Mantle deformation beneath the Alps and the physics of the subduction polarity switch: Part II – Physics of the subduction polarity switch

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Remark: Part I of the project focuses on the seismic anisotropy as a proxy for mantle deformation and flow in the alpine region (PI: Georg Rümpker; PhD: Frederik Link)

Here we focus on the most important geodynamic modelling results achieved so far. Our aim was a better understanding of the physical processes that could have triggered the proposed temporal subduction polarity switch beneath the Eastern Alps. To reach this goal we use thermo-mechanical modelling in 2D and later in 3D. First a self-consistent polarity switch in 2D as a result of continent-continent collision is investigated in a parametric study. In addition, a "double subduction" side project was initiated together with N. Froitzheim & R. Keppler from the University Bonn. Froitzheim et al. (2003) suggested for the Adula nappe in the Central Alps, which is a high- and ultrahigh-pressure unit surrounded by low-pressure units, an exhumation concept that is related to double subduction (see Fig. 2). The aim of this study is to test this concept with 2D thermo-mechanical models.

To study the polarity switch we use the thermo-mechanical finite difference code FDCON which has been extended to include a free surface with an erosion/sedimentation mechanism. For the geometrical setup an oceanic plate is placed between two continental plates. Subduction of the oceanic plate beneath the right plate is prescribed. The overriding plate (right) is then pushed by constant kinematic boundary conditions. Among other parameters we varied a) the plastic strength of sediments (very weak to strong), b) the ductile rheology of the lower crust (felsic or mafic) and c) the convergence velocity of the two continents (1 - 10 cm/a). From our results we can identify at least two different mechanisms for a subduction polarity switch:

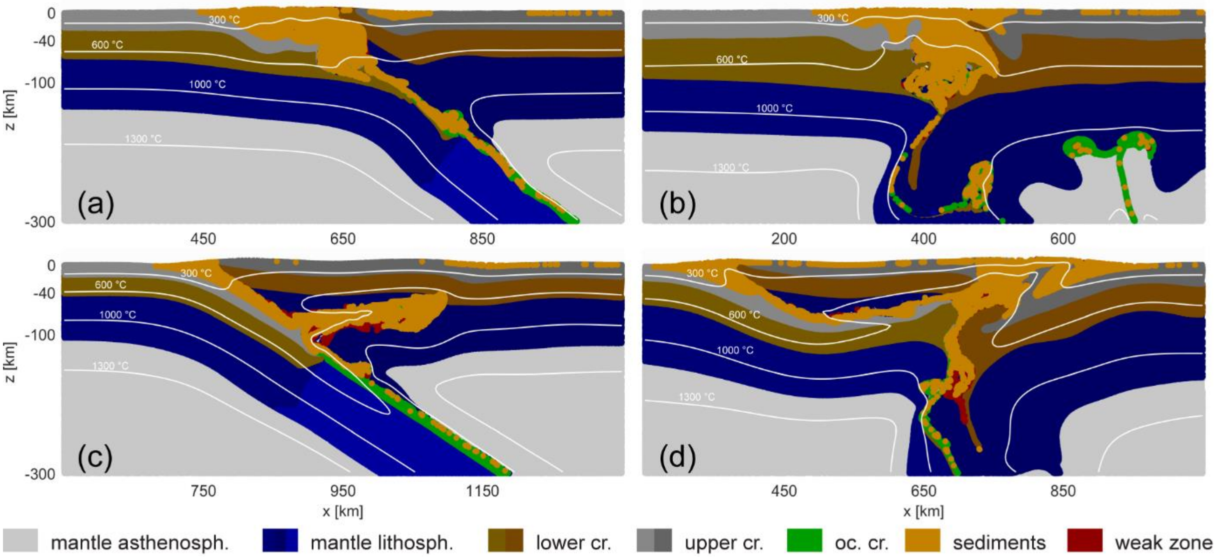

Figure 1: (a) Folding of the overriding plate front at the beginning of the collisional stage (b) Subduction polarity has already switched (Typ I). The left lithospheric mantle is delaminated and subducts while the two crusts collide and thicken (c) Large amounts of sediments already intruded into the overriding mantle lithosphere and have risen to the lower crust (d) Subduction polarity has already switched (Typ II). Lithospheric mantle together with parts of the lower crust of the overriding plate subduct cutting the left mantle lithosphere

