Integrating MAGNETOTELLURIC & SEISMIC observations to improve UPPER MANTLE VISCOSITY

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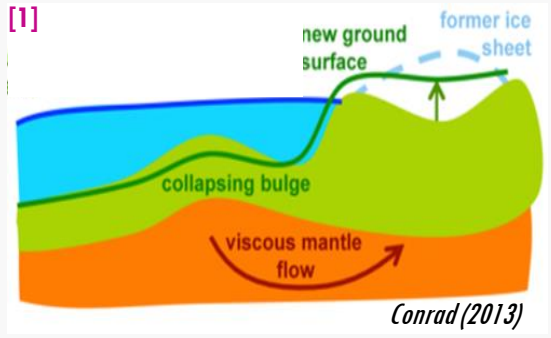
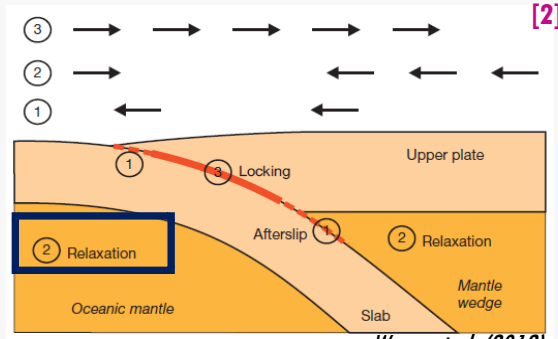
What are the common approaches in constraining upper mantle viscosity? What are their limitations?

[1]



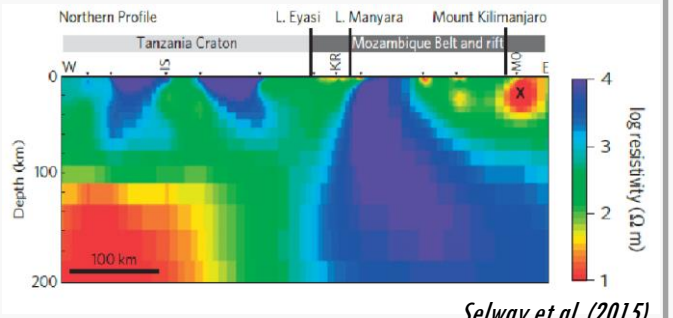
Conrad (2013)

[2]



Wang et al. (2012)

[3]



Selway et al. (2015)

Approach	Limitations
[1] From GIA (glacial isosostatic adjustment) observables	Geographically-bounded, low depth resolution and usually provides 1D viscosity profile, restricts us from inferring lateral viscosity variations
[2] From postseismic relaxation	Geographically-bounded, data-limited
[3] Geophysical measurements: Seismics alone, MT alone	uncertainties involved are poorly constrained

Why use geophysical observables (MT & seismics)?

- scan beneath the region of interest
- Probe mantle parameters that relate to mantle viscosity, and potentially detect lateral variations in these parameters

Relationship between geophysical observations and mantle viscosity

Paramaters influencing mantle viscosity

Olivine (for upper mantle) deformation:

[power law creep]

Strain rate

$$\dot{\epsilon} = A\underline{\sigma^{n}}\,\underline{d^{-p}}\,\underline{C_{OH}^{r}}\exp(\underline{\alpha\varphi})\exp\left(-\frac{E^{*}+PV^{*}}{\underline{RT}}\right)$$

(5) (4) (2) (3) (1)

Activation energy; Pressure; Activation volume

Hirth & Kohlstedt, 2003

Controlling factors:

(1) Temperature
(2) Water content
(3) Melt fraction
(4) Grain size
(5) Stress

Constrain these parameters from:

Seismics

From seismic velocity:

(1) Temperature

(3) Melt fraction

From seismic attenuation:

(4) Grain size

Karato, 2008
Jackson et al., 2002

Magnetotellurics

From electrical conductivity:

