MeProRisk – 3-D geothermal reservoir modeling in the North German Sedimentary Basin

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Motivation

The MeProRisk project aims the improvement of geophysical methods for the exploration of geothermal energy. Therefor geological, seismic and geophysical borehole data are analyzed to define a 3-D structure model and its boundary conditions. Litholgical units which show specific values for thermal and hydraulic flow properties have to be defined. Those values were derived from borehole and cutting data and finally used as input data for thermal modeling.

3-D model based on stratigraphic information

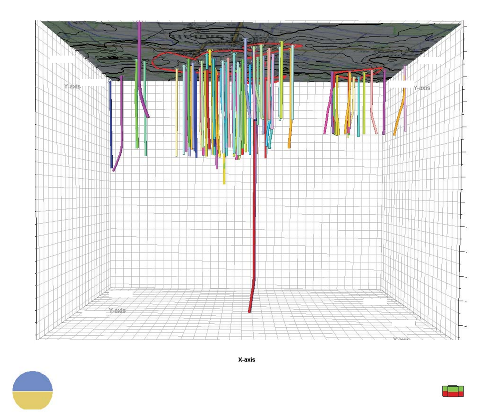

Fig. 1 : Surface model and distribution of available boreholes within the

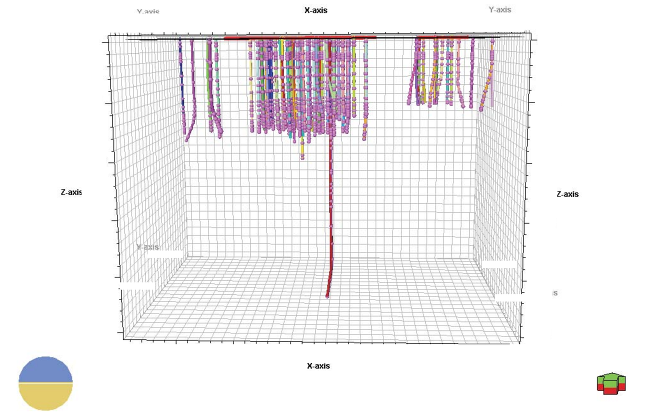

Fig. 2 : Stratigraphic boundaries along the boreholes.

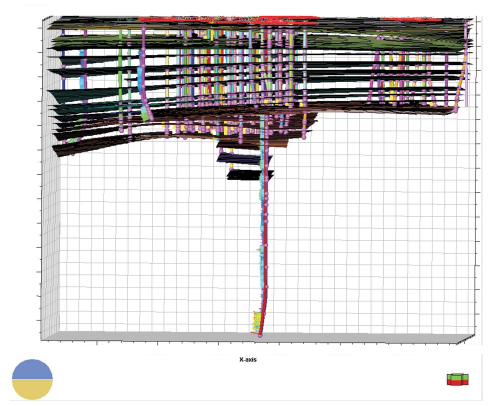

Fig. 3: Horizons interpolated from stratigraphic boundaries.

To develop a first 3-D structure model, the coordinates and depths of 104 boreholes were loaded into a special software **(Fig. 1)**. In a next step, the stratigraphic information from cutting discriptions were added **(Fig. 2)**. Finally, each stratigraphic boundary was interpolated between the different boreholes **(Fig. 3)**. The deepest borehole which serves as the reference borehole reaches a depth of ~ 5000 m and enters the Rotliegend volcanic rocks. Most of the boreholes reach the Juras-