I. Folding of the front of the overriding plate with a resulting new intra-lithospheric subduction zone in the overriding plate (moderate sediment strength, 6 - 10 cm/a, weak felsic lower crust), see Fig. 1 (a) & (b)

II. Intrusion of a cold but buoyant sediment diapir from the subducting oceanic plate into the overriding plate. The diapir can rise to the lower crust or even to the surface initiating a new subduction zone (strong to moderate sediment strength, 4 - 10 cm/a, strong mafic lower crust), see Fig. 1 (c) & (d)

In contrast to our models which predict a polarity switch only for relatively high convergence rates (≥ 4 cm/a), the alpine convergence rates of the Eastern Alps are believed to be in the order of 1 - 3 cm/a. In addition, we assumed an initially 40 km thick continental crust which is not in agreement with the Moho-map of Spada et al. (2013). While our results are useful for the understanding of the physics and dynamics of a temporal subduction polarity switch it remains open, whether for alpine conditions (lower convergence rates) other conditions such as a thinner initial crustal thickness or including 3D would lead to a polarity switch with either mechanism I or II. Anyway, our models suggest that it would be useful to identify pre-switch structures such as intrusions of sediment diapirs (mechanism II) or folds of the front of the initially overriding plate (mechanism I) in specific orogens such as the Eastern Alps.

For the "double subduction" project we also used FDCON with a geometrical setup according to Froitzheim et al. (2003). Two oceanic plates (Ligurian ocean and Valais ocean) are placed between two continental plates (European and Adriatic plate). In the middle of the model the two oceanic plate are divided by a terrane (Briançonnais terrane). Subduction of the Ligurian ocean is prescribed and inside the Valais plate a weak zone with a constant viscosity is placed. The Adula nappe is the upper crust of the European continental margin. We varied the convergence velocity (1 - 10 cm/a), the weak zone viscosity (10^{17} - 10^{23} Pa s) and the plastic sediment strength. Our results show that for very weak sediments a second subduction zone is never developing even for weak zone viscosity of 10^{17} Pa s. For stronger sediments a second subduction zone develops (Fig. 4 (a)) up to weak zone viscosities of 10^{21} - $5 \cdot 10^{21}$ Pa s depending on the convergence rate. For alpine-like convergence rates (1 - 3 cm/a) the PT-condtitions of the exhumed Adula nappe (Fig. 4 (b) & (d)) match in first order the values given in Froitzheim et al. (2003). We observe a slight north to south pressure increase (Fig. 3 & Fig. 4 (c)) for the Adula unit in agreement with Froitzheim et al. (2003). If the embedment of the Adula unit into a low-pressure setting is reproduced is not clear up to now.

