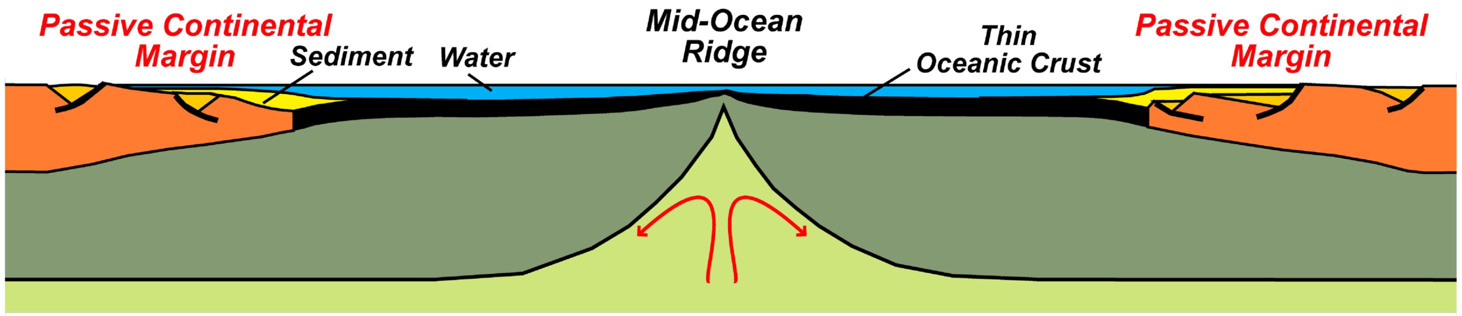
Forced subduction initiation near spreading centers: effects of brittle-ductile damage

Mingqi Liu, Taras Gerya

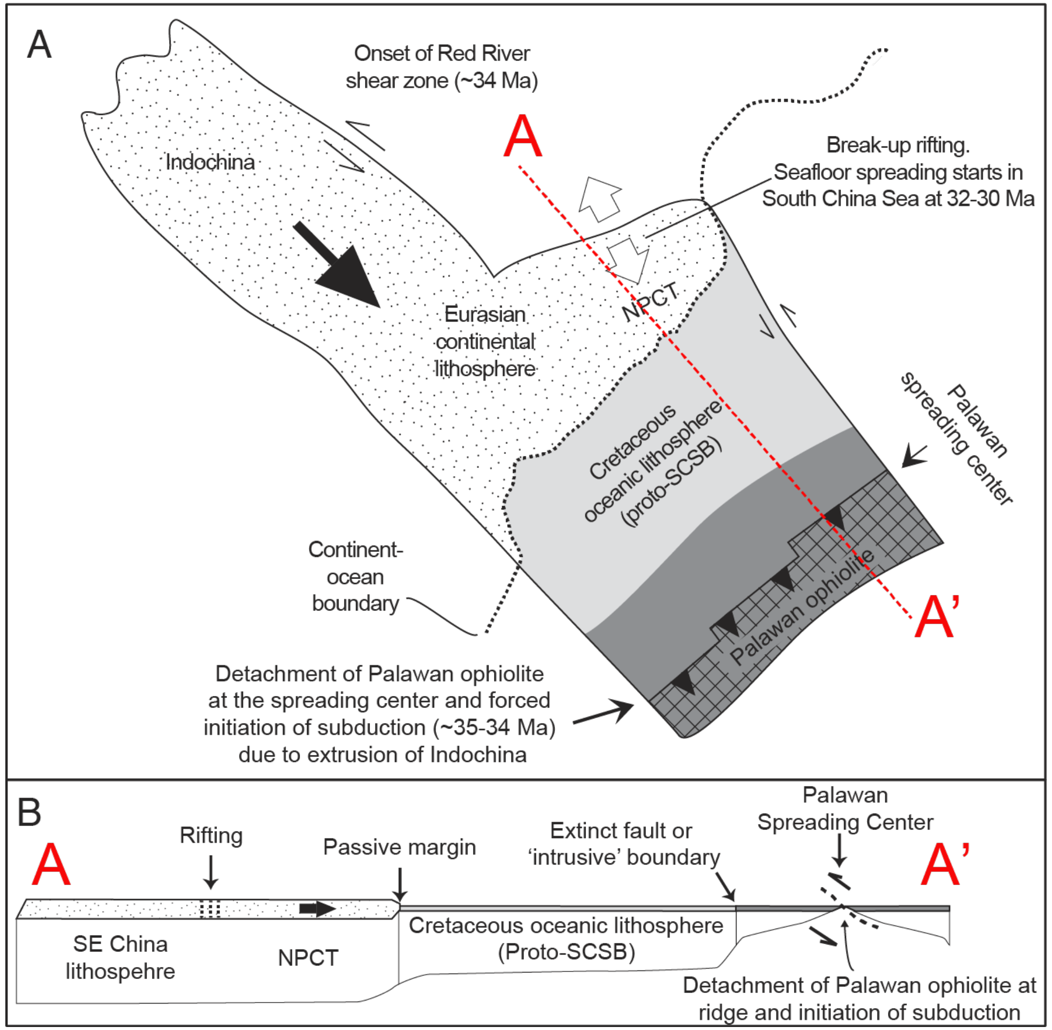
Department of Earth Sciences, ETH Zurich, Sonneggstrasse 5, CH-8092 Zurich



