depth (temperature). Experiments are performed in a thermomechanical shortening box, where a 3 °C vertical temperature difference (from 37 to 40 °C) in the paraffin models is attained. In our experimental configuration a velocity discontinuity is imposed at the subduction slot, where the base plate is pulled below a rigid backstop. The mobile base plate dips 5°. Three different backstop dips are used, 90°, 60° and 30° (measured clockwise from the base plate), for constant convergence rates of 10^{-5} and $5x10^{-5}$ s^{-1}. The length, stress, and time scale factors are $6x10^5$, $2x10^6$ and $3x10^{10}$, respectively. Model results show that: (i) fast convergence rates produce steep surface tapers and narrow deformed areas; (ii) low convergence rates produce lower taper topographies and wider deformed areas during self-similar growth; and (iii) a decrease in the backstop dip angle corresponds to a widening of the deformed areas, with two deforming regions facing in opposite directions. In doubly vergent models, the stable tapers are a function both of backstop configuration and imposed convergence rate. Slow convergence rates and shallow-dipping backstops produce shallow-dipping surface slopes for both the retrowedge and prowedge.

The Variscan orogeny in Central Europe: strength evolution of the orogen through time

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We discuss the evolution of the Variscan orogeny as an equivalent of the Tibetan system in terms of a visco-elastic type of deformation of continents using the concept of a thin-viscous sheet deformation in front of an indenter. This is discussed using structural, metamorphic, geochronological and geochemical data combined with thermomechanical modeling.

The first stage is marked by Silurian to early Devonian subduction of oceanic lithosphere in front of a Saxothuringian/Armorican continent (SA) below an easterly peri-Gondwana (PG) derived continent. Back-arc Palaeozoic basins developed on Upper-Proterozoic (PG) foreland crust associated with abundant calc-alkaline volcanism. Early Devonian continental underthrusting, with obduction of blueschists and eclogites over the Armorican domain is connected with pure-shear ductile to brittle–ductile shortening and moderate thickening of the foreland, development of Barrovian metamorphism and inversion of the back-arc Palaeozoic basin.

The continuous underthrusting of SA lithosphere below the sub-continental mantle wedge generates a calc-alkaline to shoshonitic Andean-type magmatic belt of early Carboniferous age which is emplaced into a compressional regime about 100–150 km distant from the SA–PG suture zone. Thickening of the orogenic root in front of the subducting SA continent reached 60 to 70 km, leading to development of HP granulites, HT eclogites and to metamorphism of sub-crustal mantle due to intense thermal weakening during thickening.

Final deformation of the orogenic root system is due to its distinct nature with respect to the rest of stable continental lithosphere, which acted as a rigid indenter that compressed the weak orogenic root. Lateral compression led to the development of vertical high-grade fabrics and to vertical extrusion of rocks. The system collapsed gravitationally at the conditions of mid-pressure granulite facies, where a flat high-grade fabric developed due to sideways sub-horizontal flow. At the margin of the eastern continent an inverted typical Barovian metamorphism developed due to overthrusting of the hot orogenic root.

The early obductional period of orogeny is a strong one, and is related to the transmission of stress over large distance, deformation of the foreland and widening of the deformed zone. It is not excluded that at this period an Andean type orogenic root formed. The second period is not related to the important horizontal stress transfer, but rather the stress is consumed by building of a deep orogenic root. This is also the period of maximum topography change, which is reflected by clastic sedimentation first of low-grade rocks then of deep high-grade gneisses and granulites in the Lower–Culmian foreland basin. The collapsed root is finally extruded over the Culmian deposits in the form of a second generation of crustal nappes.

The modeling indicates that the observed metamorphic and magmatic history of the root system can be neither reconciled with a simple model of visco-elastic deformation of lithosphere, nor with a model of deformation of a viscous thin-sheet in front of an indenter. We suppose that an important role for building of an orogenic root and of a Tibetan-like plateau is played by the Andean pre-collisional thermal history. In addition, a prolonged magmatic anomaly is necessary to create and stabilize this orogenic root system, which becomes mechanically weak and deformable with ongoing thermal weakening.

Deformation of the foreland lithosphere due to mantle flow caused by slab-retreat: a new working hypothesis

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Convergence between lithospheric plates is mainly accommodated by oceanic subduction. When continents collide oceanic subduction meets its end and the slab may roll back, become steeper, delaminate and break-off. However, to a certain extent intralithospheric delamination also may allow for continental subduction. Slab retreat of the subducting plate is widely accepted as a mechanism that causes back-arc extension in the upper plate (hinterland) during ongoing convergence. To date, however, little attention has been paid to possible effects of slab retreat on the foreland, although a retreating slab implies considerable mantle deformation (mantle flow) behind itself and below the foreland lithosphere. Whenever a slab retreats mantle material has to escape from behind it and material is drawn in in front of it. Analogue models show that this generally leads to a divergent flow behind and to a convergent flow in front of the slab. Moreover the mantle flow pattern induced by a retreating slab strongly depends on the dimensions of the slab, the geometry of ambient lithosphere and the viscosity distribution in the mantle. The question now is whether and under which conditions such mantle flows can deform the foreland lithosphere. For example is the viscous drag exerted at the base of the lithosphere effective enough to deform the lithosphere by flow or failure? It seems possible that this second order mantle flows can trigger or contribute to foreland deformation. The coupling between the asthenosphere and the lithosphere, i.e., essentially the viscosity gradient across the lithosphere/asthenosphere boundary layer, seems to allow transmission of stresses into the lithosphere which may locally contribute to overcoming yield strength or flow resistance. Horizontal divergent flows behind a retreating slab may cause foreland extension parallel to the collision belt, resulting in foreland rifts more or less orthogonal to the belt. Furthermore deviatoric flows at the base of the lithosphere may lead to contrarotating lithospheric domains. Such a scenario may throw new light on fan shaped graben systems in the Hercynian and Alpine forelands. Under certain circumstances mantle flows due to sublithospheric displacements (like push down of orogenic roots, slab retreat etc.) may also escape upwards arching pre-existing weak zones of the lithosphere. However, additional quantitative modelling is required to test this hypothesis.