Tectonophysics 460 (2008) 215–229

Contents lists available at ScienceDirect

Tectonophysics

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

Heat flow and lithospheric thermal regime in the Northeast German Basin

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ARTICLE INFO

Article history:
Received 15 January 2008
Received in revised form 12 August 2008
Accepted 19 August 2008
Available online 5 September 2008

Keywords:
Northeast German Basin
Heat flow
Thermal modelling
Thermal structure
Thermal lithosphere

ABSTRACT

New values of surface heat flow are reported for 13 deep borehole locations in the Northeast German Basin (NEGB) ranging from 68 to 91 mW m^{-2} with a mean of 77±3 mW m^{-2}. The values are derived from continuous temperature logs, measured thermal conductivity, and log-derived radiogenic heat production. The heat-flow values are supposed free of effects from surface palaeoclimatic temperature variations, from regional as well as local fluid flow and from thermal refraction in the vicinity of salt structures and thus represent unperturbed crustal heat flow. Two-D numerical lithospheric thermal models are developed for a 500 km section along the DEKORP-BASIN 9601 deep seismic line across the basin with a north-eastward extension across the Tornquist Zone. A detailed conceptual model of crustal structure and composition, thermal conductivity, and heat production distribution is developed. Different boundary conditions for the thickness of thermal lithosphere were used to fit surface heat flow. The best fit is achieved with a thickness of thermal lithosphere of about 75 km beneath the NEGB. This estimate is corroborated by seismological studies and somewhat less than typical for stabilized Phanerozoic lithosphere. Modelled Moho temperatures in the basin are about 800 °C; heat flow from the mantle is about 35 to 40 mW m^{-2}. In the southernmost part of the section, beneath the Harz Mountains, higher Moho temperatures up to 900 to 1000 °C are shown. While the relatively high level of surface heat flow in the NEGB obviously is of longer wave length and related to lithosphere thickness, changes in crustal structure and composition are responsible for short-wave-length anomalies.

1. Introduction

In recent years, the Northeast German Basin (NEGB, Fig. 1) has been subject of renewed interest for studying heat flow and the crustal and lithosphere structure. The principal aim of this study is to report new surface heat flow (q_s) data for the NEGB and to combine these values with the wealth of recent information from different seismic, seismologic and other geophysical studies to generate a consistent lithospheric thermal model. The paper (1) presents new q_s values determined at 13 borehole sites based on continuous temperature logs and recent measurements of thermal properties, (2) provides estimates on mantle heat flow (q_m) by accounting for the radiogenic heat production within the crust, (3) develops a numerical model of the lithospheric thermal structure, (4) investigates the sensitivity of parameter changes, including thickness of thermal lithosphere, to temperature and heat-flow distribution and (5) discusses implications for the geodynamic state of the basin.

Three-dimensional thermal models down to the Moho were made by Scheck (1997) and Bayer et al. (1997) for the NEGB. The thermal parameters used for the sedimentary sequence reflect the state of knowledge at that time. The boundary conditions of the model were either a fixed Moho temperature (600 °C) or a fixed Moho heat flow (25 mW m^{-2}). The crustal domain below the sediments was simplified to a block model, in which thermal conductivity (λ) and radiogenic heat production (A) decrease linearly to a depth of 30 km. No lateral compositional variations were considered for the crust. These models were slightly modified by Ondrak et al. (1998) by varying locally the input parameters for the crust and the boundary conditions of the model to attain a better fit to measured borehole temperature profiles.

Other published thermal models of the NEGB consider a coupled temperature and burial history, calibrated by organic-maturity parameters and temperature recordings in boreholes and with heat-flow values below the sedimentary veneer used as a boundary condition (Friberg et al., 2000; Friberg, 2001). Vosteen et al. (2004) estimated the present-day heat-flow distribution at 6 km depth in the basement across the NEGB using inverse modelling of the steady-state conductive thermal regime based on λ, A, and borehole temperature information.

