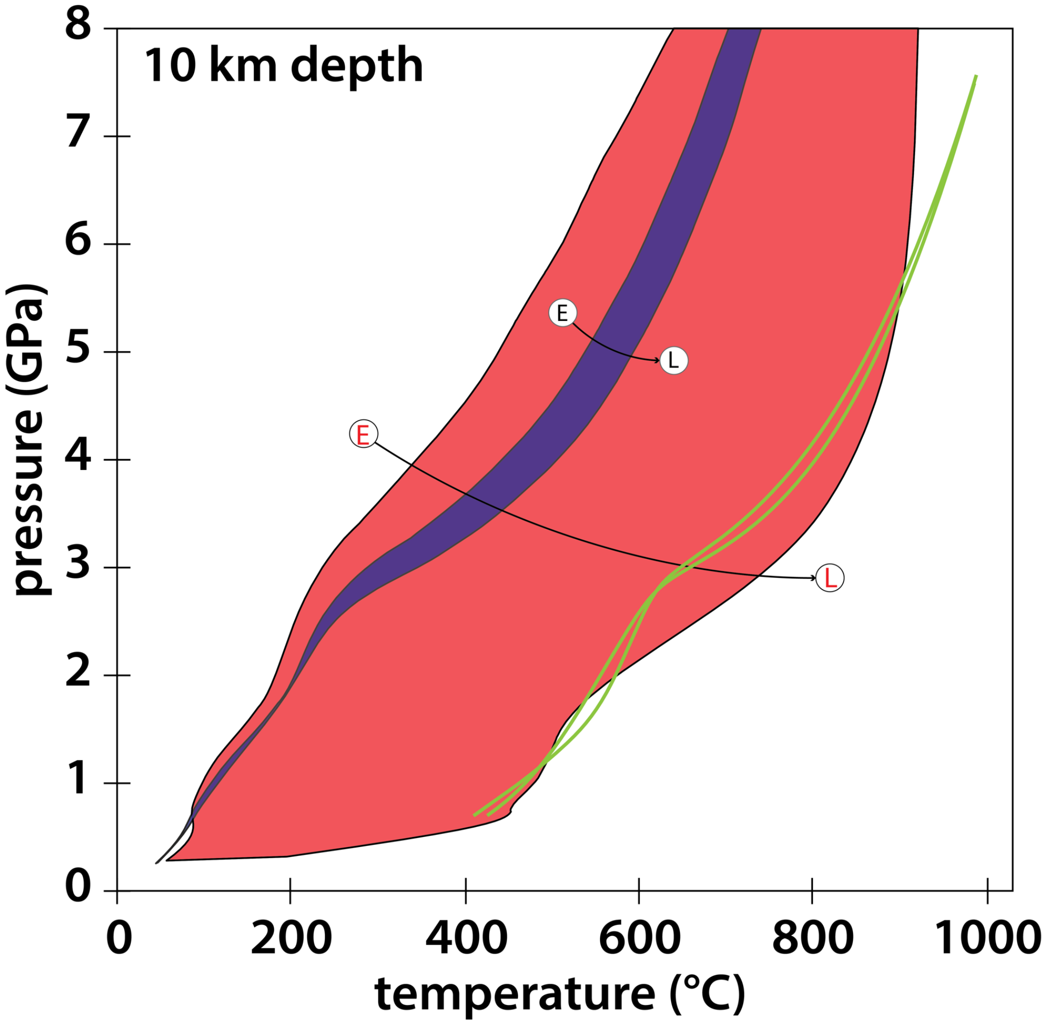
Causal association in our 2D model

Epstein et al., in prep.

