Geophysical Research Abstracts
Vol. 21, EGU2019-16580, 2019
EGU General Assembly 2019

The Alpine cycle: Modelling orogenic wedge formation from generation of hyper-extended passive margins and forced subduction to continent-continent collision

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Many orogens, such as the Western Alps, are characterised by the collision of hyper-extended margins. Before the onset of subduction these margins may have undergone several phases of deformation including rifting periods and periods without significant deformation in which the margins have been thermally relaxed. In consequence, modelling orogenic wedge formation in a self-consistent manner with application to the Western Alps requires modelling over large time spans (∼200 Ma) and sufficiently high resolution of the distinct deformation phases in both space and time.

We perform high resolution long-term (>200 Ma) 2D thermo-mechanical numerical simulations including the lithosphere and upper mantle down to 660 km depth to study the dynamics of the Alpine cycle. Modelling of this cycle is subdivided into the following four stages: (I) in a slow spreading rift system of 60 Ma duration a ∼400 km wide basin is generated which contains exhumed lithospheric mantle and is bounded by regions of hyper-extended continental crust. (II) the modelled basin and hyper-extended passive margin system is thermally relaxed for 70 Ma. During this stage, the lithosphere is neither compressed nor extended. No spontaneous subduction initiation due to the densification of the cooling exhumed mantle occurs in the models. (III) the evolved system is shortened and a one-sided, forced subduction is initiated by thermal softening within the proximal part of the passive margin without prescribing any weak zone. (IV) after ca. 60 Ma of convergence the basin is closed and an orogenic wedge forms during continent-continent collision.

We first quantify the impact of the initial geometric configuration from the onset of rifting on the Alpine cycle by varying the mechanical strength of the crust, being either an alternating sequence of horizontal mechanically strong and weak layers, or a homogeneous crust. Second, we investigate the control of lithospheric mantle characteristics on the Alpine cycle by (I) varying the rheological flow law of the mantle, (II) computing effective densities by either using a linearized equation of state, or a precomputed look-up table using Perple_X and (III) investigating the impact of serpentinisation of the lithospheric mantle exhumed in the basin by replacing the olivine rheology of the topmost 7 km by an antigorite rheology.

First results show that rheology and density structure of the mantle lithosphere have a strong impact on the establishment and intensity of upper mantle convection. When convection cells are established a long-term thermal field is stabilised so that Moho temperatures do not decrease during the 130 Ma of extension and thermal relaxation. The geothermal profile across the passive margins is a crucial parameter for their effective strength and for subsequent forced subduction initiation by thermal softening. The flow law of the mantle lithosphere hence controls upper mantle convection which controls the pre-convergence thermal state which controls subduction initiation and the style of deformation within the resulting orogenic wedge.