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Crustal memory and basin evolution in the Central European Basin System—new insights from a 3D structural model

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Abstract

The Central European Basin System (CEBS) is composed of a series of subbasins, the largest of which are (1) the Norwegian–Danish Basin (2), the North German Basin extending westward into the southern North Sea and (3) the Polish Basin. A 3D structural model of the CEBS is presented, which integrates the thickness of the crust below the Permian and five layers representing the Permian–Cenozoic sediments. Structural interpretations derived from the 3D model and from backstripping are discussed with respect to published seismic data. The analysis of structural relationships across the CEBS suggests that basin evolution was controlled to a large degree by the presence of major zones of crustal weakness. The NW–SE-striking Tornquist Zone, the Ringkøbing-Fyn High (RFH) and the Elbe Fault System (EFS) provided the borders for the large Permo–Mesozoic basins, which developed along axes parallel to these fault systems. The Tornquist Zone, as the most prominent of these zones, limited the area affected by Permian–Cenozoic subsidence to the north. Movements along the Tornquist Zone, the margins of the Ringkøbing-Fyn High and the Elbe Fault System could have influenced basin initiation. Thermal destabilization of the crust between the major NW–SE-striking fault systems, however, was a second factor controlling the initiation and subsidence in the Permo–Mesozoic basins. In the Triassic, a change of the regional stress field caused the formation of large grabens (Central Graben, Horn Graben, Glückstadt Graben) perpendicular to the Tornquist Zone, the Ringkøbing-Fyn High and the Elbe Fault System. The resulting subsidence pattern can be explained by a superposition of declining thermal subsidence and regional extension. This led to a dissection of the Ringkøbing-Fyn High, resulting in offsets of the older NW–SE elements by the younger N–S elements. In the Late Cretaceous, the NW–SE elements were reactivated during compression, the direction of which was such that it did not favour inversion of N–S elements. A distinct change in subsidence controlling factors led to a shift of the main depocentre to the central North Sea in the Cenozoic. In this last phase, N–S-striking structures in the North Sea and NW–SE-striking structures in The Netherlands are reactivated as subsidence areas which are in line with the direction of present maximum compression. The Moho topography below the CEBS varies over a wide range. Below the N–S-trending Cenozoic depocentre in the North Sea, the crust is only 20 km thick compared to about 30 km below the largest part of the CEBS. The crust is up to 40 km thick below the Ringkøbing-Fyn High and up to 45 km along the Teisseyre–Tornquist Zone. Crustal thickness gradients are present across the Tornquist Zone and across the borders of the

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Ringkøbing-Fyn High but not across the Elbe Fault System. The N–S-striking structural elements are generally underlain by a thinner crust than the other parts of the CEBS.

The main fault systems in the Permian to Cenozoic sediment fill of the CEBS are located above zones in the deeper crust across which a change in geophysical properties as P-wave velocities or gravimetric response is observed. This indicates that these structures served as templates in the crustal memory and that the prerift configuration of the continental crust is a major controlling factor for the subsequent basin evolution.

Keywords: Central European Basin System; 3D structural model; Backstripping; Basin analysis; Structural analysis; Sorgenfrei–Tornquist Zone; Teisseyre–Tornquist Zone; Elbe Fault System

1. Introduction

The Central European Basin System (CEBS) covers an area extending from the southern North Sea across Denmark, The Netherlands and northern Germany to Poland (Fig. 1) and is composed of a series of subbasins that were initiated after the Variscan orogeny. These subbasins developed on the continental crust south and southeast of the Sorgenfrei–Teisseyre–Tornquist Zone and north of the Variscan domains outcropping along its southern border. Major subbasins are (1) the Norwegian–Danish Basin, (2) the North German Basin extending westward into the southern North Sea and (3) the Polish Basin. Mesozoic differentiation of these basins led to the development of the N–S-oriented Central, Horn and Glückstadt Grabens and the NW–SE-oriented Sole Pit Basin, the Broad Fourteens Basin, the West Netherlands Basin, the Lower Saxony Basin and the Subhercynian Basin along the southern margin of the CEBS. Due to its economically important resources of hydrocarbons, the CEBS has been extensively explored over the past decades. Although numerous local studies are available ranging in scale from the area of a salt structure to the scale of the large subbasins, the latest regional discussion covering the entire basin system (Ziegler, 1990b) predates more recent insights concerning both new geophysical data and new geoscientific methods. This is partially due to commercially motivated restrictions of data use. In the course of increasing European collaboration, a more intensive exchange of information has begun, for example, in the EU-funded TMR network Paleozoic Amalgamation of Central Europe (PACE) (Winchester, 2002) or in the ESF-funded project EUROPROBE Trans-European Suture Zone (TESZ) (Pharaoh et al., 1997)). As Ziegler (1990a,b) already stated and as the European projects confirmed, the different subbasins are characterized by partially correlating subsidence histories since Permian times despite the fact that they are located on a puzzle of different crustal domains with Precambrian, Caledonian and Variscan consolidation ages. The buried Caldonian deformation front (Fig. 1) is supposed to be somewhere beneath the southern margin of the RingkØbing-Fyn High (RFH) (Abramovitz and Thybo, 2000), whereas the Variscan Deformation front is assumed to be below the central part of the Northeast German Basin and the southern margin of the Northwest German Basin (Franke et al., 1996). The crustal block between the Caledonian and the Variscan sutures is commonly referred to as Avalonia (Pharaoh et al., 1997).

Previous detailed work in the NE German Basin (Scheck and Bayer, 1999) and in the Polish Basin (Lamarche et al., 2003) resulted in a 3D structural model of each of these subbasins. These studies as well as the results of other studies (Dadlez et al., 1995; Kiersnowski et al., 1995; Krzywiec, 2002; Plein, 1995; Van Wees et al., 2000) showed that the evolution of the two subbasins was not only similar but even connected. Studies of the Norwegian–Danish Basin (Clausen and Pedersen, 1999; Hansen et al., 2000; Vejbaek, 1997) demonstrate that it experienced an evolution which was similar to that of the North German and Polish basins. In all three basins, initial rifting in Early Permian times was accompanied by widespread volcanic activity followed by postrift thermal subsidence with deposition of Lower Permian Rotliegend clastics and Upper Permian Zechstein salt. After differential subsidence in the Mesozoic, Late Cretaceous–Early Cenozoic inversion and renewed subsidence in the Cenozoic are observed. From the