GEOTHERMAL DATA ANALYSIS FROM LOW ENTHALPY RESOURCE MAPPING

Thomas Kohl [1] and Nathalie Andenmatten[2]

[1] *Institute of Geophysics, ETH Zürich*

[2] *Geowatt AG, Dohlenweg 28, 8050 Zürich*

ABSTRACT

With increasing interest in geothermal energy, also geothermal data analysis is becoming an important issue. The portion of geothermal among all renewable energy sources in Switzerland and its undiminished growth highlight the need for regional resource evaluations. Rather 1-D models have interpreted the temperature data, systematically collected since many years, however, only now the computing power allows for joint interpretations, including for large-scale 3-D effects from geological, topographical and hydrogeological features. By our study an integrated assessment and evaluation of the geothermal potential is intended, accounting for individual utilization scenarios and their specific requirements. The state-of-the-art compilation is based on comprehensive 3D geological and thermal regional models of 20-40 km extent. Thereby, zones of significant convective flow or preferential sites for borehole heat exchanger systems (BHE) should be identified. In contrast to results obtained from earlier geothermal resource assessments, now, existing geological, hydrogeological information and petrophysical data are comprised within a full 3D numerical evaluation. First results are now obtained from a well-documented subsurface area in Northern Switzerland and from a Alpine topographies in central Switzerland. Among various studies that have been performed on these sites, we could demonstrate that geological mapping procedure provides accurate results when compared to small-scale high-resolution 3D seismic profiles. The necessity for these considerations is demonstrated by temperature data analyses.

1 ANALYSES OF THERMAL DATA

A major goal of thermal potential mapping is not only the quantification of heat in place (i.e. temperature) but also the evaluation of hydro-thermal zones which allow to use the heat. Very often, these hydro-thermal zones can be identified as thermal anomaly [*Kohl et al.*, 2000] already at shallower depths. It is therefore a preferential task in our approach that a sophisticated data analysis will be carried out, that should allow to account for possible structural effects and should identify high-permeability zones in subsurface.

In the past, many global geothermal data have been interpreted on the basis of the 1-D Fourier law, relating the measured values of thermal conductivity, λ, heat production, A, and temperature gradient, ∇T, to the vertical heat flow [*Chapman and Rybach*, 1985]. Further model attempts have than accounted for fluid flow on the basis of 1-D Péclet analysis or 2-D effects [*Forster and Smith*, 1989]. The thermal perturbations of topography [*Birch*, 1950] and transient, climatically induced ground surface temperature variations [*Cermak and Bodri*, 1995] have also been evaluated, however, on the basis of reducing these effects from thermal data, rather than accounting for simultaneously. Under typical situations of Europe with pronounced morphology, simple 1-D interpretations are often not sufficient and the temperature field needs to be evaluated solving the following thermal energy equation:

$$\langle \rho c_p \rangle \frac{\partial T}{\partial t} = \quad \nabla \cdot \left(\langle \lambda \rangle \cdot \nabla T \right) \quad - \left[\rho c_p \right]_f \cdot \mathbf{v} \cdot \nabla T \quad - A$$

TRANSIENT *DIFFUSION* *FLUID ADVECTION* *SOURCE*

In Alpine environment, an additional uplift term would add, to account for the mixed effect of uplift and erosion. In the following sections, this equation is solved by the finite element package FRACTure in 3-D [*Kohl and Hopkirk*, 1995] [*Rybach et al.*, 1980]using a well elaborated data processing with a geological visualisation tool. The basis of our considerations are thermal data archived by the Swiss Geophysical Commission [*Schärli and Kohl*, 2002] . An extensive example will be illustrated on an area in Northern Switzerland.

2 GEOLOGICAL AND NUMERICAL MODEL

The subsurface in Northern Switzerland is well explored from nuclear waste disposal studies. Many seismological sections and boreholes have been drilled through the sedimentary cover into the crystalline basement. Fig. 1 illustrates the location of borehole data together with the structures of the Muschelkalk and Malm units and topography. The South dipping geological layers are clearly identified.

