On the thermal situation at the KTB drill site

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ABSTRACT

As Swiss contribution to the German KTB drilling project, a numerical simulation study aims at the understanding of the hydro-thermal field in the surroundings of the KTB site. The simulations include known, state-of-the-art petrophysical aspects relevant for deep, pressurised and high temperature structures. The thermal flow model presented in this study was set up in order to integrate the measured properties and geological aspects of the KTB region. The model can explain the measured temperature data by purely diffusive mechanisms.

THERMAL CHARACTERIZATION

In the upper 500 m low heat flow values about 0.05 W m^{-2} and at greater depths higher values between 0.08 and 0.09 W m^{-2} were measured. Therefore unexpectedly high temperatures have been encountered at greater depth (229°C in 8110 m). The temperature profile is best indicated by a 4000 m deep VB temperature log. Only BHT values are available during the HB phase. The appearance of the low heat flow zone at the topmost 500 m was extensively studied by geothermal models. This feature may be explained either by a paleoclimatic effect or by a hydraulic influence on heat transfer (Rybach 1992, Jobmann & Clauser 1994). However, the present study focuses on the region below that depth.

INTERPRETATIONAL BACKGROUND

A combination of the excellent laboratory datasets with standard geothermal simulations was attempted. Different heat flow regimes at depth are suggested. At least three zones can be considered: the topmost 500 m, the upper crust below 500 m and the mid / lower crustal region. Our intention is to simulate the thermal field of the upper crust (< 10 km) that accounts for the complexity of the geological structures, but that limits the necessary heat transport mechanisms to the simplest, sensible model.

FINITE ELEMENT CODE

The simulation tool is our own 3D finite element code FRACTure (Kohl et al., 1993). Among other features, the program allows steady state and transient simulations between the coupled hydraulic and thermal processes in the underground. Special emphasis is given to non-linearities of the three temperature and pressure dependent parameters: density, viscosity and thermal conductivity. Salinity effects of fluids at depth can be also treated.

UPPER CRUST MODEL: 500 m - 10 km depth

Model Description

The most complete geological interpretation for the drilled KTB depth section is presented by Hirschmann (1994). Since no assumption for any abrupt change in lithology is provided a two-dimensional interpretation of the section between 500 m and 10 km seems to be sufficient.

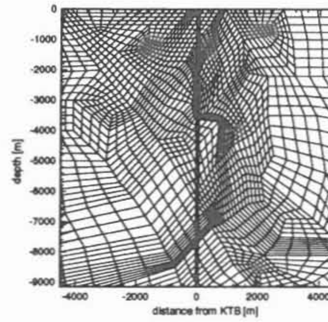

Fig. 1 Detail of finite element mesh

We attempted to explain the measured thermal data with the variation of the diffusive parameters (changing under current thermal and hydraulic conditions) and a rather fixed geometry. The SW-NE striking profile was discretised with our mesh generator FRAM. On Fig. 1 a detail of the refined finite element mesh in the KTB neighbourhood is shown. The model contains 2839 nodes and 2748 elements.

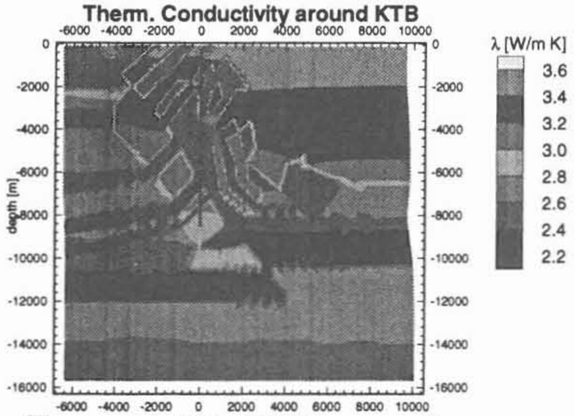

Fig. 2 The calculated thermal conductivity profile

The mean annual surface temperature of 7.4°C was assumed as surface boundary condition. The lower boundary was placed at a depth of 16000 m in the mid crust. Temperature was set at the lower boundary to 440°C. This value corresponds to a vertical heat flow in this depth of 0.065 W m^{-2}. The lateral borders located (6 km to the SW and 10 km to the NE from the KTB) assume "no flow"-boundary conditions. This diffusive model consists of the following materials: sediments, metabasites, steeply dipping gneiss, flat dipping gneiss, granite and lower crustal material. The material choice for the lower crust is not very critical to the thermal conductivity since the temperature dependence leads to a small bandwidth; the in-situ values range are expected to be 2 W m^{-1}K^{-1}. The values of the diffusive material properties were taken from measurements in the KTB Field Laboratory and from thermal conductivity measurements, that were performed on samples from surrounding material. They are shown below (at 25°C reference temperature and zero pressure).

