Tectonophysics 601 (2013) 53–77

Contents lists available at SciVerse ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

3D lithosphere-scale density model of the Central European Basin System and adjacent areas

Yuriy Petrovich Maystrenko [a,b,*], Magdalena Scheck-Wenderoth [a]

[a] Helmholtz Center Potsdam, GFZ German Research Center for Geosciences, Section 4.4, Telegrafenberg, 14473 Potsdam, Germany
[b] Geological Survey of Norway (NGU), Postboks 6315 Sluppen, 7491 Trondheim, Norway

ARTICLE INFO

Article history:
Received 26 July 2012
Received in revised form 16 April 2013
Accepted 20 April 2013
Available online 28 April 2013

Keywords:
Central Europe
Crustal structure
3D gravity modeling
3D structural/density model
Lithosphere
Tectonics

ABSTRACT

To analyze the first-order structural features characterizing the crust and the lithospheric mantle below the Central European Basin System and adjacent areas, a new lithosphere-scale 3D structural/density model has been derived that integrates published knowledge with 3D gravity modeling. With this study we aim to integrate previous results on sub-domains of the study area and regional results of limited resolution in conjunction with 3D gravity analysis to derive the configuration of the lower crust and lithospheric mantle that is consistent with the known density distribution of the sediment fill and with observed deep seismic data as well as with observed gravity.

The derived 3D density model resolves the internal configuration of the crystalline crust below the Central European Basin System and adjacent areas at the regional scale and shows that the crystalline crust is characterized by a layered structure. The upper to middle crystalline crust is characterized by relatively low seismic p-wave velocities and densities. It shows strong variations in thickness across the study area that partly correlate spatially with the inherited segmentation in response to crustal amalgamation. This upper to middle crystalline crust is underlain by a continuous high-density/high-velocity lower crustal layer, locally more than 30 km thick beneath the East European Craton and generally decreasing in thickness from the older to the younger tectonic domains. Though the thickness of this high-density lower crust is generally small below the Permo-Cenozoic Central European Basin System, it can reach locally more than 18 km below the Northeast German and the Norwegian–Danish basins.

The derived depth to the lithosphere–asthenosphere boundary confirms previously proposed geometries and is up to 230 km deep beneath the Precambrian domain, but less than 100 km deep beneath the Phanerozoic domains, implying that the average thermal gradient is higher in the Phanerozoic lithosphere than in the Precambrian part.

1. Introduction

The intracontinental Central European Basin System (CEBS) includes the Southern and Northern Permian basins (Ziegler, 1990) with superimposed post-Permian sub-basins, such as the Polish Basin, the North German Basin, the Norwegian–Danish Basin, the Central Graben as well as the basins of the Netherlands and southern North Sea (Fig. 1). Structurally, this basin system is situated between two deep reaching fault zones, the Tornquist Zone in the north-east and the Elbe Fault System in the south-west. As a result of a multi-stage evolution and of structural differentiation both at the crustal level and within the deep lithospheric mantle, the Central European Basin System represents a complex basin system (Littke et al., 2008).

During the last decades, the knowledge about the regional distribution of sediments within the basin system has been summarized by several integrated studies (Baldschuhn et al., 2001; Dadlez, 2003; Evans et al., 2003; Littke et al., 2008; Maystrenko et al., 2010, 2012; PGS Reservoir, 2003; Scheck-Wenderoth and Lamarche, 2005; Wong et al., 2007). Accordingly, the present-day basin configuration is well-known for the Permian to Cenozoic sedimentary successions (Fig. 2). Both, the top pre-Permian surface as well as the cumulative thickness of the Permian to Cenozoic units indicate a strong segmentation of the basin system with locally more than 12 km thick deposits. Besides, the deep structure of the Central European Basin System has extensively been investigated by deep seismic experiments (Fig. 3), as well as by gravity modeling, and magnetic and magnetotelluric studies, providing new insights into the structure of the crystalline crust and upper mantle. Based on these data, regional maps of the Moho topography have been compiled for the area (Grad et al., 2009; Tesauro et al., 2008; Ziegler and Dèzes, 2006) and several crustal domains have been delineated (Fig. 4) on which the

* Corresponding author at: Geological Survey of Norway (NGU), Postboks 6315 Sluppen, 7491 Trondheim, Norway. Tel.: +47 73904438.
E-mail address: Yuriy.Maystrenko@NGU.NO (Y.P. Maystrenko).

