Convection and grain size evolution in mantle and lithosphere of the Earth

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Two phase flow and localization of deformation

FORMALISM OF BERCOVICI & RICARD 2012

- Grain size evolution for phase i:

$$\frac{D\mathcal{R}_i}{Dt} = \frac{G_i}{p\mathcal{R}_i^{p-1}} Z_i - \chi_1 \frac{\mathcal{R}_i^2}{3\gamma_i} f_G (1-f_I) \bar{\Psi}_{i,disl} Z_i^{-1} + \beta_\phi \left(\frac{3}{4\pi}\right)^{1/3} \dot{\phi}_i$$

- Evolution of the curvature between 2 phases:

$$\frac{D\mathcal{C}}{Dt} = 3\phi_1\phi_2 \frac{G_I}{q\mathcal{C}^{q-1}} - \frac{1}{3\phi_1\phi_2} \frac{\mathcal{C}^2}{\gamma_I} f_I \bar{\Psi}$$

- Zener Pining term:

$$Z_i = 1 - \chi_2 (1-\phi_i) \left(\frac{\mathcal{R}_i}{\mathcal{C}}\right)^2$$

Transition from diffusion to dislocation creep?

Rheological boundaries can be defined within this framework considering strain rate equalities. Perhaps the most important boundary for the mantle is the diffusion-dislocation boundary $\dot{\underline{\epsilon}}_{df} = \dot{\underline{\epsilon}}_{ds}$:

$$\tau_{df,ds} = \left(\frac{A_{df}}{A_{ds}} d^{-m}\right)^{\frac{1}{n-1}} \exp\left(-\frac{(E_{df}-E_{ds}) + P(V_{df}-V_{ds})}{(n-1)RT}\right)$$

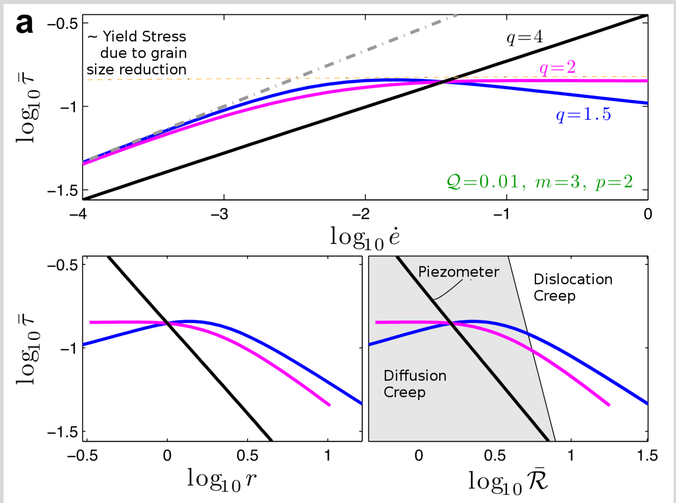
This stress transition is very parameter-dependent. One can also express this transition in terms of transitional grain size:

$$d_{df,ds} = \left(\tau^{1-n} \frac{A_{df}}{A_{ds}}\right)^{1/m} \exp\left(-\frac{(E_{df}-E_{ds}) + P(V_{df}-V_{ds})}{mRT}\right)$$