At lithospheric scale, Marotta et al. (2000) present lithosphere strength profiles and a 2-D flexural model along the BASIN 9601 seismic line including a general steady-state thermal model with 1600 K at about 80 km depth as the constant lower thermal boundary condition and no lateral variations in the thermal properties of the crust. Gemmer et al. (2003) modelled the late Cretaceous–Cenozoic evolution of the North German Basin in a general 3D thermomechanical numerical

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0040-1951/$ – see front matter
doi:10.1016/j.tecto.2008.08.022

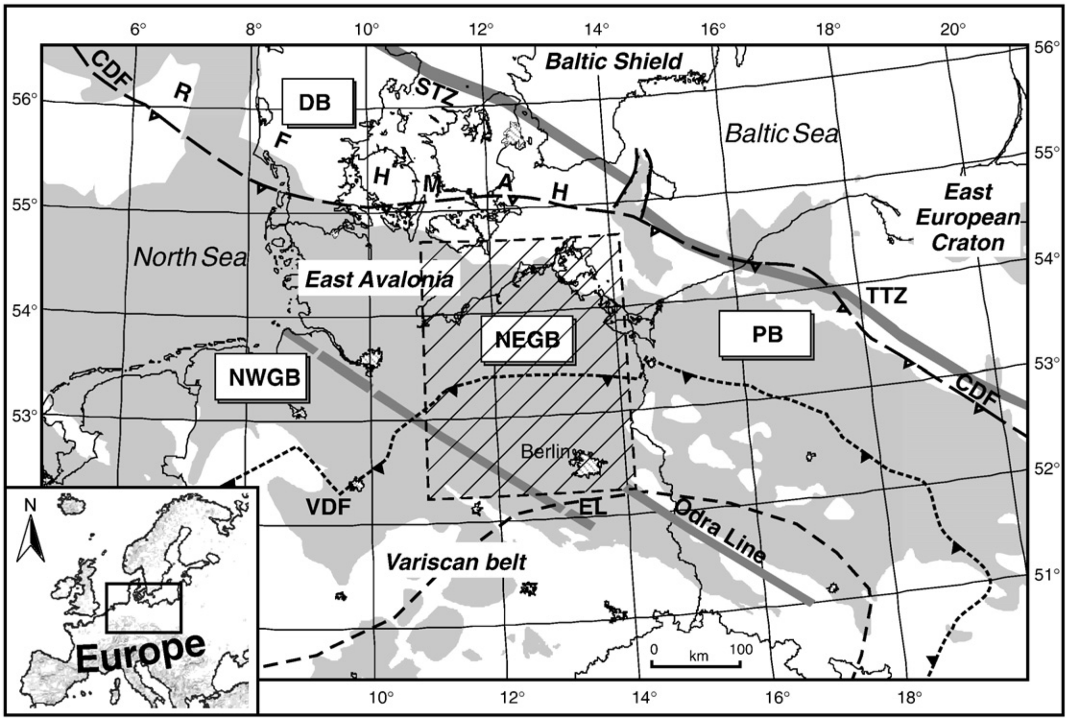

Fig. 1. Study area and main tectonic units of the Southern Permian Basin and adjacent areas (after Lokhorst, 1998; Karnkowski, 1999; Pharaoh, 1999; Ziegler, 1990; Bayer et al., 2002). Abbreviations: CDF Caledonian Deformation Front; DB Danish Basin; EL Elbe Line; MAH Møn Arkona High; NEGB Northeast German Basin; NWGB Northwest German Basin; PB Polish Basin; RFH Rynkøbing Fyn High; STZ Sorgenfrei–Tornquist Zone; TTZ Tornquist-Teisseyre Zone; VDF Variscan Deformation Front. The distribution of Rotliegend (Permian) sedimentary units is gray shaded.

model in which vertical movements caused by lithospheric compression and stress relaxation played a dominant part.