Imposed Plate Younging

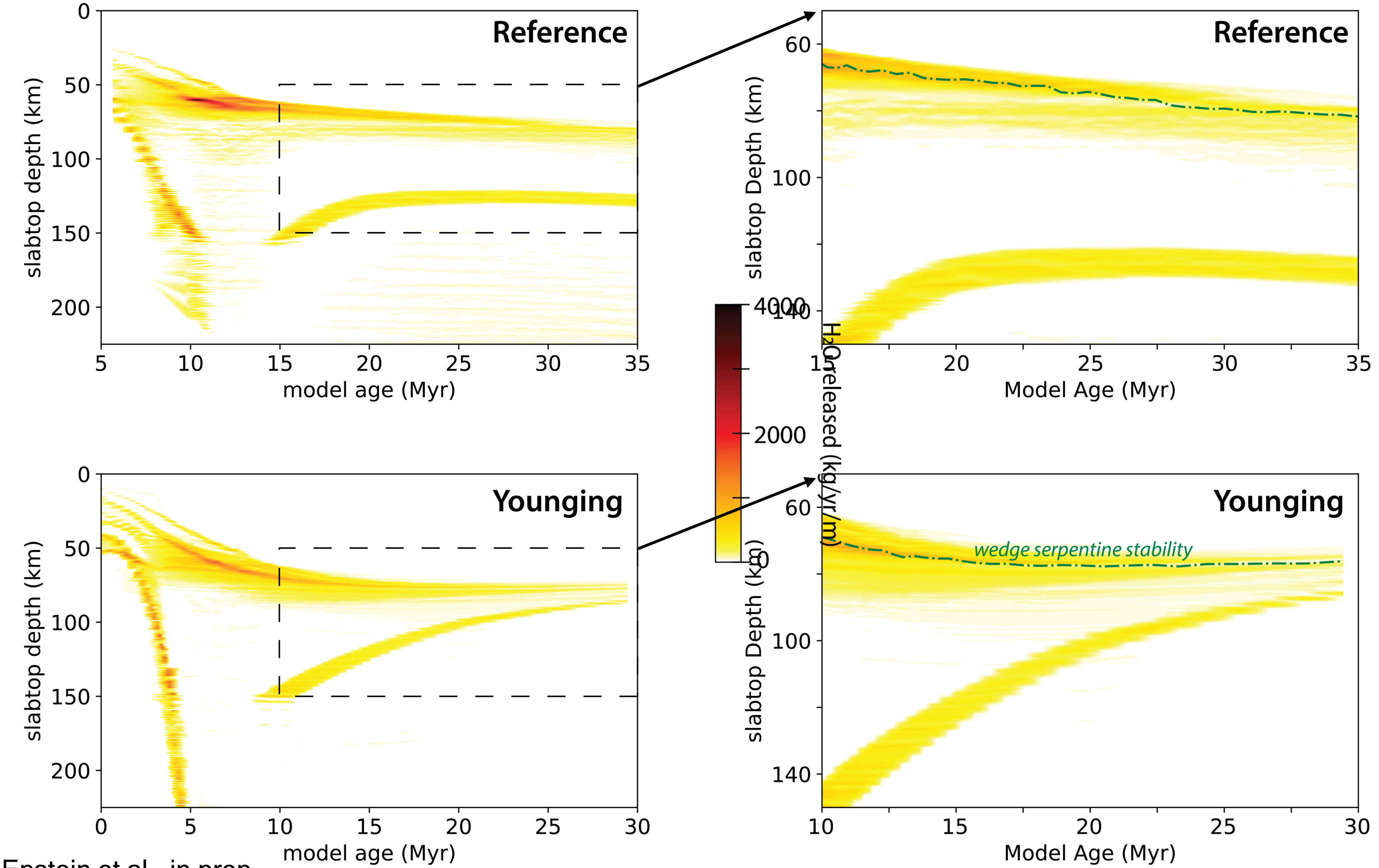
Plate younging induces ”bottom-up” heating:
$\Delta T_{moho} >> \Delta T_{slabtop}$





Epstein et al., in prep.

