# Early evolution and dynamics of Earth from a molten initial stage

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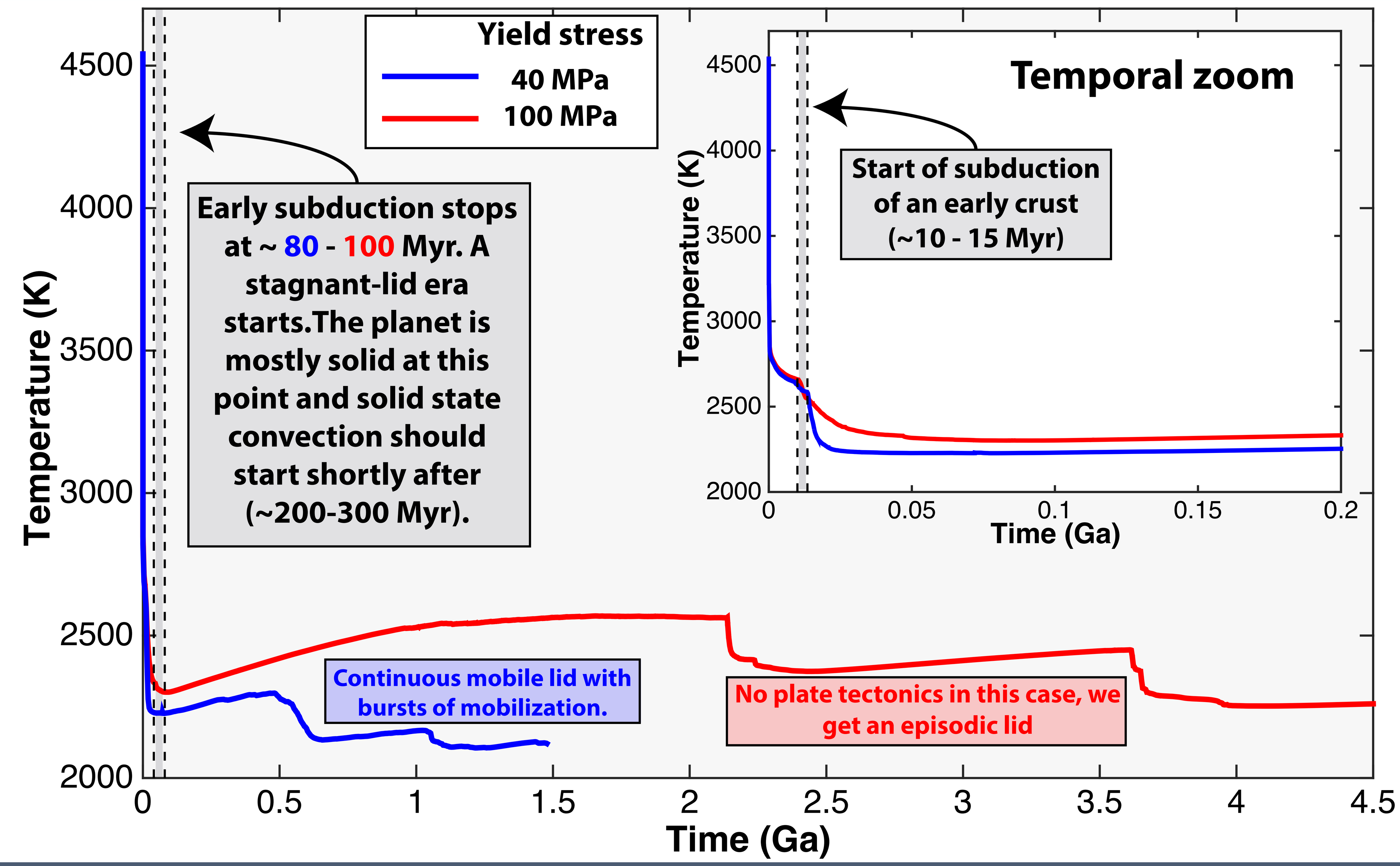
## Introduction

Most of the terrestrial planets underwent a magma ocean stage during their accretion. On Earth, it is probable that at the end of accretion, giant impacts like the hypothesized Moon-forming impact, together with other sources of heat, melted a substantial part of the mantle. The thermal and chemical evolution of the resulting magma ocean most certainly had dramatic consequences on the history of the planet.

Considerable research has been done on magma oceans using 1-D models[1,2,3]. However, some aspects of the dynamics may not be adequately addressed in 1-D and therefore require the use of 2-D or 3-D models.

The goal of our study is to understand and characterize the influence of melting on the long-term thermo-chemical evolution of rocky planet interiors, starting from an initial molten state (magma ocean). Our approach is to model viscous creep of the solid mantle, while parameterizing processes that involve melt as previously done in 1-D models.