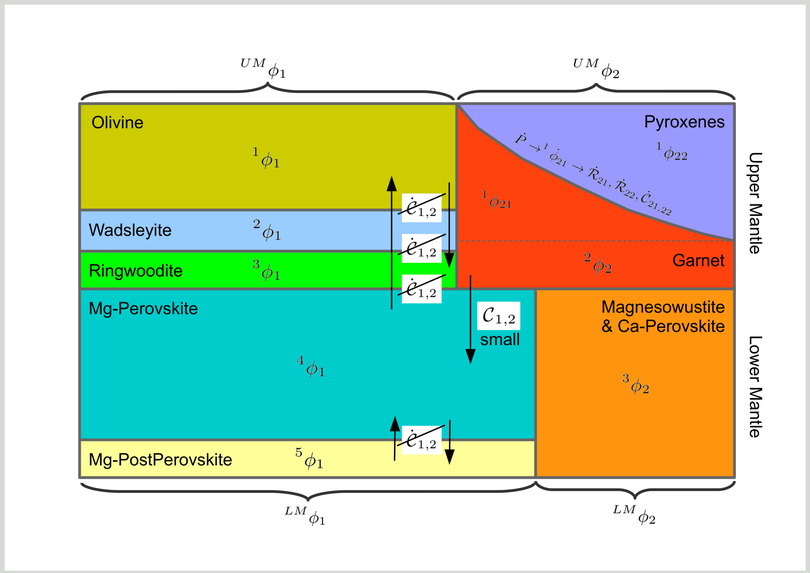
Parameter definitions

- ϕ_i: volume fraction of phase i.
- $\mathcal{R}_i$: average grain size (from a full distribution) of phase i.
- $\mathcal{C}$: average curvature of grain boundaries between phases.
- G_i: temperature-dependent growth factor of phase i.
- G_I: temperature-dependent growth factor of curvature.
- p: grain growth exponent.
- γ_i, γ_I: surface tensions.
- f_G, f_I: partitioning coefficients < 1.
- Ψ mechanical work.
- $\Psi_{i,disl}$ mechanical work in dislocation creep in phase i.
- χ_1, χ_2: constants.

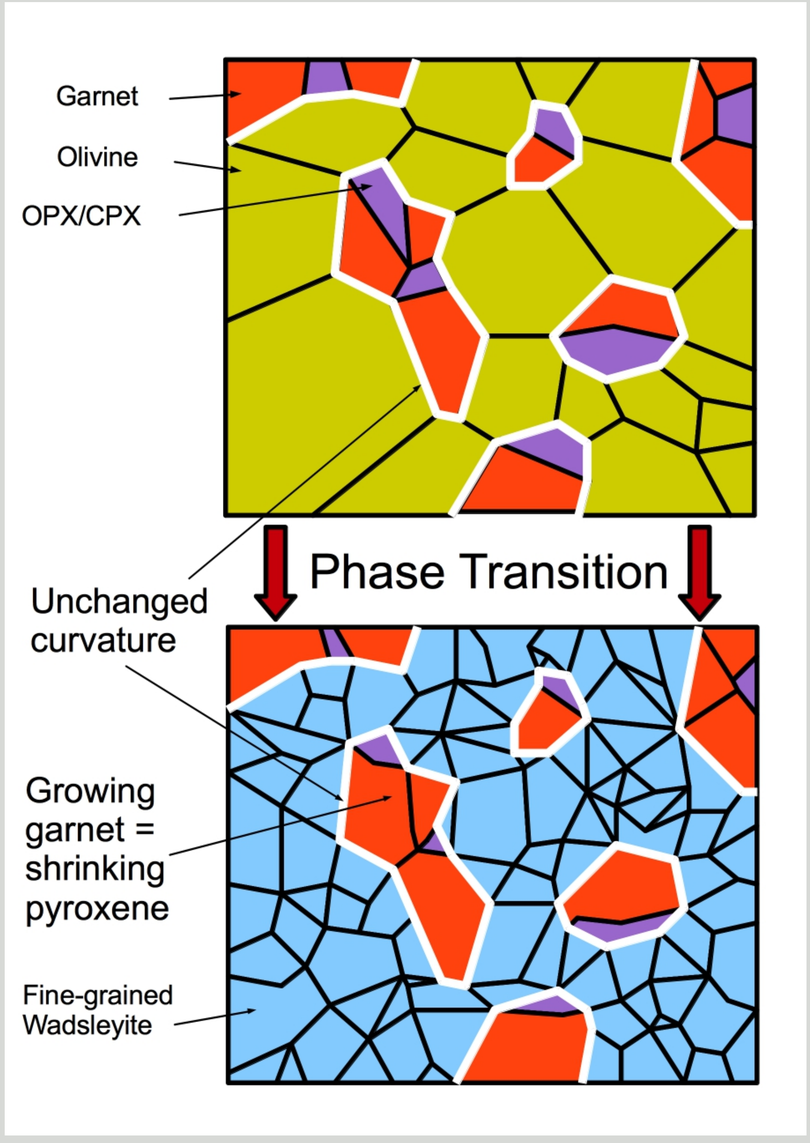
Piezometer – adapted from Bercovici & Ricard (2012 PEPI)



