Poster
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Project GeoPower: Basic subsurface information for the utilization of geothermal energy in the Danish-German border region

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INTRODUCTION

Information on both hydraulic and thermal conditions of the subsurface is fundamental for the planning and use of hydrothermal energy. In the framework of the Interreg4a GeoPower project, fundamental geological and geophysical information of importance for the planning of geothermal energy utilization in the Danish-German border region was compiled and analyzed.

A 3D geological model was developed and used as structural basis for the setup of a regional temperature model. In that frame, new reflection seismic datawereobtainedtocloselocal data gaps in the border region. The analyses and reinterpretation of available relevant data (old and new seismic profiles, core and well-log data, borehole data, literature data) and a new time-depth conversion (new velocity model) allowed correlation of seismic profiles across the border.

Based on the consistent geological model depth and thickness maps for three potential geothermal reservoir complexes were drawn and visualized together with lithological parameters at well locations.

The interpretation of petrophysical data (core data and well logs) allows to evaluate the hydraulic and thermal rock properties of geothermal formations and to develop a parameterized 3D thermal conductive subsurface temperature model.

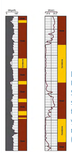
New local surface heat-flow values (range: 72–84 mW/m²) were determined and predicted temperature were calibrated and validated by borehole temperature observations. Finally, new temperature maps for relevant layer boundaries (e.g. Rhaetian/Gassum, Middle Buntsandstein) and selected constant depth intervals (1 km, 2 km, etc.) were compiled.

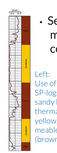
Geophysical survey - structural data

- Evaluation of geological, stratigraphical, petrophysical, and geophysical data from 224 wells in the project area.
- Geophysical exploration campaign:
  - (1) Reflection seismic profiles to compensate lag of field data near Tastrup/Flensburg (Mecking et al., 2014)
  - (2) Gravimetrical measurements in areas with salt diapirs (Glückstadt Graben) (Schmidt et al., 2013; Götze et al., 2014)
- Interpretation of seismic profiles and borehole data in terms of lithostratigraphic layers, faults and salt diapirs.
- Validation of the Geotectonic Atlas of NW-Germany

Seismic profiles 1961 - 1984
Seismic profiles 1985 - 2007
Seismic interpolation

Border crossing correlation of seismic sections.



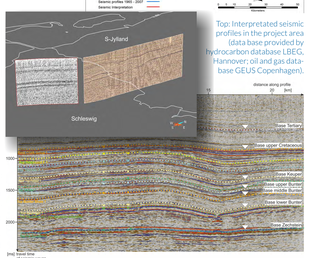


- Setup of a new velocity model for time-depth conversion.

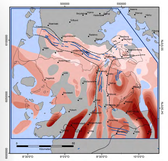
Left: Use of gamma- and SP-logs to separate sandy layers (hydrothermal reservoir, yellow) from impermeable mudstone (brown).

Middle right: Example of border crossing correlation of seismic sections.

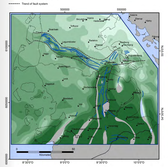
Bottom right: Example of an interpretated seismic section from Southern Jutland



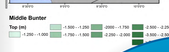
Top: Interpretated seismic profiles in the project area (data base provided by hydrocarbon database LBEG, Hannover; oil and gas database GEUS Copenhagen).



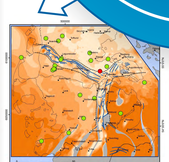
Rhaetium/Gassum (Upper Keuper)



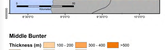
Middle Bunter



Top [m]



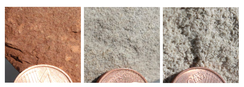
Middle Bunter



Thickness [m]

Reservoir characterization

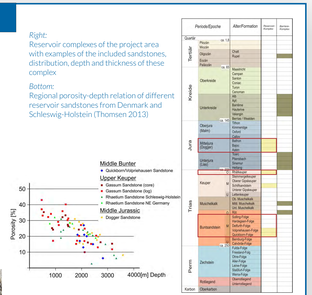
- Goal: Description and evaluation of depth, thickness, properties and distribution of hydrothermal reservoir formations.
  - Log interpretation for porosity and permeability (Hjuler, 2014)
- Major geothermal reservoir formations:
  - Middle Buntsandstein
  - Upper Keuper (Rhaetian/Gassum)
  - Middle Jurassic (Dogger)
- Geothermal reservoirs definition:
  - Thickness: 15 m
  - Porosity: 15 %
  - Permeability: 500 mD (Millidarcy)
  - Temperature: 30 °C
- Depth range of hydrothermal reservoirs: 1000-2500 m