	sediments	gneiss	metabasite	granite	mid crustal
thermal conductivity [W m^{-1}K^{-1}]	2.0	2.6 / 3.9	2.5	3.7	3.4
heat production [W m^{-3}]	0.4E-06	1.5E-06	0.8E-06	6.0E-06	1.0E-06 - 0.6E-06

The anisotropy of gneiss plays an important role for the thermal heat flow. The temperature profile is best fitted by a gneissic foliation dipping 60°. Fig. 2 shows the temperature and pressure corrected conductivity section. The same geological units can be recognized as in Hirschmann (1994).

Results and Discussions

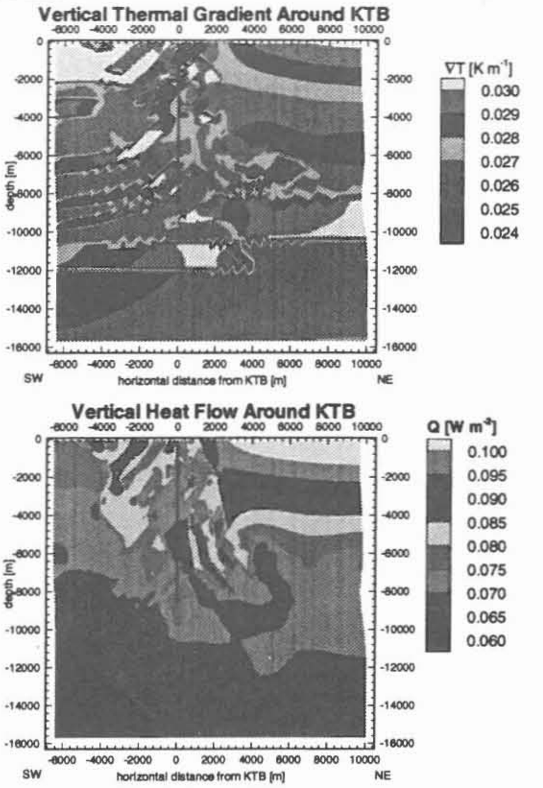

Fig. 3 Distribution of the vertical components of thermal gradient and heat flow

The thermal gradient (Fig.3) is strongly affected by a lateral displacement over 100 - 200 m within the model. The horizontal component may increase up to 15% of the vertical component. This effect suggests that temperature logging performed in the HB necessarily should differ from the VB temperature measurements. Our model provides the strongest differences near 800 m and at 4000 m. The same effect might explain the different BHT values from the VB and the HB. The heat flow preferentially follows the steeply dipping gneissic units. The area around the drillhole section in about 6 km depth indicates the best that the lateral extension of such an anomaly extends even more than 500 m into the metabasite. The effect of strongly decreasing heat flow in the granitic area is due to the effect of decreasing thermal conductivity with depth as well as the high heat production.

On Fig. 4 the interpolated results of our model along the drilled section down to the originally planned drilling depth are shown. Also plotted are the available logged and sampled data. Maximum deviations from the BHT values are 2°C (about the accuracy of the BHT measurements). The modelled and the VB thermal gradient are in good agreement. The thermal gradient between 500 m and 3000 m is well represented by the model.

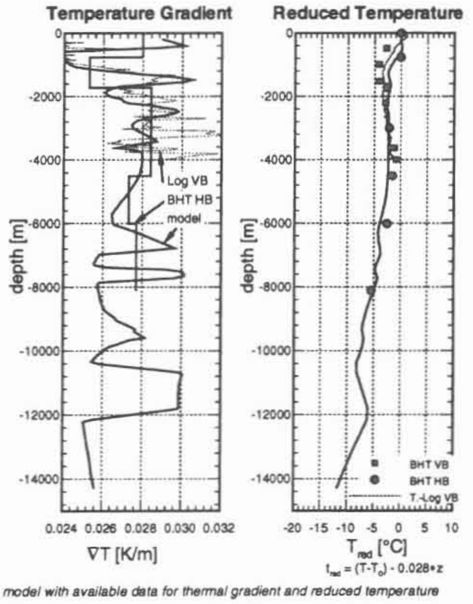

Fig. 4 Comparison model with available data for thermal gradient and reduced temperature

CONCLUSION

It was shown that both the available temperature data and the geological interpretation of the upper crust provide the basis for a geothermal interpretation by diffusive driving mechanisms. Further measurements will improve the geothermal model and possibly gives hints for a 3D interpretation.

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