Role of grain size reduction in formation and inversion oceanic detachment faults

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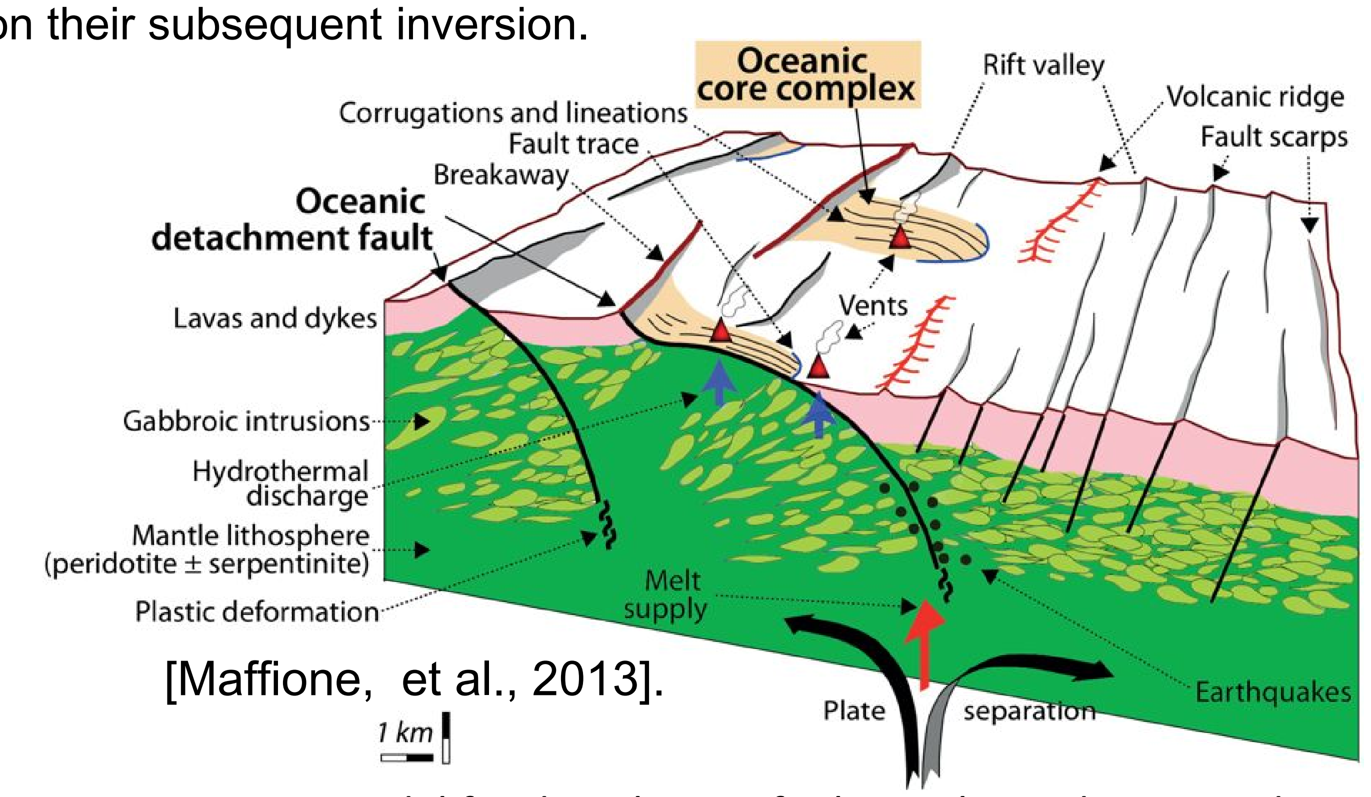
Introduction

Plate separation at slow-ultraslow spreading mid-ocean ridges is accomplished by both poor magmatic intrusion and slip by detachment faults. Previous studies showed that the offset of long-lived detachment faults needs: (1) an alteration front; (2) the brittle-plastic transition; (3) boundary between gabbro intrusions and hydrated peridotite; or (4) low magma supply. Here, we investigate numerically potential effects of grain size reduction on oceanic detachment faults formation as well as on their subsequent inversion.