Geological Setting

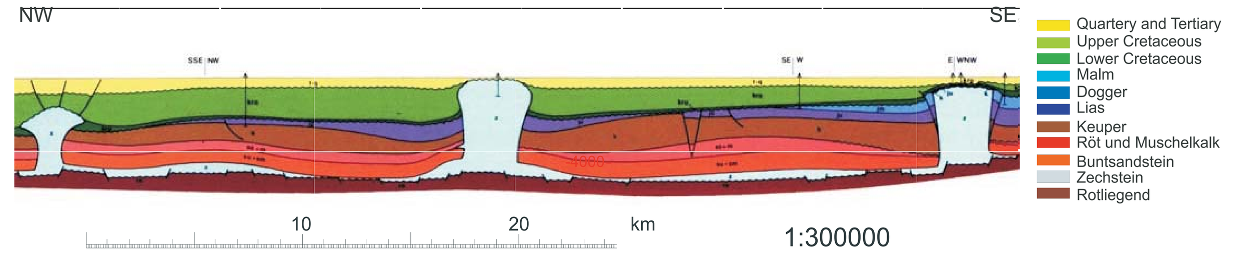

Fig. 5 : Tectonic section, north of the studied type location

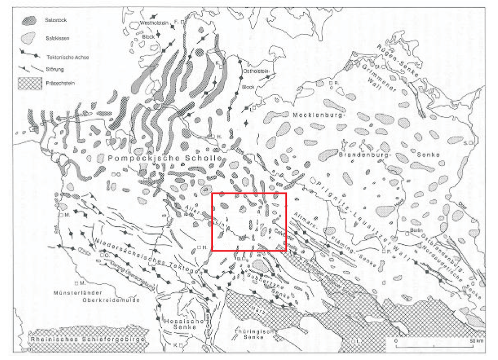

Fig. 4 : Studied area in the Northern German Sedimentary Basin.

The studied area is located in the Northern German Sedimentary Basin **(Fig. 4)**. The geological setting is well-known from oil and gas exploration. Borehole reports, logging data, cuttings **(Fig. 6)** and a 3-D seismic data set were provided by the RWE Dea AG to support this project. The tectonic situation of the subground is strongly influenced by the salt dynamic **(Fig. 5)**.

Litholgy reconstruction from logs and cuttings

Fig. 6 : Cuttings from a reference borehole.

Litholgical boundaries listed in cutting descriptions have to be corrected by log analysis as the cutting material is mixed over an interval of several meters during recovery **(Fig. 7)**. Using the gamma-ray log, it is possible to distinguish between sand and clay. Otherwise, the log of the photoelectrical effect is associated with the chemical composition of the formation. Hence, it can be used to identify limestone intervals.

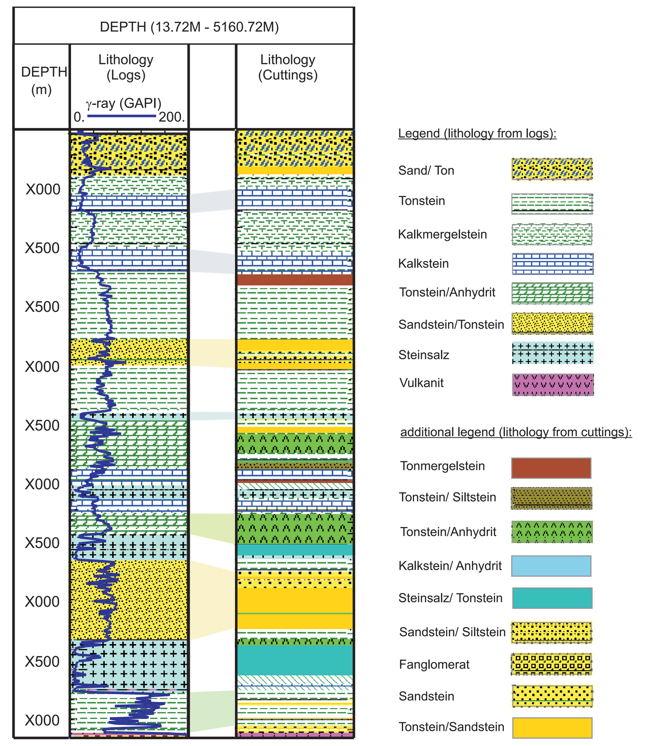

Fig. 7 : Comparison of litholgical boundaries from the drilling report and from log interpretation.