(1) Temperature

(2) Water content

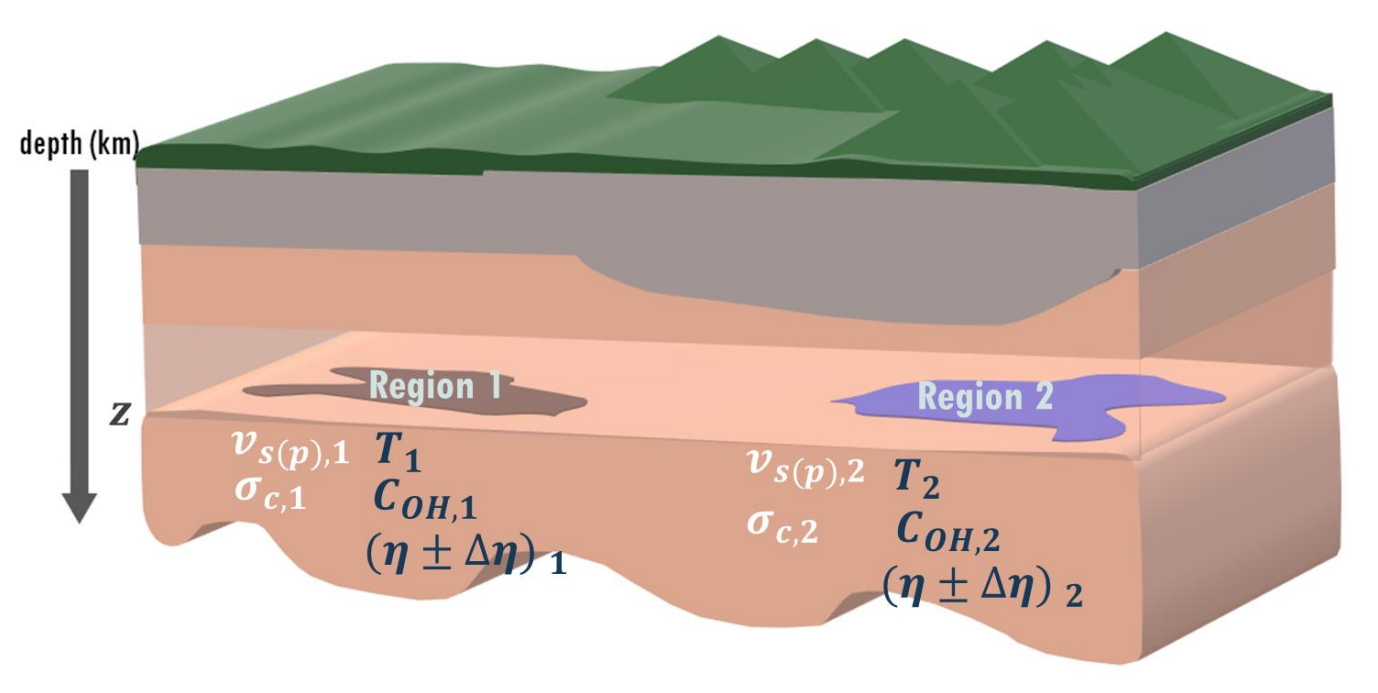
(3) Melt fraction

Gardés et al., 2014
Sifre et al., 2014

(5) Stress
Numerical models of **tectonic history** or **loading**

Set-up and method

[melt-free (olivine) upper mantle]



Step 1: Convert $v_{s(p)}$ to T, neglecting chemical effects (for now)

Step 2: Determine **water content** from MT derived-conductivity σ_c using conductivity model