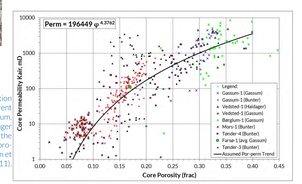


Middle Buntsandstein | Upper Keuper / Rhaetian | Middle Jurassic

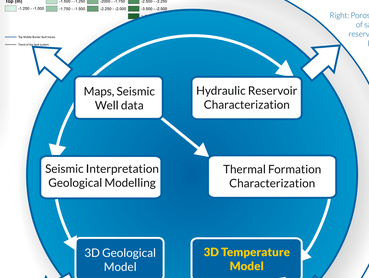
Right: Reservoir complexes of the project area with examples of the included sandstones, distribution, depth and thickness of these complex

Bottom: Regional porosity-depth relation of different reservoir sandstones from Denmark and Schleswig-Holstein (Thomsen 2013)



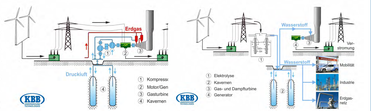


Right: Porosity-permeability relation of sandstones from different reservoir sandstones (Gassum, Bunter Sst. and Haldager Sst. formations) in the Danish part of the project area (Mathiesen et al. 2011).

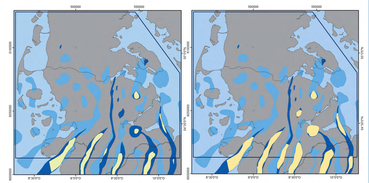


Potential storage of wind energy

Two options of energy storage in the underground are based on caverns in saltdomes: compressed air or hydrogen. A CAES (compressed air energy storage) system uses surplus electrical energy to compress air and store it in salt caverns. During periods of high energy demand the compressed air drives a generator for energy production. An example is the CAES plant in Huntdorf (Niedersachsen, Northern Ger-many) with compressor power of 60 MW (8 hours loading time of the cavern) and a peak generator power of 290 MW during 2 hours of operation. Since the compressed air must be cooled before storage in the cavern and reheated to prevent freezing of the generator the effectivity of this system is reduced to 40%. Alternatively, hydrogen can be produced from excess electrical energy by electrolysis and stored in a salt cavern before it is used, e.g., to drive gas turbines or for industrial purposes.
To meet the high pressure of the compressed air (50 - 100 bar) and the compressed hydrogen (60 - 180 bar) certain depth ranges of the salt caverns must be taken into account. After Crotogino (2011) the maximal depth for compressed air storage is 800 m and for hydrogen storage 1.300 m. A safety distance from the top of the salt to the top of the cavern must be taken into account.



Schematic view of a compressed air (left) and of a hydrogen (right) power plant using e.g. wind energy.

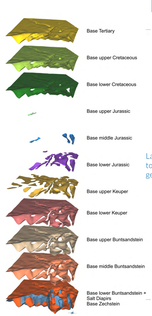


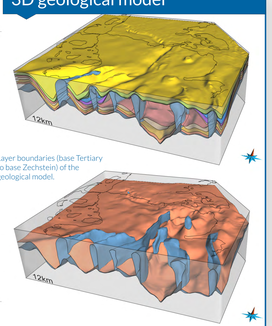
Distribution of horizons with potential locations of caverns to store compressed air (left), hydrogen (right)

Workflow

3D geological model

- Time to depth conversion of reflectors
- Correction of reflector data using borehole data
- Construction of fault plains in selected regions (not integrated into the model)
- Construction of hull surfaces of salt diapirs
- Interpolation of boundary surfaces of lithostratigraphic formations using reflectors, borehole data and datasets of the Tectonic Atlas of NW-Germany (Baldschuhn et al. 2001).