[Maffione, et al., 2013].

Figure 1. Model for detachment faults at the mid-ocean ridge.

Numerical method

Numerical models were performed using I3ELVIS, a 3D thermo-mechanical code coupled with grain size reduction [Gerya, 2019].

- Integrated rheology:

$$\eta_{eff} = \min(\eta_{plastic}, \eta_{ductile})$$

- Plastic deformation

$$\eta_{plastic} = \frac{\sigma_{yiled}}{2\dot{\varepsilon}_{II}}$$

$$\sigma_{yiled} = C_0 + P\sin(\varphi_{eff})$$

- Ductile rheology

$$\eta_{df} = \frac{1}{2A_{df}}\exp\left(\frac{E_{df}+PV_{df}}{RT}\right)\left(\frac{\pi r}{2}\right)^m$$

$$\eta_{ds} = \frac{1}{2A_{ds}}\exp\left(\frac{E_{ds}+PV_{ds}}{RT}\right)\sigma^{1-n}$$

$$\frac{1}{\eta_{ductile}} = \frac{1}{\eta_{df}} + \frac{1}{\eta_{ds}}$$

- Grain size evolution

$$\frac{Dr}{Dt} = \frac{\theta G_I}{p r^{p-1}} - \frac{f_I r^2}{\gamma_I \theta}\Psi_{DRX}$$

- Zener pinning factor

$$Z_i = 1 - C(1-\phi_i)\frac{R_g^2}{r^2} \approx 0$$

- Mechanical work

$$\Psi_{DRX} = \sigma \bullet \dot{\xi}_{ds}$$

- Healing factor

$$healing = r_{growth} / r_{damage} = \left(\frac{\theta G_I}{p r^{p-1}}\right) \Big/ \left(\frac{f_I r^2}{\gamma_I \theta}\Psi_{DRX}\right)$$

Model setup

- Layered box of 202 x 98 x 202 km, spatial resolution of 0.5 x 0.5 x 0.5 km;
- Initial temperature profile computed with a semi-infinite half space cooling model;
- Velocity prescribed for left and right boundaries from extension to compression (V_{full} = 1.0 cm/yr);
- Grain size evolution is only used in the mantle rocks;
- Initial grain size is a constant, 3000 μm.

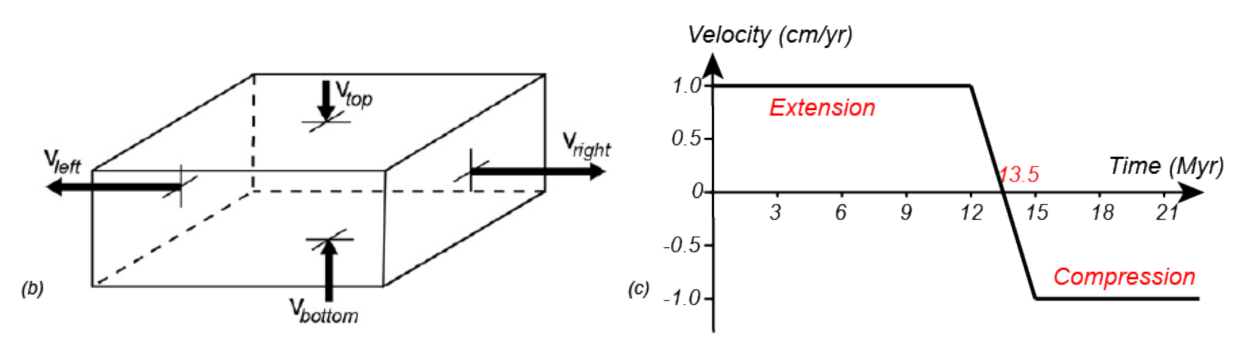


Figure 2. Initial model boundary condition. Transition time is set to 3 million years to allow for gradual deformation.

Preliminary results

Detachment faults form parallel and near the mid-ocean ridge with high stain localization, low rheological strength and small grain size.