[Lillie, 2005]

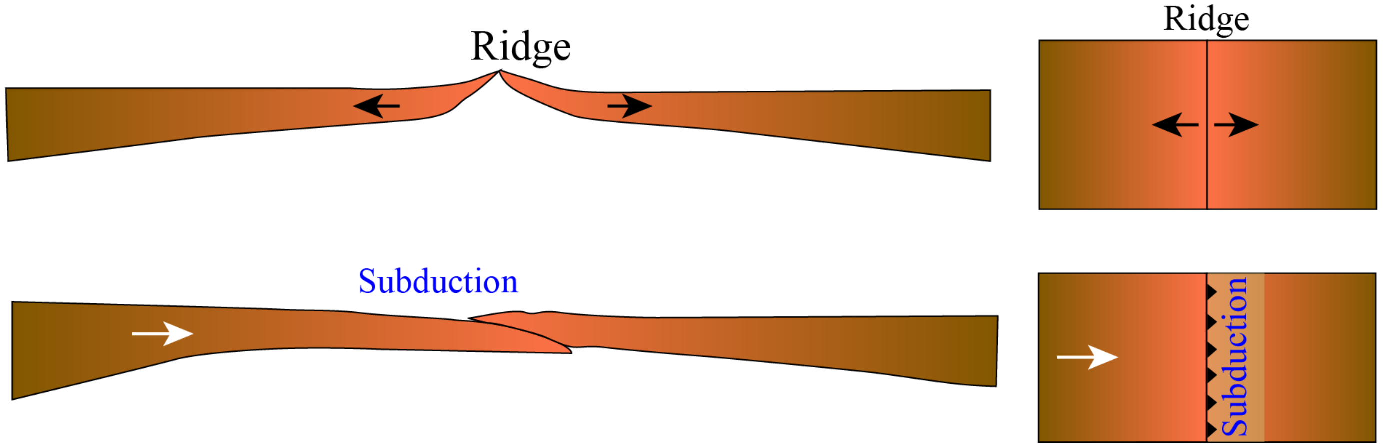
The **hot and positively buoyant** Mid-ocean Ridge prevents the spontaneous subduction initiation.

However, as the **weakest part with a hot and thin brittle layer** in the earth, it is **much easier to start subduction** than the cold ad strong passive margin during forced compression.



[Keenan et al., 2016]