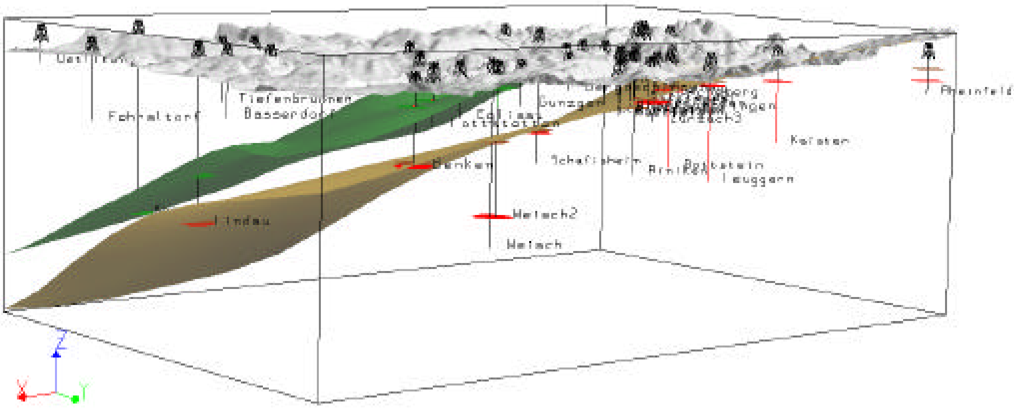

Fig. 1: Inclination of top Malm and Muschelkalk in Northern Switzerland. Available borehole data and topography are additionally shown.

The finally elaborated geological model comprised depth domains between 100 m and ~5 km and included major lithological units and local fault zones. In further steps, these results are transferred into FE schemes to highlight the possible interaction of geology and thermal transport processes.

As example of such model development a smaller subset around the Benken borehole is illustrated. Various sedimentary layers characterize the well-explored location, foreseen as preferential site for nuclear waste disposal. Top basement is at around 1000 m. Further features of interest are the large Neuhauser - Fault zone and the E-W trending permocarboniferous trough identified by several boreholes. The excellent data situation allowed to quantify the error associated by the interpolation function of geological modelling tools and also to establish a geological model which is based on numerous data sets. In detailed studies our model was compared to high-resolution seismic data: only maximum deviations of 20-40 m for the 200 and 800 m deep Malm and Muschelkalk layers were forecasted by the geological modelling tool Gocad, a fact that provides high confidence. Next, this model could be transferred into a numerical Finite Element scheme (Fig. 2) by tetrahedrisation. A first discretized model consisted of >100'000 nodes and >300'000 elements. For the thermal parameters of the 21 selected material sets the mean of measured values including anisotropy have been taken. The hydraulic conductivity was stepwise increased to evaluate their impact on a pure diffusive temperature field.

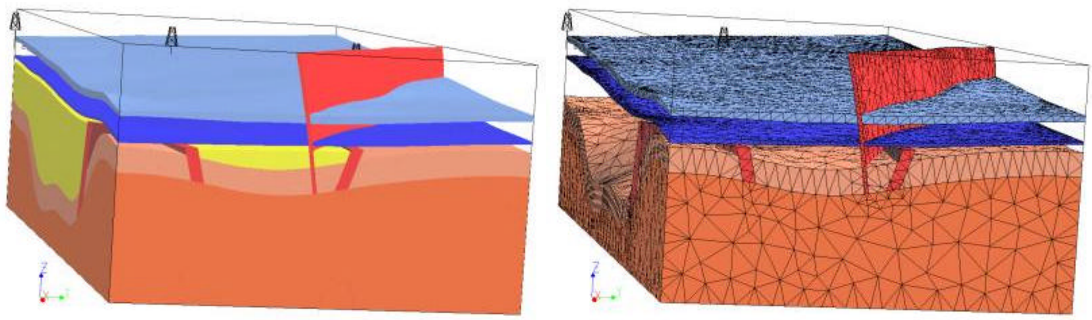

Fig. 2: Geological model (left) and numerical realisation (right) of a 20x10 km subset. The models show topography, Muschelkalk and crystalline basement. Furthermore, the E-W trending Permocarboniferous trough and the Neuhauser Fault system are also accounted for.

3 MODEL RESULTS AND OUTLOOK

First results are obtained assuming pure diffusive thermal transport. The hydraulic conductivity was taken as $<10^{-15}m^2$, values far too low to imply significant advective drive transport. A nearly sufficient model match is obtained (Fig. 3, left) without strongly adapting individual parameters, such as basal heat flow or thermal conductivity at the location of Benken. Due to the basically pure diffusive assumption, the 3D temperature field (Fig. 3, right) is not strongly influenced by individual geological layers and a nearly horizontal stratification results.