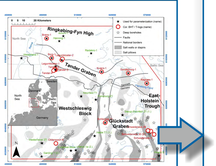


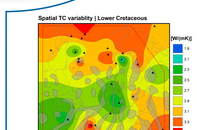


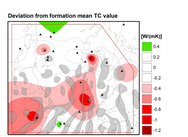
Layer boundaries (base Tertiary to base Zechstein) of the geological model.

Thermal parameterization

- Rock thermal properties are determined from geophysical well-logging data
  - Bulk TC borehole profiles are calculated applying the equations of Fuchs et al. (2015)
  - Radiogenic heat production is calculated applying the equations of Rybach (1986) as well as Bücker and Rybach (1996)
- Spatial variability of rock TC
  - considered for the sedimentary rock section
- Basal heat flow derived from boreholes
  - interval heat flow values are calculated with Bullard method







Formation TC for the example of the Lower Cretaceous. Left: Spatial variability of formation TC, right: deviations of regional values from overall formation mean TC value

Borehole	Heat-flow density [mW/m²] Interval	Surface	20 km
Varnæs-1	81.1	81.7	48.8
Lagumklosater-1	82.0	82.9	50.5
Sønderborg-1	77.4	78.5	46.2
Brønsø-1	89.0	89.7	57.5
Kegnæs-1	82.0	82.8	50.5
Kværs-1	75.7	76.8	44.3
Westerland 1	72.3	74.2	42.9
Mean value	79.9	**80.9**	**48.7**
standard deviation	5.4	5.1	4.9

Heat-flow values for borehole sites.

3D temperature model

3D FEM model (Feflow 6,2)
719,715 3D prismatic mesh elements; 1,913,692 nodes

Solving 3D conductive heat equation

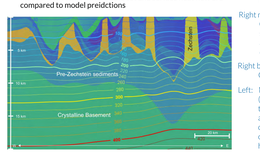
$$\rho c \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(\lambda \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(\lambda \frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(\lambda \frac{\partial T}{\partial z}\right) + H$$

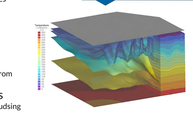
Boundary conditions
top: 9 °C; bottom: q = 49 mW/m²; sides: no flow

14 major geological units
3D geological model enriched by Pre_Zechstein data from Maystrenko and Scheck-Wenderoth (2013)

Calibration on borehole temperatures
TC and the RHP of the modelled layers are calibrated udsing the Gauss-Levenberg-Marquardt algorithm (GLMA) implemented in FePest (Doherty, 2002).

Validation on temperatures and heat flow
Independent temperature data set and surface heat flow are compared to model preidctions



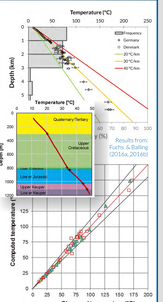


Right top: Temperature data (log data and corrected BHT values) used for calibration and validation of the temperature model.

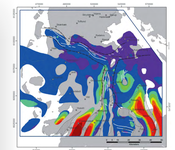
Right middle: Comparison of modelled (black crosses) and logged (red line) temperature at the Sønderborg well (continuous equilibrium T values)

Right bottom: Comparison between modelled and

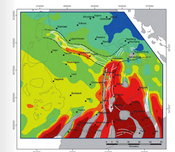
Left: Modelled temperature distribution (isotherms) along the EW section on the southern border of the study area. Thermal conductivity indicating different lithostratigraphic units is colour-shaded (low: purple-bluish, high: reddish).



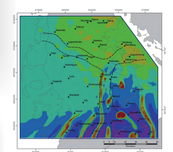
Results from Fuchs & Balling (2016a, 2016b)



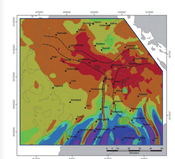
Top Rhaetian/Gassum formation



Top Bunter sandstone



1 km below sea level



2 km below sea level

Observed temperatures for stratigraphic formations and constant depth level.

SUMMARY

The GeoPower project aimed to improve the fundamental databased for planning hydrothermal installations in the INTERREG-region Südjütland -Schleswig. All available data were incorporated into a new geological and a new temperature model. Petrophysical properties of the three major geothermal reservoirs has been evaluated.

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