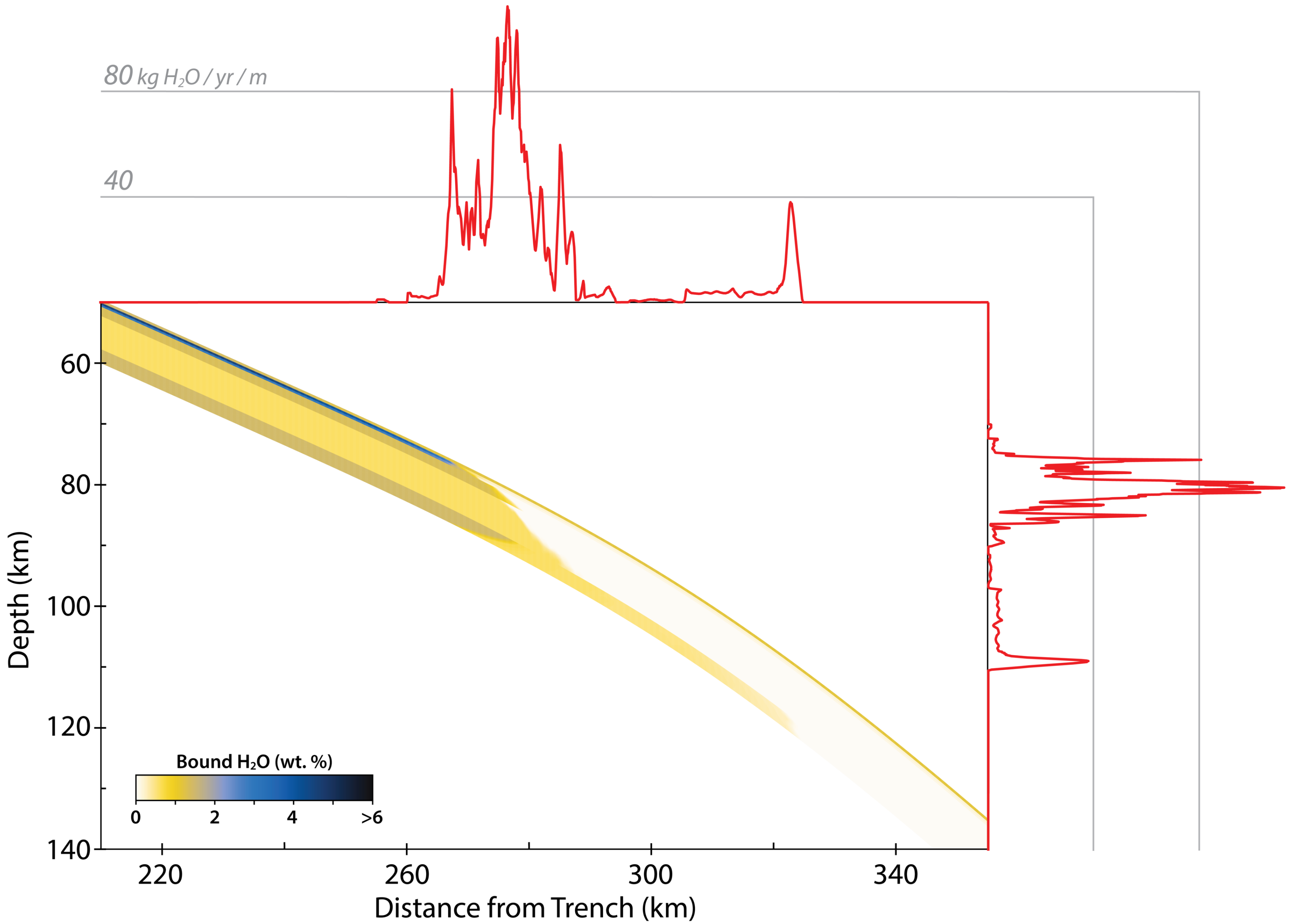
Imposed Plate Younging



Within-slab dehydration undergoes dramatic shallowing

Epstein et al., in prep.

