Geothermal Reservoir Characterization and Modelling: Methods and strategies to derive thermal properties from well data and to improve model input parameter.

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Models for risk minimization

Numerical simulations are well known as important tools for exploration of geothermal reservoirs, since they can predict thermal and hydraulic reservoir conditions and are able to simulate the development of a reservoir while production. However, reliable forecasts are only possible, if the subsurface geology of the area is known and the corresponding thermal and hydraulic properties are well defined. Therefore, as much as possible information should be compiled, in order to build up a geothermal model (Fig. 1). Usually data from geophysical field campaigns, geological investigation and information from existing wells in the area and the surrounding are used. The numerical geothermal model is based on a geological model, which provides the structures and geometries of the subsurface. If the model input-data are reliable and a careful model calibration has been performed, numerical simulation tool can predict the current steady state conditions as well as their development in time. These prospects are the basis for the planning and operation stages of a geothermal project. New information, gathered during the life-time of a project, can get implemented in order to improve the model step by step und such help to optimize the accuracy of forecast.

The strategies and methods, how to build up a geothermal model successfully, will be explained by the geothermal project "Den Haag". The city of Den Haag plans to provide in near future geothermal heat for about 6000 housings. The heat will be produced by a geothermal doublet, targeted to a sandstone reservoir at a depth of ~ 2500 m. In order to improve the temperature prediction for the target horizon, geothermal models were ordered in the planning stage.

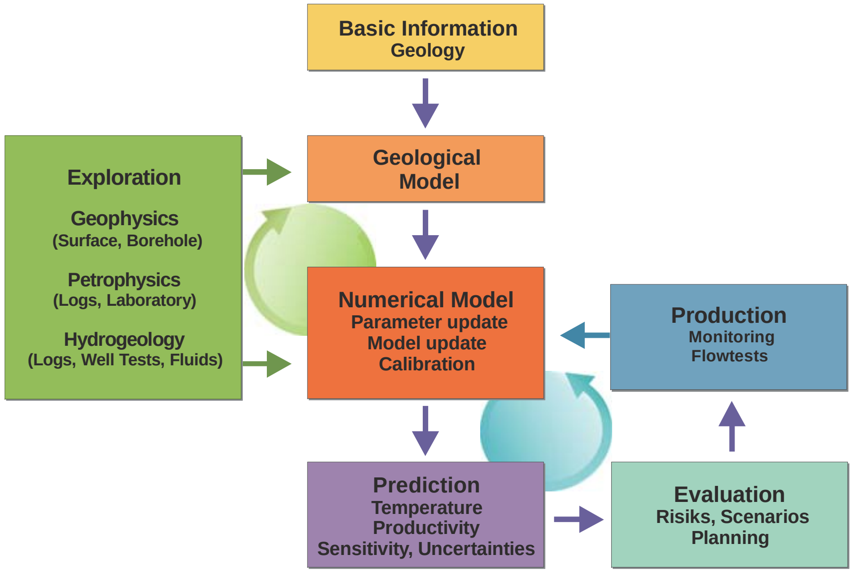

Figure 1: Flow chart visualizing the built-up of a geothermal model and the iterative model improvement during the project life time.

Thermal characterization of the model units

Reliable temperature predictions require a large amount of parameters. Heat flow density, effective thermal conductivity and radiogenic heat production of the different layer are of major importance. During several research and commercial projects, we developed methods to extract representative data sets from existing wells. Interpretation of downhole measurements, combined with laboratory work on cores and cuttings, allow the definition of statistically proven model input parameter for all geological units considered in the model. The proceeding is explained exemplary for one key well of the Den Haag project. In order to gain direct information on the thermal properties of the rocks, samples were taken in key wells from each stratigraphic layer down to a depth of 5 km. Since almost no cores are available from the wells, cuttings material was sampled and measured for thermal conductivity and matrix density in the laboratory. In parallel, well logging data from a total of 11 existing oil and gas wells were analyzed for volumetric rock composition and porosity. Combined and calibrated with the cuttings data, the log data predictions in turn were used to calculate continuous profiles of thermal conductivity for the different wells (Fig. 2). In addition, radiogenic heat production profiles were derived from the gamma ray logs. The thermal property profiles serve two purposes: a) better description of the variability of the thermal property in a statistical manner and b) improved assessment of the spatial variation of properties within one stratigraphic layer.