Standard Log Analysis

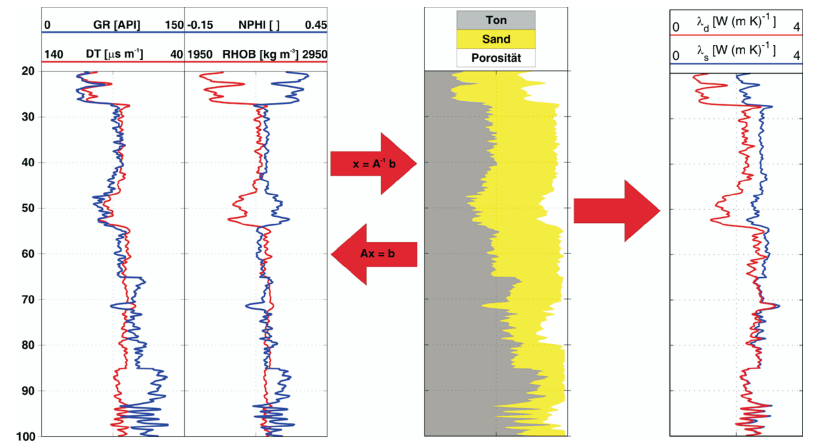

Fig. 8: Schematic presentation of standard log interpretation.

Using standard log interpretation procedures, the lithological composition and the rock porosity can be computed **(Fig. 8)**. In the simplest way, the gamma-ray is used to separate the clay and sand content, while one of the porosity sensitive logs such as density or sonic is used to calculate the formation porosity. By knowing the volumetric amount of the rock components and the porosity, continuous profiles of thermal conductivity can be generated by using the geometrical mixing law. We used the following matrix values: water: 0.6 $Wm^{-1}K^{-1}$, clay: 1.7, sand: 4.86 $Wm^{-1}K^{-1}$ and lime: 3.1 $Wm^{-1}K^{-1}$.

Log Analysis and Matrix Thermal Conductivity: Results

Lithotype	Porosity [-]	Thermal Conductivity [$Wm^{-1}K^{-1}$]	Heat Production Rate [$\mu W\ m^{-3}$]
sandstone/claystone	0.09	2.96	0.80
marlstone	0.18	2.86	0.47
limestone	0.05	2.71	0.47
claystone	0.02	2.65	1.15
rock salt	0.00	5.50	0.31
anhydrite/claystone	0.01	2.50	0.88
volcanic rocks	0.22	2.73	1.11

Tab. 1 : Values for porosity, thermal conductivity and heat production derived from logging data.

In combination with the thermal conductivity measurements on cuttings, a continuous thermal conductivity profile was generated **(Fig. 9)**. Additionally, the heat production rate was derived from the gamma-ray log. **Tab. 1** shows calculated values for porosity, thermal conductivity and heat production rate for each lithology type.

