Physical controls of intra-oceanic arc extension and trench migraton: numerical modelling

Bettina Baitsch Ghirardello, Taras Gerya, Institute of Geophysics, Department of Earth Science ETH Zurich, Switzerland

Since most of the modern intra-oceanic collision zones have an extension, it is important to understand how and where these extensions are created and what the decisive factors are. Why are there no extensions in certain subduction zones? Why can basins with a thin crust be observed, while in other places the crust spreads and a new magmatic arc is produced? How does a trench migrate through time? What is the influence of slab fluids and melt production in the mantle wedge on the extension process? In order to answer these questions we performed systematic numerical experiments with 2D coupled petrological-thermo-mechanical numerical model of an intra-oceanic subduction process. Over time, part of our numerical models developed a spontaneous slab retreat associated with flattening of the slab angle, an extension of the overriding plate and formation of a new spreading centre. Five relevant types of trench migration are established: a) retreating, b) advancing c) episodic retreating and advancing, d) periodic change of quiescence and retreating, and e) stable trench position over time.

Additionally, our results indicate that weakening effects from subduction related melts play a major role in defining where overriding plate extension is localized (i.e. in the for-arc, in the back-arc or within the arc). According to the general trend the stronger the weakening is, the more the extension shifts toward the back-arc direction. Intensity of the fore-arc weakening by slab-derived fluids also plays a notable role: if such weakening is insufficient two plates are strongly coupled, which results in compressive subduction without the overriding plate extension. Furthermore, this weakening affects the trench migration together with other physical parameters, such as subduction rate and ages of subducting and overriding plate.

Different extension types in our models agree well with observations in nature. For example, in nature, intra-arc extension may split an initially homogeneous arc in two distinct parts such as the active Mariana arc and the inactive West Mariana Ridge and create thin oceanic crust between them like the Mariana Trough, similar to our experiments. In nature, we also observe different movements of the trenches over time. For example, the extension within the Miocene Mariana arc divided into two arcs and the trench migrate backward (our model produces a back arc after 12 to 14 Ma). A change of motion in the migration of the Izu-Bonin trench is described in many papers (our model produces in some cases after 20 to 25 Myr reversal changes in motion – episodic retreating and advancing).

Furthermor, our results are partially consistent with those of Clark et al. (2008), who describe three different activities of trenches in nature, and those form Lallemand et al. (2008) escribing the relationship between the velocities of the upper and the subducting plate and the slab age at trench and with those from Miller et al. (2006), who have reconstructed tectonic motions along the Kurile-Japan-Izu-Bonin-Mariana arc system by comparing high-resolution tomographic images and updated paleogeographic reconstructions.

Experiments with different weakening effects by fluid and melt and trench migration over the time

