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Yuriy Maystrenko, Ulf Bayer
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3D structural model of the Glueckstadt Graben, NW Germany

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Overview

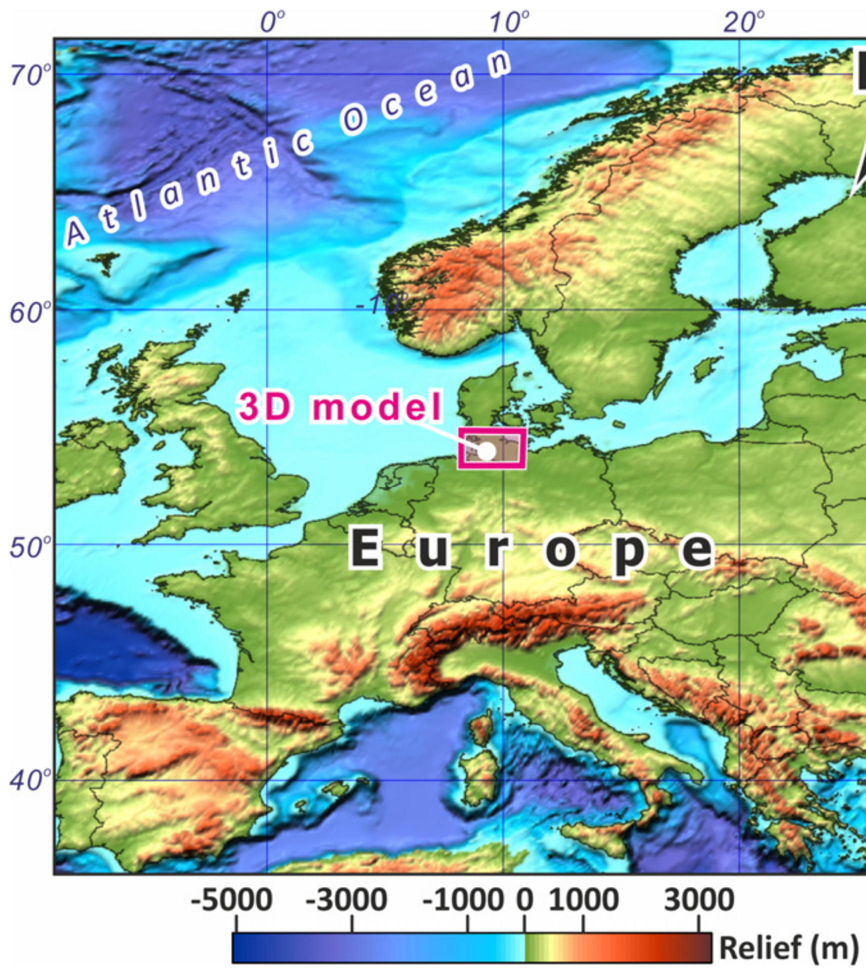

Figure 1. 3D structural model of the Glueckstadt Graben on the relief map of Europe (the topography is taken from IOC, IHO, and BODC, 2003). Magenta rectangle corresponds to the 3D structural model.

The Glueckstadt Graben is located in NW Germany (Fig. 1) between the North Sea and the Baltic Sea (Fig. 2), covering a part of the German lowlands. This means that the Glueckstadt Graben and adjacent areas are characterized by low topography within the region covered by the 3D model (Fig. 1).

Geologically, the Glueckstadt Graben represents a NNE-SSW trending post-Permian sub-basin of the Central European Basin System (Fig. 2; Maystrenko et al., 2008) which contains more than 10 km of Permian, Mesozoic and Cenozoic

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sediments (Baldschuhn et al., 1996, 2001; Maystrenko et al., 2005a, 2006). The upper part of the Permian sequence (Zechstein and salt-rich Rotliegend) consists of relatively thick evaporite deposits (mainly salt). This layer played an important role during post-Permian times when the sedimentary infill of the Glueckstadt Graben was strongly complicated by movements of Permian salt.

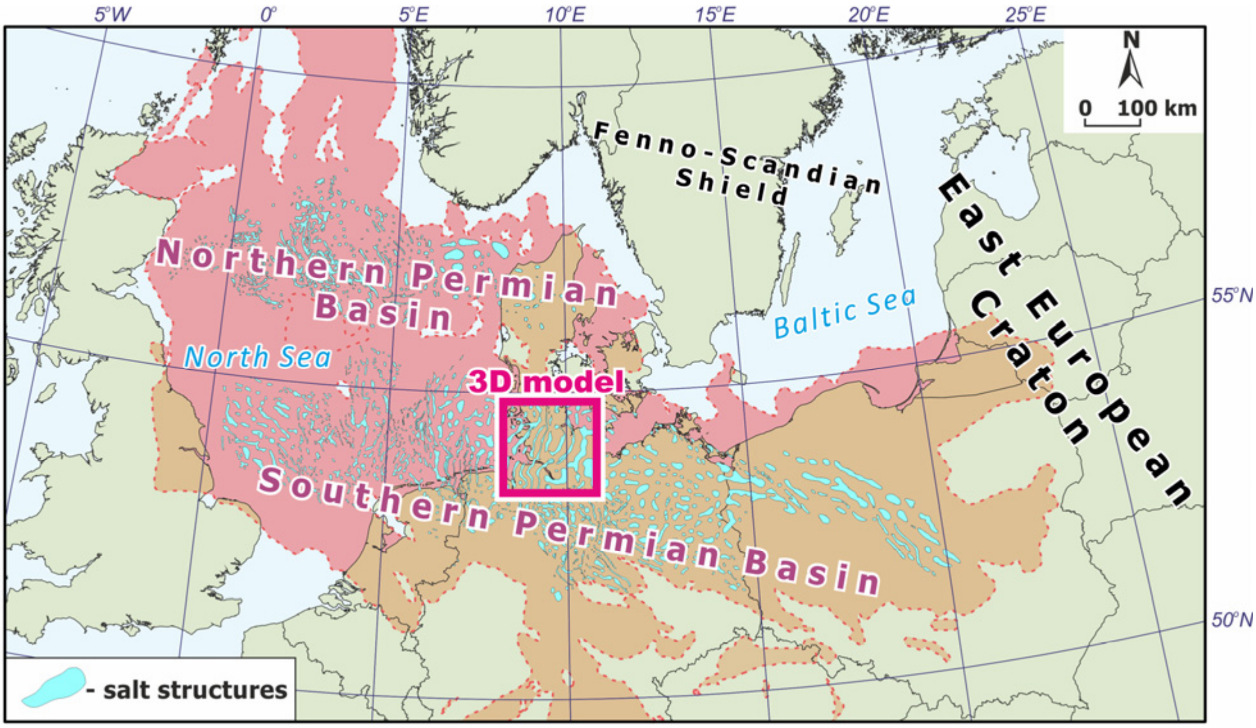

Figure 2. Structural setting of the Central European Basin System with location of the 3D structural model of the Glueckstadt Graben in relation to the Northern and Southern Permian basins (simplified after Maystrenko et al., 2010, 2011). The Permian Basins are outlined by the present-day limit of Permian deposits (after Ziegler, 1990; Lokhorst, 1998; Vejbæk and Britze, 1994; Stemmerik et al., 2000; Baldschuhn et al., 2001; Sigmond, 2002; Evans et al., 2003; Heermans et al., 2004; Geluk, 2005; Stewart, 2007). Position of the salt structures from Cameron et al. (1992), Vejbæk and Britze (1994), Lokhorst (1998), Baldschuhn et al. (2001), Dadlez (2003) and Evans et al. (2003). Magenta rectangle corresponds to the 3D structural model.