Previous numerical studies

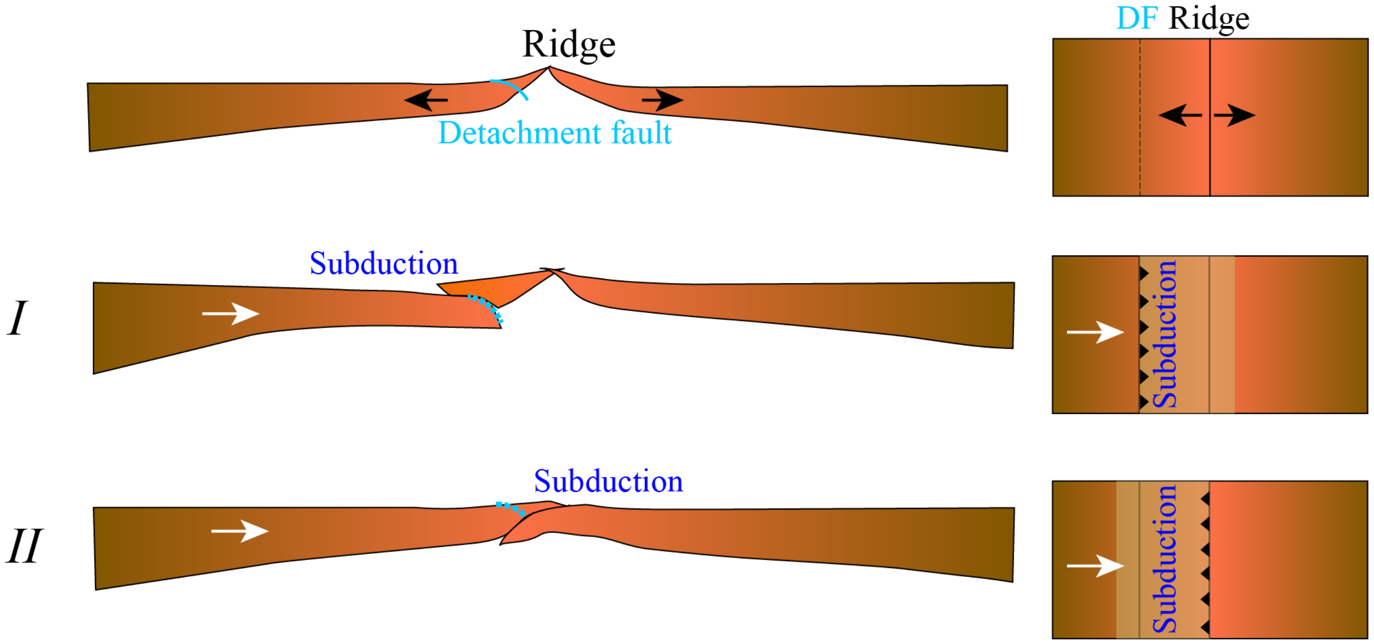


Symmetric ridge: subduction initiation occurs at the mid-ocean ridge [Qing et al., 2021]

Inherited ridge:

I. Subduction initiation is controlled by detachment faults [Maffione et al., 2015]

II. Incipient subduction cuts detachment fault [Gülcher et al., 2019]



The mechanism is not clear!

Numerical methods and model setup

- **Methods** – *Grain size evolution*

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

- **Effective rheology**

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

Brittle dominates:

$$\eta_{plastic} \le \eta_{ductile}$$

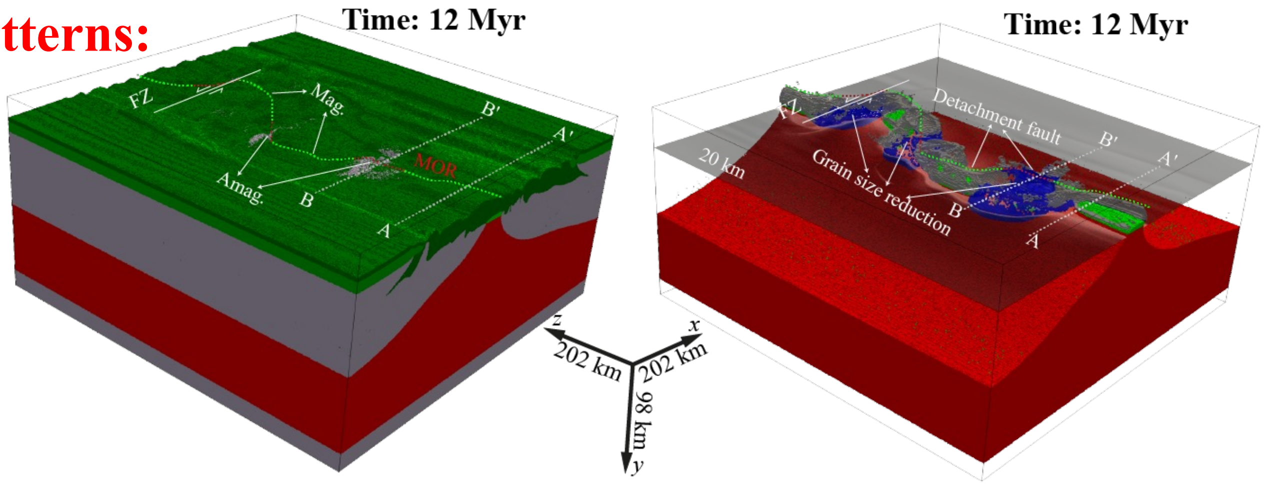
$$\eta_{eff}=\eta_{plastic}$$

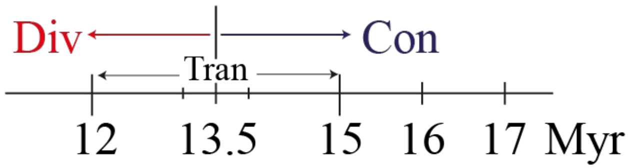
Ductile dominates:

$$\eta_{plastic} > \eta_{ductile}$$

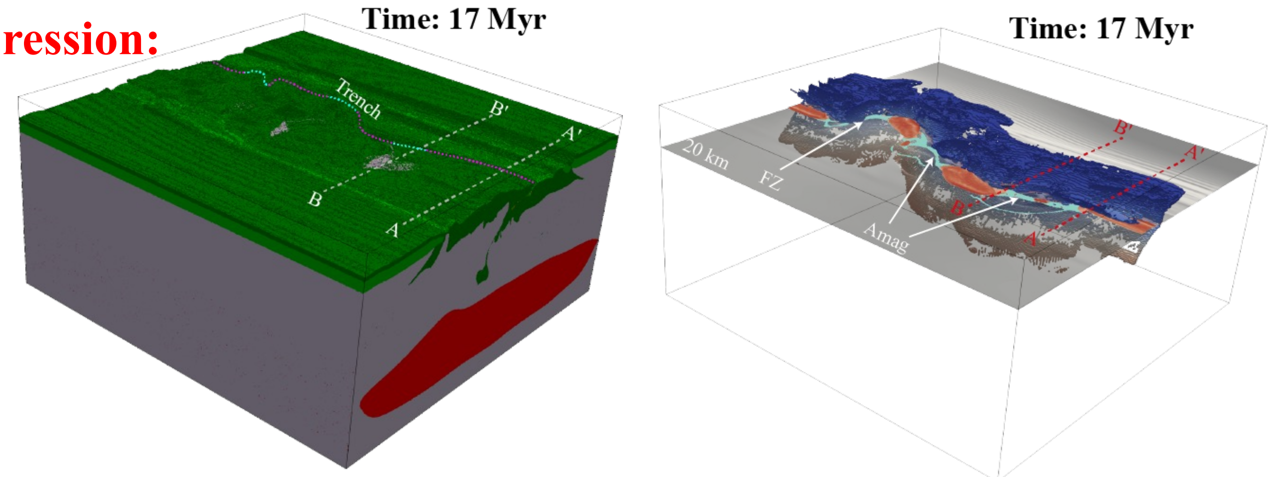
$$\eta_{eff}=\eta_{ductile}$$

Initial model with inherited patterns:





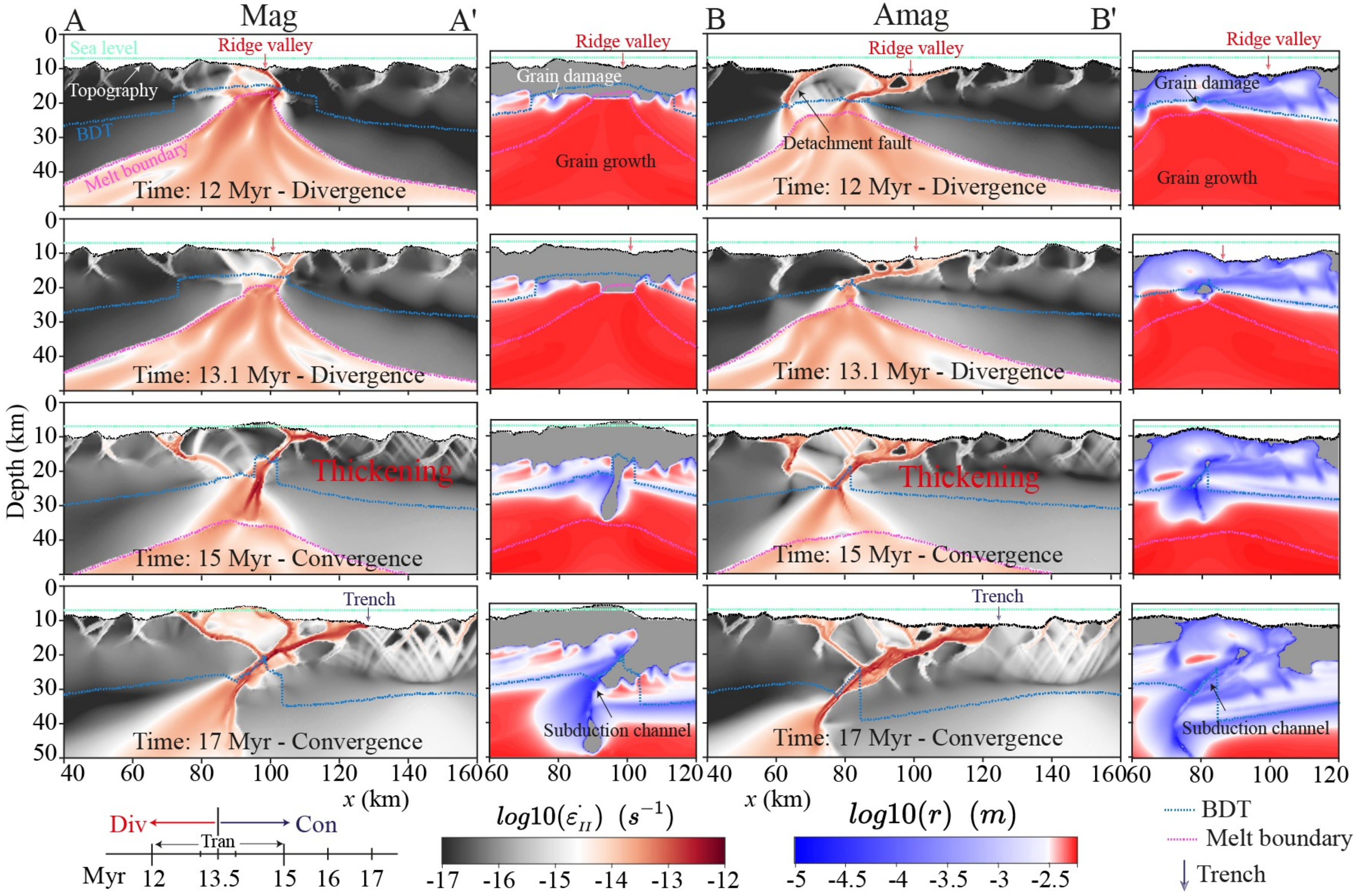
Model result after forced compression:



