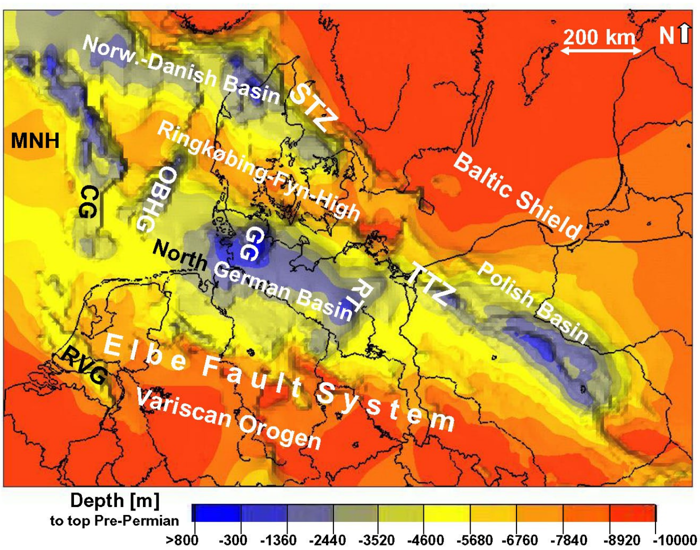
LITHMEM Lithospheric memory in North Central Europe: understanding the controls on neotectonic basin reactivation

M. Scheck-Wenderoth, J.D. van Wees, I. Artemieva, P.Aleksandrowski, M. Kaban, F. Beekmann, D. Soukoutis, H. Thybo, P. Krzywiec, M. Grad, M. Jarosinski

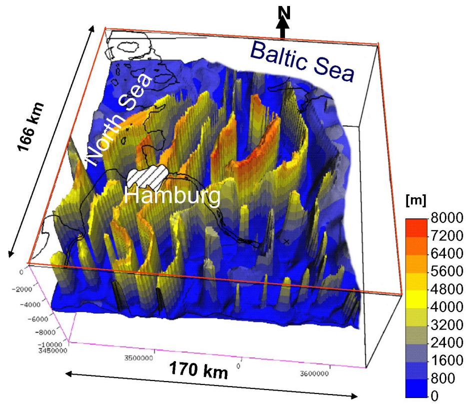
This is a short summary of a proposal that had been submitted to ESF, but has not been selected for funding despite of positive external reviews. We are currently searching for other ways of funding.

The main aim is to identify lithosphere memory structures in the Central European Basins System, which have been repeatedly reactivated by linking deformation patterns in the sediment-fill to deep seated heterogeneities in the lithosphere and/or asthenospheric mantle. Such structures substantially affect the lithospheric stress-strain distributions and may be linked to neo-tectonic evolution. Therefore we target an improved understanding of present-day topography and structure of the lithosphere, of structural inheritance and deep seated heterogeneities in the lithosphere and upper mantle. The work will be based on (1) understanding of the present structure and (2) on reconstruction of the deformation history. The evaluation of the present structure will reveal which signals of active deformation are triggered by shallow processes as salt movements or by deep processes like post-glacial isostatic readjustment, regional stress or stresses induced by density heterogeneities. We asses the present lithosphere strength and stress with regional basin-scale models of the sediments, the deeper crust and mantle using gravity, thermal, and rheological models. The reconstruction of the thermo-mechanical, transient compositional and rheological evolution of the lithosphere will focus on the Late Cretaceous to present tectonic evolution and is validated by paleo temperature-pressure indicators.
The Central European Basin System (CEBS) is a key natural laboratory to study the interplay of inherited crustal weakness zones with neotectonics, sea-level and glacio-isostatic adjustment controlling the evolution of lowlands. With more than 10 km of Permian to Cenozoic sediments it furthermore holds the record of paleo interactions of topography with tectonics and deep lithospheric processes. Improving the knowledge on the internal configuration of this system is relevant to assess current and past pathways of resources including water, petroleum and heat. The CEBS encompasses an area from the southern North Sea across Denmark, The Netherlands and northern Germany to Poland. Though this area has been extensively studied, a detailed regional integration is still missing. Studies of the CEBS at large (Scheck-Wenderoth and Lamarche, 2005; van Wees et al., 2000) or on the scale of sub-basins (Baldschuhn et al., 1996; Dadlez, 1998; Evans et al., 2003b; Hansen et al., 2005; Krzywiec, 2003; Lyngsie et al., 2006; Mazur et al., 2005; Scheck and Bayer, 1999) argue for a repeated and selective, partially recent, reactivation of two major types of structural elements, striking NW-SE and N-S respectively, under a recurrently changing stress field during basin history. Key areas of mobility may be located along these first-order fault systems and where the two types of structures intersect.