Structurally, the study area can be subdivided into three domains (Fig. 3a): (1) the Central Glueckstadt Graben; (2) the marginal Jurassic and Cenozoic troughs - Westholstein, Eastholstein and Hamburg; (3) the basin flanks - Westschleswig and

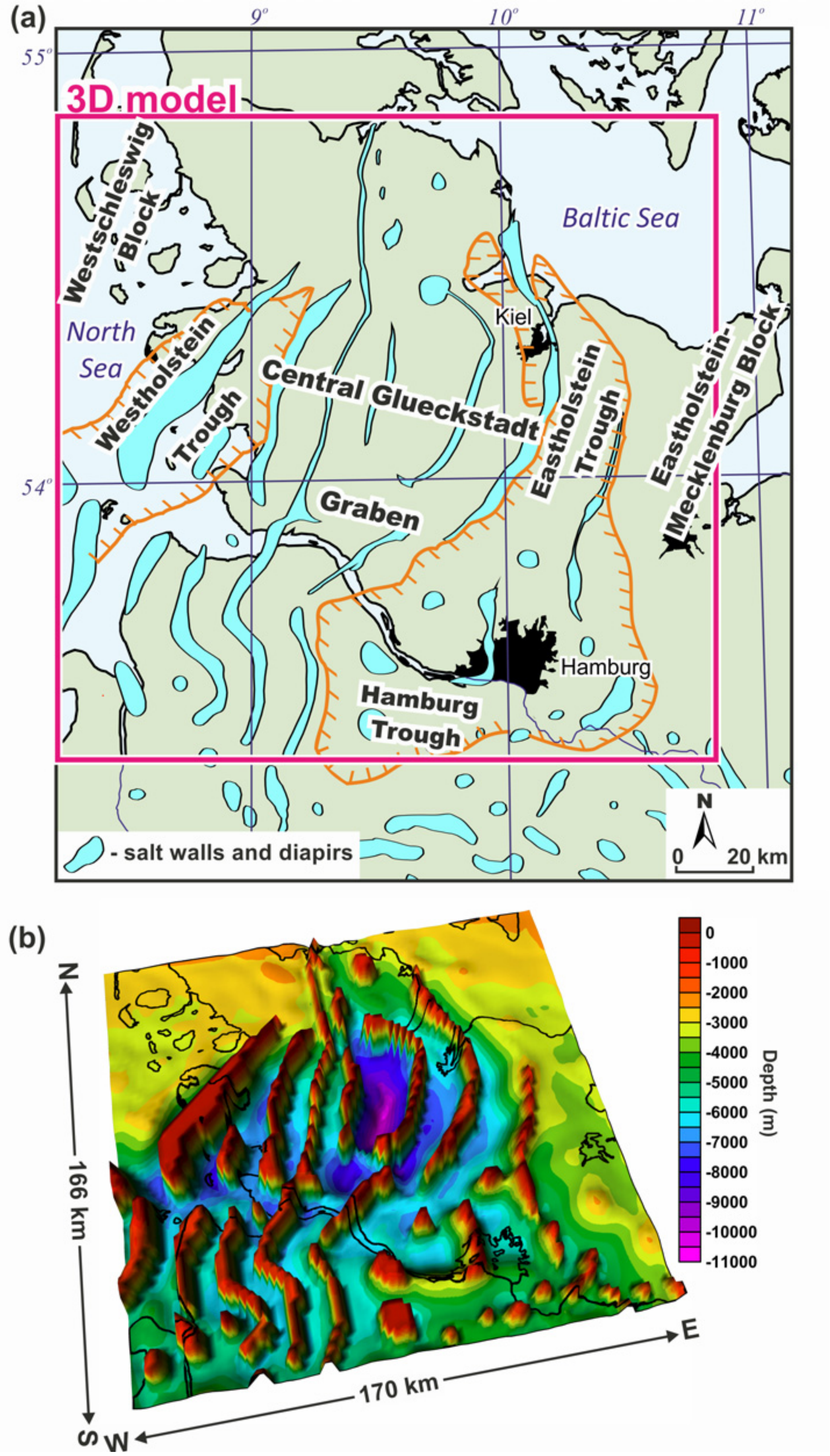

Figure 3. (a) Structural setting within the Glueckstadt Graben (position of the salt diapirs and walls after Baldschuhn et al., 2001) with the location of the 3D structural model (see magenta rectangle). (b) 3D view of the top Permian salt (undivided Zechstein plus salt-rich Rotliegend) within the area covered by the 3D model (modified after Maystrenko et al., 2005). Vertical exaggeration is 3 times.

Eastholstein-Mecklenburg blocks. The Central Glueckstadt Graben is the deepest part of the Glueckstadt Graben. In the axial part of the Glueckstadt Graben, the base of Triassic sediments is located at more than 10 km depth. Within the south-eastern margin, the Triassic depocenter is separated from the Eastholstein-Mecklenburg block by the Eastholstein and Hamburg Troughs (Fig. 3a) where the thickness of the Jurassic attains more than 1.9 km and also the Cenozoic is characterized by a strong thickening (more than 3.3 km). The sedimentary cover of the Westholstein marginal through includes more than 2.4 km of Jurassic and more than 5 km of Cenozoic, separating the Central Glueckstadt Graben from the Westschleswig block (Fig. 3a). The Westschleswig and Eastholstein-Mecklenburg blocks are covered by relatively thin post-Permian sediments (less than 4 km) and are characterized by an absence of strong salt-related deformations.

The Glueckstadt Graben is one of the well studied basins of the Central European Basin System. Accordingly, the structure and evolution of the Glueckstadt Graben have been systematically studied since the beginning of the last century (Trusheim, 1960; Sannemann, 1968; Jaritz, 1969, 1980; Best et al., 1983; Dohr et al., 1989; Brink et al., 1990, 1992; Baldschuhn et al., 1996, 2001; Kockel, 2002, 2003; Lehné and Sirocko, 2005, 2007; Maystrenko, 2005; Maystrenko et al., 2005a, b, 2006; Rodon and Littke, 2005).

The basin infill of the Glueckstadt Graben contains three major salt sequences, mainly salt-rich Rotliegend, Zechstein salt and Triassic salt beds. The Rotliegend and Zechstein evaporites formed the majority of the huge salt structures present in the area (Fig. 3). A 3D view on the top Permian salt (Fig. 3b) shows that high amplitude salt walls are located mainly within the Central Glueckstadt Graben and the marginal troughs (Westholstein, Eastholstein and Hamburg) with rapidly decreasing amplitudes towards the basin flanks.

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The main stage of subsidence within the Glueckstadt Graben occurred in the Triassic with culmination during the Late Triassic (Keuper) times, forming the Central Glueckstadt Graben. In the Jurassic, three SW-NE-trending marginal troughs (Westholstein, Eastholstein and Hamburg) formed. A major Late Jurassic-Early Cretaceous unconformity separates the Triassic/Jurassic deposits from Cretaceous sediments. This Late Jurassic-Early Cretaceous interruption of sedimentation can be related to a regional sea level fall or to a relative uplift of the area. During the Late Cretaceous-Early Cenozoic regional compression, the Glueckstadt Graben was essentially not inverted. In the Glueckstadt Graben, the Late Cretaceous-Early Cenozoic compression caused increased salt movements. During the Cenozoic, a renewed growth of salt structures mainly affected the margins of the Central Glueckstadt Graben, causing fast salt-related subsidence in the Eastholstein, Westholstein and Hamburg Troughs. As this phase of salt tectonics was accompanied by normal faulting, it could also be related to almost W-E extension, indicating changes in tectonic regime after the Early Cenozoic compressional events.

Data sources

The topography (Fig. 4) and the bathymetry (Fig. 5) within the Glueckstadt Graben and adjacent areas have been extracted from the GEBCO Digital Atlas (IOC, IHO and BODC, 2003).