Step 3: Determine η using

$$\eta_{eff} = \frac{\sigma}{\dot{\epsilon}_{tot}}$$

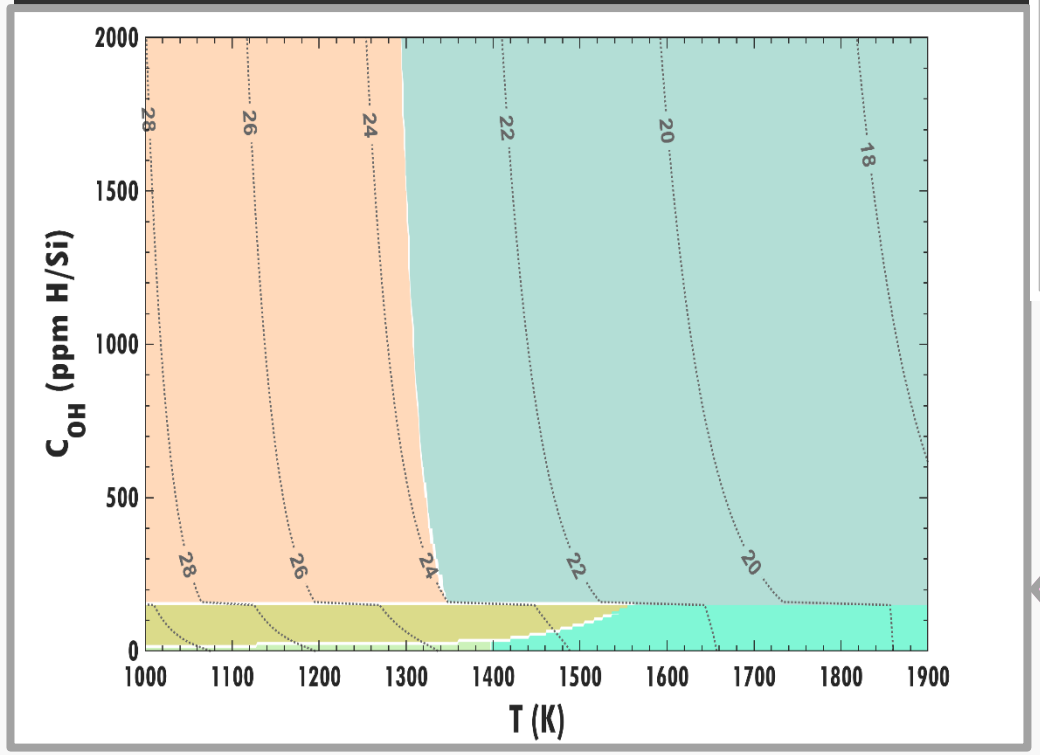
where

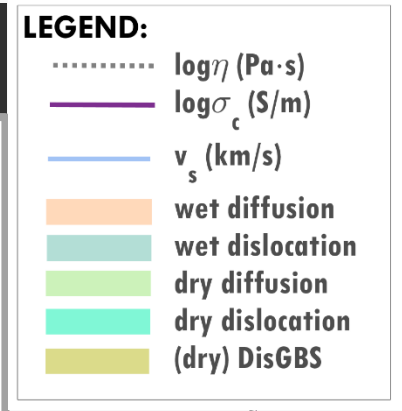
$$\dot{\epsilon}_{tot} = \dot{\epsilon}_{Dis} + \dot{\epsilon}_{Dif} + \dot{\epsilon}_{DisGBS}$$

Use of deformation map over water content and T space

[stress = 0.1 MPa, grain size = 10 mm, P = 3.5 GPa]