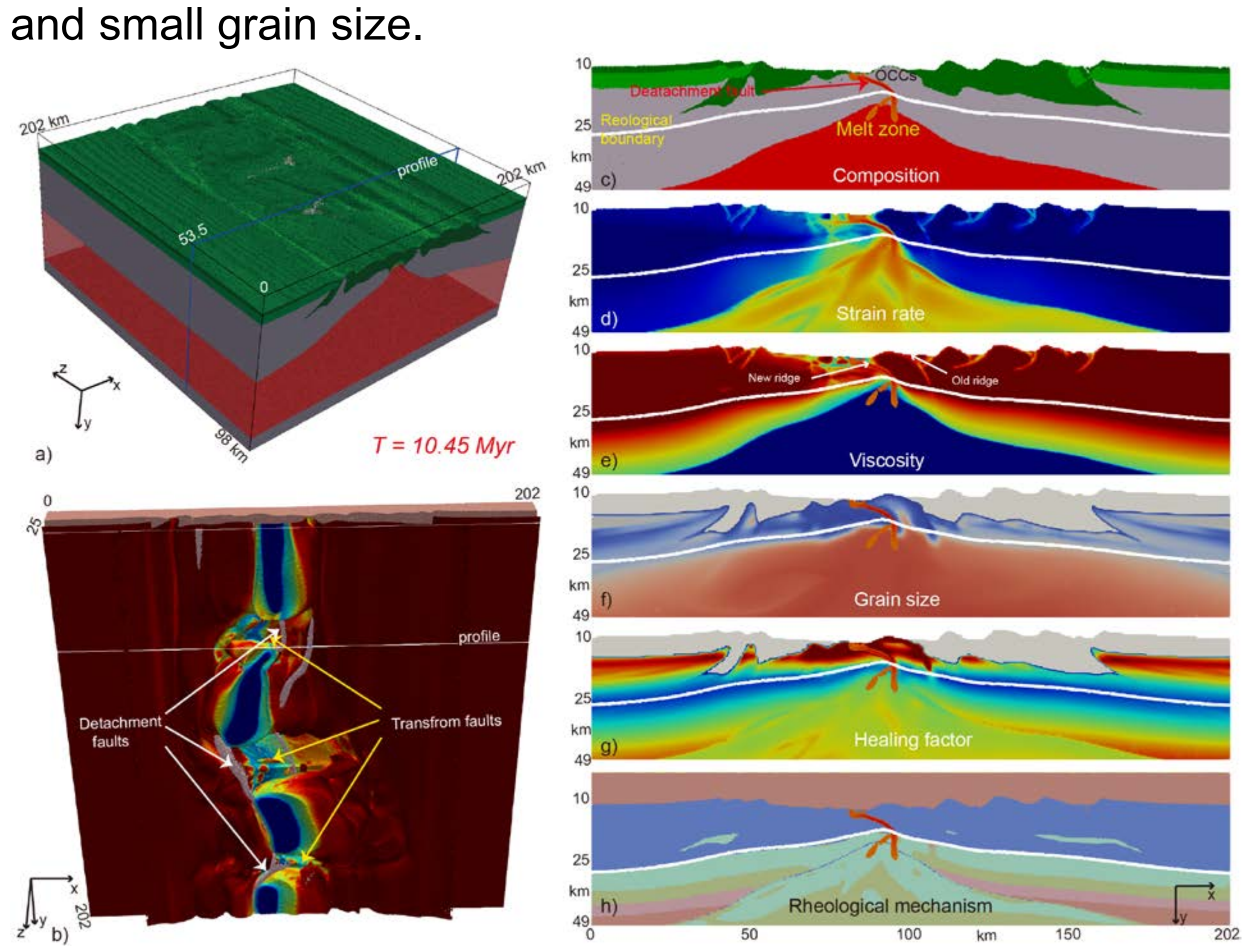


Figure 3. Numerical results at 10.45 Myr during the spreading stage. (a) composition; (b) rheological distribution below the Moho ; (c-h) profiles at z = 53.5 km. white line is the plastic and ductile deformation boundary. Red shade is detachment fault, where strain rate is higher than 7.5e-14 s^{-1}.