For the Permian-Mesozoic-Cenozoic sedimentary cover of the study area, we have used the digital version of the Geotectonic Atlas of NW Germany (Baldschuhn et al., 1996, 2001) which covers the north-western part of Germany. This atlas has been provided by the Federal Department of Geosciences and Mineral Resources (BGR) in digital form with horizontal resolution of 100 x 100 m. The digital versions

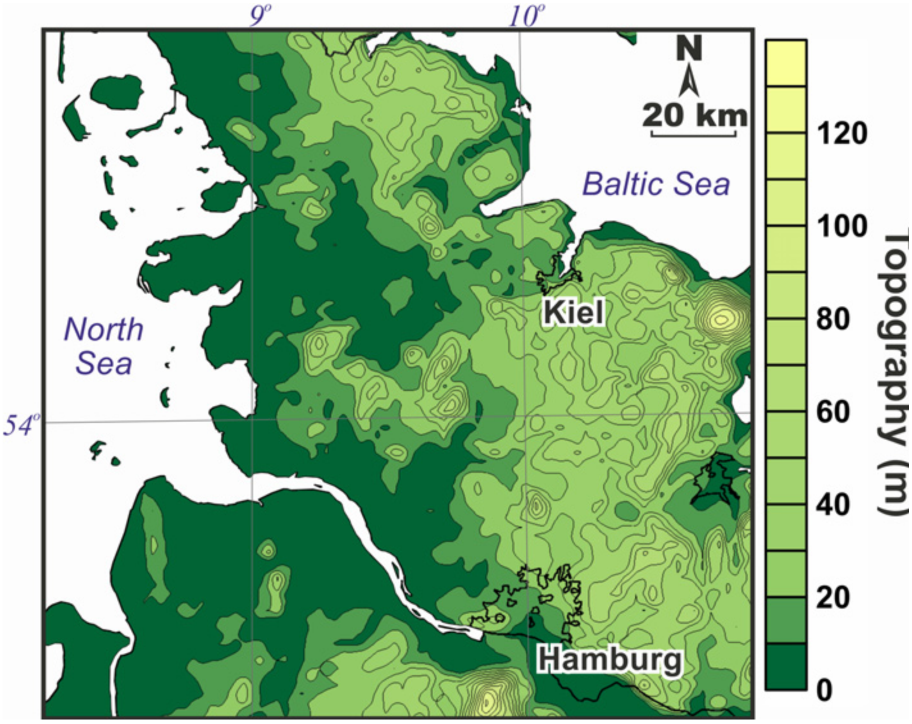

Figure 4. Topography (from IOC, IHO, and BODC, 2003) within the area covered by the 3D structural model of the Glueckstadt Graben (data file: *0_Topography.dat*).

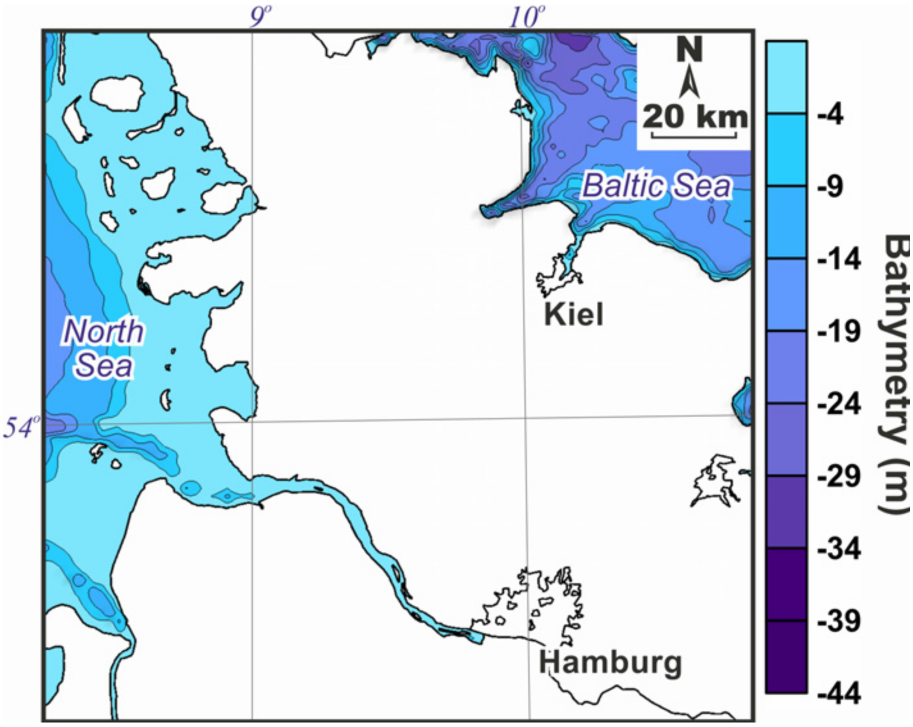

Figure 5. Bathymetry (from IOC, IHO, and BODC, 2003) within the area covered by the 3D structural model of the Glueckstadt Graben (data file: *1_Bathymetry.dat*).

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of structural depth maps from the Geotectonic Atlas of NW Germany (Baldschuhn et al., 2001) were used to calculate thickness maps of sediments which were integrated into a three-dimensional structural model. In addition, this 3D model was adjusted by use of results from seismic interpretation (Maystrenko, 2005; Maystrenko et al., 2005a, b, 2006). In critical areas, additional control points have been added before interpolation, in order to ensure consistence of contour lines with the original data. The most problematic areas were located in the vicinity of salt structures, where steeply dipping beds and strong thickness variations occur. Finally, the approved data were interpolated, gridded and merged into the 3D structural model of the Glueckstadt Graben and adjacent areas (Fig. 6).

Description of the 3D structural model

The 3D structural model of the Glueckstadt Graben (Fig. 6) covers an area that is 170 km wide and 166 km long with a horizontal grid spacing of 2000 m, and a vertical resolution corresponding to the number of integrated layers. The complete version of the 3D structural model includes 10 layers (Figs. 4, 7-15): (1) sea water; (2) the Quaternary-Neogene; (3) the Paleogene; (4) the Upper Cretaceous; (5) the Lower Cretaceous; (6) the Jurassic; (7) uppermost part of the Middle Triassic and the Upper Triassic (Keuper); (8) the Middle Triassic without uppermost and lowermost parts (Muschelkalk); (9) the Lower Triassic and lowermost part of the Middle Triassic (Buntsandstein); (10) upper part of the Lower Permian and the Upper Permian (undivided Zechstein plus salt-rich Rotliegend). The thicknesses of the layers correspond to apparent thicknesses.

The grid of each layer consists of 86 cells in W-E direction and 84 cells in S-N direction. The grid limits are the following: X_{min} is 3450000 and X_{max} is 3620000; Y_{min} is 5915100 and Y_{max} is 6081100. The vertical datum of the 3D model refers to the

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mean sea level. Model coordinates are based on the Gauss-Krueger DHDN (zone 3) system using the WGS 84 datum.