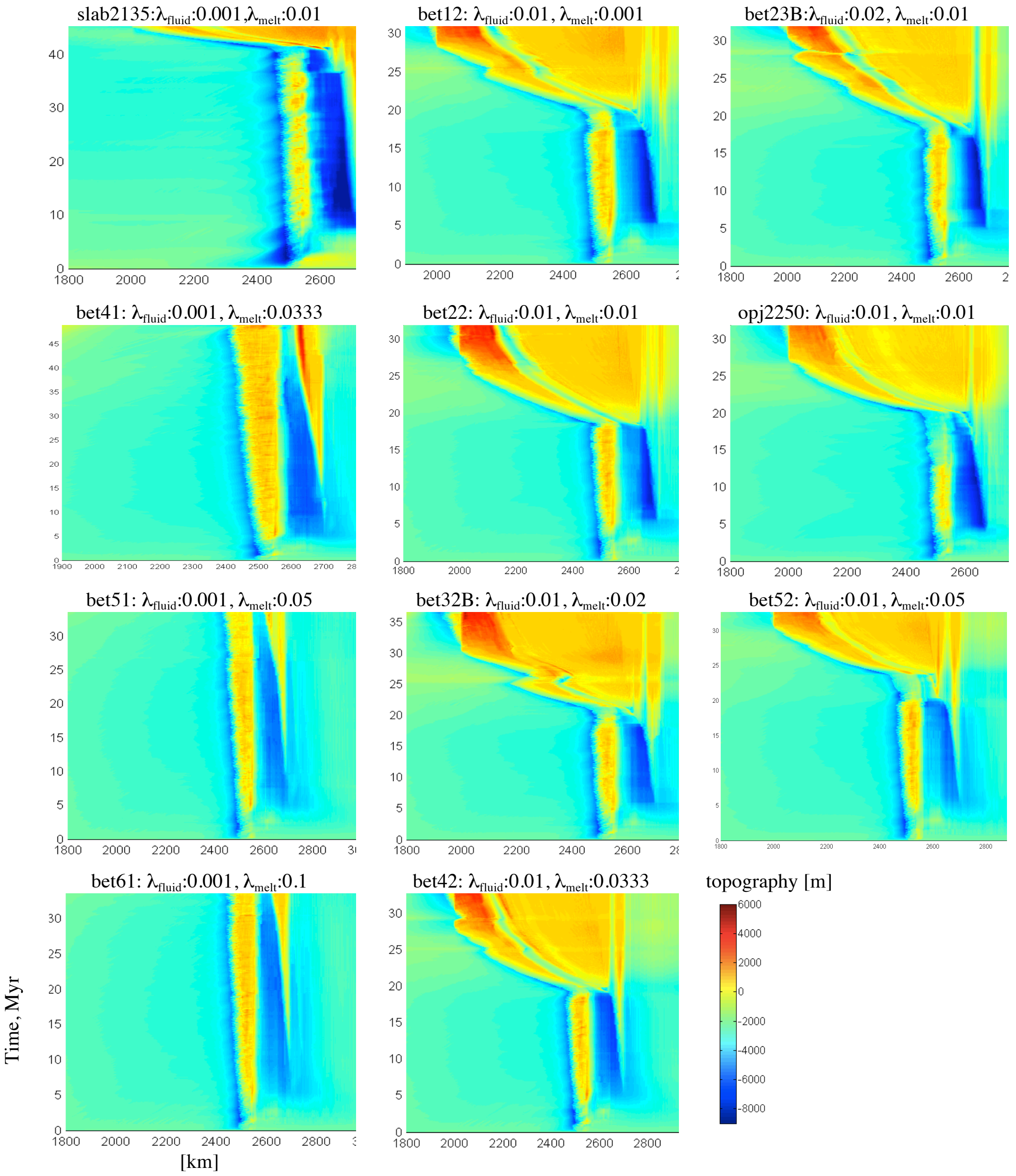

Fig. 1 Development of model topography with time as a function of model parameters (lambda fluid = 1 - P_{fluid}/P_{solid}, lambda melt = 1 – P_{melt}/P_{solid}).

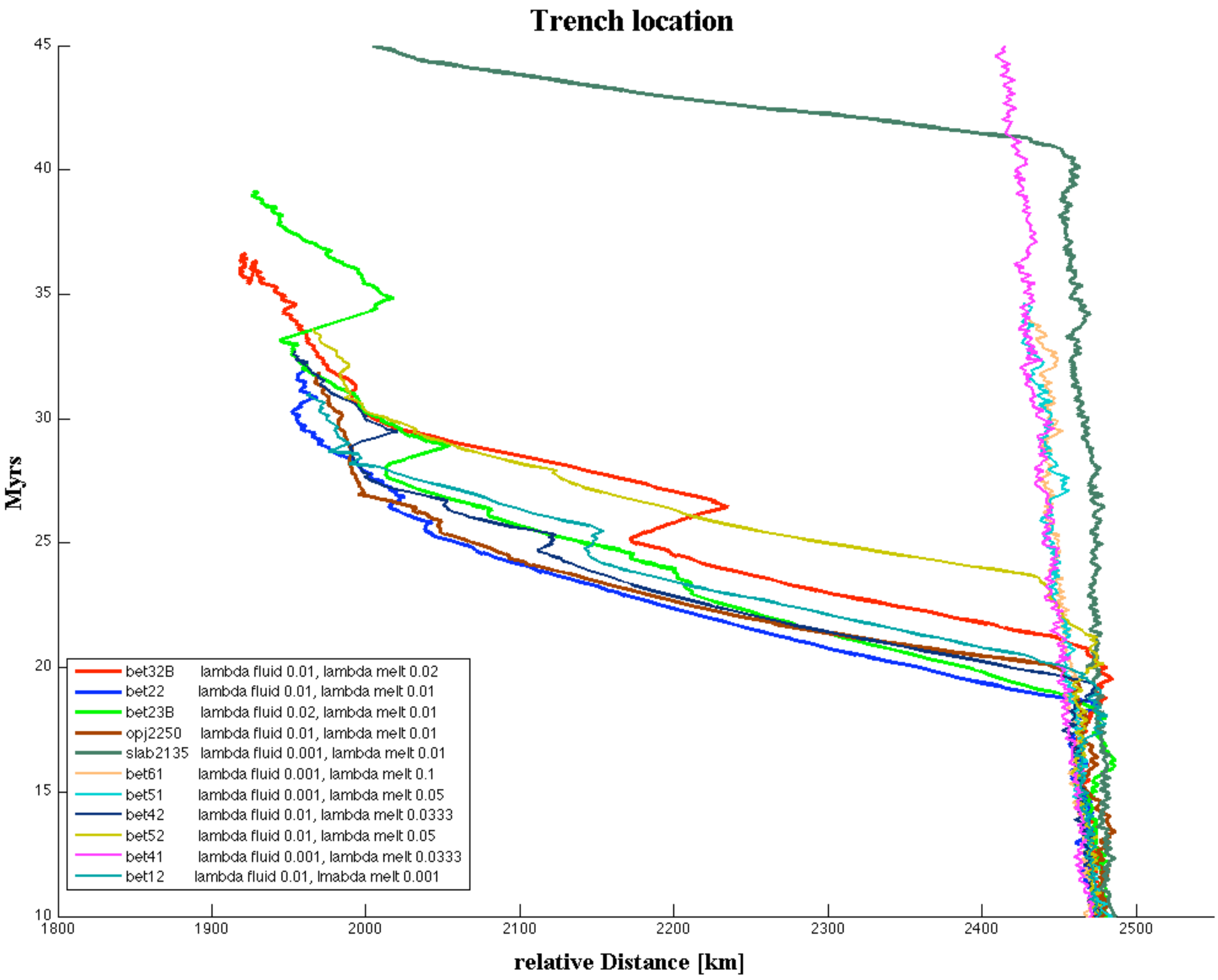

Fig. 2 Evolution of trench position with time for models with variable fluid/melt rheological weakening effects (lambda fluid = 1 - P_{fluid}/P_{solid}, lambda melt = 1 – P_{melt}/P_{solid}).