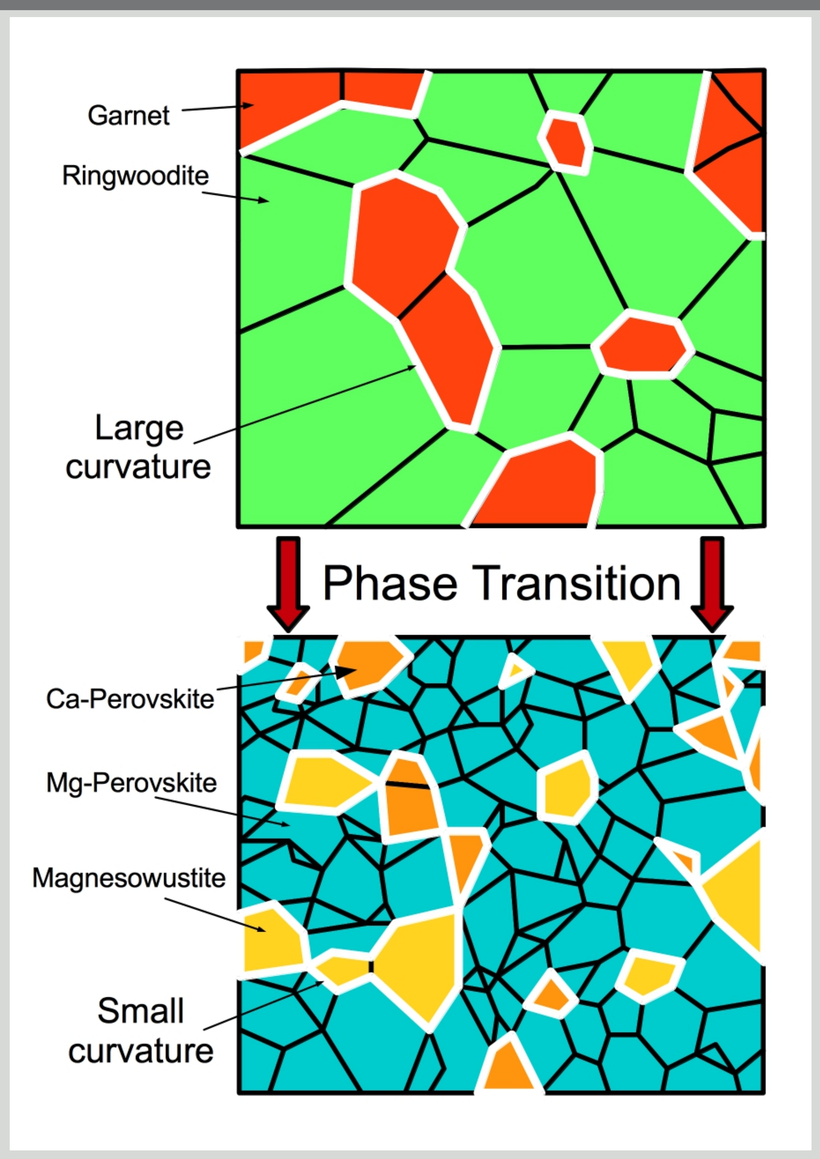
Grain Size in the Mantle?



