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Variation of the present-day stress field within the North German Basin—insights from thin shell FE modeling based on residual GPS velocities

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Abstract

We present a finite element-based dynamic modeling study of the recent stress conditions within the North German Basin, which is part of the Central European Basin System, based on geological, geophysical and geomorphological data. After compilation and evaluation of existing data, thin shell modeling is applied to understand the recent structural evolution of the Central European Basin System (CEBS) and its transition towards the Baltic Shield. In contrast to previous modeling approaches, we include a complex pattern of major faults from the Alpine Front to the Sorgenfrei–Tornquist Zone (STZ) and GPS measured residual velocities to define the boundary conditions of the model. Major deviations of the stresses occur along strong contrasts in the lithospheric structure and influence the stress pattern significantly. High intraplate compression is a responsible large-scale reactivation of the faults associated with the pre-existing basin framework in northern Central Europe, with an important record on vertical motions. The modeled slip/subsidence rates of the faults in the North German Basin are in the order of 0.01 and 0.2 mm year^{-1}, which are in accordance with field observations, because no fault exhibits large Quaternary displacement rates in the study area.

Keywords: Stress; North German Basin; Thin shell modeling; FE model

1. Introduction

During recent years, several attempts have been made to model past and recent stress fields in Central Europe (Grünthal and Stromeyer, 1992; Gölke and Coblentz, 1996). Most models incorporated plate boundary forces, such as the Mid-Atlantic ridge push and collisional forces within the Alpine Mobile belt and its foreland. In the model of Goes et al. (2000), the area was extended to the Urals Range, where the authors placed the eastern boundary of the Eurasian Plate, while the aforementioned authors considered

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only parts of the European Plate. Also, boundary forces applied are based on relative plate motions according to NUVEL (DeMets et al., 1990, 1994). On the contrary, Marotta et al. (2001, 2002) focused on viscous modeling of an area between the Alpine Front and southern Sweden, but also applying plate boundary forces and calculating results with different lithosphere rheologies. All models have in common that they ended at major lithospheric boundaries where major shear stresses vanish usually but normal stresses do not. Furthermore, the assumption of an elastic rheology is generally thought to be incompatible with the occurrence of intraplate seismicity (Bird, 1999), which leads to significant modeling errors. Bird (1999) also doubts the validity of viscous rheology in the lithosphere. Also, most of these attempts focus on modeling stress trajectories on a continental scale with extremely simplified lithospheric models, omitting local influences on the stress field like topography, variations in the lithospheric structure on a smaller scale and the influence of faults. These models reproduce the overall stress field in Central Europe quite accurately, but they fail predicting of local features. Results of the more sophisticated models of Marotta et al. (2001, 2002) help to explain the fan-like stress pattern in northern Germany (Roth and Fleckenstein, 2001), assuming a strong lithosphere underneath the North German Basin. A reference velocity along the Alpine Front of 0.4 cm $year^{-1}$ is considered to be too high for the present state of stress (Marotta et al., 2001, 2002, based calculations on an average velocity since the beginning of the Alpine Collision approximately 32 Mio years ago), resulting in an overall compressional regime. Additional important factors are not taken into account in the model which are supposed to influence the stress field in northern Germany, like the horizontal forces of the postglacial rebound (Scherneck et al., 1998) and the influence of the reactivated Cainozoic rift systems in western Europe (e.g., the Upper and Lower Rhine Graben).

In this paper, we present a new modeling approach starting with a mechanically uniform and inelastic plate and including major faults in Central Europe. We investigate the intraplate forces acting on the North German Basin which arise from both the Alpine compression and the postglacial isostatic rebound and their influence on a local scale. Therefore, a compilation and evaluation of existing data (heat flow, crustal and lithospheric thickness, topography) is necessary which serve as input later for thin shell modeling carried out to understand the Recent structural evolution of the North German Basin and its transition towards the Baltic Shield. In contrast to the previously discussed approaches, the program Shells (Kong and Bird, 1995) provides a realistic frictional/dislocation-creep rheology, spherical shell elements and the integration of faults.

2. Regional setting

The Central European Basin System (CEBS), which contains the North German Basin, developed on the Paleozoic platform of western Europe (Fig. 1). The basin formation was initiated in the Late Paleozoic and was followed by several subsidence and inversion episodes (e.g., Ziegler, 1990; McCann, 1999, Petmecky et al., 1999; Scheck and Bayer, 1999; van Wees et al., 2000). During the latest Late Cretaceous and earliest Tertiary, Alpine inversion processes affected the CEBS: the stresses in the mobile Alpine belt were transmitted into its distant foreland. These subsequent inversion and basin forming processes since the Paleozoic resulted in a complex crustal and lithospheric structure (DEKORP'96 Basin Research Group, 1999; Bayer et al., 1999; TOR experiment, e.g., Gossler et al., 1999; Hossein Shomali et al., 2002).

The area modeled in this study has experienced three major orogenic phases, characterized by marked suture zones. These are from north to south and, also from old to young, the Caledonian Chains (i.e., the Avalonia Suture; McKerrow et al., 2000; Krawczyk et al., 2002; CDF in Fig. 1), the Variscan Chains and suture (370–320 Ma), and the Alpine Chains (Late Cretaceous–Early Tertiary, and from Oligo-Miocene onward; Fig. 1). The deeper crust of the western Baltic represents the transition between the Baltic Shield and the North German Caledonides. The main structural elements are NW–SE-directed: (1) the Caledonian Deformation Front (CDF), which is considered to represent the northern transition from the Avalonia terrane; (2) the Trans-European Suture Zone (TESZ), which parallels the CDF to the south; (3) the Elbe line situated further to the south near Hamburg. The TESZ probably marks the southernmost tip of the Precambrian crust of the Baltic Shield, overthrust by the