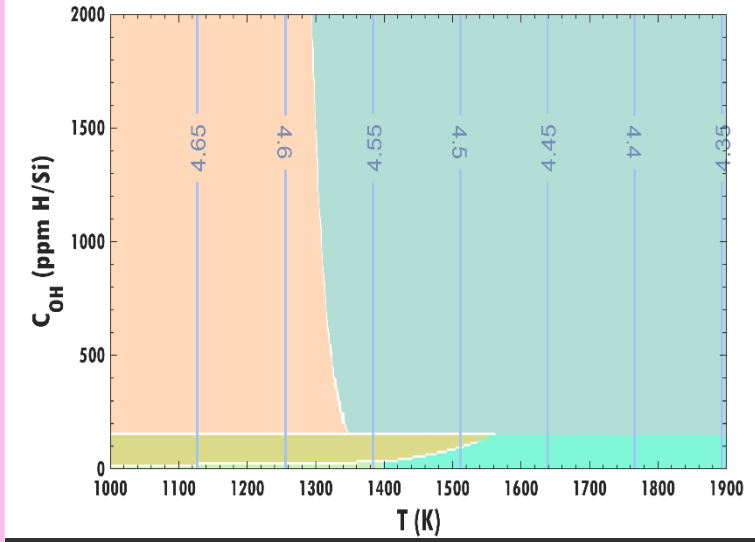
Effective Viscosity



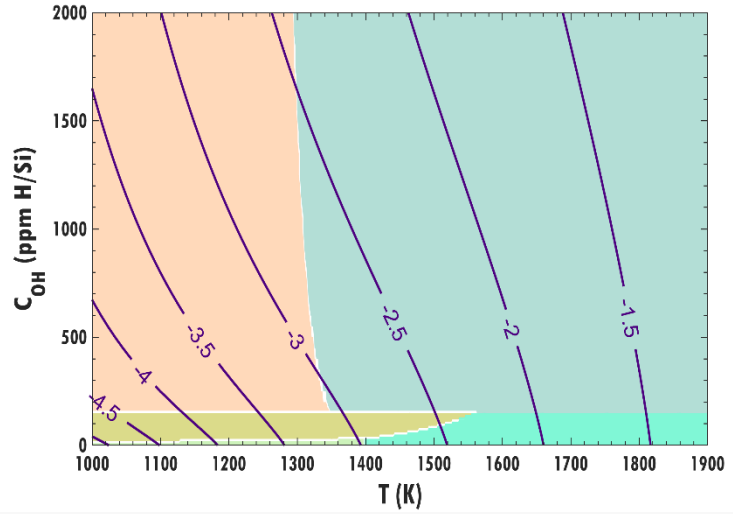


OVERLAP to estimate VISCOSITY for a given geophysical observation

Shear wave velocity*



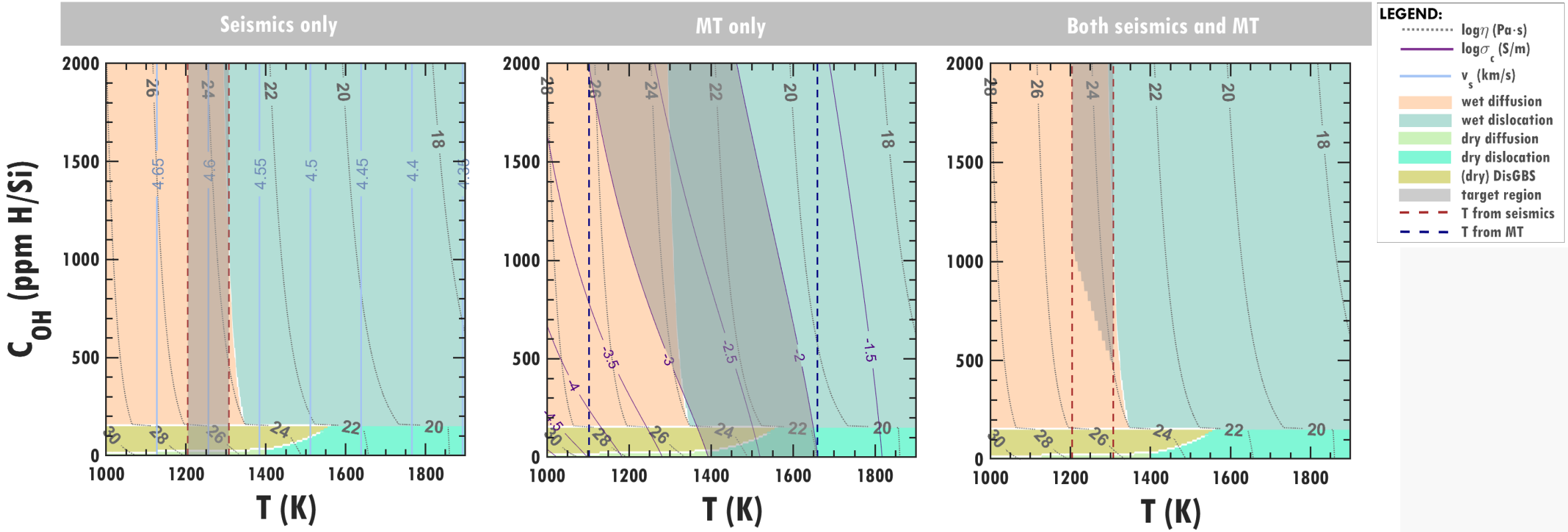
Electrical conductivity*



*seismic velocity and electrical conductivity for olivine at any C_{OH} and T are calculated using Hacker and Abers (2004) and Gardés et al. (2014), respectively

Estimating viscosity for a certain region

[stress = 0.1 MPa, grain size = 10 mm, P = 3.5 GPa]