Numerical results

Profiles AA’

Profiles BB’



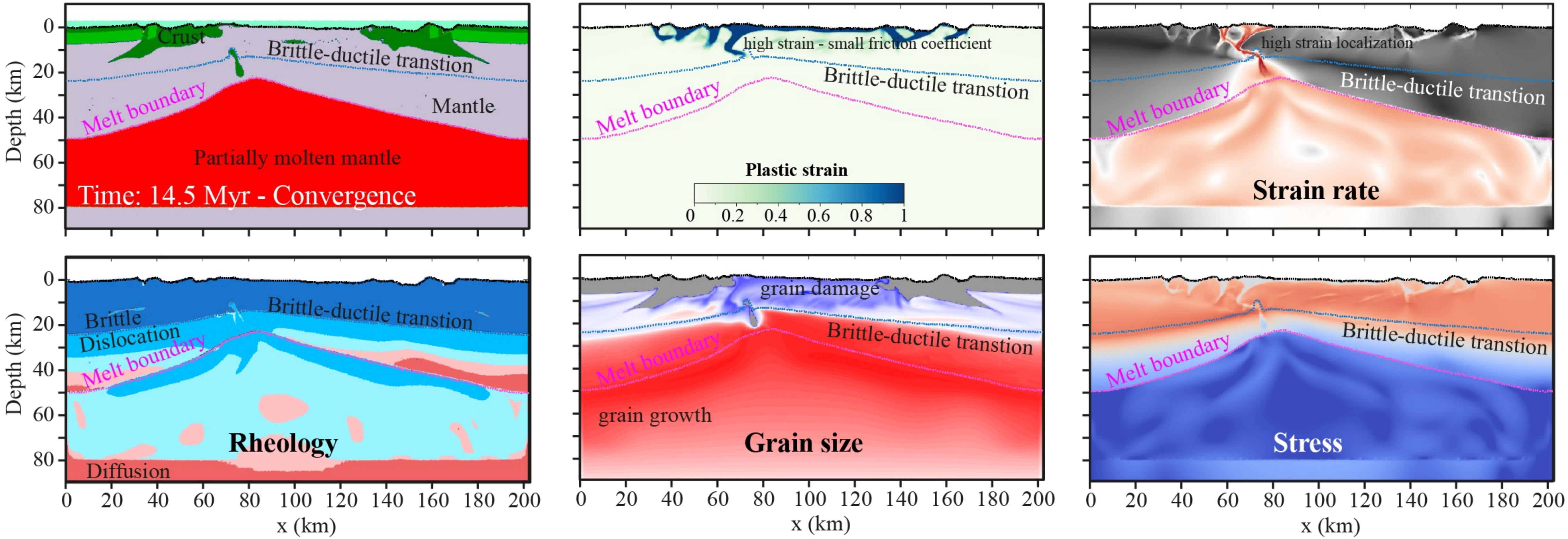
Inherited spreading patterns

Shortening and thickening under compression

Forming a new weak shear zone

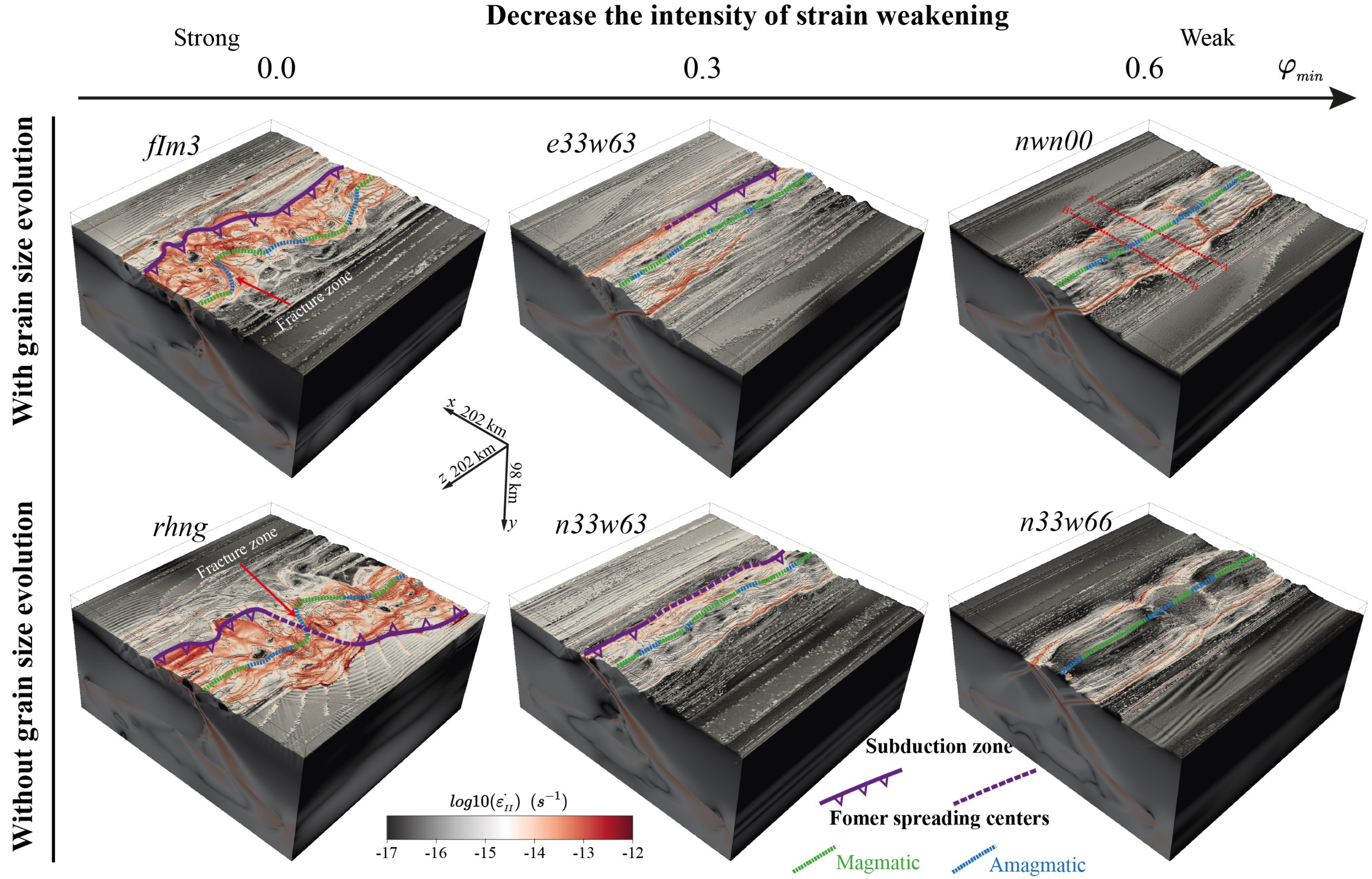
Subduction along the new shear zone