First order NW-SE striking fault systems border the major sub-basins of the CEBS, the most prominent of which are the Sorgenfrei- Teisseyre-Tornquist Zone (STZ and TTZ; Berthelsen, 1998; Thybo, 2000; Grad, et al. 2001), the border faults of the Mid-North Sea-Ringkøbing-Fyn-High, separating the Norwegian- Danish and German basins, and the Elbe Fault System (Scheck et al., 2002) limiting the CEBS against the Variscan Orogen in the South. All these fault systems coincide with geophysical discontinuities in the deeper crust or even in the upper mantle, observed in deep seismic experiments (Abramovitz and Thybo, 2000; BABEL-Working-Group, 1993; DEKORP-BASIN-Research-Group, 1999; Gregersen and Voss, 2002; Grad et al, 2003, Malinowski et al., 2005) as well as in maps of the potential fields and their gradients (Wybraniec et al., 1998). The fault systems are interpreted as the remains of old suture zones and their repeated reactivation during later tectonic phases as the consequence of a reduced strength inherited from Caledonian and Variscan collision processes. The largest vertical movements along these zones (up to 4 km) occurred during the Late Cretaceous-Early Cenozoic inversion of the CEBS (Mazur et al., 2005; Senglaub et al., 2005; Voigt et al., 2004). A comparison of main faults, seismicity and Quaternary subsidence patterns suggest a neotectonic activity of some of these faults as for example the NW–SE trending fault systems of the Roer Valley Graben (RVG, Cloetingh et al., 2006).

First order N-S striking elements are the Central Graben (CG), the Horn-Brande-Oslo Graben (OBHG), the Glückstadt Graben (GG) and the Rheinsberg Trough (RT), all of them dissecting the NW-SE elements. The N-S elements may likewise represent inherited older zones of lithosphere weakness probably originating from Paleozoic tectonic phases (Lie and Andersson, 1998; Wilson et al., 2004). Reactivation resulted in localized subsidence during Mid-Triassic to Early Jurassic and during the Cenozoic, which in parts appears to be ongoing today. Late Cenozoic subsidence observed in the Southern North Sea (Evans et al., 2003), in NW Germany (Maystrenko et al., 2005) and along the northern segment of the European Cenozoic Rift System (Cloetingh et al., 2006) demonstrate that in particular the recent history of these structures is highly relevant for coast protection management.



Salt thickness and geometry in the subsurface of NW Germany

As a third major player influencing the present stability of the CEBS, the thick layer of mobile Upper Permian Zechstein salt has to be mentioned. 3D Studies reconstructing the evolution salt structures for sub-areas suggest that phases of accelerated salt movement directly correlate with phases of tectonic activity and that the salt has not yet reached equilibrium conditions in consequence of glacial unloading but is currently rising in specific areas (Hansen et al., 2005; Maystrenko et al., 2005; Scheck et al., 2003).

Studies relating the present and paleo stress fields to the variations in lithospheric strength (Cloetingh and Van Wees, 2005; Cloetingh et al., 2005; 2006; Jarosinski et al., 2006; Marotta et al., 2002; Reinecker et al., 2003) show (1) that the area is subjected to stresses resulting from a superposition of Alpine compression and Altlantic ridge push and (2) that a correlation between rheologically weak areas and young deformation is obvious. However, the spatial resolution of previous studies is not resolving the internal characteristics of the CEBS and respective strength models incorporate strongly simplified assumptions on lithosphere composition, treating the sediments as one layer with uniform properties.

