SOME EXPERIMENTAL INSIGHTS INTO SUBDUCTION ROLLBACK, ARC FORMATION AND BACK-ARC EXTENSION

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Results of scaled analogue experiments are presented to model the processes of subduction rollback, arc formation and back-arc extension. Two different types of models have been build. The first type investigates the processes of arc formation and back-arc extension, focussing on the structural evolution in the back-arc region for various boundary conditions applied to the overriding plate. The second type investigates the process of slab rollback in the upper mantle resulting from the slab's negative buoyancy and the role of slab rollback in upper mantle convection.

In the back-arc extension models, analogue experiments have been build with a two-layered brittle-ductile system confined in a box, representing the overriding lithosphere, overlying a low-viscosity layer representing the asthenosphere. An extensional boundary condition was applied to one side of the box simulating the retreat of the subducting slab, which resulted in extension and spreading of the overriding model lithosphere. Three different extensional boundary conditions were applied simulating three different types of back-arc spreading and extension: radial (e.g. Hellenic arc), unidirectional (e.g. Scotia arc) and asymmetrical spreading (e.g. New Hebrides arc). The results of the asymmetrical model are most realistic (Fig. 1), resulting from the boundary conditions in this model that closely reflect the boundary conditions in natural examples of asymmetrical rollback and back-arc extension. The asymmetrical model provides an explanation for spreading ridges and graben structures striking at high angle to the arc, which are found in several back-arc regions that supposedly formed due to asymmetrical rollback (e.g. North Fiji Basin, Kuril Basin + Sea of Okhotsk).

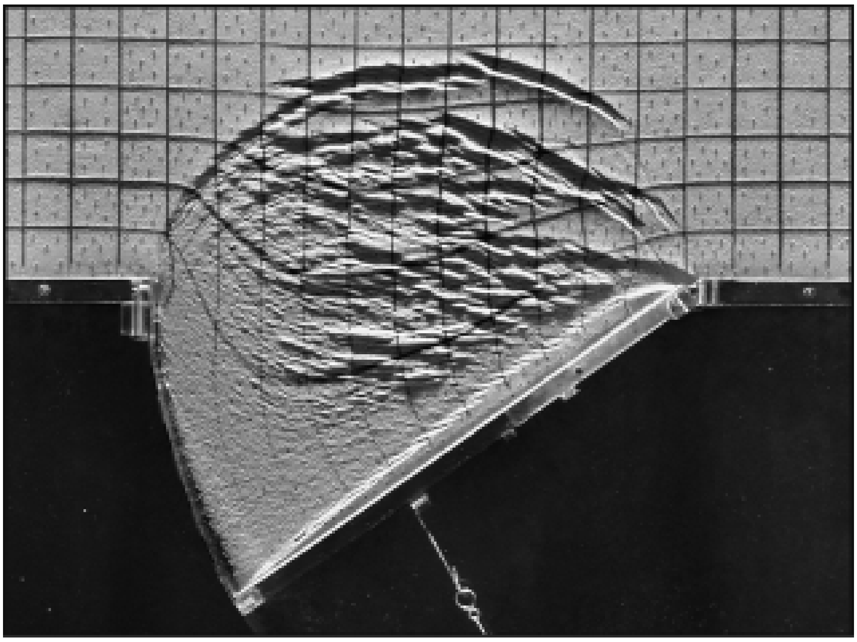

Fig. 1. Top view of experiment 3 showing asymmetrical extension of a two-layered system (simulating overriding lithosphere) during retreat of a door (simulating retreating hinge-line) after 2 hours and 54 minutes. Grid-line spacing is 3 cm.

In the subduction rollback models, three-dimensional fluid dynamical experiments have been build with a high-viscosity high-density layer (subducting lithosphere) overlying a low-viscosity lower-density layer (sub-lithospheric upper mantle). A small subduction instability was created at the tip of the lithosphere and the system was then allowed to evolve naturally (Fig. 2). The trailing edge of the subducting lithosphere is either fixed, free or is being pushed at a constant velocity by a piston. Results show that without a piston push, hinge-line migration is in all cases regressive.

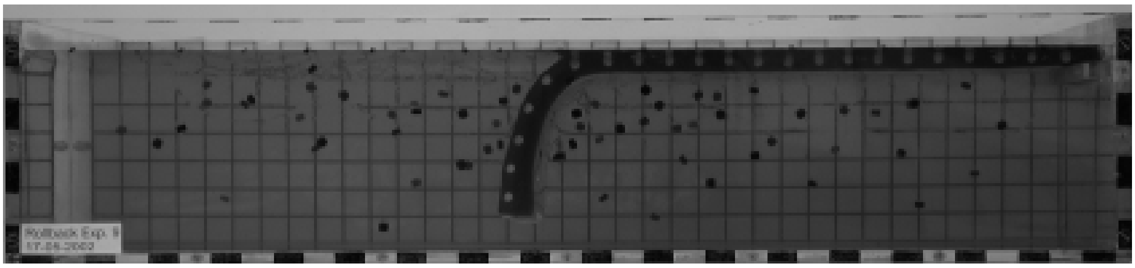

Fig. 2. Side view of experiment 9 showing subduction and rollback of a dense plate (simulating subducting lithosphere) into a less dense layer (simulating sub-lithospheric upper mantle) after 16 minutes. Plate is fixed at trailing edge. Grid-line spacing is 2 cm.

The migration rate increases exponentially during the free sinking of the slab until it approaches the bottom of the box (simulating upper-lower mantle discontinuity assumed to be impenetrable), resulting in a decrease in migration rate followed by a renewed increase and finally approaching a steady state. Slab retreat results in forced convection of sub-lithospheric mantle from underneath the slab towards the mantle wedge. The experimental results show that flow underneath the slab tip is negligible and almost all flow occurs laterally around the edges of the slab. This lateral flow forces the hinge-line of the subducting plate to attain a convex shape towards the direction of retreat. During the free sinking of the slab, it transmits tensional stresses to the horizontal part of the plate, which increase with increasing slab length and slab dip angle but constitute only a small percentage of the total negative buoyancy force of the slab. Finally, the slab preferentially retreats when its dip has an angle close to 90°. In this position, the slab does not sink vertically downwards but sinks at an inclined angle in a regressive manner in order to minimise internal slab deformation and asthenosphere flow.

Keywords: arc formation, back-arc extension, lithospheric slab, subduction, rollback, upper mantle, convection, analogue modelling.