Build up of numerical 3-D models

Based on the geological structure model, which was provided by TNO - Netherlands, a large scale 3-D geothermal model (22.5 * 24.3 * 5 km) and a smaller scaled reservoir model for the target horizon were constructed. Simulations were performed with the 3-D Finite Differences Code (FD) SHEMAT (Simulator for Heat and Mass Transport, Clauser, 2003).

The objective of the large scale model is to predict the current temperature conditions and to serve as frame for the reservoir model. The model consist of a total of 9 model units, each one corresponds to a major stratigraphic unit. Input parameter, which have been derived from cuttings and log analyses, were then applied to the model units. Figure 3 shows the calculated temperature distribution of the large scale model. Temperature predictions have been controlled by BTH data. The total of 10 corrected BHT data have been in good agreement with the calculated temperature values. The simulation results reveal the strong influence of the geometry and layering of the subsurface. Tectonic elements such as synclines and anticlines can affect the local temperature gradients, which can lead to significant temperature variations within one depth layer. This is shown exemplary for a horizontal cross section at a depth of 2300 m (Fig. 4). Lateral temperature variation in this depth is up to 10 K within the model area. This important model result was used to fix the target point for the production well and to optimize the drilling pathway in economical terms.

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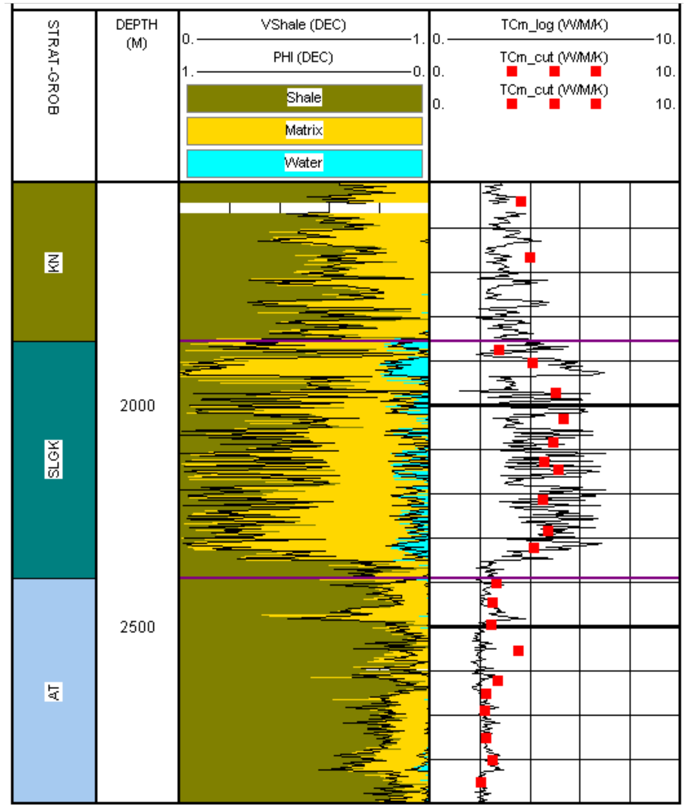

Figure 2: The right track shows a comparison of thermal conductivity measured on cuttings with the log derived prediction (depth section: 1500-2900 m).

In a second project stage a detailed reservoir model was implemented in the large-scale model. The objective of the reservoir model is the prediction of the temperature while production and injection over several decades. The boundary conditions of the reservoir model are provided by the regional temperature model. Reservoir simulations were performed using varying hydraulic parameters for the reservoir sandstone horizon. The results confirmed the implemented geothermal doublet design as sustainable, since the aspired production temperatures are calculated to be constant over more than 50 years of production.