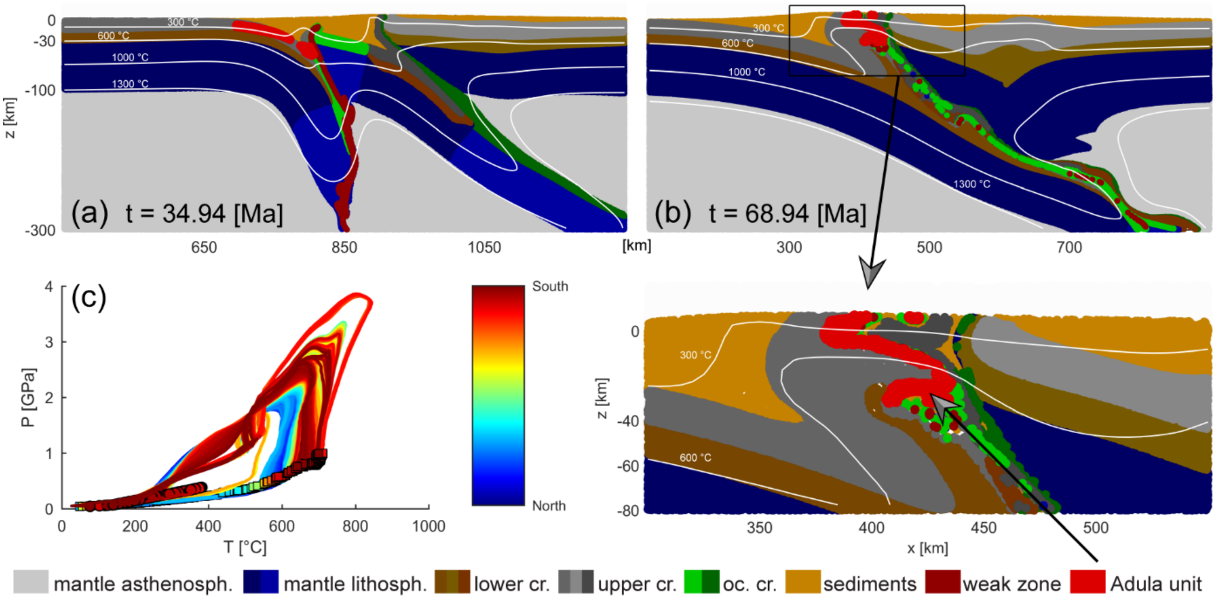

Figure 2: (a) Stage where two subduction zones are active at the same time. The upper crust of the terrane already undergoes exhumation and the Adula unit starts to exhume (b) Stage of continent-continent collision. The Adula unit has been exhumed from large depth and lies partly beneath the upper crust of the terrane (c) PT-conditions for the Adula unit (red markers). The color scale defines the final position (blue more in the north and red more in the south)

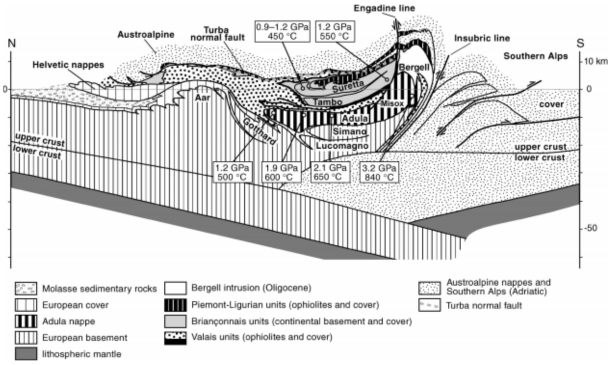

Figure 3: North-south cross section of eastern Central Alps, modified after Schmid et al. (1996) (from Froitzheim et al. 2003)

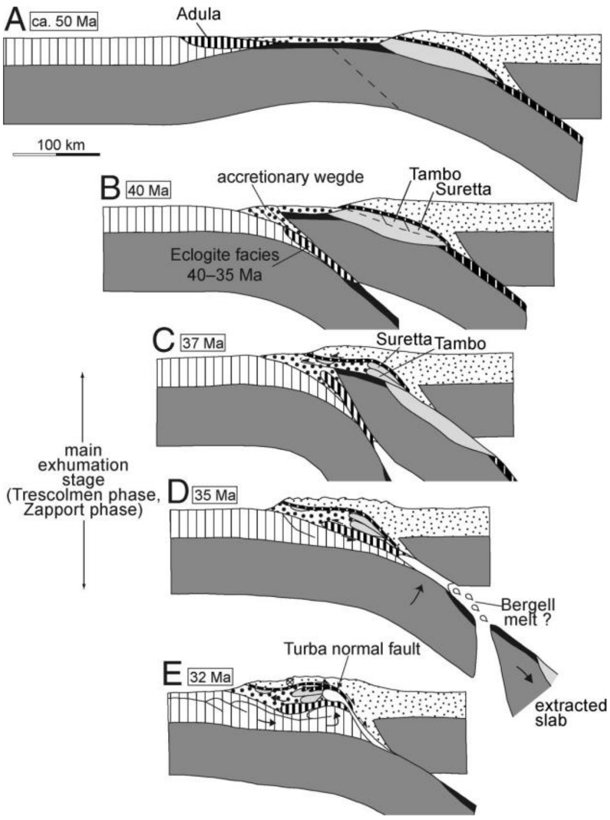

Figure 4: Reconstruction of tectonic evolution of eastern Central Alps (from Froitzheim et al. 2003)

Publication list:

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