## Results: temperature evolution




## Model

We used the code StagYY[4] with several improvements to treat melt:

- Ability to treat large melt fractions of up to 100 %
- Solid motion is completely resolved but processes involving melt are parameterised
- Magma effective-thermal-conductivity ($k_{eff}$) treatment for temperature
- Melt-solid separation at all melt fractions
- Radiative surface boundary condition: $F = \sigma T_e^4$
- Coupling to a parameterised core heat balance

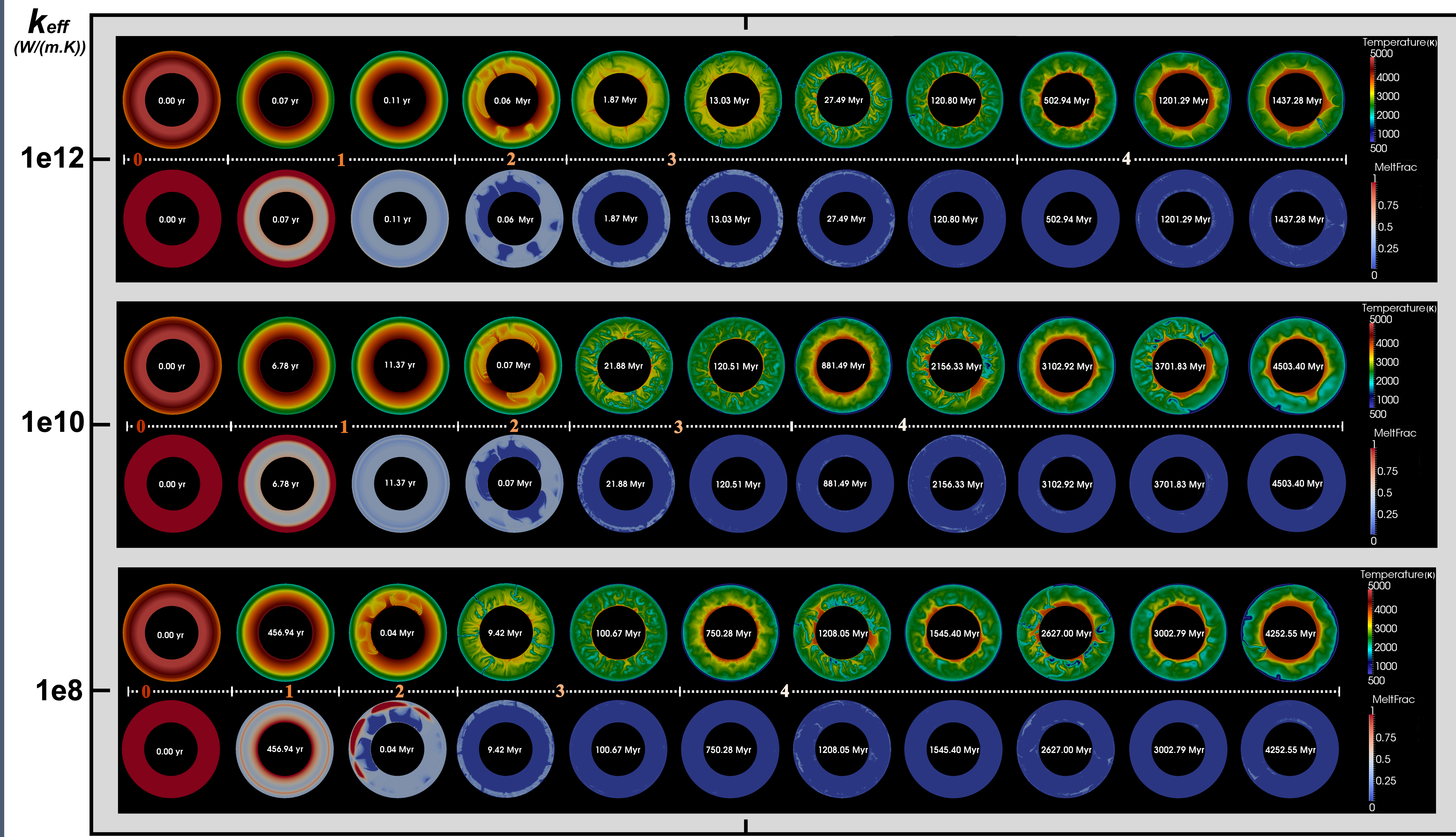
We vary in our tests:

- Effective-thermal-conductivity
- Initial mantle and core temperatures
- Use of treatment for core cooling
- Melt segregation (different densities for different melt phases)

## Bibliography

[1] Abe, Y. (1997), *Physics of the Earth and Planetary Interiors*
[2] Solomatov, V. S. (2007), *Treatise on geophysics*
[3] Elkins-Tanton, L. T. (2008), *Earth and Planetary Science Letters*
[4] Tackley, P. J. (2008), *Physics of the Earth and Planetary Interiors*

## Modelling results




**0.** Mantle starts fully molten in all cases.

**1.** Rapid cooling and crystallization until the rheological transition, then much slower crystallization (for lower $K_{eff}$, a molten layer above the CMB can stay for a longer time).

**2.** Large-scale overturn well before solidification (for lower $K_{eff}$, as a consequence of the cold downwellings, large areas in the upper mantle melt).

**3.** Formation and subduction of an early crust while a partially-molten upper mantle is still present.

**4.** Transitioning to mostly-solid-state long-term mantle convection and episodic lid/plate tectonics.

$T_{cmb}$ = 6000 K; $T_{0\_potential}$ = 4000 K; *With* core cooling