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3D Lithofacies Model Building of the Rotliegend Sediments of the NE German Basin

Abstract

Static 3D geological models are essential to reservoir characterization and dynamic models. We introduce an approach of combining pre-existing and newly generated data to assess lithofacies distributions and sandstone permeability of a clastic reservoir within the Rotliegend II of the NE German basin. The target is in 4300 m depth and situated north of Berlin (Germany) in the vicinity of a former gas exploration well, drilled in 1990 and currently acting as geothermal in-situ laboratory.

This second hand well was re-opened in 2000 and deepened in two steps to 4309m TVD. An extensive logging program was performed between various stimulations and hydraulical tests. Porosity/permeability data are available from logging data as well as from abundant porosity (290 samples) and permeability measurements (109) on cores.

A basic 3D structural geological model of an area of 120 km^2 was calculated using pre-existing well data and 2D seismic profiles. Detailed well data provided information to develop a 3D lithofacies model, comprising five lithotypes. The facies grids were calculated with a 3D minimum tension technique. In this procedure each facies grid was normalized, calculated against each other and reconciled by creating a 0-isoenvelop, that clearly defines the faciestype body. The isoshells were set in each fault block of the structural model and processed to a comprehensive 3D structural lithofacies model. This volumetric 3D model allows an assessment of both matrix driven and fracture driven permeability. This approach can be applied to any region, where detailed structural and sedimentological data are available.

Introduction

The well Groß Schönebeck 3/90 (GrSk 3/90; NE of Berlin/Germany; Fig. 1) was drilled in 1990 assigned to gas exploration in East-Germany. The borehole was been closed due to lack of gas.

In 2000 the well was re-opened to use the borehole as in-situ laboratory for geothermal low

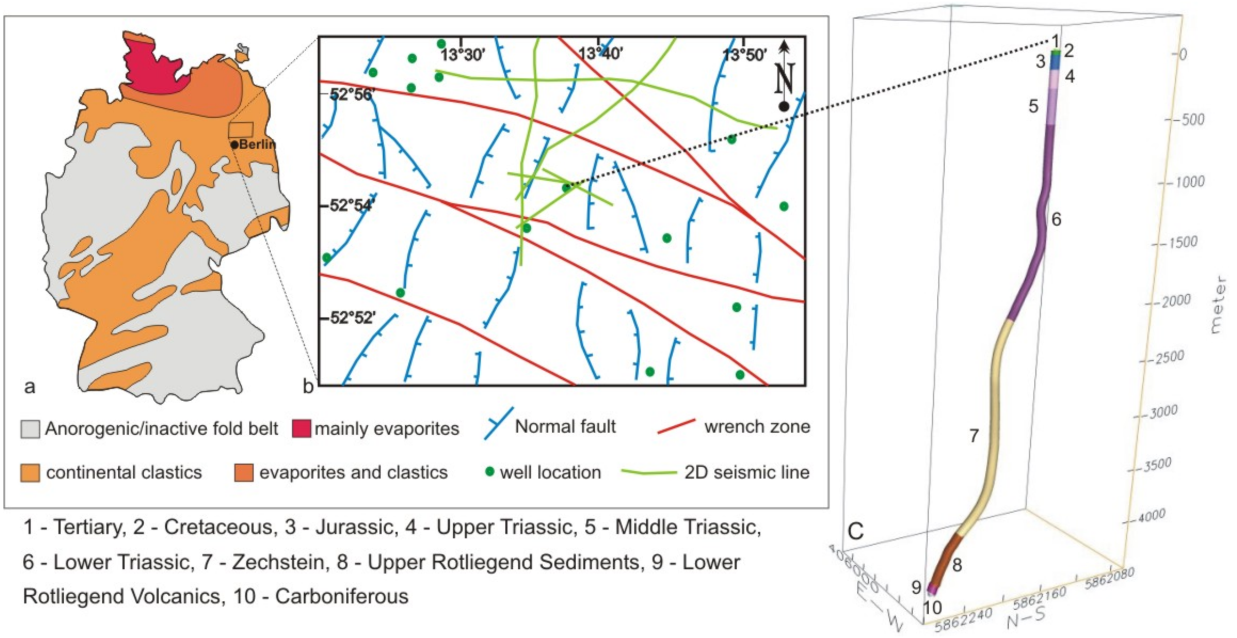

Fig. 1. (a) Distribution of Rotliegend sediments in Germany. Box indicates the investigation area (modified after Ziegler, 1988). (b) Rotliegend structural pattern after Baltrusch et al. (1993). (c) Well path of the geothermal well GrSk 3/90.

enthalphy reservoir studies. The geothermal reservoir is situated in the Rotliegend II strata as part of the NE German Basin (NEGB). The NEGB is part of an extensive basin system which extends from the North Sea towards Poland. It is bounded in the north by the Baltic Shield and in the south by the Variscan fold belt. Initial basin extension occurred between the latest Carboniferous and the early Permian and was accompanied by the deposition of volcanic rocks which were subsequently covered by a siliciclastic sequence of alluvial fans, ephemeral stream, playa deposits and aeolian sands (Rieke et al., 2001). Thick cyclic evaporites and carbonates were deposited during the Zechstein which are overlain by a thick strata of Mesozoic and Cenozoic sediments. The basic scientific function of the in-situ laboratory consists in the development of hydraulic stimulation techniques in order to enhance the permeability in siliciclastic and volcanic formations of the Rotliegend. In order to assess the permeability of both the sandstone matrix and the fracture porosity, an extensive logging program is carried out, while the geometry of the reservoir is revealed by 3D structural model building procedures.