The present paper fills a gap by investigating the thermal regime of the crust and upper mantle beneath the NEGB using modelling procedures similar to those used for adjacent areas, such as along a transect from the southern part of the Baltic Shield across the Sorgenfrei–Tornquist Zone (STZ) and the Caledonian Deformation Front (CDF) into the Northwest German Basin (NWGB) (Balling, 1995) and across Poland including the Polish Basin to the east (Majorowicz et al., 2003; Majorowicz, 2004).

2. Geological setting and geodynamic evolution

The NEGB is part of the mid-European basin system formed in Permian time south of the Tornquist Zone (e.g. Ziegler, 1990; Glennie, 1998). The basin is connected to the west with the NWGB and to the east with the Polish Basin (PB) (Fig. 1). These basins formed part of a regional Southern Permian Basin.

The basement of the NEGB is comprised of rocks of variable composition and age (Katzung and Ehmke, 1993; references therein) pertaining in the south to the Variscan belt (folded Namurian and older units) and in the north to the Variscan foredeep. Whereas in the southern part of the Variscan foredeep the Namurian to Westphalian rocks were deformed during the Variscan orogeny, Namurian to Stephanian sediments in the northern part of the foredeep remained unaffected. The Carboniferous and Devonian rocks of the foredeep discordantly overlie basement units that were either folded in Caledonian time (northern part) or consolidated in earlier times (southern part). Meissner et al. (1994) termed the northern part of the Variscan foredeep, south of the Caledonian Front, (East) Avalonia (Fig. 1). It is a microcontinent that originated from the northern rim of Gondwana and joined with Baltica during the Caledonian cycle. Krawczyk et al. (1999) interpreted from the DEKORP-BASIN 9601 line (Fig. 2) the presence of Baltica crust perhaps as far south as the depocenter of the basin (Fig. 3). In general, details of structure and composition of the crust beneath the NEGB are a matter of interpretation and discussion (cf. Bayer et al., 1999; Krawczyk et al., 1999).

Tectonic movements in the late Stephanian have caused activation of preferentially NNE and subordinately NNW- to NW-trending fault systems associated with a Permian–Carboniferous volcanic series that is up to 2000-m-thick and emplaced in pull-apart basins (Benek et al.,

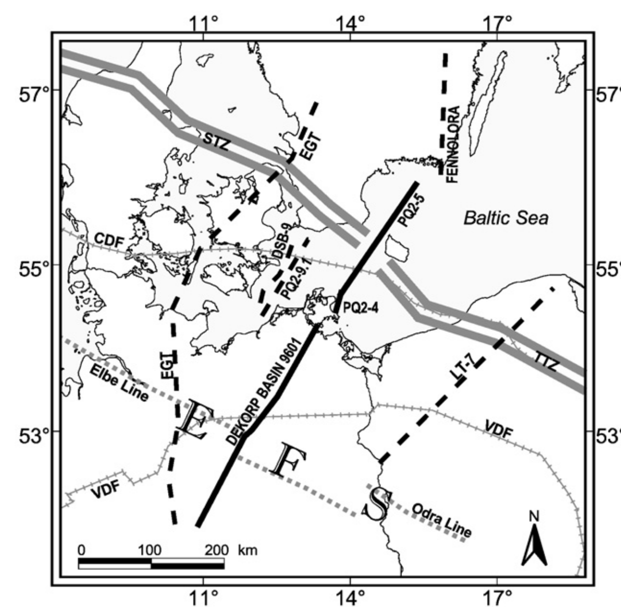

Fig. 2. Selected seismic lines across the Trans-European Suture Zone. Lithosphere thermal modelling was performed by Balling (1995) for the EGT and the FENNOLORA profiles and by Majorowicz et al. (2003) and Majorowicz (2004) for the LT-7 profile and other profiles in Poland. The lithosphere thermal modelling presented in this paper is performed along the DEKORP-BASIN9601 profile and its north-eastern extension (PQ2-4 and PQ2-5, together with PQ2-9.1 and DSB-9).