# Stress and Strain modelling of the Central European Basin System

**Diplom-Physiker**

**Mauro Cacace**

vom Fachbereich Geowissenschaften

der Freien Universität Berlin

zur Erlangung des akademischen Grades eines

Dr. rer. nat

genehmigte Dissertation

Berlin, 2008

<u>Gutacher:</u>

Prof. Dr. U. Bayer

Prof. Dr. D. Gajewski

Tag der Disputation: 4. Juli 2008

## Part 1: Classical numerical models of basin formation and evolution with application to the Central European Basin System (CEBS)



## Part 2: Tectonic evolution of the Central European Basin System: constraints from numerical modelling

# List of figures ______________________________ Pages

# Acknowledgments

The present study was done at the Helmholtz-Zentrum Potsdam Deutsches GeoForschungsZentrum - GFZ in Section 4.3.
The author would like to acknowledge the financial support from the German Research Council provided within the DFG-SPP1135 “Dynamics of sedimentary systems under varying stress conditions by example of the Central European Basin System”.

During the preparation of the present work I was helped and encouraged by many people to whom I’m really grateful and whom I’d love to thank.

First of all, I’d like to thank my supervisor Prof. Dr. Ulf Bayer (FU, Berlin) for his constant support throughout this project. I’m much in debt with him for sharing with me his wide experience in the field of science and for all the time dedicated to discuss the results.

Special thanks to professor Anna Maria Marotta (University of Milan) for offering me the opportunity to do this Ph.D. and for providing me with the basic numerical codes.

I thank also Dr. Magdalena Scheck-Wenderoth for providing geological data and for having helped me during the project.

I’m really grateful to Dr. Yurij Maystrenko for providing me with additional geological data and for the tolerance shown everytime. I greatly benefited from his extensive collaboration throughout the project.

A special thank to Dr. Fabien Magri for his constant help and for being a real friend. Grazie!

My gratitude to Björn Lewerenz for his computer assistance.

I wish to thank Prof. Brian Horsfield and all colleagues at the GFZ for offering a friendly work environment.

I thank Katja Hirsch and Judith Sippel for the nice time sharing the office while writing this dissertation.

Special thanks to my family for their love and support during my entire life.

Finally, there’s one person more I really love to thank for her smiling presence and patience even during the more obscure periods of our living together: THANK YOU Margherita!

# Abstract

A basin may be called "complex" if its temporal evolution was complicated by several tectonic or thermal events like stretching and inversion or if it is composed of a variety of regionally distributed sub-basins with differing histories. In this regard, the Central European Basin System (CEBS) provides an exceptional example for a complex sedimentary basin. It can be regarded a complex basin in terms of (1) having suffered stretching and inversion phases, (2) being located above a highly heterogeneous crust and even mantle, derived form the accretion of different terrains during the Palaeozoic, (3) having a complex upper crust due to repeated activation of salt tectonics, and (4) consisting of a complex set of sub-basins. Geophysical data have provided insight into a rather heterogeneous lithosphere structure between the different regional units at deeper crustal and mantle level. Accordingly, the observed differential deformation patterns may be attributed to interactions between regional or local variations in rheology beneath the different sub-areas while only minor changes occurred at the stress boundaries.

In addition, the CEBS may be regarded an outstanding "natural laboratory" for testing different modelling techniques. Almost all currently available models have been applied sometimes to the CEBS. Part 1 provides an overview concerning different models with practical applications to the Central European Basin, thereby the main problems encountered in modelling complex sedimentary basins are elucidated. Also all the models described in Part 1 have been applied to the basin system with some success in order to highlight some special aspects of its tectonic evolution, these models have not been able to capture the complex processes causing the evolution of sub-basins and localized inversion zones in details. By example, the relative simple classical kinematic models for continental deformation (e.g. McKenzie's or Wernicke's models) focus only at local subsidence without regarding the horizontally active stress and strain system. On the other hand, more complex stress and strain models (e.g. thin sheet or thin plate models) only considered the recent state of the basin system or alternately focused at relatively small domains preventing a unifying description of the basin.

Aware of these aspects, Part 2 describes the results obtained from a two dimensional modelling technique concerning the regional tectonic evolution of the CEBS. The modelling approach is the thin-sheet model, however, in spherical coordinates, allowing to include large scale spatial deformation patterns. The approach provides information concerning the state of stress within the lithosphere and it allows deriving stress-to-strain relations due to lateral heterogeneities as well as changing boundary forces.

The results for present day and past (post Palaeozoic) development of the basin system are presented and discussed. Thereby the relevance of inherited large-scale lithospheric structures is analysed with regard to the kinematics and dynamics of the study area. The model finally provides insight into the evolution of major subsidence centres and uplift areas through time in combination with the variable stress boundary conditions as defined by large-scale (palaeo)tectonic plate reconstructions.

A satisfactory agreement for the recent stress and strain field has been found between model results and geodetic observations concerning both regional and more local features. Following these results, the presence of different structural domains at both shallow and/or deeper levels within the lithosphere is necessary and sufficient to explain processes like strain localization and major bending in the principal stress orientation. Rheological/structural contrasts within the continental lithosphere can localize deformation under mechanically weak areas thus inducing the formation of major fault zones. In this

regard, fault formation is most likely the natural result of structural heterogeneities within the lithosphere. Consequently, artificial model devices (e.g. shear zone or deep penetrating faults) are not necessary to model the observed asymmetry in lithospheric deformation. In contrary the observed asymmetry in the patterns of continental deformation structurally reflects the asymmetric configuration and composition of continental lithosphere. Moreover, the presence of contrasting crustal and mantle structures together with varying stress boundary conditions controls and even determines the evolution of the different sub-basins including inversion through time.

In the final part of the study I summarize the main conclusions derived within the frame of the obtained modelling results concerning the formation and evolution of the basin system.