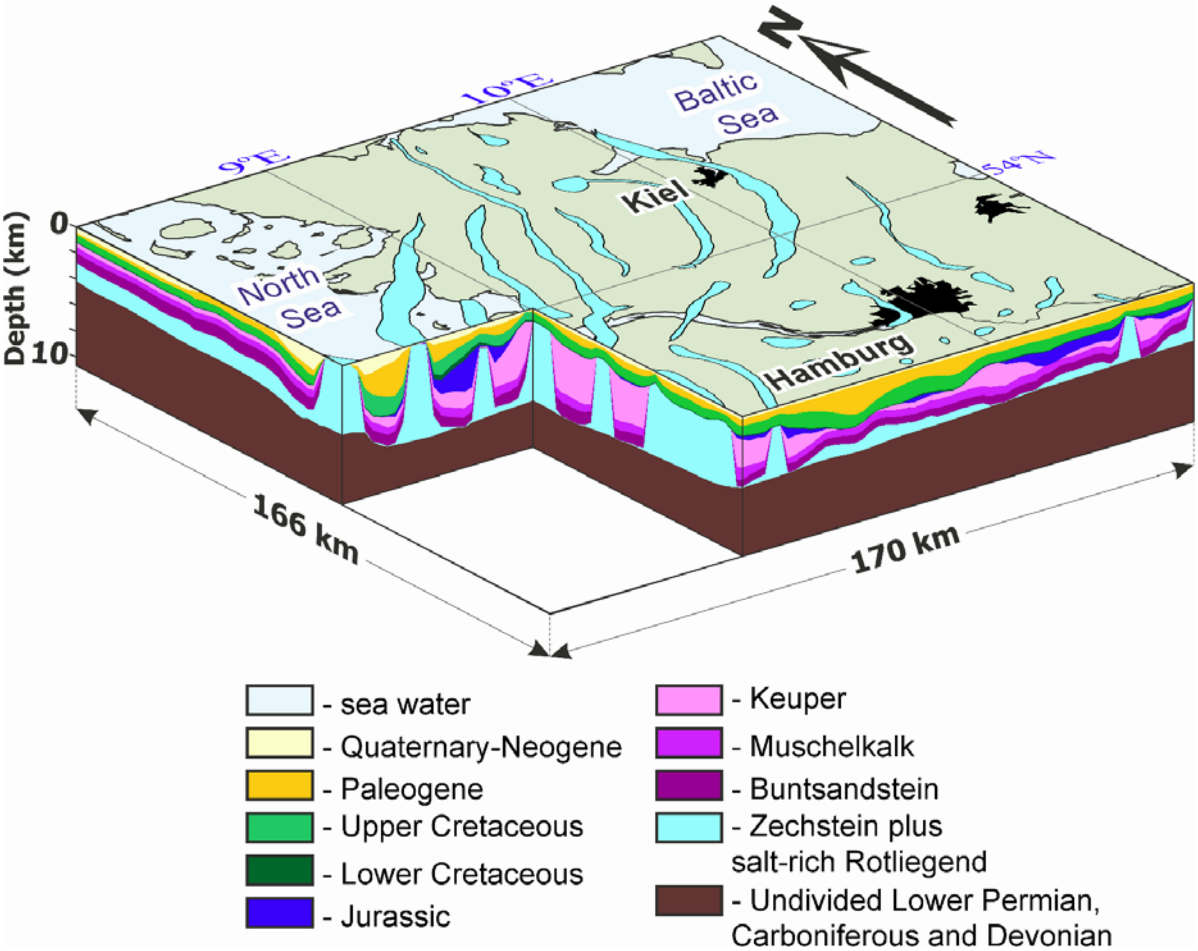

Figure 6. 3D structural model of the Glueckstadt Graben and adjacent areas, showing major features of the internal structure of the study area (modified after Maystrenko, 2005 and Maystrenko et al., 2006). Vertical exaggeration is 3 times.

The data format is ASCII and contains three columns (X, Y and Z), where X and Y are coordinates; Z is thickness of the layer or structural depth (base of the layer). For example:

	X	Y	Z
Thickness:	3450000	5915100	414.8037109375
Structural depth:	3450000	5915100	-599.1790863037

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Data files from the 3D structural model of the Glueckstadt Graben and adjacent areas are in the sequence of the layers from top to bottom of the model:

Thicknesses data (thickness values of 0.1000000014901 or close to 0.1 correspond to zero values, i.e. absence of sediments)

1_thickness_sea_water.dat

2_thickness_Quaternary_Neogene.dat

3_thickness_Paleogene.dat

4_thickness_Upper_Cretaceous.dat

5_thickness_Lower_Cretaceous.dat

6_thickness_Jurassic.dat

7_thickness_Keuper.dat

8_thickness_Muschelkalk.dat

9_thickness_Buntsandstein.dat

10_thickness_Permian_salt.dat

Structural depth data

1_Bathymetry.dat

2_base_Neogene.dat

3_base_Paleogene.dat

4_base_Upper_Cretaceous.dat

5_base_Lower_Cretaceous.dat

6_base_Jurassic.dat

7_base_Keuper.dat

8_base_Muschelkalk.dat

9_base_Buntsandstein.dat

10_base_Permian_salt.dat

In addition, topography can be found in the following file: *0_Topography.dat*.

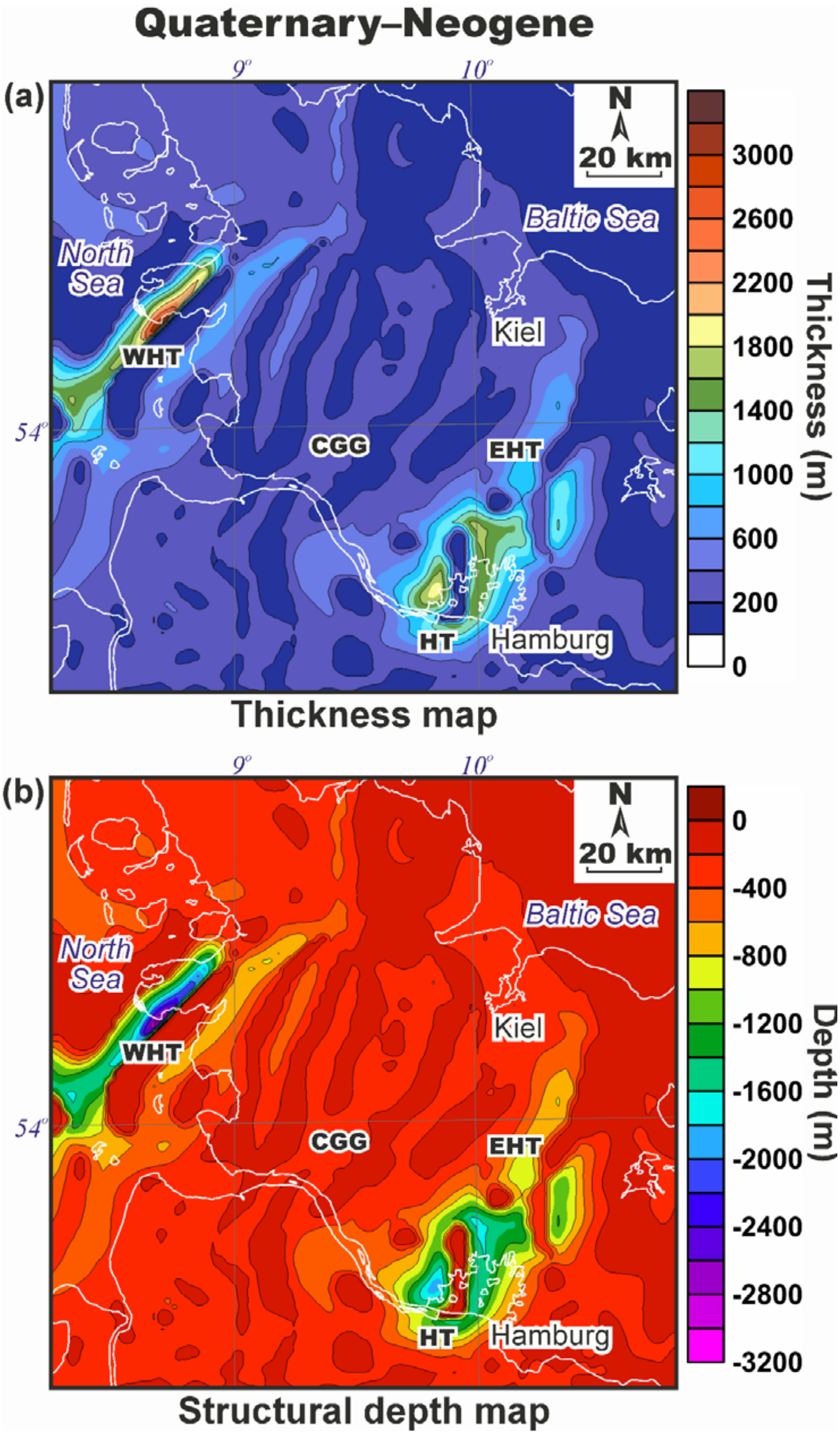

Figure 7. Layer 2 - the Quaternary–Neogene: (a) thickness map (data file: *2_thickness_Quaternary_Neogene.dat*) and (b) structural depth map of the base (data file: *2_base_Neogene.dat*). Abbreviation: CGG - Central Glueckstadt Graben, EHT - Eastholstein Trough, HT - Hamburg Trough, WHT - Westholstein Trough.

