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Passive margins getting squeezed in the mantle convection vice

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Quaternary coastal geomorphology reveals that passive margins underwent wholesale uplift at least during the glacial cycle. In addition, these not-so-passive margins often exhibit long term exhumation and tectonic inversion, which suggest that compression and tectonic shortening could be the mechanism that triggers their overall uplift. We speculate that the compression in the lithosphere gradually increased during the Cenozoic. The many mountain belts at active margins that accompany this event readily witness this increase. Less clear is how that compression increase affects passive margins.

In order to address this issue, we design minimalist 2D viscous models to quantify the impact of plate collision on the stress regime. In these models, a sluggish plate is disposed on a less viscous mantle. It is driven by a "mantle conveyor belt" alternatively excited by lateral shear stresses that represent a downwelling on one side, an upwelling on the other side, or both simultaneously. The lateral edges of the plate are either free or fixed, respectively representing the cases of free convergence and collision. In practice, it dramatically changes the upper boundary condition for mantle circulation and subsequently, for the stress field. The flow pattern transiently evolves almost between two end-members, starting from a situation close to a Couette flow to a pattern that looks like a Poiseuille flow with an almost null velocity at the surface (though in the models, the horizontal velocity at the surface is not strictly null, as the lithosphere deforms). In the second case, the lithosphere is highly stressed horizontally and deforms. For an equivalent bulk driving force, compression increases drastically at passive margins if upwellings are active because they push plates towards the collision. Conversely, if only downwellings are activated, compression occurs on one half of the plate and extension on the other half, because only the downwelling is pulling the plate. Thus, active upwellings underneath oceanic plates are required to explain compression at passive margins.

This conclusion is corroborated by "real-Earth" 3D spherical models, wherein the flow is alternatively driven by density anomalies inferred from seismic tomography -and therefore include both downwellings at subduction zones and upwellings above the superswells- and density anomalies that correspond to subducting slabs only. While the second scenario mostly compresses the active margins of upper plates and leave other areas at rest, the first scenario efficiently compresses passive margins where the geological record reveals their uplift, exhumation, and tectonic inversion.