Transition in the upper mantle – Downwelling at 410 km

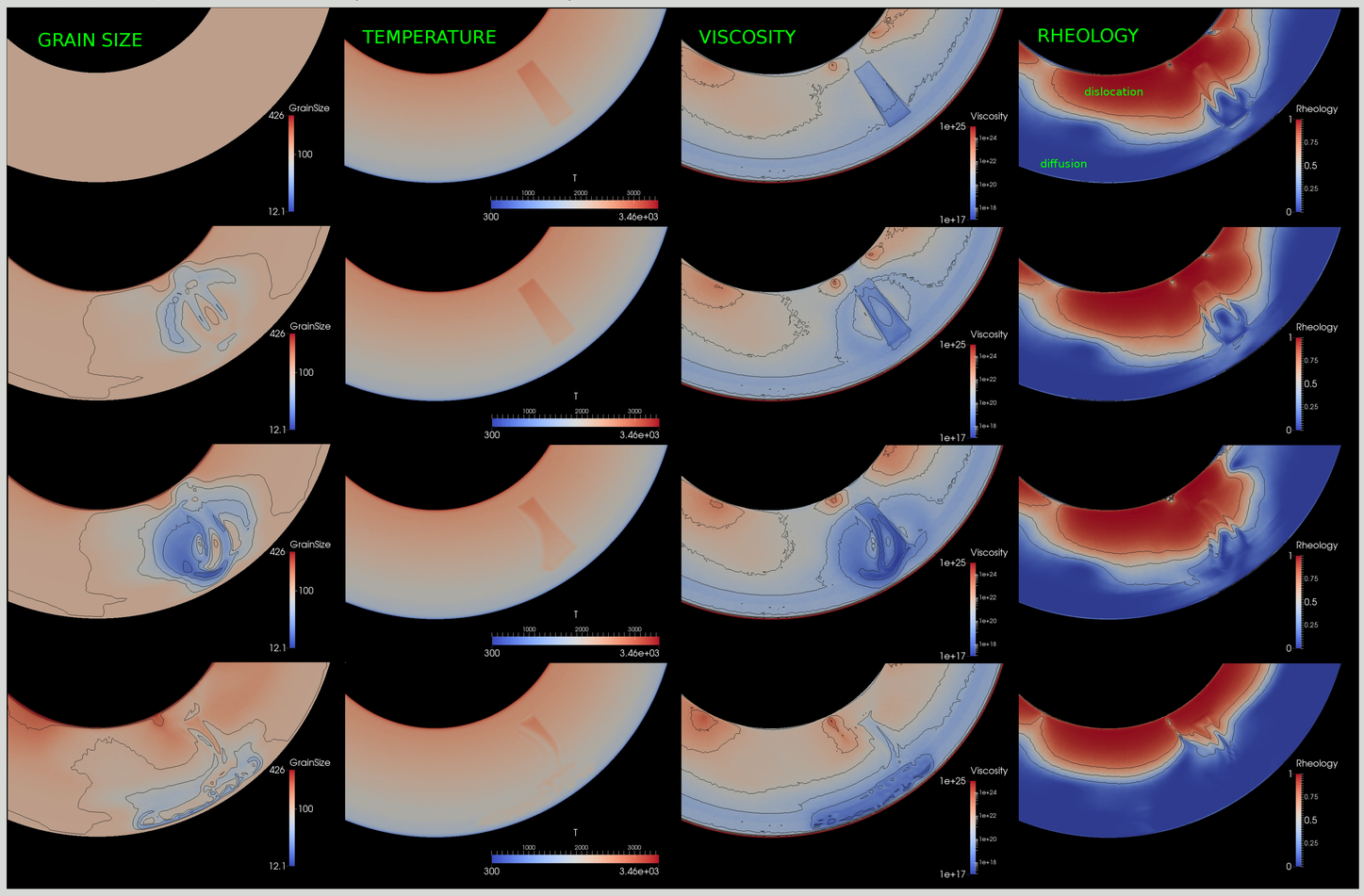


Transition to lower mantle – Downwelling at 660 km



Grain Size in the Mantle?

- First tests with StagYY in 2D spherical annulus geometry
- No phase transitions
- Single phase grain size evolution (see Rozel et al. 2011)



Grain Size in the Mantle? – Phase transitions

- Simplified phase transitions (Grain size = 5 microns around phase transitions)
- Single phase grain size evolution (see Rozel et al. 2011)