Geophysical Research Abstracts
Vol. 14, EGU2012-7805, 2012
EGU General Assembly 2012

A free plate surface and weak oceanic crust produce single-sided subduction on Earth

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Subduction zones on present-day Earth are strongly asymmetric features (Zhao 2004) composed of an overriding plate above a subducting plate that sinks into the mantle. While global self-consistent numerical models of mantle convection have reproduced some aspects of plate tectonics (e.g. Tackley 2000, van Heck & Tackley 2008), the assumptions behind these models do not allow for realistic single-sided subduction. Here we demonstrate that the asymmetry of subduction results from two major features of terrestrial plates: (1) the presence of a free deformable upper surface and (2) the presence of weak hydrated crust atop subducting slabs. We show that by implementing a free surface on the upper boundary of a global numerical model instead of the conventional free-slip condition, the dynamical behaviour at convergent plate boundaries changes from double-sided to single-sided. Including a weak crustal layer further improves the behaviour towards steady single-sided subduction by acting as lubricating layer between the sinking plate and overriding plate.

For this study we perform experiments in 2-D and global 3-D spherical, fully dynamic mantle convection models with self-consistent plate tectonics. These are calculated using the finite volume multigrid code StagYY (Tackley 2008) with strongly temperature and pressure-dependent viscosity, ductile and/or brittle plastic yielding, and non-diffusive tracers tracking compositional variations (the 'air' and the weak crustal layer in this case). The free surface is implemented using a „sticky air" layer, which is proven to be a good approximation if its thickness and its viscosity are sufficiently high and low, respectively (Schmeling et al., 2008; Crameri et al., submitted).

In conclusion, a free surface is the key ingredient to cause single-sided subduction, while a weak crustal layer does not cause single-sided subduction on its own, but helps to stabilise on-going subduction.

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