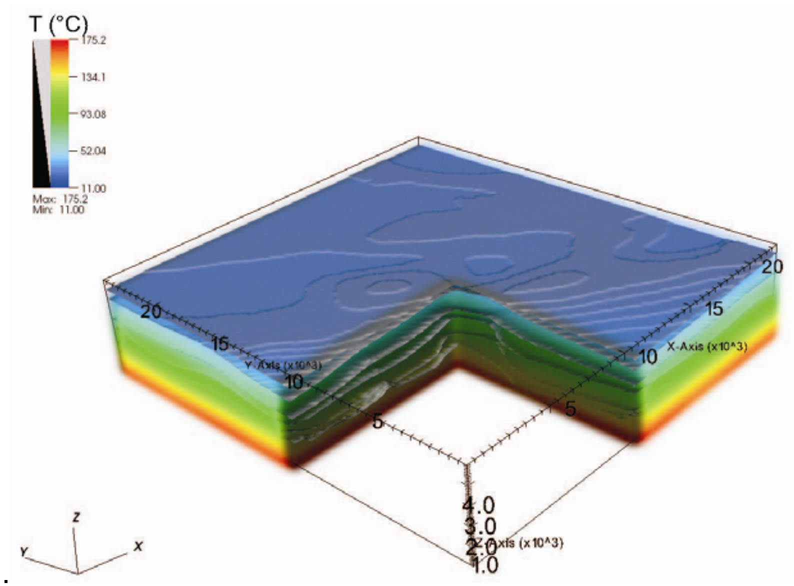

Figure 3: Diagram of the large scale geothermal model. Temperatures are calculated down to 5 km depth.

Summary and outlook

The case study shows that a careful data handling and analyses will lead to representative input-values for numerical geothermal models. The combination of log data analyses and laboratory measurements on core and/or cuttings has been proved as a very reasonable approach. The applied log–cuttings integration produces significant values for entire stratigraphic succession of a target area. Beside the case study presented, this method was successfully applied also for formations of the South German Molasse Basin, the North German Basin, the Lower Rhine Basin, the Rhenish Massif and the Gippsland Basin, Australia. In a slightly modified version, the method could be adopted also to drill holes located in the South German crystalline basement (Urach, KTB).

The results of case study further show, that well defined and calibrated models are able to produce reliable forecasts on subsurface temperatures. This autumn, the first drilling of the Den Haag project has successfully reached the target horizon and confirmed the model based predicted temperatures (http://www.aardwarmtedenhaag.nl).

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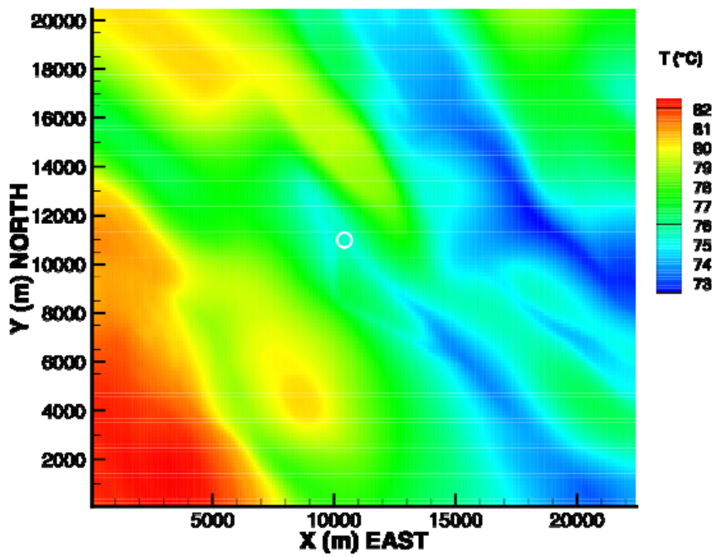

Figure 4: Horizontal cross section of the temperature model in a depth of 2300 m. Temperature varies up to 10 K in this depth.