Lithosphere-Scale 3D Thermal Models of the Norwegian Continental Shelf

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Introduction: To reveal key features of the 3D thermal pattern of the SW Norwegian continental shelf, a 3D structural model has been taken as a realistic structural background for a 3D thermal modeling, which has been made with the help of COMSOL Multiphysics® software.

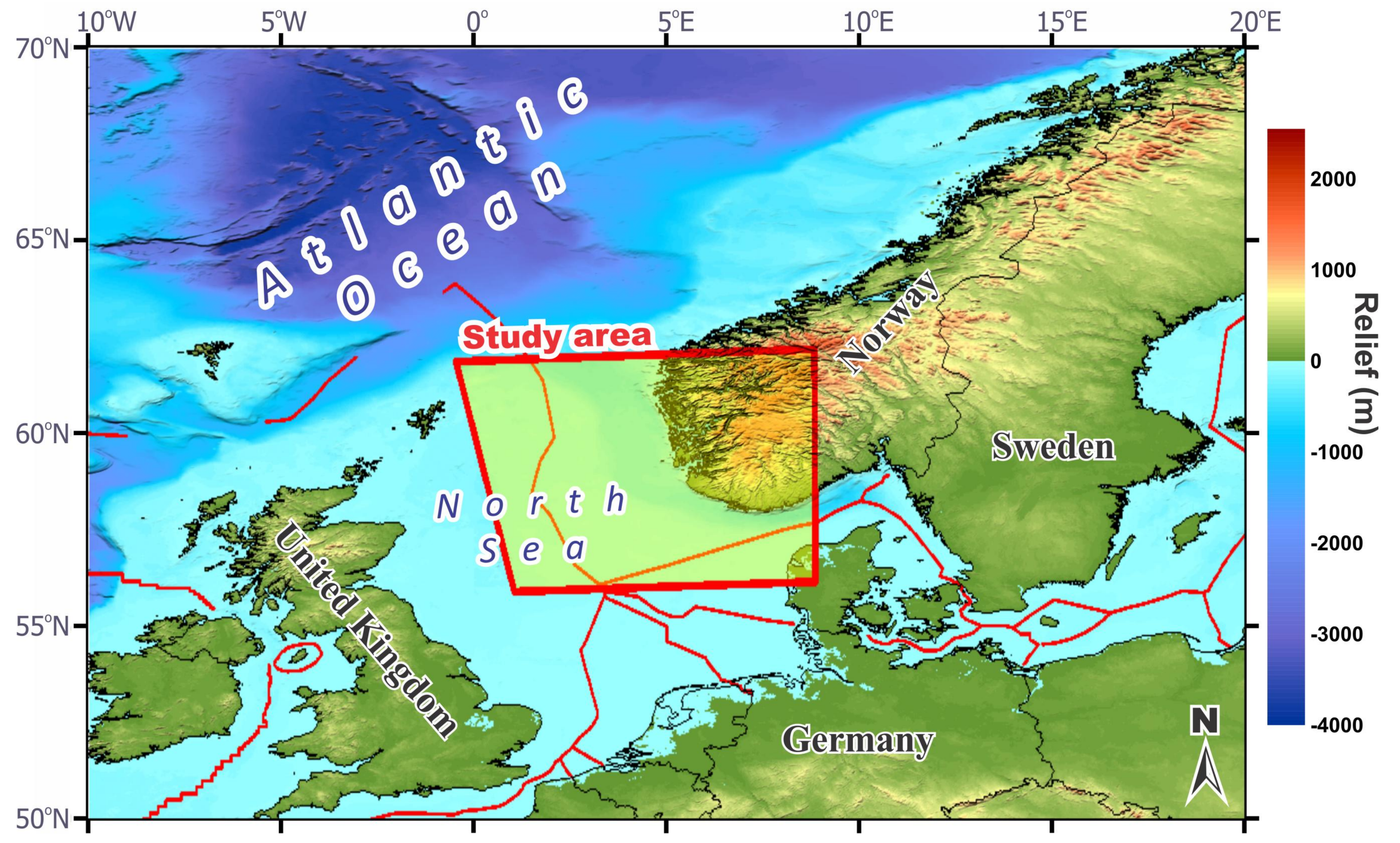

Figure 1. Overview map of northwestern Europe with location of the study area (relief from IOC, IHO, BODC 2003).