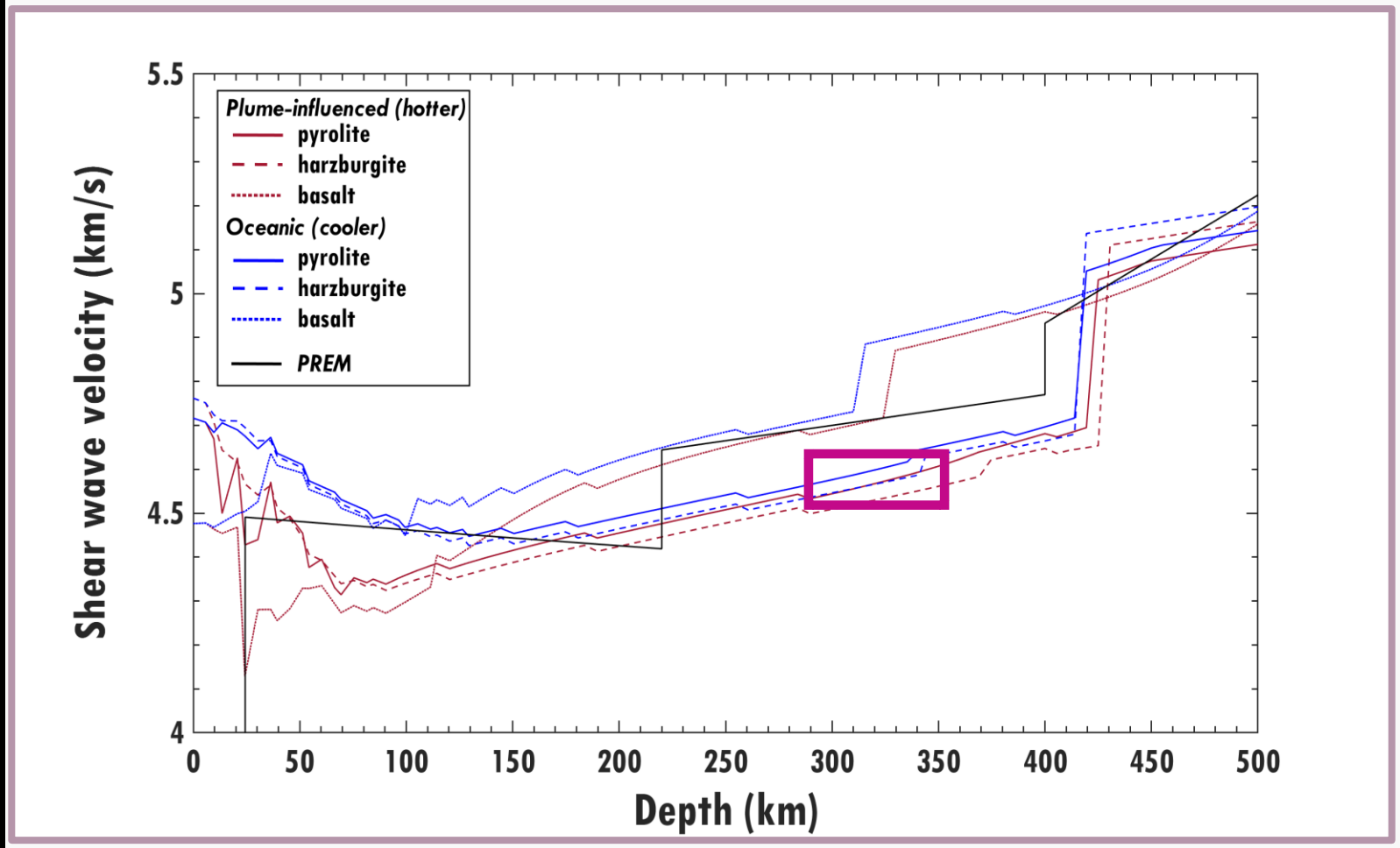


assumed	$v_s = (4.60 \pm 0.02)$ km/s
inferred	$T = (1256 \pm 51)$ K

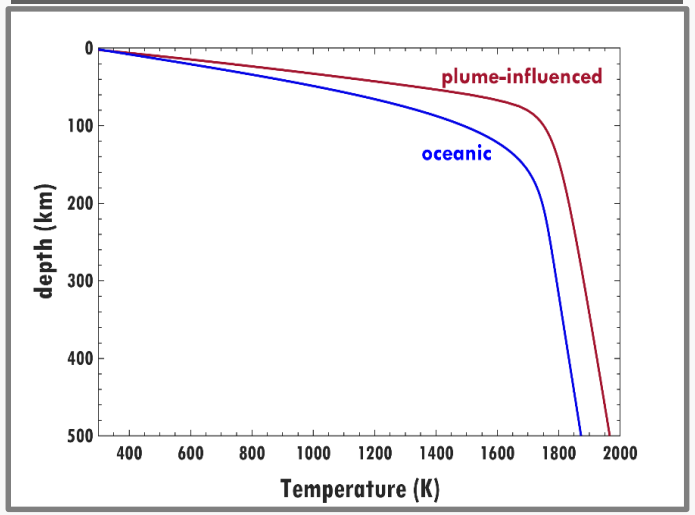
$\sigma_c = 10^{-(2.5\pm0.5)}$ S/m

both MT and seismics put tighter bounds on viscosity estimate

Tradeoff between temperature and composition in determining velocity?



GEOTHERMS