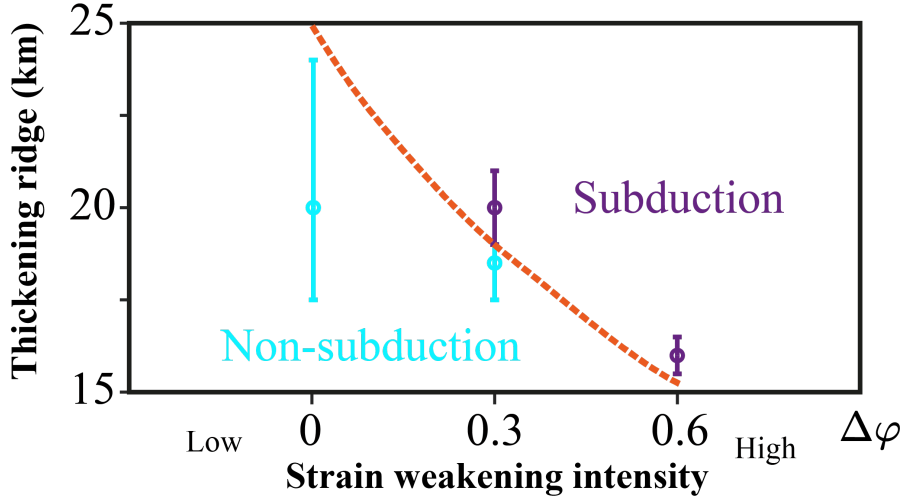
Effects of brittle-ductile damage



During forced compression, the effect of grain size reduction is not enough to dominate and reduce the effective viscosity. The shortening process is mainly controlled by strain weakening.