Imposed Plate Younging

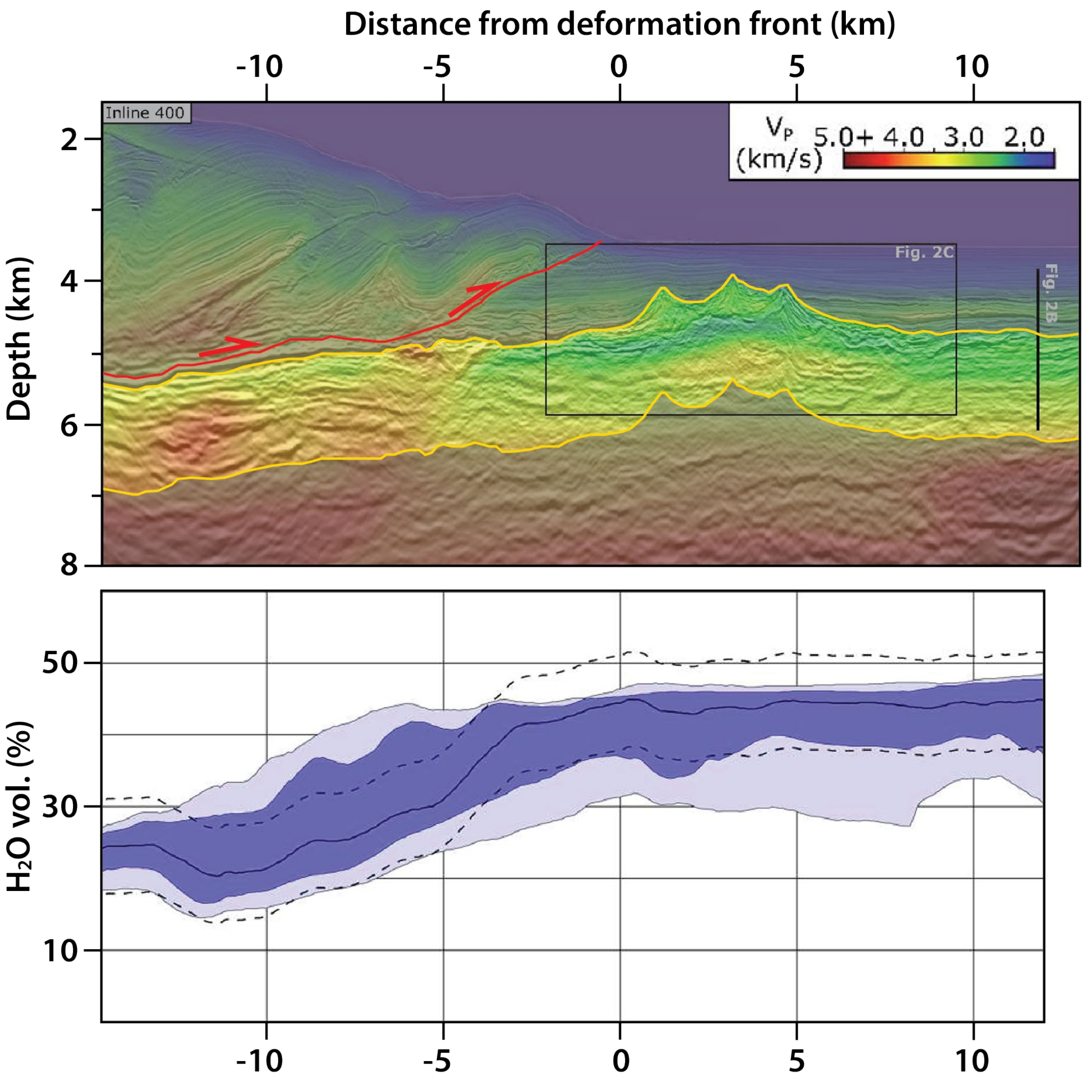


Consistent with present-day models of Cascadia dehydration structure

Epstein et al., in prep.