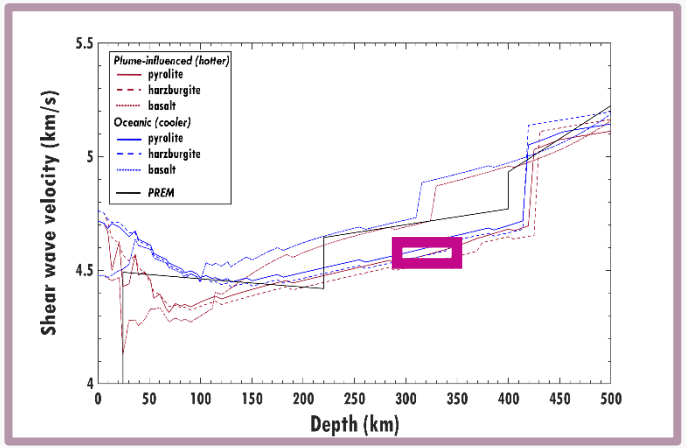
Seismic velocity is sensitve to both

[1] composition

[2] temperature

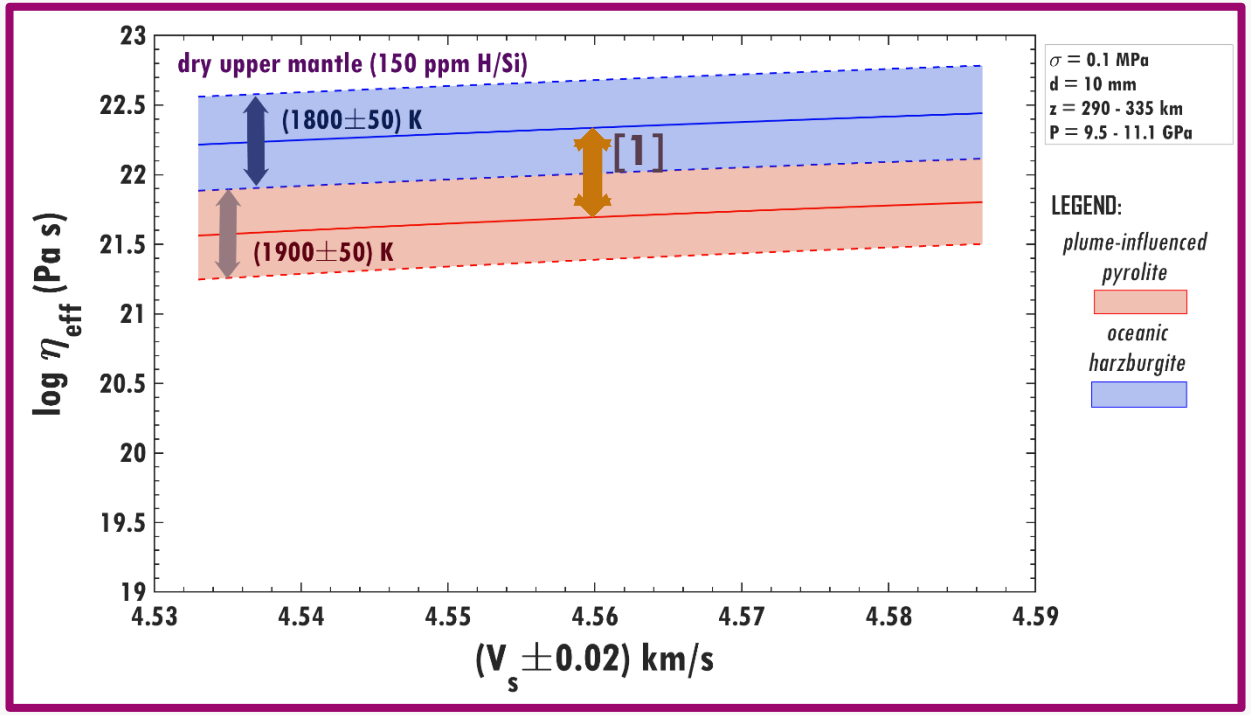
Models courtesy of Prof. C. Lithgow-Bertelloni using self-consistent thermodynamic formalism (Stixrude and Lithgow-Bertelloni, 2005) and bulk composition in Xu et al. (2008)