Role of grain size

Grain size reduction induces the strain localization and decreases the strength of detachment faults.

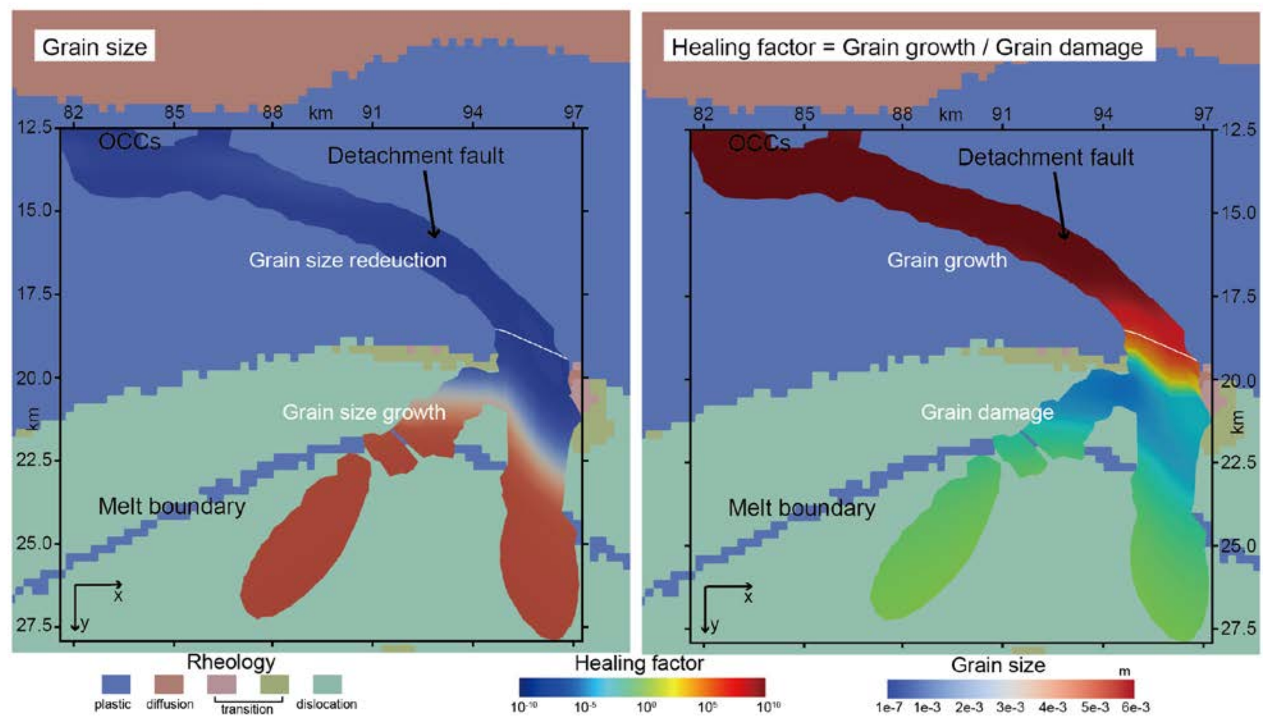


Figure 4. Grain size and healing factor distribution in the model with grain size evolution. In the left panel, grain size reduction induces diffusion creep. White line is the rheological boundary.