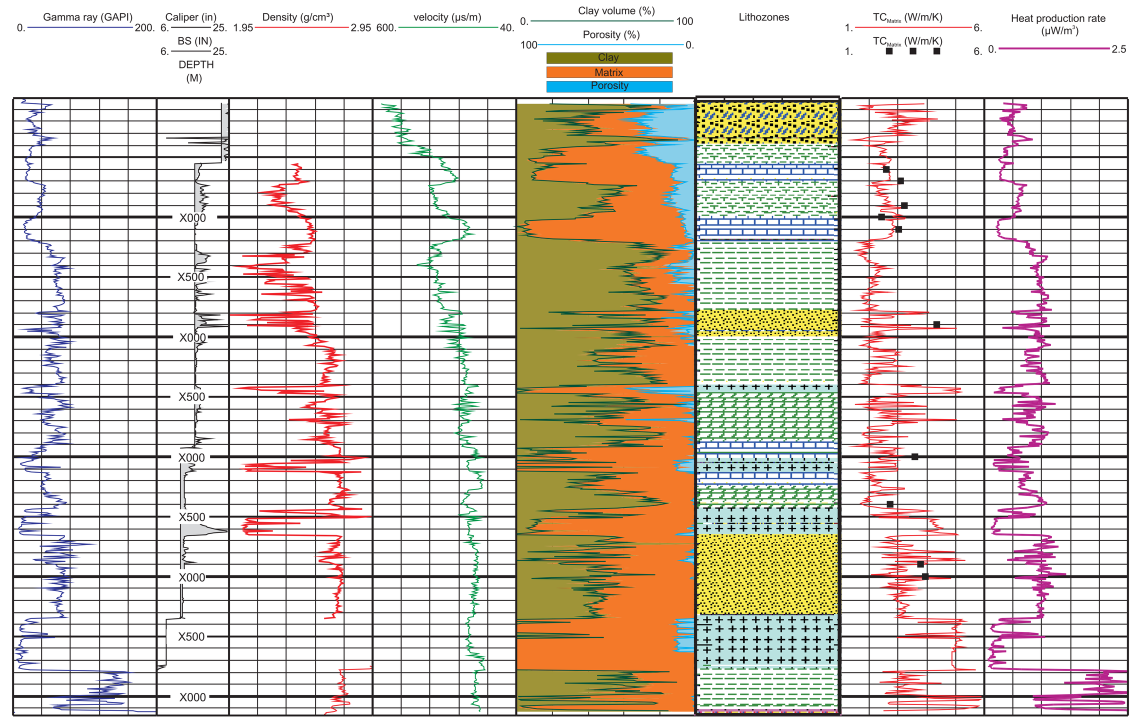

Fig.9 : Log interpretation of the reference borehole.

3-D Model: Layers from Seismic Surveys

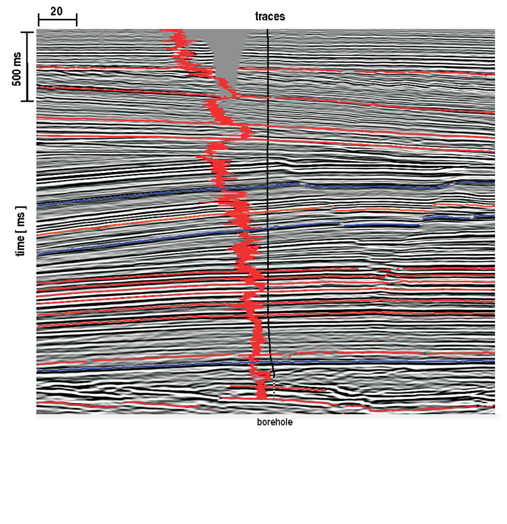

Fig. 10: Seismic profile with picked horizons and the p-wave velocity log.

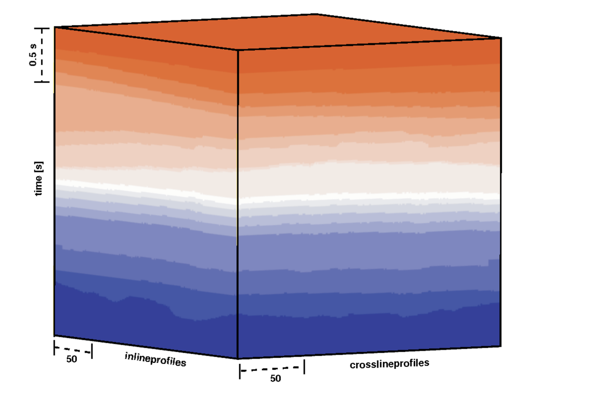

Fig. 11: Structure model of geothermally relevant lithological sequences from 3D seismic data.

The multitude of layers were merged into geothermally relevant lithological units which were then picked on every fifth profile in the 3D-seismic dataset. After that, the missing traces are interpolated to fill the gaps in the horizons. For the construction of the structure model a rock identification number to each gridpoint was assigned **(Figs. 10 & 11)**.