Computational Methods: The 3D temperature distribution beneath the northern North Sea and adjacent areas has been calculated using the Heat Transfer Module by simulating stationary and time-dependent heat transfer in solid materials. This has been performed based on physical principles of the heat conduction by solving the heat equation in 3D:

$$\rho C_p\,(\partial T/\partial t) = \nabla \cdot (k\,\nabla T) + Q$$

where ρ is the density [kg/m^3], C_p is the specific heat capacity [J/kgK], T is the temperature [K], k is the thermal conductivity [W/mK], ∇T is the temperature gradient [K/m], t is the time [s], Q is the radioactive heat production [W/m^3], $\partial T/\partial t$ denotes the change of temperature with time, and ∇ is the operator giving the spatial variation in temperature.

The lateral boundaries were closed to heat transfer, assuming that the temperature gradient is zero across the thermally insulated lateral boundaries. The time-dependent temperatures at the sea floor and at the Earth´s surface have been set as the upper thermal boundary with taking into account major changes of the paleoclimate. The lithosphere-asthenosphere boundary has been taken as a lower thermal boundary, corresponding to the 1300 °C isotherm.

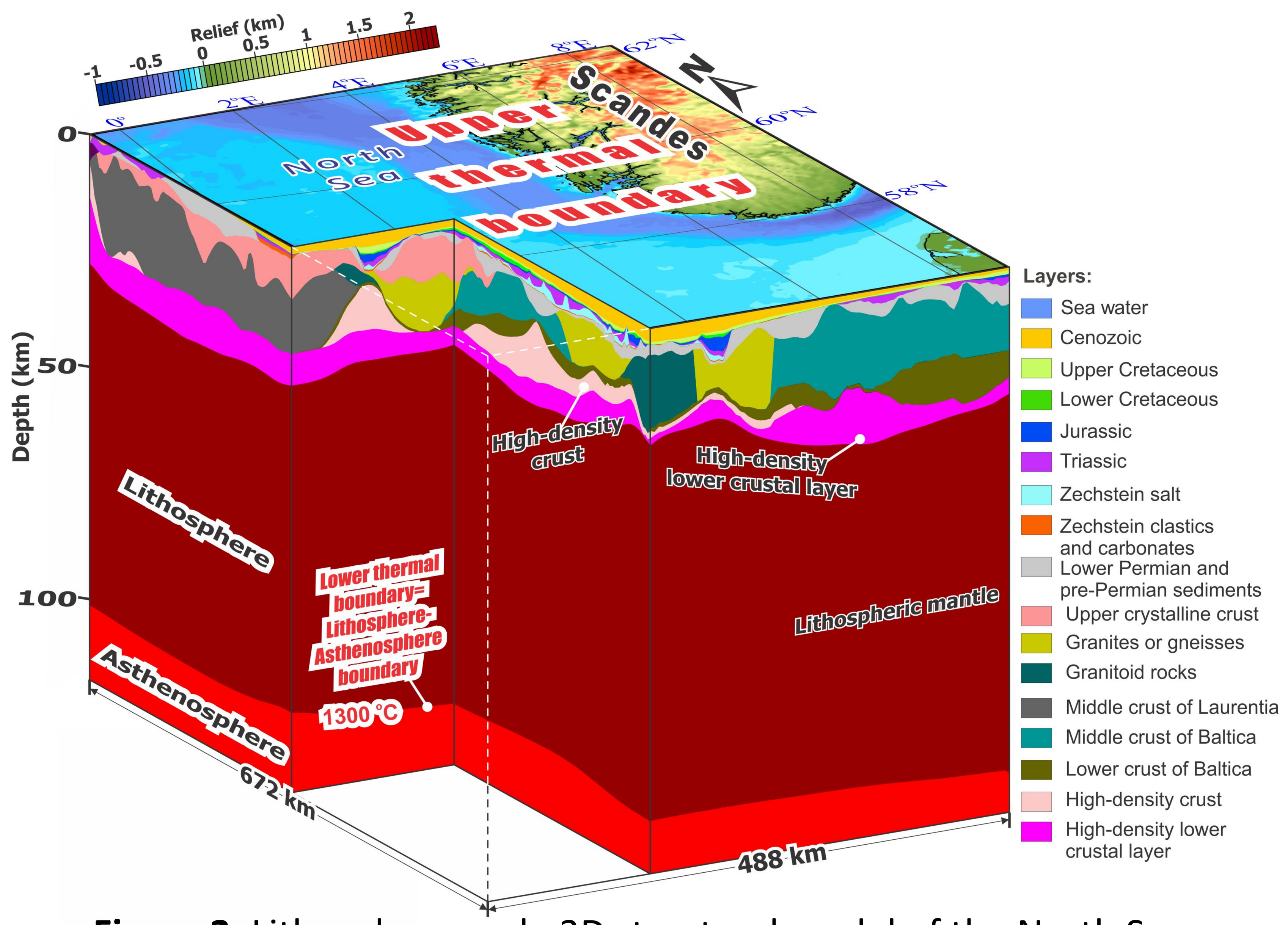

Figure 2. Lithosphere-scale 3D structural model of the North Sea and adjacent areas of the continent (4 times vertically exaggerated).

Acknowledgments: I am thankful to Aker BP, BayernGas, BKK, Conoco Phillips, Dea, DONG energy, Engie, Eni, E.ON, Lundin, Maersk, NGU, Noreco, NPD, Repsol, Statoil, Total, VNG, and Wintershall for supporting this reasearch in the framework of “Crustal Onshore-Offshore Project, Phase 1”.

Results: The modelled temperatures have been compared with the measured temperatures in the available boreholes within the uppermost part of the 3D thermal model, indicating that there is a reasonable agreement between the measured and modeled temperatures and implying that deep modeled temperatures are also in a reasonable range.