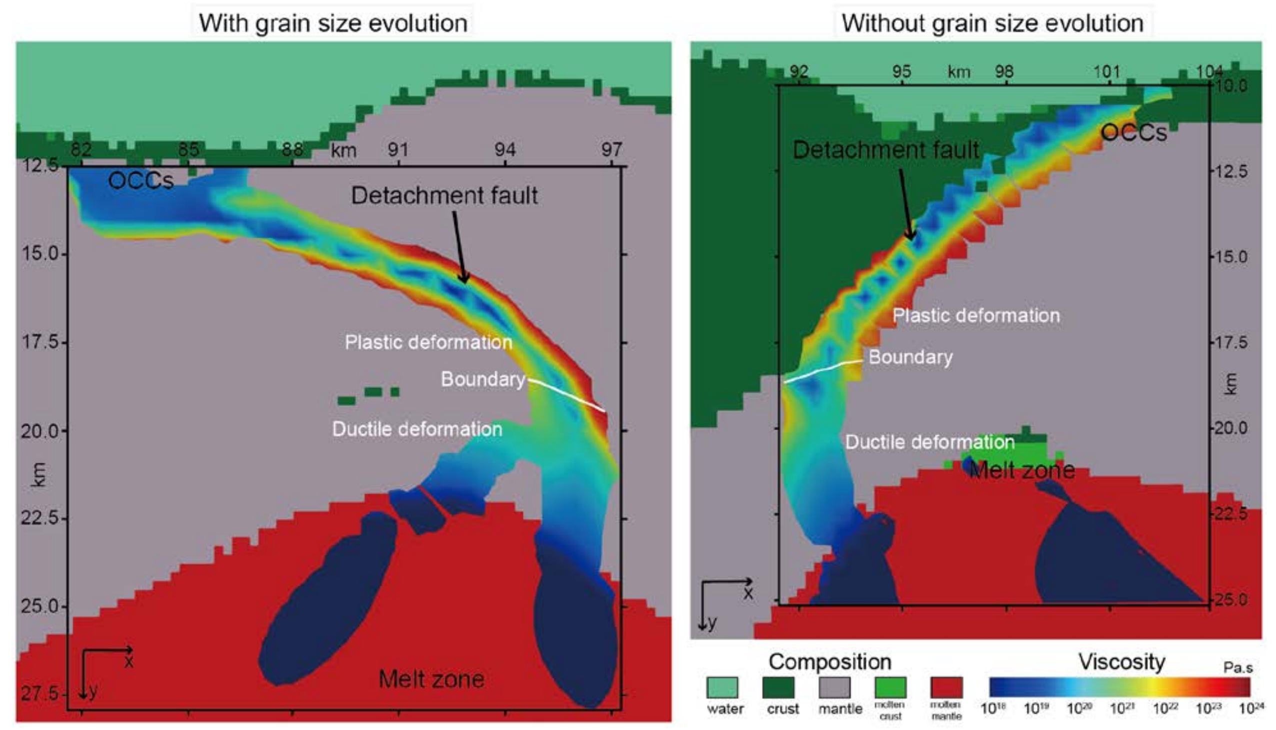


Figure 5. Zoom in the detachment faults in numerical results with and without grain size evolution.

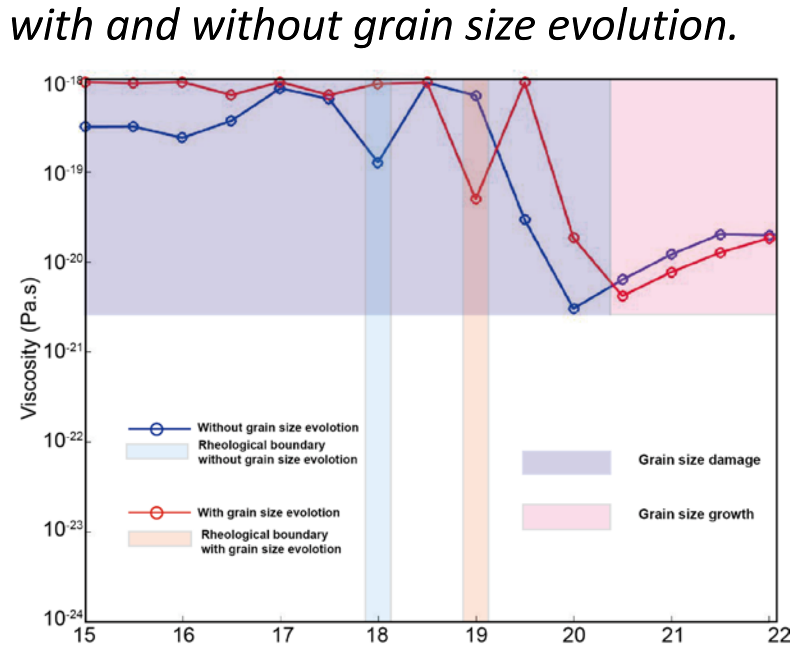


Figure 6. The strength of detachment faults.