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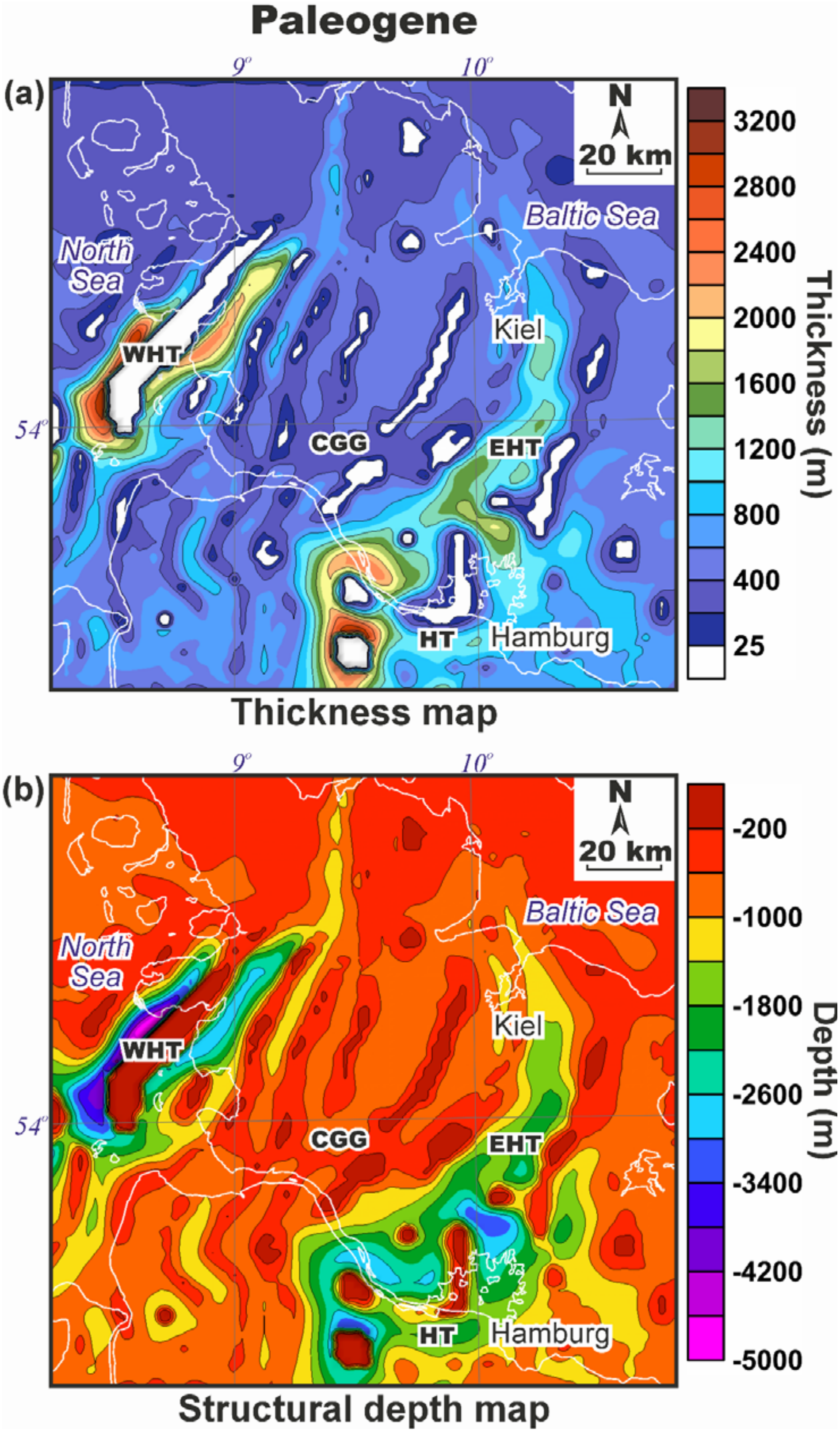

Figure 8. Layer 3 - the Paleogene: (a) thickness map (data file: *3_thickness_Paleogene.dat*) and (b) structural depth map of the base (data file: *3_base_Paleogene.dat*). Abbreviation: CGG - Central Glueckstadt Graben, EHT - Eastholstein Trough, HT - Hamburg Trough, WHT - Westholstein Trough.

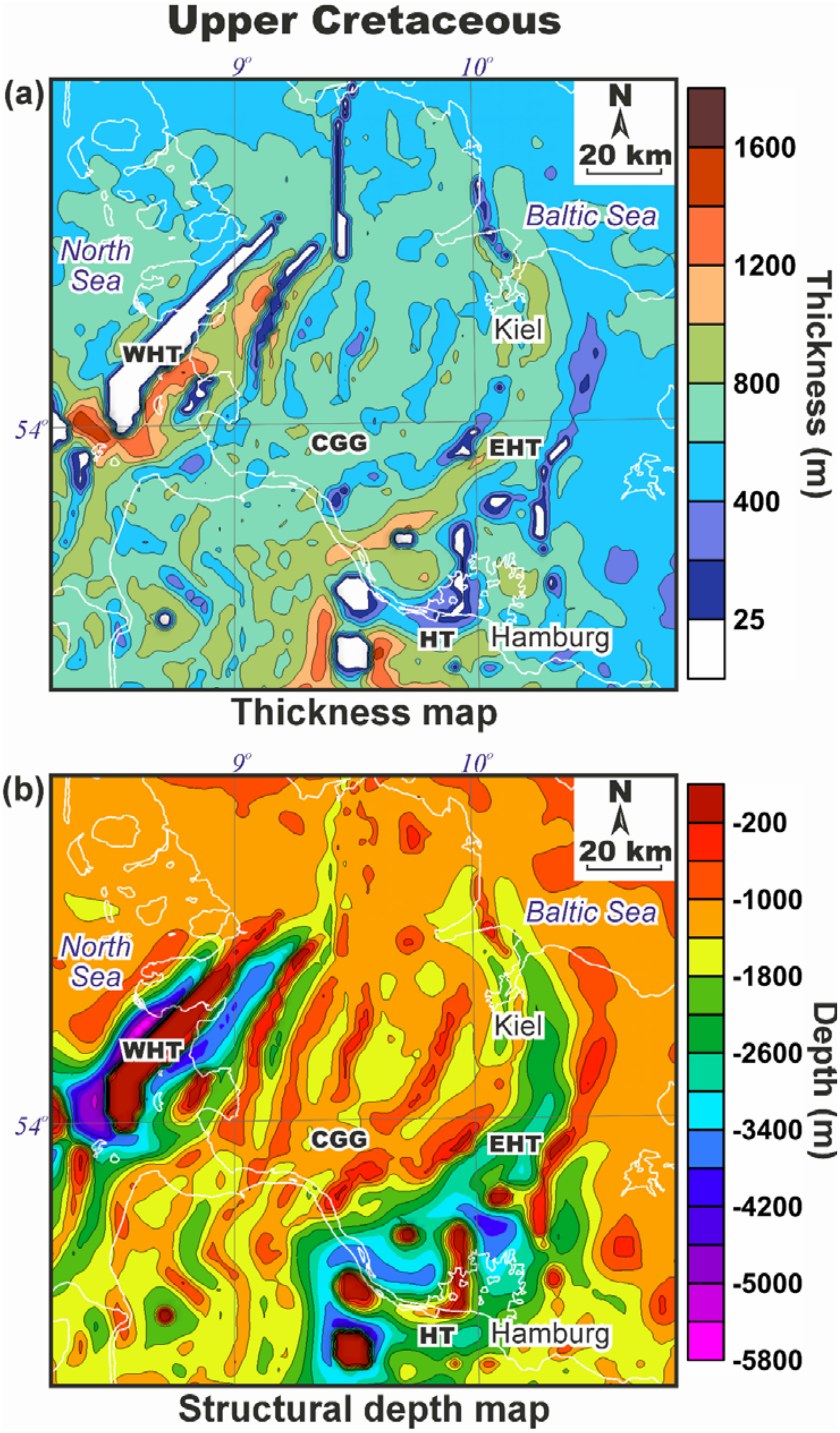

Figure 9. Layer 4 - the Upper Cretaceous: (a) thickness map (data file: *4_thickness_Upper_Cretaceous.dat*) and (b) structural depth map of the base (data file: *4_base_Upper_Cretaceous.dat*). Abbreviation: CGG - Central Glueckstadt Graben, EHT - Eastholstein Trough, HT - Hamburg Trough, WHT - Westholstein Trough.