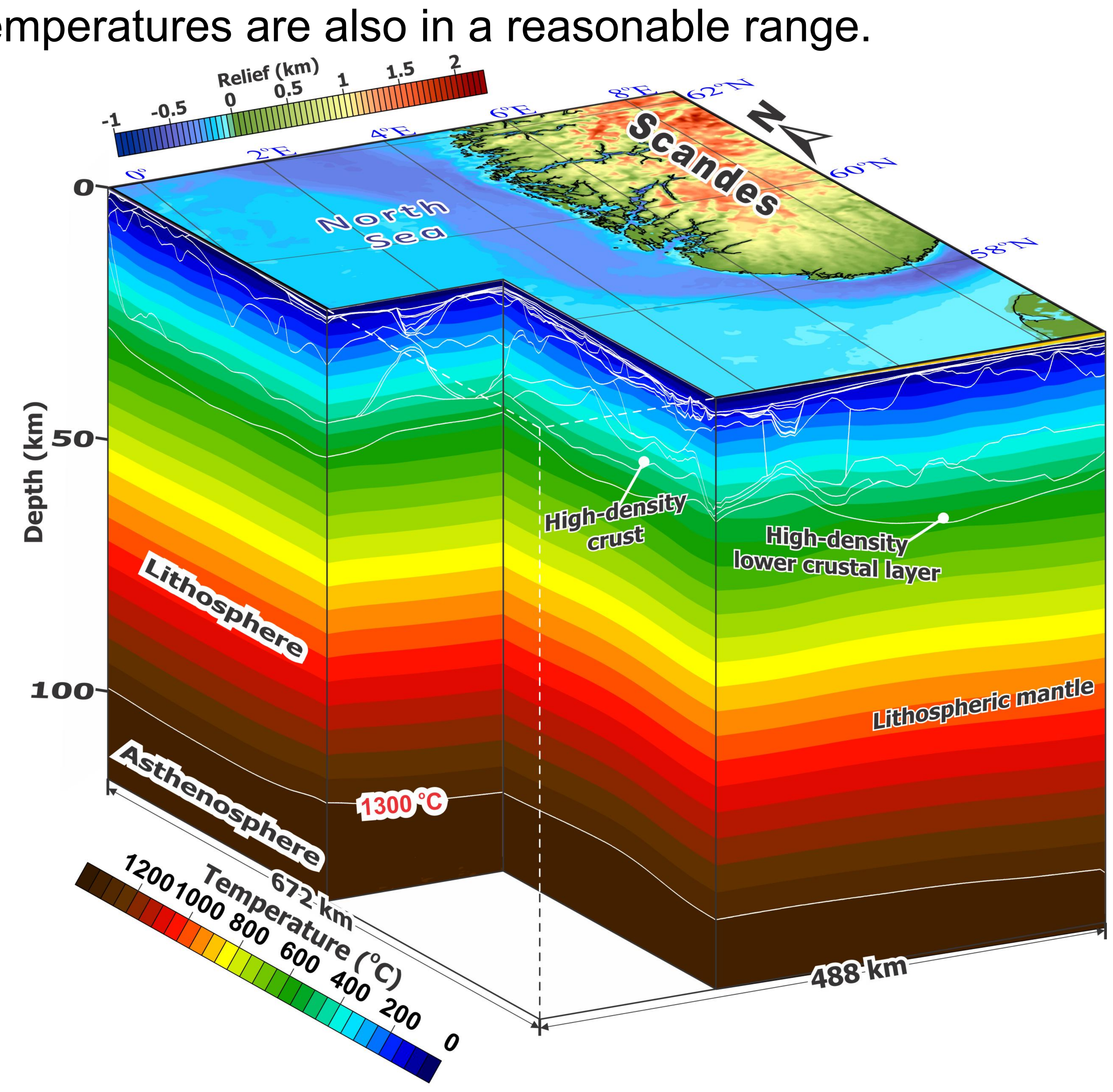

Figure 3. Lithosphere-scale 3D thermal model of the North Sea and adjacent areas of the continent (4 times vertically exaggerated).

Layer of the 3D structural model	Dominant lithology	Specific heat capacity C_p [J/kgK]	Thermal conductivity scale value k_r [W/mK]	Radiogenic heat production S [μW/m^3]
Tertiary	clastics	1180	3.30	0.7
Upper Cretaceous	carbonates, clastics	1000	3.00	1
Lower Cretaceous	clastics	1180	3.15	1.5
Jurassic	clastics	1180	3.20	1.6
Triassic	clastics, carbonates	1180	3.25	1.6
Upper Permian salt	rock salt	840	3.35 and 6	0.3
Non-salt Upper Permian (Zechstein)	clastics, carbonates, anhydrites	1120	4.00	0.8
Lower Permian - pre-Permian sediments	clastics, carbonates	1180	3.60	1.6
Middle-upper crustal intrusions	intrusive rocks	880	2.55	0.4
Upper crustal magmatic rocks	gabbro to anorthositic rocks	880	2.90	0.4-0.5
Low-density upper crustal layer	metasediments or granite	880	3.25	2.0
Upper crustal layer	granite and gneiss	880	3.10 (3.00-3.20)	1.8 (1.3-3.3)
Eastern central North Sea rocks	granitoids and/or gneiss	950	3.20 (2.95-3.35)	0.7 (0.3-3.0)
Western central North Sea rocks	granitoids and/or gneiss	950	3.10 (3.0-3.25)	0.8 (0.7-2.8)
Middle crust of Laurentia and Avalonia	granitoids and/or gneiss	950	3.00-3.10	0.7-0.8
Middle crust of Baltica	granitoids and/or gneiss	950	2.10 (3.05-3.20)	0.8 (0.6-1.0)
Lower crust of Baltica	metamorphic rocks	1050	2.90	0.3
High-density crust	mafic granulites, gabbros	1050	3.00-3.10	0.2-0.3
High-density lower crustal layer	gabbros, high-grade metamorphic rocks	1100	2.80-2.85	0.2
Lithospheric upper mantle	peridotite	1200	4.79	0.03