When compared the model without grain size evolution, grain size damage decreases the detachment fault strength and induces the diffusion creep.

3D distribution

The irregular of intrusion magma along the spreading center induces uneven plastic and ductile transition and leads to the corrugations on the exhumed footwall. In addition, ridge migration in low magma supply can develop the megamullion.

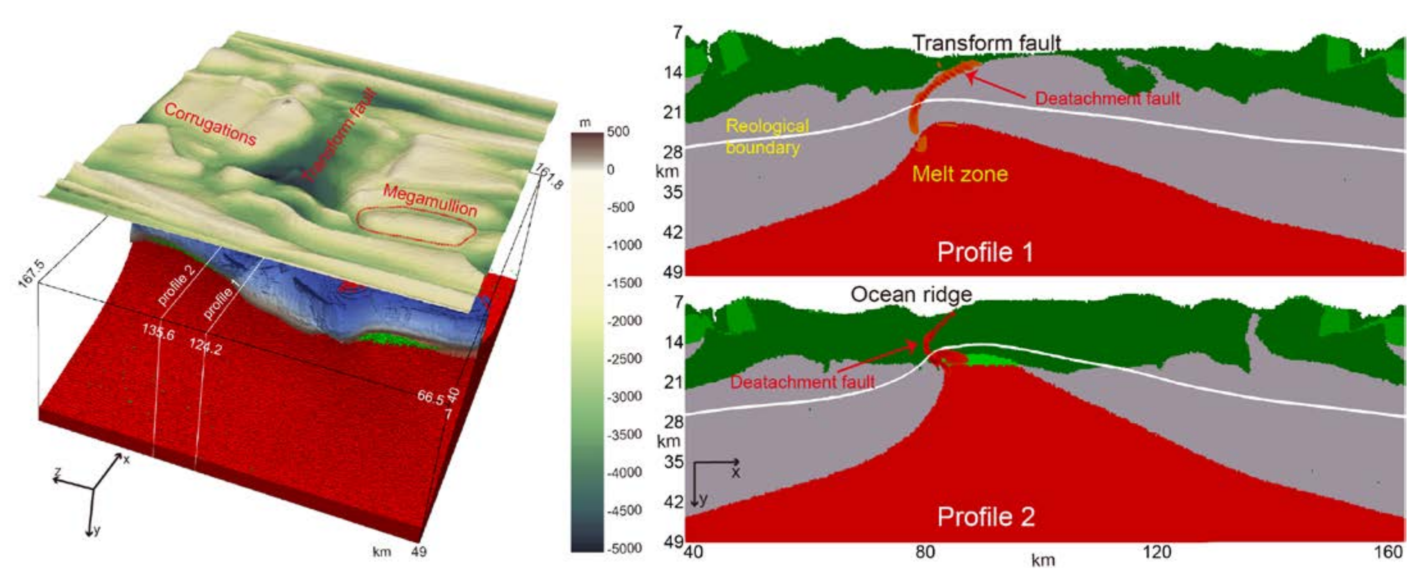


Figure 7. Topography, magma chambers and detachment fault.

At the slow-ultraslow spreading rate, poor magma supply induces the exhumation of lower crustal and mantle rocks by the detachment at the mid-ocean ridge. However, the ridge offsets, inducing the much less magma at the transform fault, which mainly exhumes mantle rocks and is characterized by very deep bathymetry.

Conclusions

- Grain size reduction induce the diffusion creep with strain localization and decreases the strength of detachment faults;
- The fault angle changes from flat to steep in the plastic deformation and is near-vertical in the ductile deformation.
- Irregular of intrusion magma induces the corrugation and ridge migration leads to the megamullion;
- Offset of ridge results in the less magma and develops the transform fault.

References

[1] Gerya, T. (2019). [2] Maffione, M., et al. (2013). Scientific reports.

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