0040-1951/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.tecto.2013.04.023

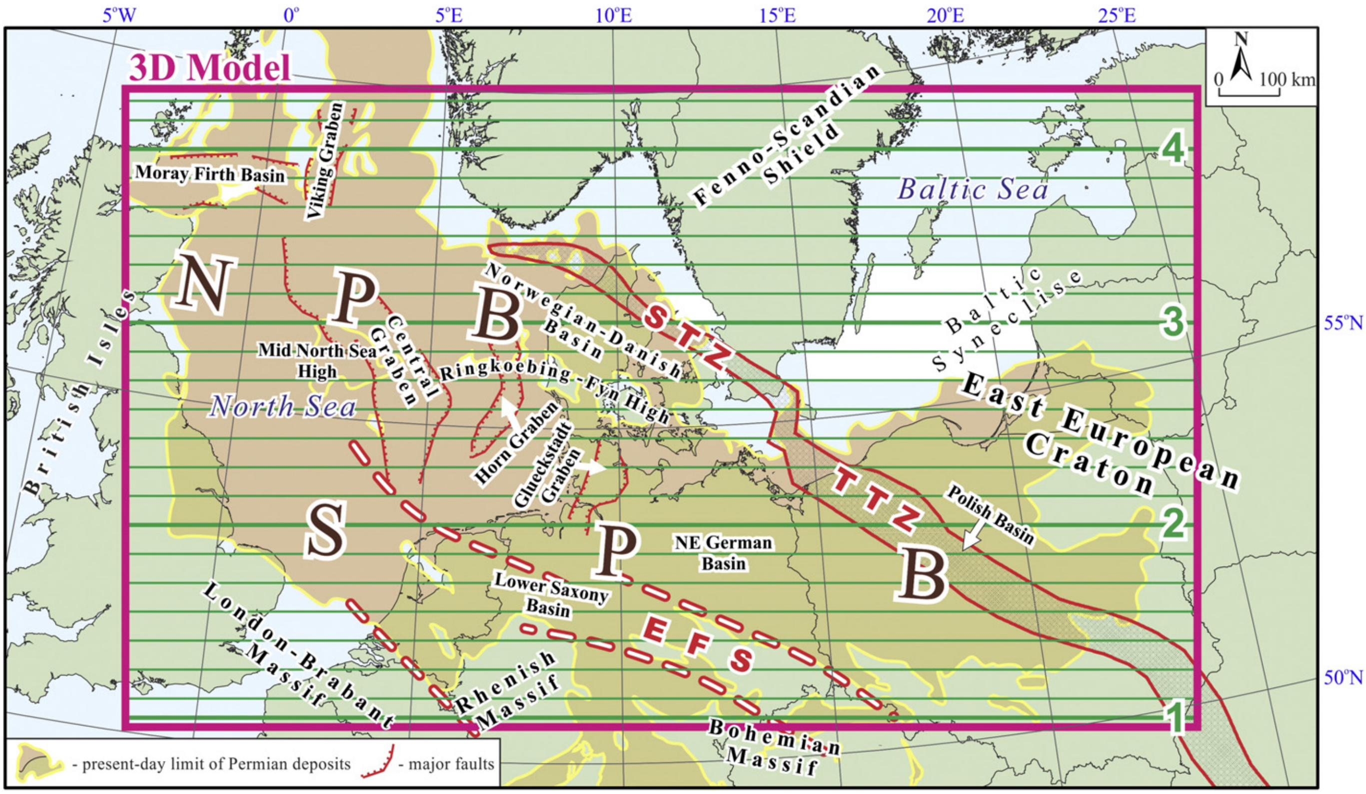

Fig. 1. Overview map of the Central European Basin System and adjacent areas with location of the lithosphere-scale 3D structural/density model (pink frame) and the vertical slices through the 3D density model (green lines; representative slices are highlighted by bold lines and numbering). Structural elements — EFS: Elbe Fault System; NPB: Northern Permian Basin; SPB: Southern Permian Basin; STZ: Sorgenfrei–Tornquist Zone; and TTZ: Teisseyre–Tornquist Zone.
Outlines of the Northern and Southern Permian basins (present-day limit of Permian deposits) and location of the major faults and fault zones are after Ziegler (1990), Vejbæk and Britze (1994), Lokhorst (1998), Pharaoh (1999), Stemmerik et al. (2000), Baldschuhn et al. (2001), Sigmond (2002), Evans et al. (2003), Heeremans et al. (2004), Geluk (2005), Scheck-Wenderoth and Lamarche (2005), Maystrenko et al. (2006) and Stewart (2007).

Central European Basin System evolved including (1) the Precambrian crust of Baltica in the north-east, (2) the Caledonian crust of Avalonia and Laurentia below the western and central parts of the basin system, and (3) the Variscan crust in the south (Pharaoh, 1999). Also, our understanding of the lithosphere–asthenosphere boundary below the study area has significantly improved in the last years, though the proposed geometries of this boundary are still debated and strongly depend on the method used to derive it. Accordingly proposed depths to the lithosphere–asthenosphere boundary vary and different terms as the thermal (Artemieva and Thybo, 2008; Artemieva et al., 2006; Cloetingh et al., 2007), seismological (Geissler et al., 2010; Plomerová and Babuška, 2010; Tesauro et al., 2009) and magnetotelluric (Jones et al., 2010) lithosphere–asthenosphere boundaries have been defined.

Together, these results on the crust and lithosphere jointly provide an exceptional background for further evaluation of the deeper lithosphere. Here, we integrate this available knowledge for the area with 3D gravity modeling to derive a new 3D density model of the entire Central European Basin System and adjacent areas. We use this 3D density model as a base to analyze the first order structural features with respect to concepts proposed earlier and discuss how far the derived present-day deep structure of the lithosphere can be related to tectonic events that have influenced the area over its history. The constructed 3D model is available in digital form (see Appendix A. Supplementary data).