The evaluation of the present-day structure will reveal which signals of active deformation are triggered by mechanisms acting at different depth levels. These include shallow processes as salt movements or compaction-driven fluid expulsion but also deeper processes like post-glacial isostatic readjustment, regional compression or stresses induced by density heterogeneities or tectonic forces. We integrate regional basin-scale models of the sediment fill with new results on the deeper crust to evaluate heterogeneities seated in the upper mantle high-resolution models of crustal properties and calculate 3D thermal models of the CEBS lithosphere constrained by borehole heat flow measurements. These models will be further used for (1) joint interpretations of seismic and gravity data to distinguish deep-seated compositional and structural heterogeneities within the lithosphere and (2) to asses the present rheological state of the lithosphere and lithosphere strength.

The second component of the project focuses on the reconstruction of the thermo-mechanical, transient compositional and rheological evolution of the lithosphere with special focus on the Late Cretaceous tectonic inversion of the basin system and on the Cenozoic evolution. For that we will design and apply 3D basin history inversion models and evaluate the thermal state of the lithosphere. In the inversion strategy knowledge on the deep structure of the lithosphere is used to constrain basin evolution scenarios which, in turn are validated by paleo temperature-pressure indicators preserved in the sedimentary record. The validated lithosphere evolution scenarios serve as input for reconstructions of stress-strain interactions applying numerical and analogue modelling to unravel the role of lithosphere memory during reactivation processes and large scale linkage effects. In addition, 3D backstripping with salt redistribution is applied to reconstruct local deformation for key areas.

References

Abramovitz, T. and Thybo, H., 2000. Seismic images of Caledonian, lithosphere-scale collision structures in the southeastern North Sea along MONA LISA profile 2. Tectonophysics, 317: 27-54.

BABEL-Working-Group, 1993. Integrated seismic studies of the Baltic shield using data in the Gulf of Bothnia. Geophysical Journal International, 112(3): 305-324.

Baldschuhn, R., Frisch, U. and Kockel, F. (Editors), 1996. Geotektonischer Atlas von NW-Deutschland / Tectonic Atlas of NW-Germany. BGR / Federal Institute for Geosciences and Natural Resources, Hannover.

Berthelsen, A., 1998. The Tornquist Zone northwest of the Carpathians: an intraplate pseudosuture. Geol. Fören. Stockh. Förh., 120: 223–230.

Cloetingh, S. et al., 2006. Neotectonics and intraplate continental topography of the northern Alpine Foreland. Earth Science Reviews, 74(3-4): 127-196.

Cloetingh, S. and Van Wees, J.D., 2005. Strength reversal in Europe's intraplate lithosphere: Transition from basin inversion to lithospheric folding. Geology, 33(4): 285-288.

Cloetingh, S. et al., 2005. Lithospheric memory, state of stress and rheology: Neotectonic controls on Europe's intraplate continental topography. Quaternary Science Reviews, 24(3-4 SPEC. ISS.): 241-304.

Dadlez, R., Marek, S, Pokorski, J., 1998. Palaeogeographic Atlas of Epicontinental Permian and Mesozoic in Poland(1: 2 500 000). Polish Geological Institute, Warszawa.

DEKORP-BASIN-Research-Group, 1999. Deep crustal structure of the Northeast German basin: New DEKORP-BASIN '96 deep-profiling results. Geology, 27 (1): 55-58.

Evans, D., Graham, C., Armour, A. and Brathust, P., 2003. The Millenium Atlas: petroleum geology of the central and northern North Sea. The Geological Society of London.

Grad, M., Guterch, A. and Mazur, S., 2002. Seismic refraction evidence for crustal structure in the central part of the Trans - European Suture Zone in Poland. In: J.A. Winchester, T.C. Pharaoh and J. Verniers (Editors), Paleozoic Amalgamation of Central Europe. Geological Society of London, Special Publications, London, pp. 295-309.

Gregersen, S. and Voss, P., 2002. Summary of project TOR: delineation of a stepwise, sharp, deep lithosphere transition across Germany–Denmark–Sweden. Tectonophysics, 360(1-4): 61-73.