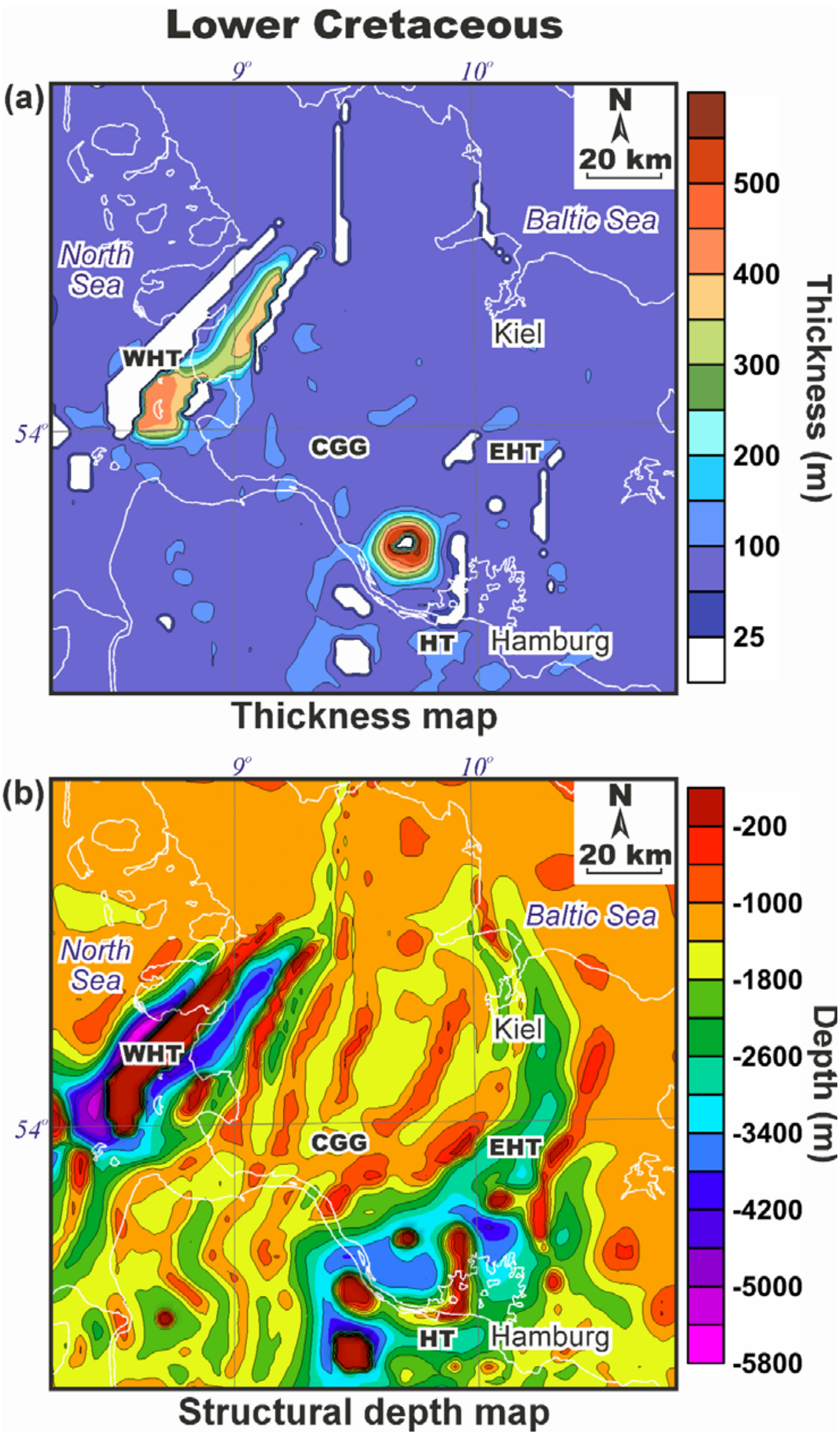

Figure 10. Layer 5 - the Lower Cretaceous: (a) thickness map (data file: *5_thickness_Lower_Cretaceous.dat*) and (b) structural depth map of the base (data file: *5_base_Lower_Cretaceous.dat*). Abbreviation: CGG - Central Glueckstadt Graben, EHT - Eastholstein Trough, HT - Hamburg Trough, WHT - Westholstein Trough.

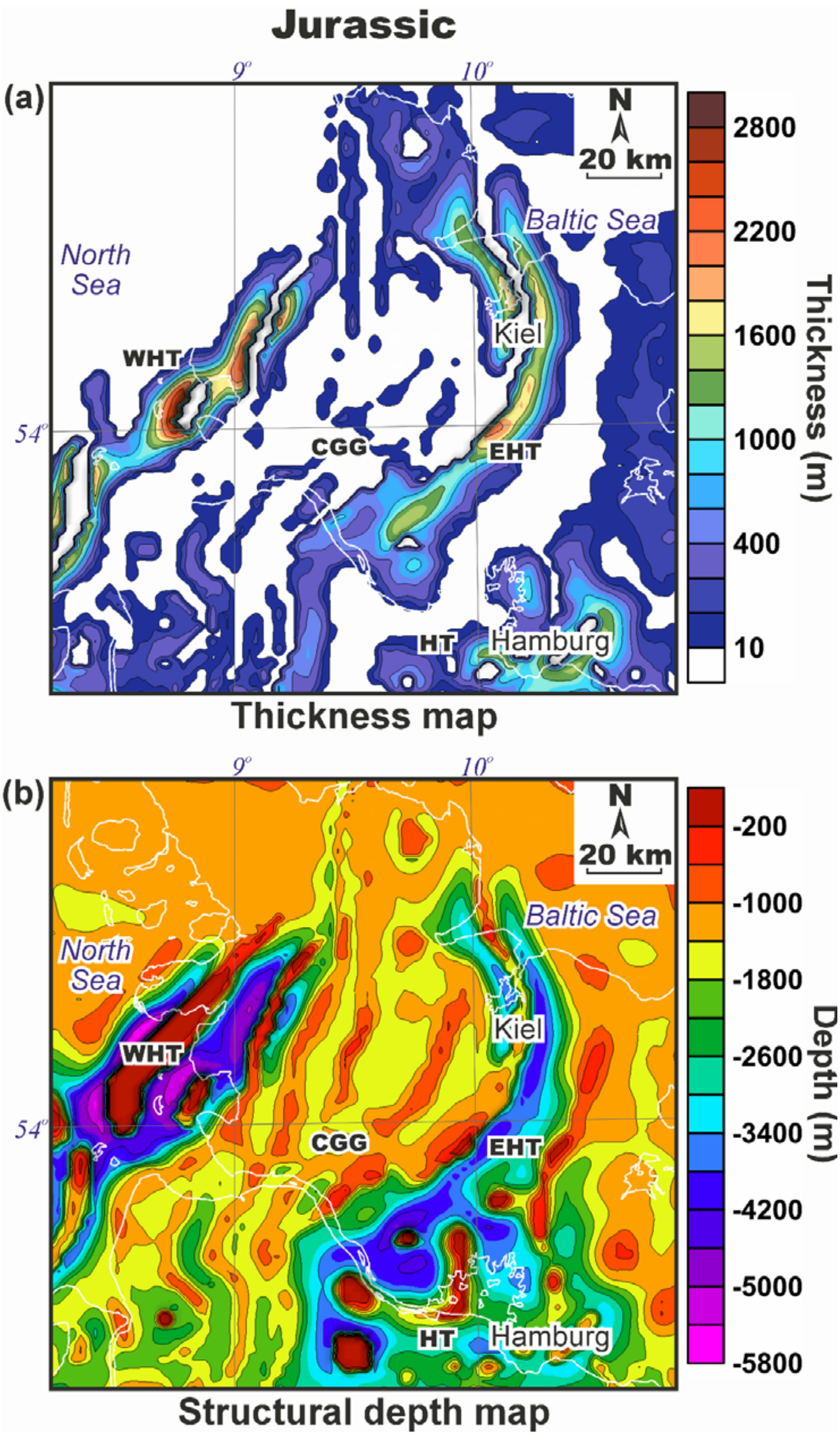

Figure 11. Layer 6 - the Jurassic: (a) thickness map (data file: *6_thickness_Jurassic.dat*) and (b) structural depth map of the base (data file: *6_base_Jurassic.dat*). Abbreviation: CGG - Central Glueckstadt Graben, EHT - Eastholstein Trough, HT - Hamburg Trough, WHT - Westholstein Trough.