Table 1. Thermal properties of the layers of the 3D model.

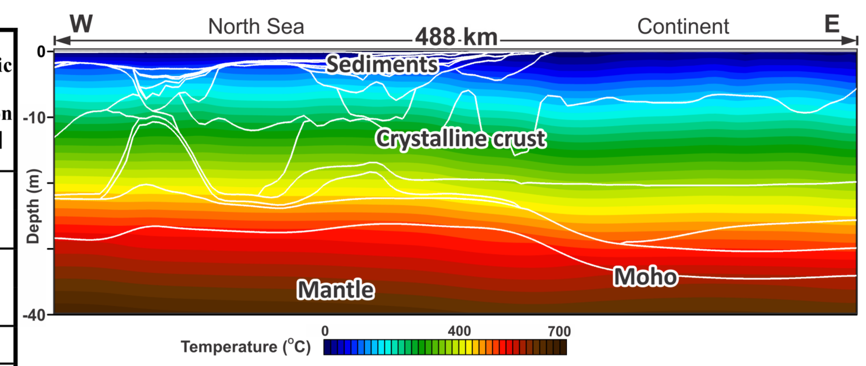

Figure 4. Modelled temperature along 2D vertical slice through the middle part of the 3D model.

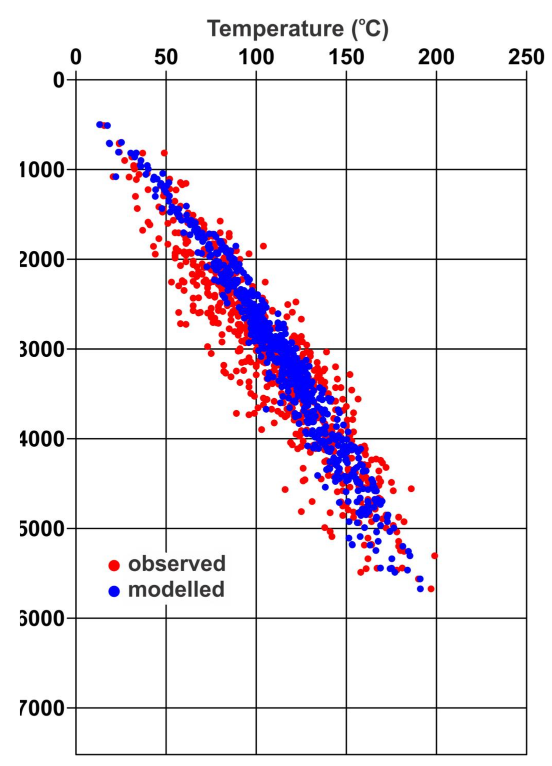

Figure 5. Calculated and observed temperatures for the boreholes.

Conclusions: The results of the 3D thermal modelling provide significant progress in our understanding of the first-order characteristics of the conductive thermal field within the northern North Sea and adjacent areas. These results have revealed some key features of the thermal state of the study area that are extremely important factors in the exploration for hydrocarbons in the sedimentary basins and in evaluations of the deep geothermal potential within the Norwegian mainland.

Reference:

IOC, IHO & BODC 2003: Centenary Edition of the GEBCO Digital Atlas, published on CD-ROM on behalf of the Intergovernmental Oceanographic Commission and the International Hydrographic Organization as part of the General Bathymetric Chart of the Oceans; British Oceanographic Data Centre, Liverpool, UK.