Hansen, M.B. et al., 2005. The Mesozoic–Cenozoic structural framework of the Bay of Kiel area, western Baltic Sea. Intern. Journ. of Earth Sciences, 95(4-5): 1070 - 1082.

Jarosinski, M., Beekman, F., Bada, G. and Cloetingh, S., 2006. Redistribution of recent collision push and ridge push in Central Europe; insights from FEM modelling. Geophysical Journal International, 167(2): 860-880.

Krzywiec, P., Kramarska, R. and Zientara, P., 2003. Strike-slip tectonics within the SW Baltic Sea and its relationship to the inversion of the Mid-Polish Trough—evidence from high-resolution seismic data. Tectonophysics, 373(1-4): 93-105.

Lie, J.E. and Andersson, M., 1998. The deep-seismic image of the crustal structure of the Tornquist Zone beneath the Skagerrak Sea, NW Europe. Tectonophysics, 287: 139-155.

Lyngsie, S.B., Thybo, H. and Rasmussen, T.M., 2006. Regional geological and tectonic structures of the North Sea area from potential field modelling. Tectonophysics, 413(3-4): 147-170.

Malinowski, M. et al., 2005. Seismic and geological structure of the crust in the transition from Baltica to Palaeozoic Europe in SE Poland; CELEBRATION 2000 experiment, profile CEL02. Tectonophysics, 401(1-2): 55-77.

Marotta, A.M., Bayer, U., Thybo, H. and Scheck, M., 2002. Origin of the regional stress in the N German Basin: results from numerical modelling. Tectonophysics, 360: 245-264.

Maystrenko, Y., Bayer, U. and Scheck, W.M., 2005. Structure and evolution of the Glueckstadt Graben due to salt movements, Dynamics of sedimentary basins; the example of the Central European Basin system. Springer International, Berlin, Federal Republic of Germany, pp. 799-814.

Mazur, S., Scheck, W.M. and Krzywiec, P., 2005. Different modes of the Late Cretaceous-early Tertiary inversion in the North German and Polish basins, Dynamics of sedimentary basins; the example of the Central European Basin system. Springer International, Berlin, Federal Republic of Germany, pp. 782-798.

Reinecker, J., Heidbach, O. and Mueller, B., 2003. The 2003 release of the World Stress Map.

Scheck, M. and Bayer, U., 1999. Evolution of the Northeast German Basin - inferences from a 3D structural model and subsidence analysis. Tectonophysics, 313: 145-169.

Scheck, M., Bayer, U. and Lewerenz, B., 2003. Salt redistribution during extension and inversion inferred from 3D backstripping. Tectonophysics, 373(1-4): 55-73.

Scheck, M. et al., 2002. The Elbe Fault System in North Central Europe - a basement controlled zone of crustal weakness. Tectonophysics, 360: 281-299.

Scheck-Wenderoth, M. and Lamarche, J., 2005. Crustal memory and basin evolution in the Central European Basin System;new insights from a 3D structural model, Integration of geophysical and geological data and numerical models in basins. Tectonophysics. 397,1-2:143-165.

Senglaub, Y., Brix, M.R., Adriasola, A.C. and Littke, R., 2005. New information on the thermal history of the southwestern Lower Saxony Basin, northern Germany, based on fission track analysis. International Journal of Earth Sciences, 94(5-6): 876-896.

Thybo, H., 2000. Crustal structure and tectonic evolution of the Tornquist Fan region as revealed by geophysical methods. Bulletin of the Geological Society of Denmark, 46: 145-160.

van Wees, J.-D. et al., 2000. On the origin of the Southern Permian Basin, Central Europe. Marine and Petroleum Geology, 17: 43-59.

Vejbaek, O.V., 1997. Dybe strukturer i danske sedimentaere bassiner. Geologisk Tidsskrift, 4: 1-31.

Wilson, M. et al., 2004. Permo-Carboniferous magmatism and rifting in Europe. Geological Society Special Publications, London, United Kingdom.

Wybraniec, S. et al., 1998. New Map Compiled of Europe's Gravity Field. EOS, Transactions, AGU, 79 (37): 437,442.