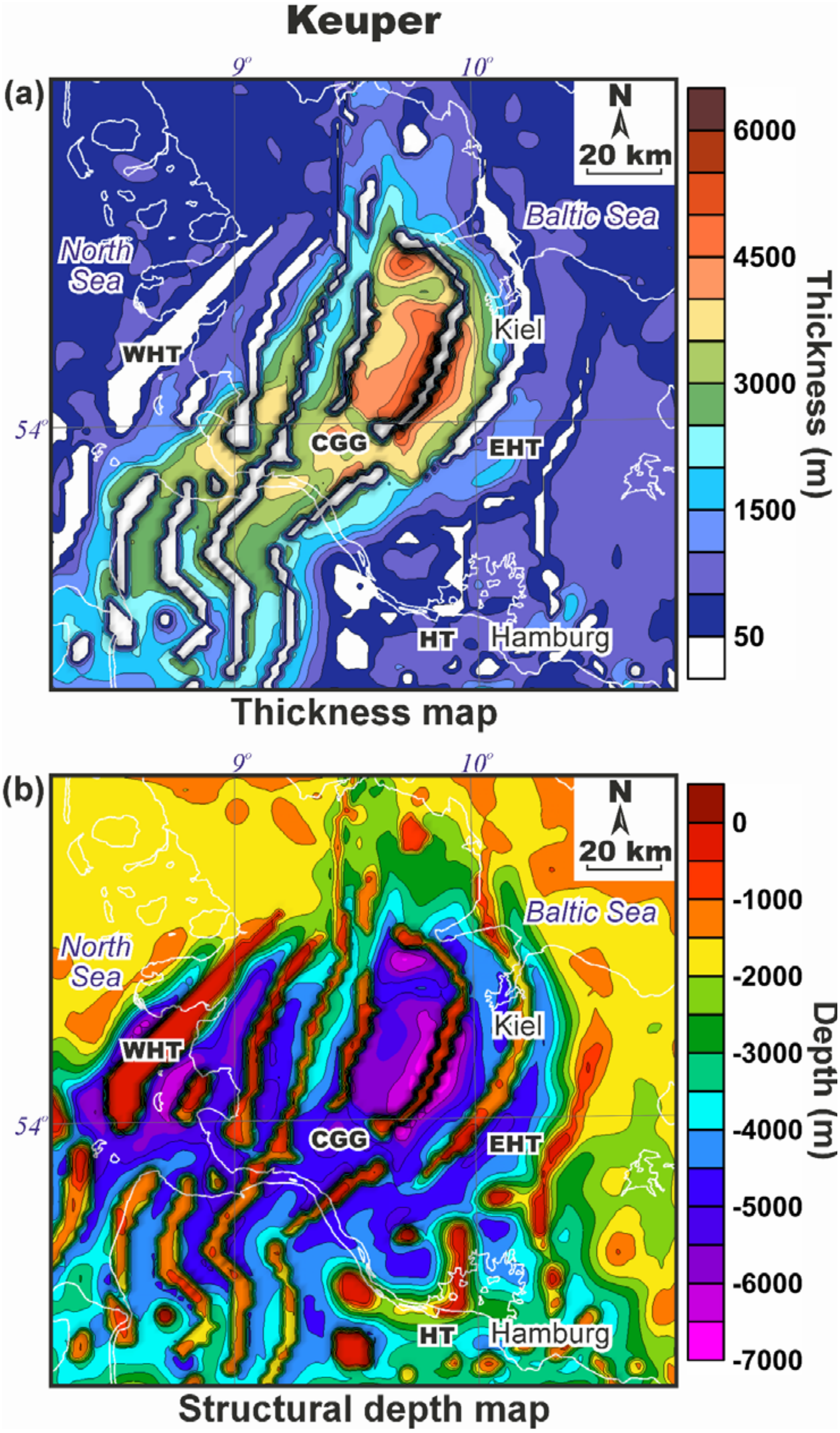

Figure 12. Layer 7 - uppermost part of the Middle Triassic and the Upper Triassic (Keuper): (a) thickness map (data file: *7_thickness_Keuper.dat*) and (b) structural depth map of the base (data file: *7_base_Keuper.dat*). Abbreviation: CGG - Central Glueckstadt Graben, EHT - Eastholstein Trough, HT - Hamburg Trough, WHT - Westholstein Trough.

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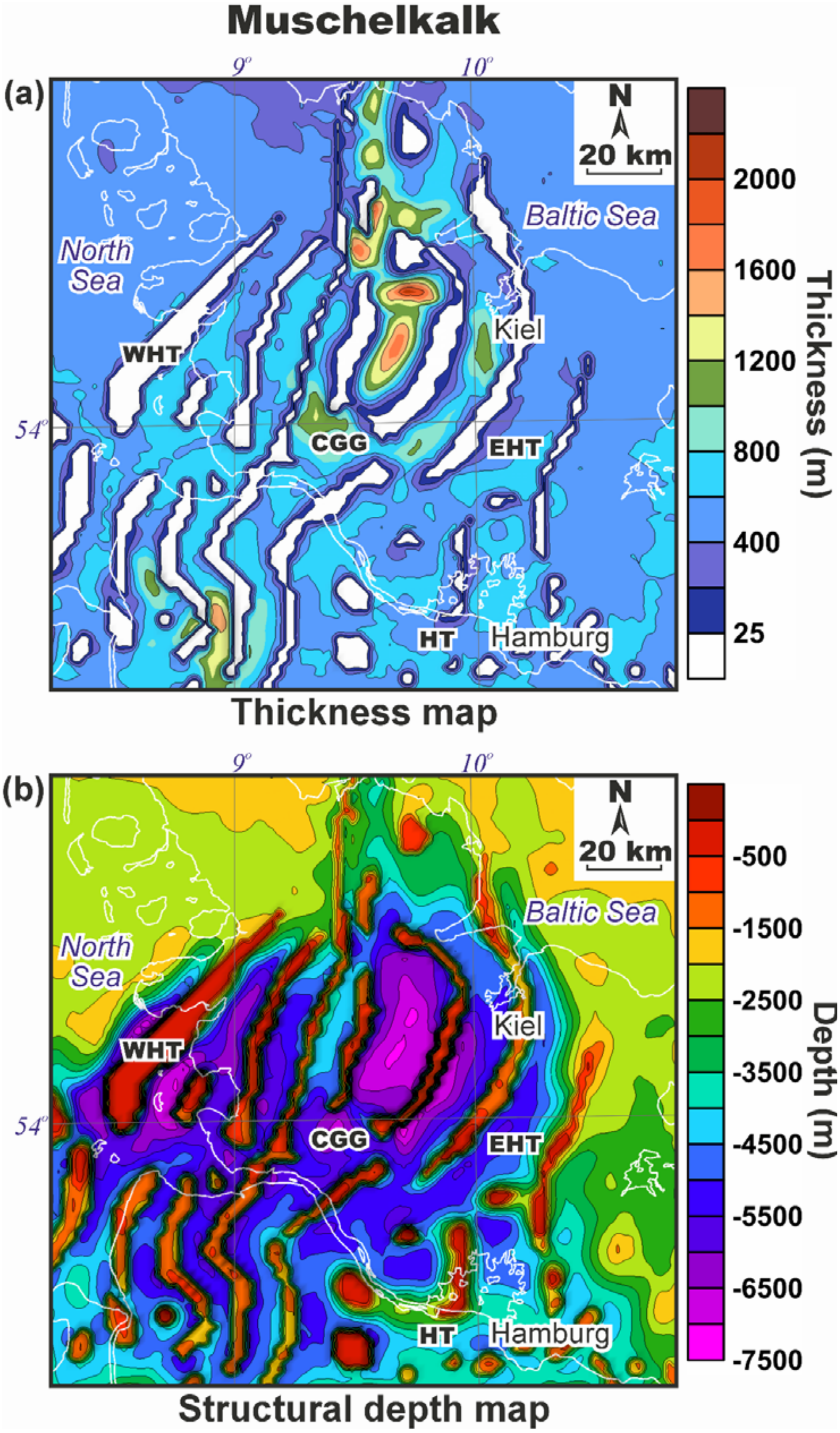

Figure 13. Layer 8 – the Middle Triassic without uppermost and lowermost parts (Muschelkalk): (a) thickness map (data file: *8_thickness_Muschelkalk.dat*) and (b) structural depth map of the base (data file: *8_base_Muschelkalk.dat*). Abbreviation: CGG - Central Glueckstadt Graben, EHT - Eastholstein Trough, HT - Hamburg Trough, WHT - Westholstein Trough.