Only by future cross-comparisons with calculations from adjacent boreholes, the validity of the present model results can be shown. The non-uniqueness of simulation results can be strongly reduced if more data are accounted for. Our experienced has shown that it is well possible to constrain 3D data by assuming identical boundary conditions. Our approach will therewith quantify deep regional boundary conditions and deeper energy transfer. Thereby, possible deep-rooted fluid circulation would be characterized by a regional analysis.

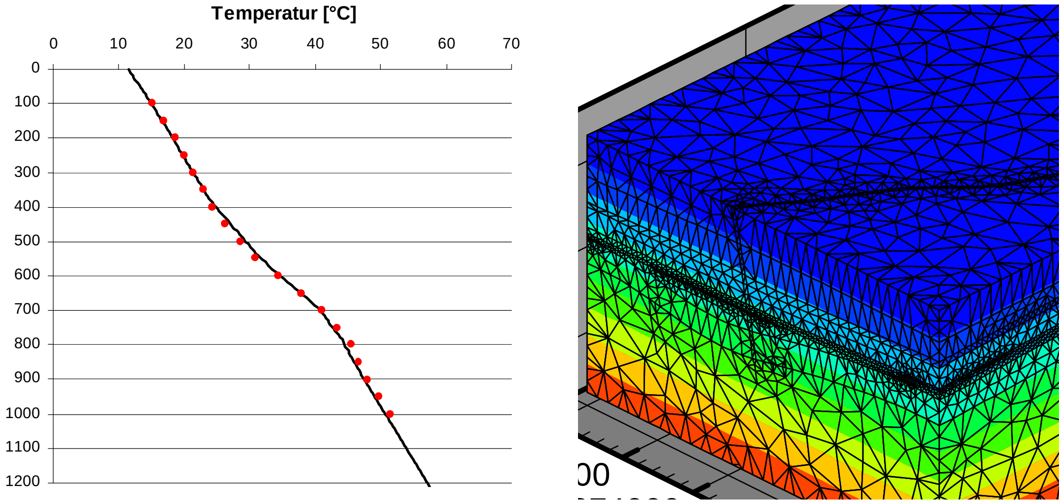

Fig. 3: Temperature data of Benken (left, red dots) and model fit (straight line). A detail of the 3D thermal model is also shown (right).

ACKNOWLEDGEMENTS

The authors want to thank the Gocad group in Nancy for their support and advice. The financial support of the Swiss Geophysical Commission is gratefully acknowledged.

REFERENCES

Birch, F., Flow of heat in the Front Range Colorado, *Bull. Geol. Soc. Am.*, *61*, 567–630, 1950.

Cermak, V., and L. Bodri, Three-dimensional deep temperature modelling along the European geotraverse, *Tectonophysics*, *244* (1-3), 1-11, 1995.

Chapman, D.S., and L. Rybach, Heat Flow Anomalies and their Interpretation, *Journal of Geodynamics*, *4*, 3-37, 1985.

Forster, C.B., and L. Smith, The Influence of Groundwater Flow on Thermal Regimes in Mountainous Terrain: A Model Study, *Journal of Geophysical Research*, *94* (B7), 9439-9451, 1989.

Kohl, T., D. Bächler, and L. Rybach, Steps towards a comprehensive thermo-hydraulic analysis of the HDR test site Soultz-sous-Forêts, in *World Geothermal Congress 2000*, pp. 3459-3464, Kyushu-Tohoku, Japan, 2000.

Kohl, T., and R.J. Hopkirk, "FRACTure" a simulation code for forced fluid flow and transport in fractured porous rock, *Geothermics*, *24* (3), 345-359, 1995.

Rybach, L., S. Mueller, A.G. Milnes, J. Ansorge, D. Bernoulli, and M. Frey, The Swiss Geotraverse Basel-Chiasso - A Review, *Eclogae Geol. Helv.*, *73* (2), 437-462, 1980.

Schärli, U., and T. Kohl, Archivierung und Kompilation geothermischer Daten der Schweiz und angrenzender Gebiete, *Beiträge zur Geologie der Schweiz: Geophysik*, *36*, 1-134, 2002.