Modelling the effect of gravitational instabilities on the subduction zone initiation at passive margins

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Subduction is a widely studied process, but the mechanisms leading to the initiation of a new subduction zone are poorly understood. Two main types of subduction zone initiation (SZI) are currently recognised: induced, when tectonic convergence is dominant, and spontaneous, when SZI is mainly driven by local forces, i.e., the negative buoyancy due to the gravitational instability of the plate (Stern 2004; Stern and Gerya 2018; Crameri et al. 2020). The passive margins are potential sites for spontaneous SZI due to the natural gravitational instabilities that characterize these geodynamic settings, caused by density, composition, strength and temperature lateral contrasts, topographic discontinuity and sedimentary loading. These instabilities should favor the initiation of a new subduction zone (Stern and Gerya 2018; Lallemand and Arcay 2021; Arcay et al. 2020), but previous research suggests that these local forces are not strong enough to develop a self-sustained subduction and that the collapse of a passive margin without horizontal tectonic forcing would require an unlikely coincidence of multiple weakening mechanisms, casting doubt on the feasibility of spontaneous subduction under present-day tectonic conditions (Lallemand and Arcay 2021; Arcay et al. 2020).

In this work we explore if and how an initial gravitational phase, even if it doesn't lead to a passive margin collapse resulting in a spontaneous subduction initiation, induces weakening and deformation in the margin, and how this influences the induced SZI and the eventual subduction style once convergence begins to affect the margin. induced SZI and the eventual subduction style once convergence begins to affect the margin.

We performed 225 2D simulations using the finite-element code FALCON (Regorda et al. 2023) on a domain 3000 Km wide and 700 Km deep, representing a passive margin composed by a 20 Myr old oceanic lithosphere and a 90 Km thick continental lithosphere.

The models undergo a first gravitational phase, simulated with free-slip lateral boundaries, that can last for 0, 10, 20 or 30 Myr. After the gravitational phase, the convergence begins, simulated by imposing a convergence velocity of 0.01, 0.05, 0.1, 0.25, 0.5 or 1 cm/yr at the lateral boundaries, along all the lithospheric thicknesses. To investigate the response of the margin to the gravitational instability, we set up 3 viscous weakening intervals and 3 plastic laws, for a total of 9 weakening combinations.

The failure and the evolution of the passive margin have been explored in post processing, by evaluating the area within a certain distance from the trench in which the strain rate is higher than $2\ 10^{-14}$ 1/s, and the mean strain rate within this area.

During the gravitational phase, the models with a strong enough weakening combination show a strain rate localization, controlled by the plastic weakening law in the surface and by the viscous weakening interval in depth, that slowly fades over time. Once the convergence begins, this damaged zone is reactivated, and if the convergence velocity is high enough it evolves in a subduction plane. The subduction zone initiation starts before in the models that experienced strain rate localization during the gravitational phase, leading to the conclusion that the gravitational instabilities can trigger weakening processes capable of affecting the passive margin stability and the impact of the tectonic convergence on it.

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