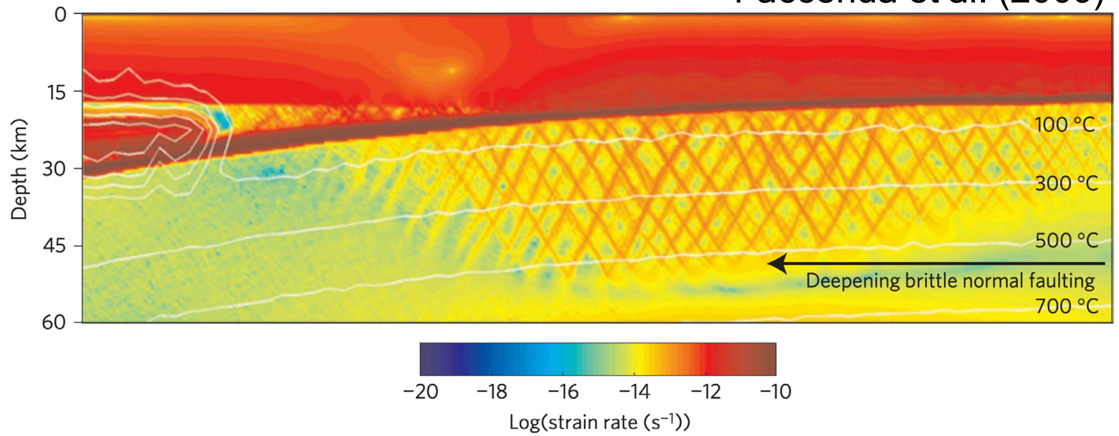
Time Dependence of Hydration State

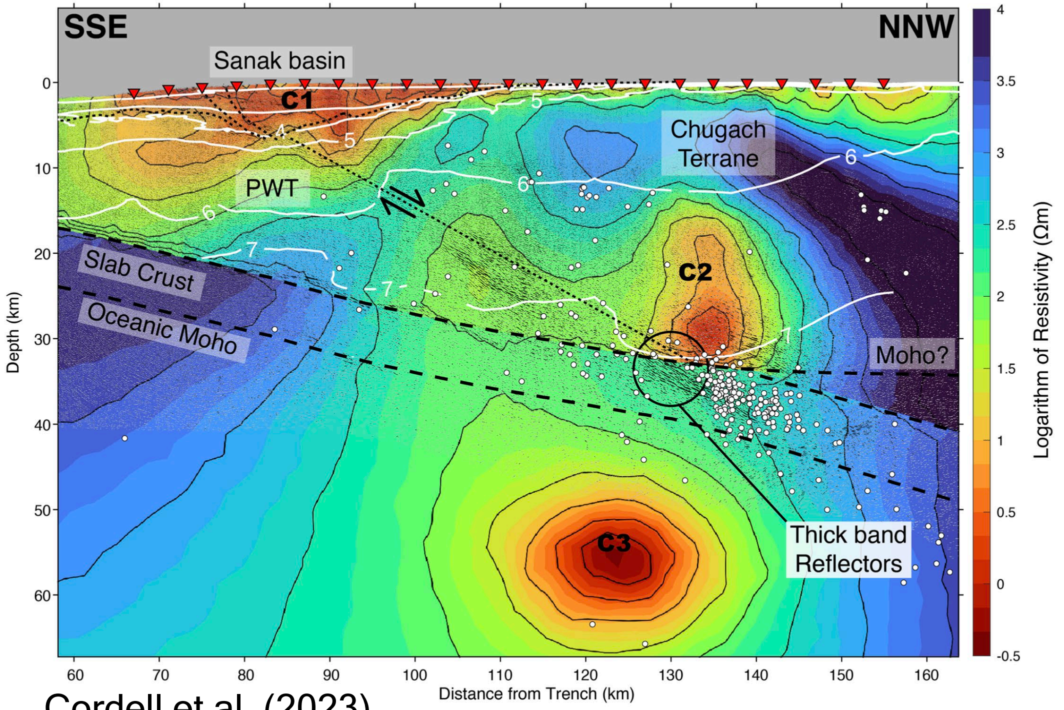
Heterogenous Hydration



Gase et al. (2023)

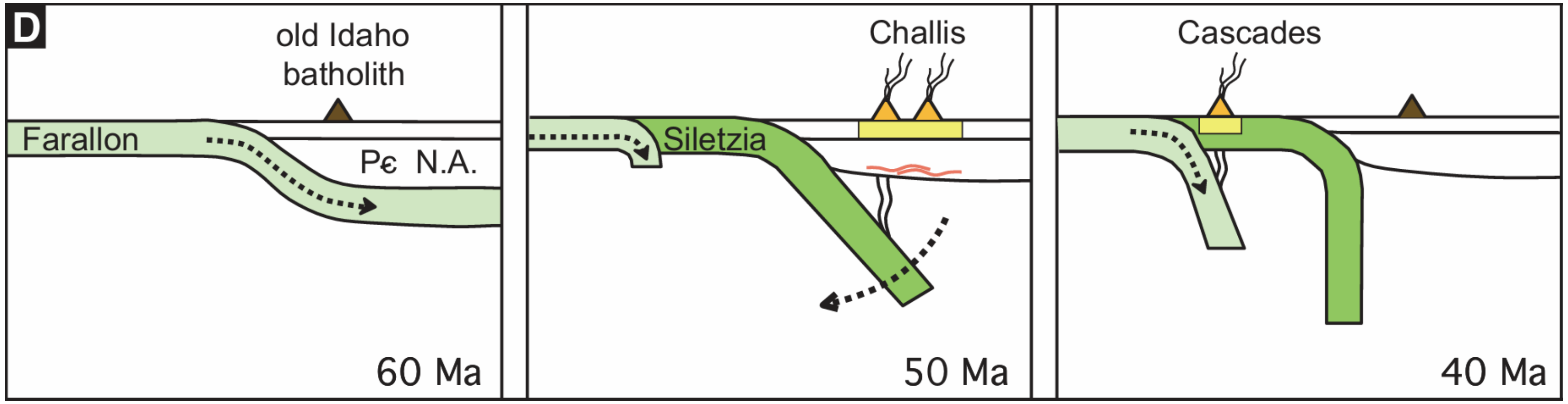
Faccenda et al. (2009)





Cordell et al. (2023)

Cascadia - Myr Variations



Schmandt & Humphreys (2011)

