Evolution and structure of the Upper Rhine Graben — quantitative insights from numerical modelling approaches *Vortrag*

Michael Schwarz[1]

Introduction

The Upper Rhine Graben forms the major segment of the Cenozoic Rift system of Western Europe. Although the rift was the target of many seismic and geological investigations, the style of lithospheric extension below the inferred faults, the depth to detachment, and the amounts of horizontal extension and lateral translation are still being debated. In this study, the date base to the Upper Rhine Graben was subjected to a finite element approach in order to include thermomechanical processes of the lithosphere as well as erosion and sedimentation. The study concentrated on the consequences of extension and lateral translational events on the structure and evolution in terms of basin geometry, sediment layer thicknesses, Moho elevation, and shoulder uplift on a lithospheric scale. The numerical approach was three dimensional in order to incorporate the lateral crustal heterogenities in the Upper Rhine area and the varying ambient stress field.

The thermomechanical simulation of a real rift requires the knowledge of the parameters controlling its structure and evolution. Furthermore, field data are needed for assessing the modelling results. Both preconditions could be met by the production of comparative data sets as well as by a parameter study before the modelling of the rift evolution. The critical validation of the research level allowed the extraction of the parameters to be determined. The results of the parameter study already gave some cues on the points of controversy mentioned above.

In anticipation of the parameter study, a hypothesis on continental rifting processes was formulated. It describes the consequences of the potential factors controlling the vertical displacements of the graben, shoulder, and Moho under simplified conditions. Opposite to other concepts, the hypothesis also takes into account the mechanical behaviour of faults as a primary factor. The numerical results of the parameter study were compared with the forecasts of the hypothesis in order to identify additional processes acting in the more complex setting of the Upper Rhine Graben area. Moreover, the comparison allowed disclosing functional relationships between the vertical displacements and the controlling parameters. Apart from these insights in the continental rifting process the parameter variations rendered some important results specific to the Upper Rhine rift system. They are in detail:

1. The vertical displacements in the rift system are controlled primarily by the friction, depth, and geometry of the border faults in the brittle domain. The consequences of the temperature and rheology in the creep regime are of minor importance. The same holds for the effects of the erosion and sedimentation.

2. The boundary faults are sub-listric down to maximum depth of 15 to 16 km. The geometry of the faults

[1] Geologisches Institut, Universität Freiburg, Albertstr. 23B, 79104 Freiburg i. Breisgau

remains the same during the rifting. In the pre-rift setting, they flatten from a dip angle of around 65° to some 40° at greater depth. Beneath, the deformation is accommodated by ductile creep without a need for discrete shear zones in the lower crust and upper mantle.

3. The apparent frictional coefficients mostly lie around 0.3 bis 0.4, but at every point on the fault surfaces lower than 0.5.

4. There are no crustal horizons where a considerable restoration of the isostatic equilibrium takes place.

5. High viscosities can be excluded at any depth in the lower crust. The variability of the lower crustal compositions is of no consequence for the rift evolution.

6. The upper crustal creep behaviour can be simulated only with much higher viscosities as it is predicted by the quarzite rheology. The requirement can be followed by using the creep parameters of a felsic granulite.

These results were put into the actual modelling of the Rhine Graben evolution. Therein, the implementation of the thermomechanical processes and the balancing on a lithospheric scale allowed reconstructing the vertical displaments of the graben, Moho, and shoulder over time. The comparative data sets are matched with a rift evolution in two phases. An extension being approximately orthogonal to the Rhine Graben is replaced by lateral translation which leads to a reactivation of the rift in a sinistral sense. The horizontal extension of 7.5 to 8.5 km and a sinistral displacement across the entire graben of 4.5 km at most are necessary in order to accommodate the sedimentary thicknesses. Dextral and sinistral displacements along the border faults take place during the period of orthogonal extension as well. These displacements are located at the fault segments where the friction coefficients change laterally due to a switch of the rift polarity. There, the graben block is extended parallel to the graben accompanied by a reduction of the principal stress in the same direction which causes the lateral displacements.

The conduction keeps pace with the advection of heat at any time during the rift evolution. There is no need for a thermal input of subcrustal origin for initiation of the rift. No thermal anomaly is created by the rifting in the Upper Rhine Graben area. The modelling results confirmed the ideas of the graben as an example of a passive rift.

The numerical outcomes can serve as decision guidance for solving conflictive positions about the geodynamics of the graben system. The fit between model and reality gives preferences for an evolution of the graben in two periods with different kinematics. The lateral displacements calculated in the study lie at the upper end of values which are inferred from structural and geophysical observations in the Rhine Graben region. Other stretching directions than orthogonal would result to additional strike-slip displacements above this threshold and, therefore, have to be declined. In the period of lateral translation during the Neogene, the regional strike slip setting disintegrates into different tectonic regimes along its strike. The configuration resembles the recent kinematics in the Rhine Graben region. Thus, the study approves the assumption of regional stress field being nearly constant since the beginning of the Miocene.

The modelling results refer only to periods of sedimentary record. They contain no information about the tectonosedimentary evolution in times with hiatuses. The hiatuses are located predominantly in the period of rift-parallel translation. This is at conflict with the calculated displacements which are already at the top of the values inferred for the Upper Rhine Graben from other observations. However, the results show that the graben subsidence, especially in a strike slip regime, is highly sensitive to the mechanical properties of the border faults and their orientation to the local stress field. Slight modifications of these factors can result in a sticking behaviour of these faults over large distances which may account for the hiatuses.

Apart from continental rifting, south-western Germany was affected by the migration of the Alpine peripheral forebulge into the Rhine Graben region. The modelling outcome permits separating the vertical displacements due to rifting from those related to the bulging processes. Future thermomechanical modelling studies require an implementation of these processes in order to achieve a holistic reconstruction of all geodynamic processes which were active in the Upper Rhine Graben area during the Cenozoic. Therefore, this study is regarded only as a first step to understand the interaction between extension, and lateral translation in a spatially and temporally varying stress field with a pre-existing structural inventory.