Effects of brittle-ductile damage

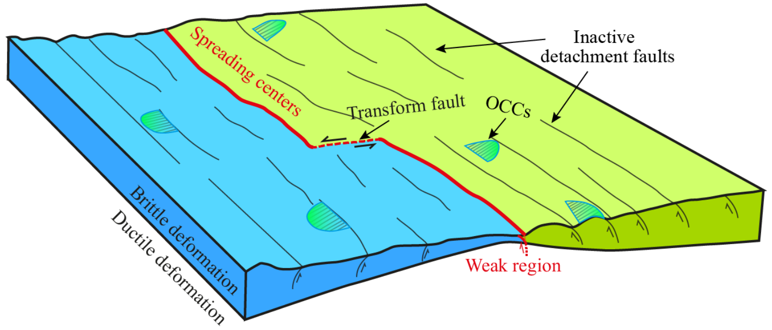


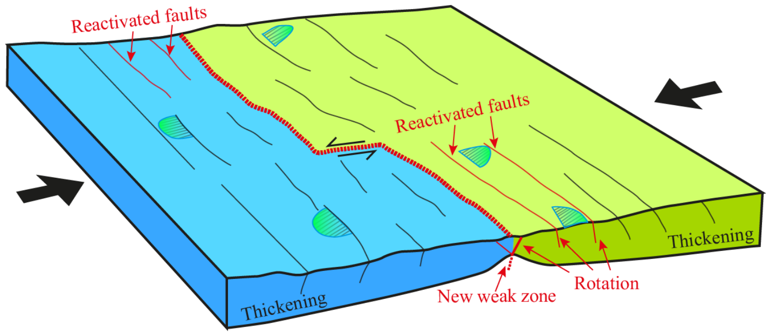


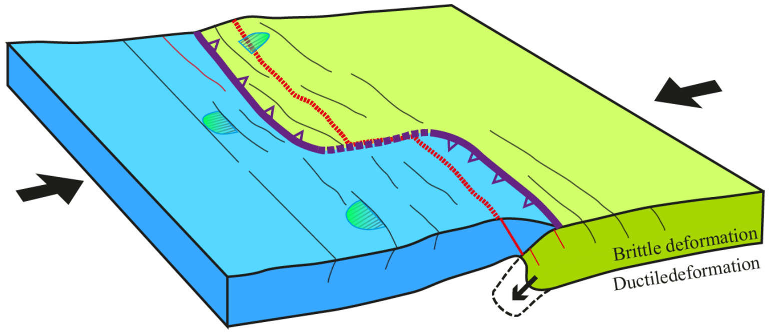
Fault strength (caused by strain weakening intensity) is the key factor in controlling the near ridge subduction initiation.

Conclusion

Evolution processes:


(a) ***Initial stage - mature tectonic patterns***


(b) ***Shortening and thickening under compression***

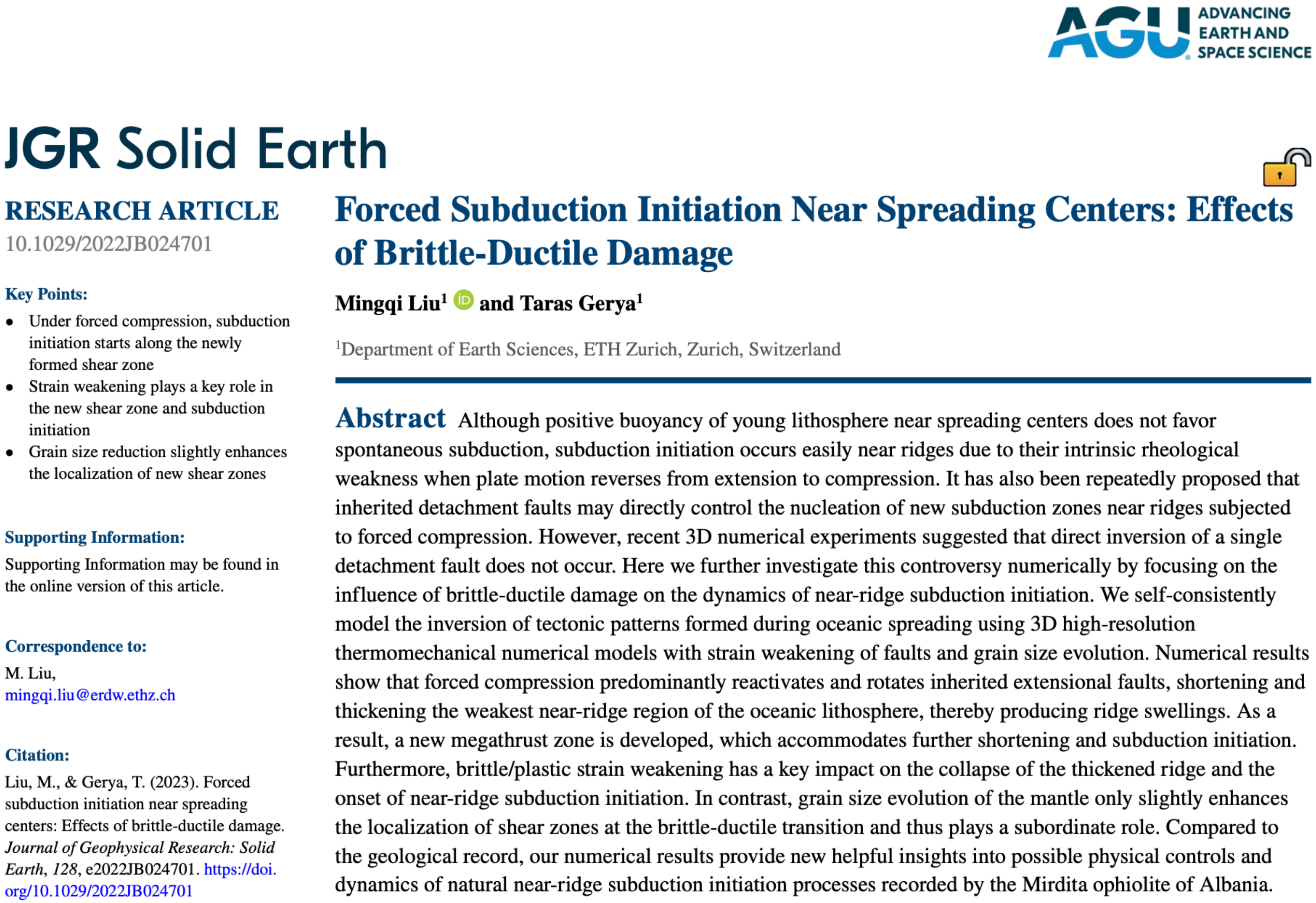

(c) ***Subduction initiation along the new weak zone***

Mature spreading ridges with inherited faulting patterns and spreading modes.

- Shortening and thickening through rotation of inherited faults
- Form a new weak shear zone
- Controlled by the fault strength

- Subduction along the newly formed shear zone
- Spreading patterns control subduction modes

Thank you for your attention!



AGU ADVANCING EARTH AND SPACE SCIENCE

JGR Solid Earth

RESEARCH ARTICLE
10.1029/2022JB024701

Key Points:

- Under forced compression, subduction initiation starts along the newly formed shear zone
- Strain weakening plays a key role in the new shear zone and subduction initiation
- Grain size reduction slightly enhances the localization of new shear zones

Supporting Information:

Supporting Information may be found in the online version of this article.

Correspondence to:

M. Liu,
mingqi.liu@erdw.ethz.ch

Citation:

Liu, M., & Gerya, T. (2023). Forced subduction initiation near spreading centers: Effects of brittle-ductile damage. *Journal of Geophysical Research: Solid Earth*, *128*, e2022JB024701. https://doi.org/10.1029/2022JB024701

Forced Subduction Initiation Near Spreading Centers: Effects of Brittle-Ductile Damage

Mingqi Liu[1] and Taras Gerya[1]

[1]Department of Earth Sciences, ETH Zurich, Zurich, Switzerland

Abstract Although positive buoyancy of young lithosphere near spreading centers does not favor spontaneous subduction, subduction initiation occurs easily near ridges due to their intrinsic rheological weakness when plate motion reverses from extension to compression. It has also been repeatedly proposed that inherited detachment faults may directly control the nucleation of new subduction zones near ridges subjected to forced compression. However, recent 3D numerical experiments suggested that direct inversion of a single detachment fault does not occur. Here we further investigate this controversy numerically by focusing on the influence of brittle-ductile damage on the dynamics of near-ridge subduction initiation. We self-consistently model the inversion of tectonic patterns formed during oceanic spreading using 3D high-resolution thermomechanical numerical models with strain weakening of faults and grain size evolution. Numerical results show that forced compression predominantly reactivates and rotates inherited extensional faults, shortening and thickening the weakest near-ridge region of the oceanic lithosphere, thereby producing ridge swellings. As a result, a new megathrust zone is developed, which accommodates further shortening and subduction initiation. Furthermore, brittle/plastic strain weakening has a key impact on the collapse of the thickened ridge and the onset of near-ridge subduction initiation. In contrast, grain size evolution of the mantle only slightly enhances the localization of shear zones at the brittle-ductile transition and thus plays a subordinate role. Compared to the geological record, our numerical results provide new helpful insights into possible physical controls and dynamics of natural near-ridge subduction initiation processes recorded by the Mirdita ophiolite of Albania.

Email: mingqi.liu@erdw.ethz.ch