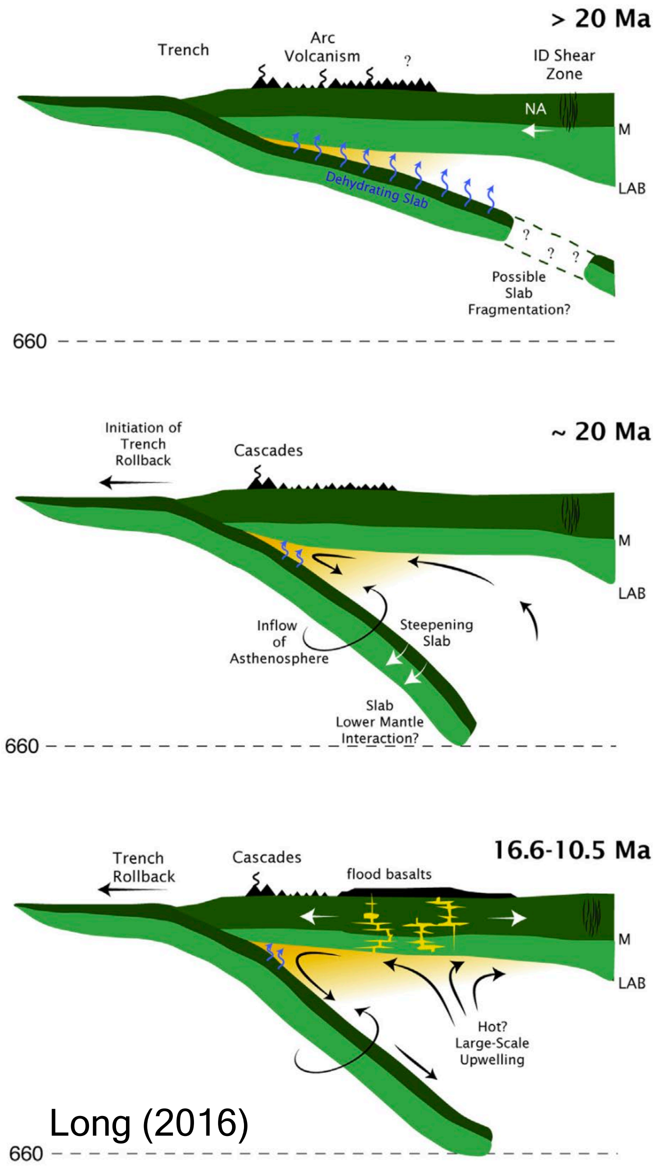
Consideration of temporal variation in slab dehydration is important along the Cascadia margin

Certain parameters are affected more, e.g.:

Major effect:
Wedge hydration
Flux melting fluid source

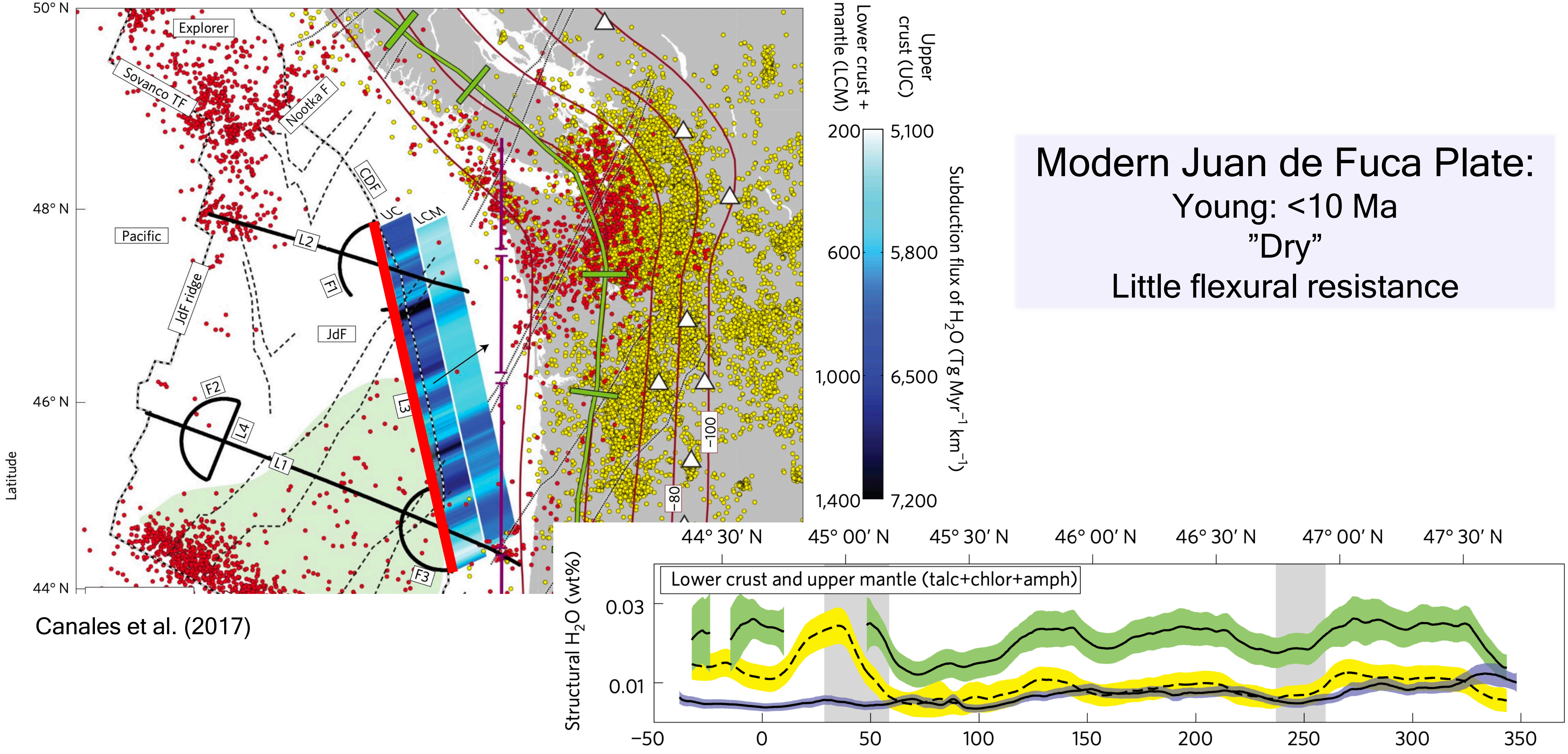
Some effect (?):
Arc migration
Upper Plate Stresses