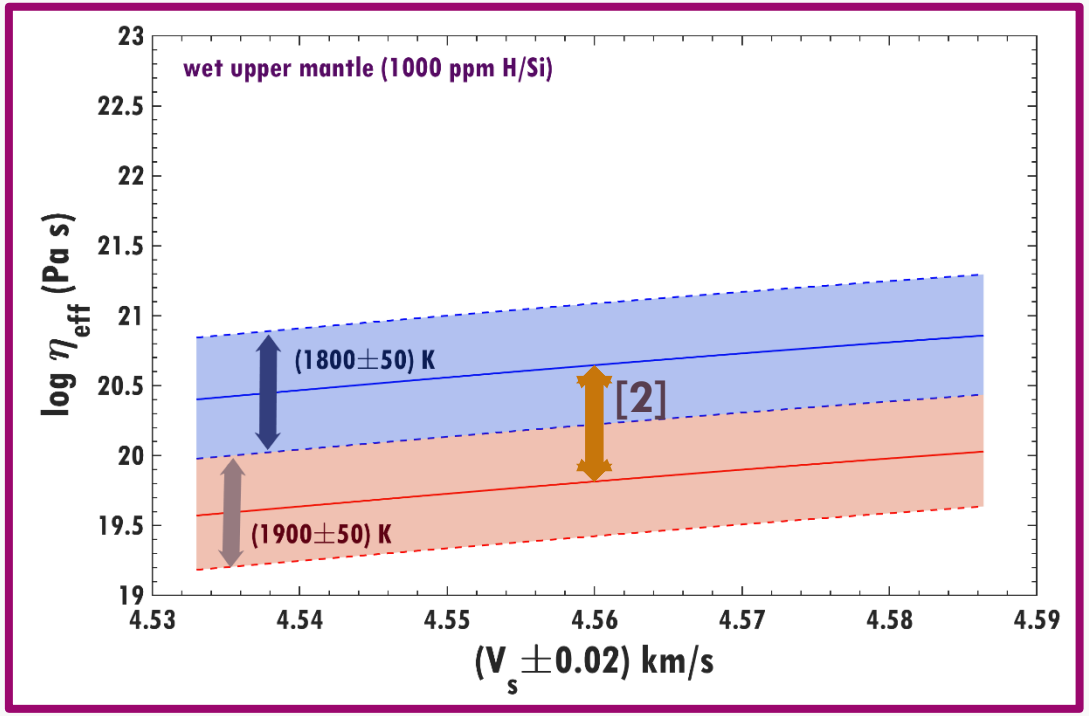
Different viscosity estimates for upper mantle with same seismic velocity (different T and composition)



[1] dry upper mantle: ~0.6 order magnitude difference

[2] wet upper mantle: ~0.8 order magnitude difference



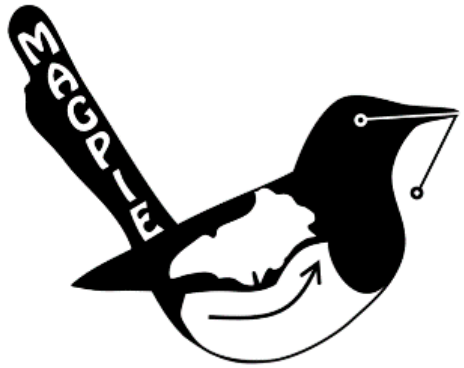


Take home message

[1] Mantle viscosity (and its lateral variations) can be better constrained by utilizing both seismic and MT geophysical constraints.

[2] We identify a trade-off between temperature and composition when converting seismic velocity to viscosity.

[3] It is necessary to account compositional variations when estimating viscosity. (FOR FURTHER INVESTIGATION)



THANK YOU!