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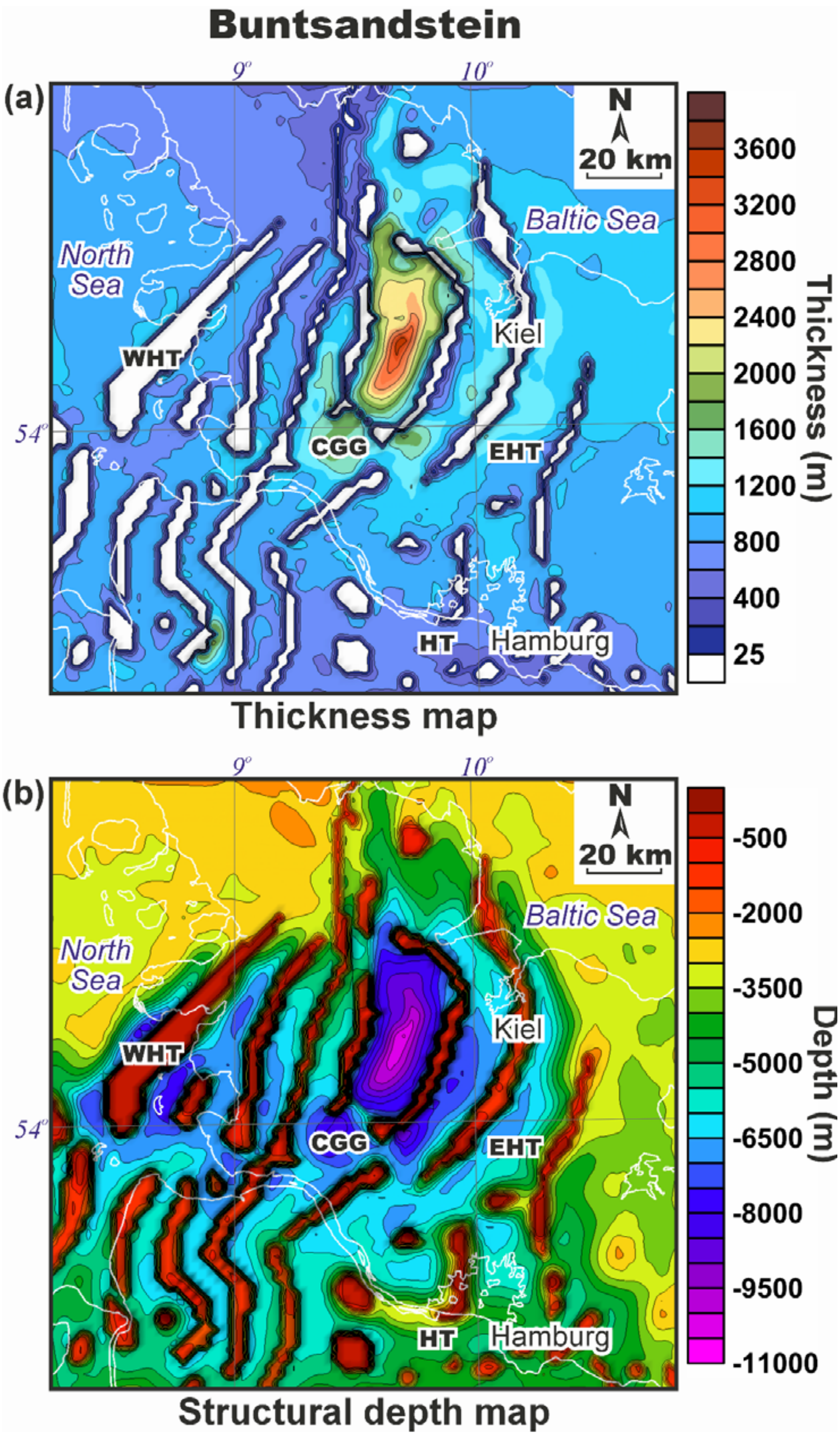

Figure 14. Layer 9 – the Lower Triassic and lowermost part of the Middle Triassic (Buntsandstein): (a) thickness map (data file: *9_thickness_Buntsandstein.dat*) and (b) structural depth map of the base (data file: *9_base_Buntsandstein.dat*). Abbreviation: CGG - Central Glueckstadt Graben, EHT - Eastholstein Trough, HT - Hamburg Trough, WHT - Westholstein Trough.

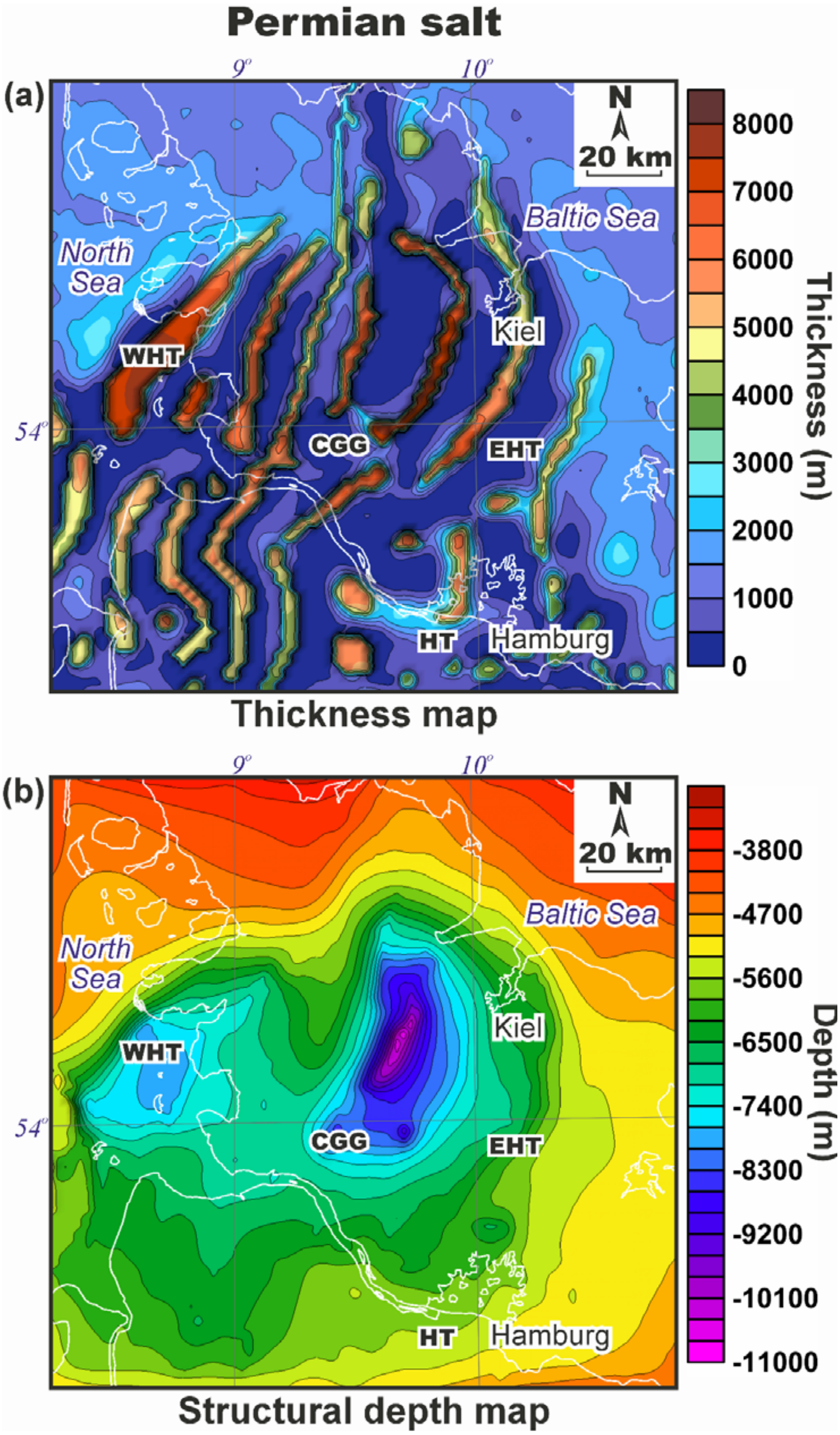

Figure 15. Layer 10 – upper part of the Lower Permian and the Upper Permian (undivided Zechstein plus salt-rich Rotliegend): (a) thickness map (data file: *10_thickness_ Permian_salt.dat*) and (b) structural depth map of the base (data file: *10_base_Permian_salt.dat*). Abbreviation: CGG - Central Glueckstadt Graben, EHT - Eastholstein Trough, HT - Hamburg Trough, WHT - Westholstein Trough.

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