Minor effect:
Present day *P-T*



Long (2016)

Incoming Plate Hydration



Canales et al. (2017)

Modern Juan de Fuca Plate:

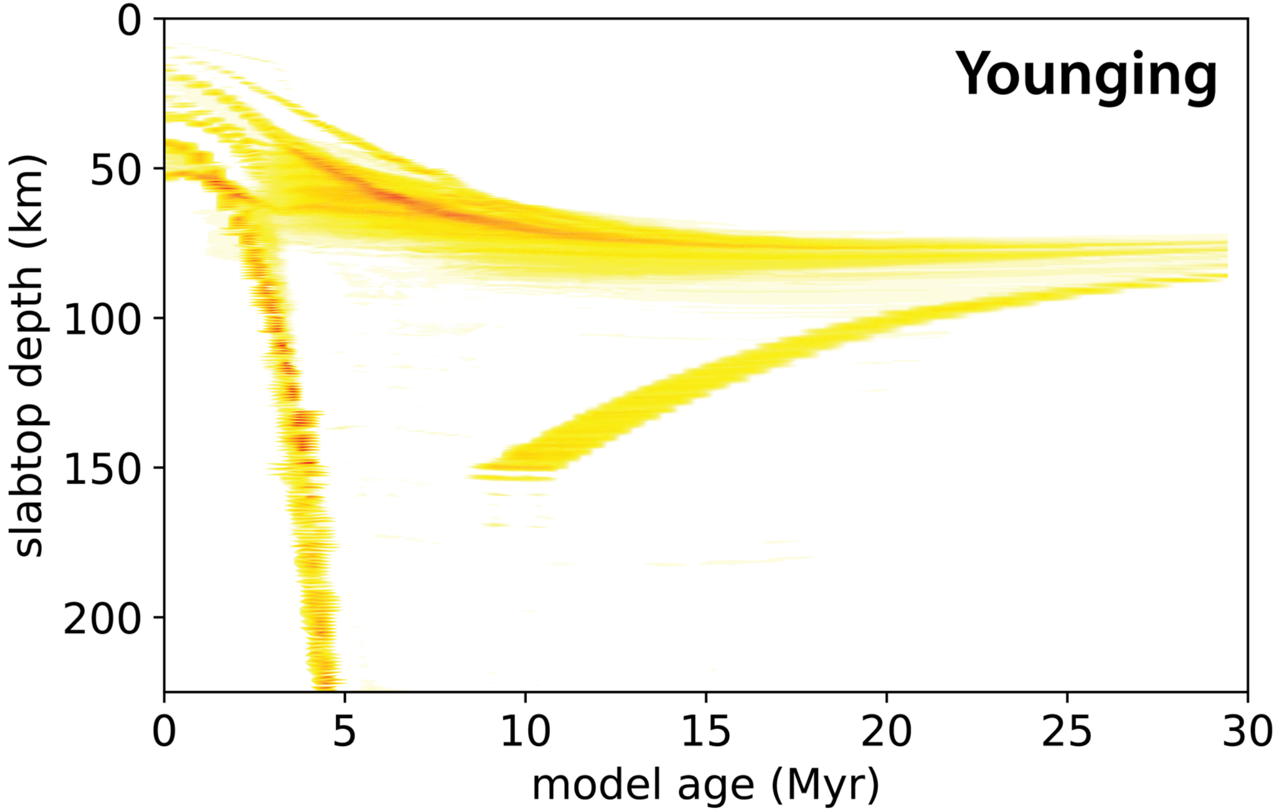
Young: <10 Ma

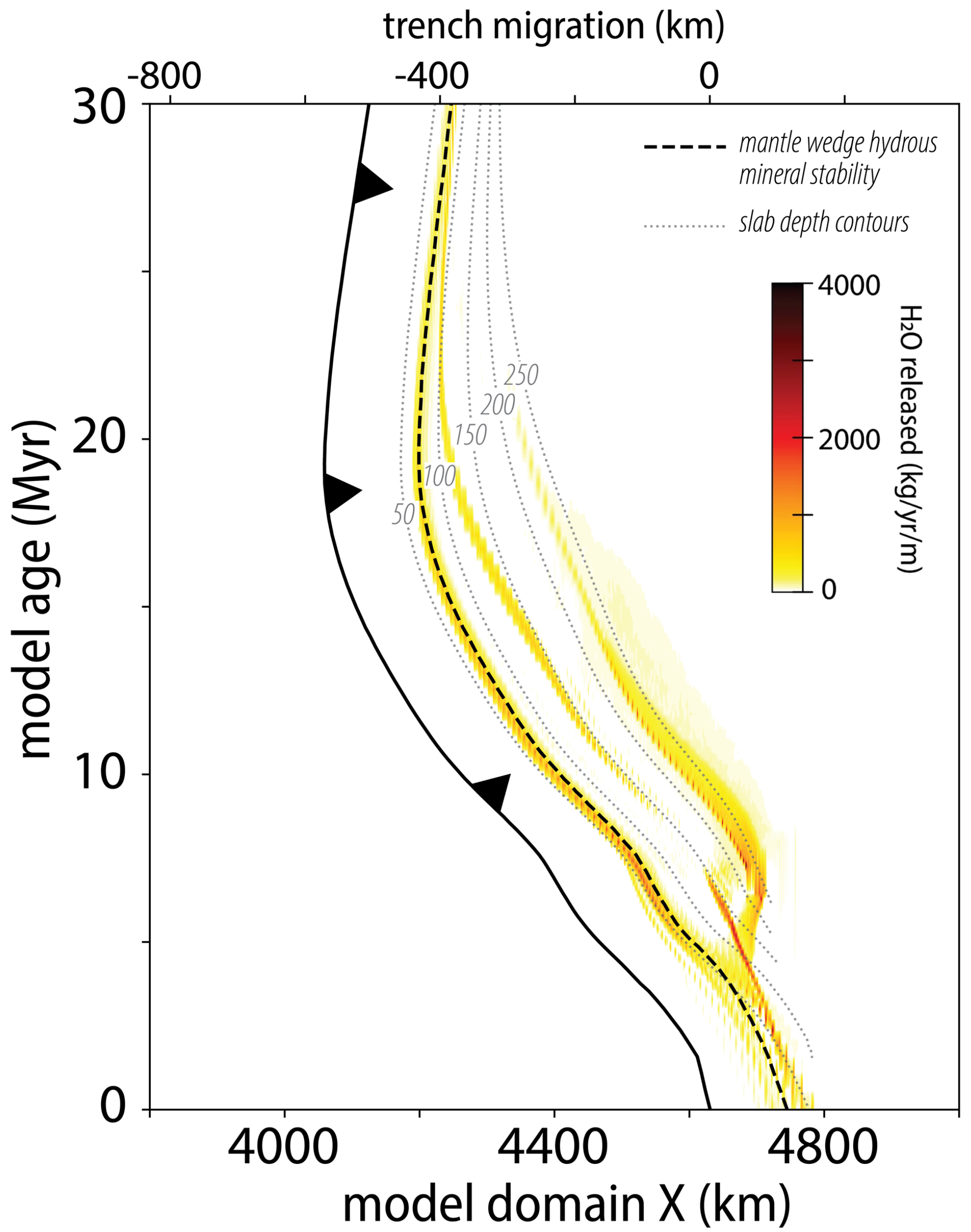
"Dry"

Little flexural resistance

The assumption of steady state . . . ?

Timescale of a process dictates the need for consideration of temporal evolution





Take Aways

Slab dehydration is variable over a range of timescales, and can be attributed to:

Inherent thermal evolution: due to a subduction zones lifecycle
Imposed thermal variation: due to pulsed changes in geodynamic variables
Hydration variability: time-dependent changes or heterogenous hydration

Time dependence should be considered for problems that integrate geologic processes over pertinent timescales, e.g.:

Wedge hydration
Rheologic/kinematic evolution*
Arc magma genesis

*See Ryan Stoner's Poster this afternoon!