2. Structural evolution and relation with crustal setting

The assemblage of crustal domains on which the Central European Basin System evolved from Latest Carboniferous–Early Permian onward, is the result of terrane accretion to the Archean–Proterozoic crust of Baltica during the Precambrian and the Palaeozoic. These terranes are characterized by different crustal and lithosphere thicknesses as well as by a specific velocity structure each. The most prominent transition between lithosphere blocks of contrasting properties is the Tornquist Zone (Gregersen et al., 2005; Shomali et al., 2006; Thybo, 2001), which in its upper crustal part is expressed as a deep reaching fault system (Berthelsen, 1992). The Tornquist Zone (Figs. 1 and 4) consists of two branches (EUGENO-S Working Group, 1988). The south-eastern branch, the Teisseyre–Tornquist Zone is a well-studied example of a paleo-collision zone between the Archean–Proterozoic East European lithospheric plate and the Palaeozoic plate of Central Europe (Berthelsen, 1992). In contrast, the north-western Sorgenfrei–Tornquist branch represents a zone of strong faulting within the south-western edge of Baltica (Franke, 1993).

Fig. 2. (a) Bathymetry of the model area using data from the GEBCO Digital Atlas (density of sea water is 1030 kg/m^3) (IOC, IHO, BODC, 2003); (b) depth to the base of Permian–Cenozoic sediments, including Permo-Carboniferous volcanics (after Maystrenko et al., 2010); and (c) cumulative thickness of Permian–Mesozoic–Cenozoic sediments and Permo-Carboniferous volcanics (density is 2480 kg/m^3; red lines correspond to offshore political boundaries).
Structural elements — CG: Central Graben; EFS: Elbe Fault System; GG: Glueckstadt Graben; HG: Horn Graben; MFB: Moray Firth Basin; NEGB: Northeast German Basin; NDB: Norwegian–Danish Basin; NPB: Northern Permian Basin; PB: Polish Basin; RFH: Ringkøbing-Fyn High; SPB: Southern Permian Basin; STZ: Sorgenfrei–Tornquist Zone; TTZ: Teisseyre–Tornquist Zone; and VG: Viking Graben.