3-D Reservoir Model: Thermal and hydraulic Properties

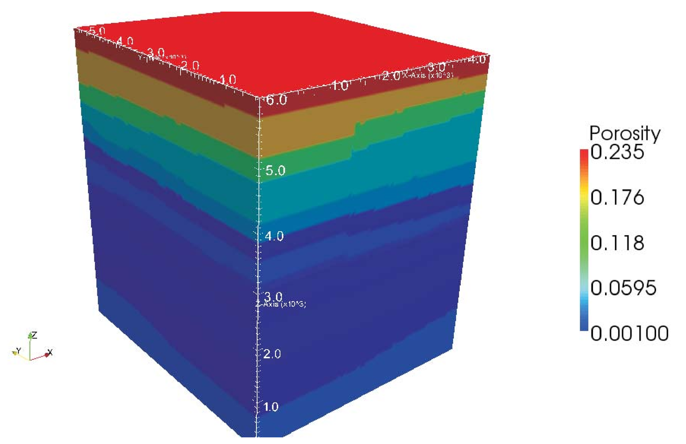

Fig. 12: Thermal conductivity distribution in the 3-D model.

According to the interpretation of seismic and borehole data the distribution of thermal conductivity **(Fig. 12)**, porosity **(Fig. 13)** and temperature **(Fig. 14)** could be modeled in a 3-D model. Specific values for the different litholgies are shown in **Table 1**.

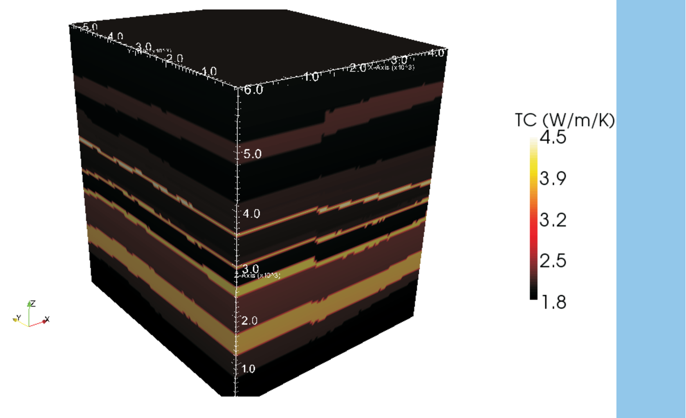

Fig. 13: Porosity distribution in the 3-D model.

Conclusion

- Built up of a first structure model using stratigraphic data
- Advancement of the structure model by seismic data
- Calculation of porosity, thermal conductivity and heat production rate for one reference borehole using logging data
- Definition of lithological units with specific thermal and hydraulic properties using logging and seismic data
- Numerical models of porosity, thermal conductivity and temperature

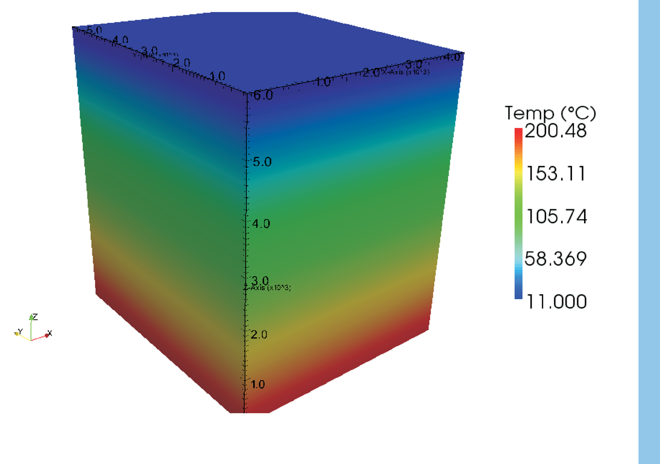

Fig. 14: Steady state temperature field of the model.

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