Methods

Logging Program

The first geophysical logging program was carried out in 1991 to explore a potential gas reservoir in the Rotliegend sediments. Erdöl Erdgas GmbH (EEG) provided logging data in digital format for this project (caliper, spectral gamma ray, resistivity, neutron, density, sonic & dipmeter). The GeoForschungsZentrum (GFZ) logging operations were performed by the Operational Support Group (OSG) implementing caliper, electric, spectral gamma ray, resistivity and acoustic measurements. The last logging campaign was executed by Schlumberger during the winter 2003. Two new logging tools were used in addition to the GFZ logging program. The latest porosity measurement is achieved by Reservoir Saturation Tool logs (RST, mark of Schlumberger) and is used for a comparison with laboratory data.

3D Model Building

The basic 3D structural model is calculated based on data of 6 pre-existing, re-processed 2D seismic sections and 15 wells (locations see Fig. 1). This modeling procedure comprises the development of a 3D conceptual model interpreted from a time-thickness map of the Rotliegend II, and the calculation of a final 3D structural model of the reservoir integrating the seismic section and well data with the conceptual model (Fig. 2; see also Fig. 4, track lithology).

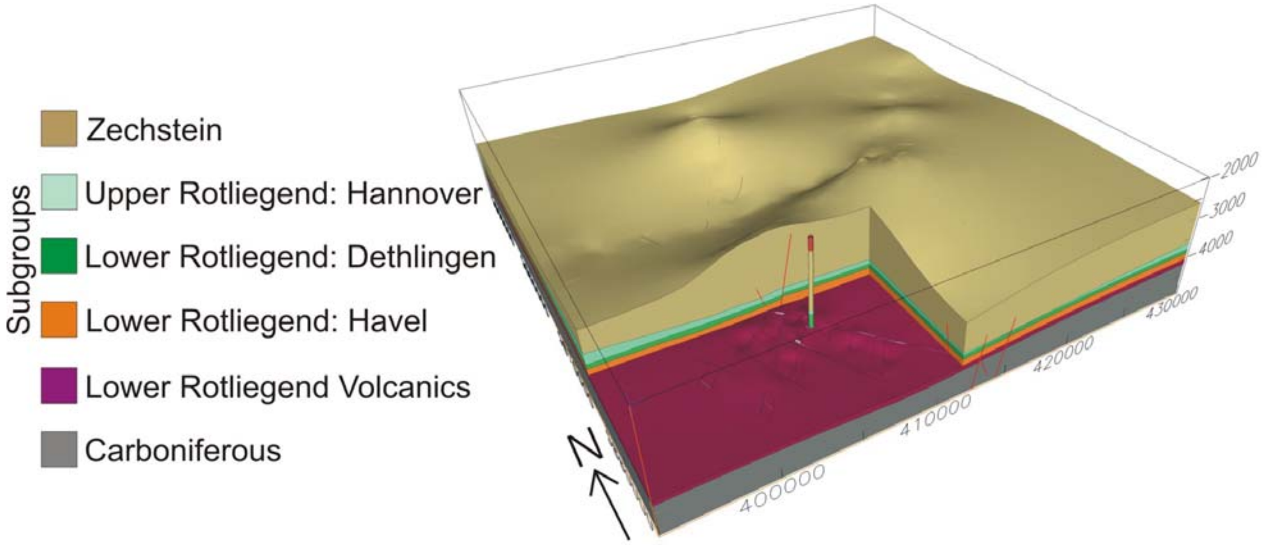

Fig. 2. Basic 3D structural model of the geothermal reservoir. The tube is the geothermal well.

The calculation of grids is carried out with an iterative minimum tension algorithm, the fault model is developed according specific fault hierarchies and the horizon model is processed according geological intersection rules. Lithofacies data are provided by the well data, resulting in following 5 lithotypes: (1) mudstone, (2) siltstone, (3) fine grained sandstone, (4) middle grained sandstone, (5) coarse grained/conglomerates. To obtain both the structural and the lithofacies information in one coherent model, an adequate workflow is specified for the 3D lithofacies modeling. (I) Faulted property grids of each facies type are calculated over the entire model range, based on the intial structural reservoir model. Each property grid is the result of the catenation of property grids of each fault block, effectively the fault throw is taken into account (Fig. 3a). (II) Each facies grid is normalized between values of 1.0 and 0.0 in order to delimit the property grid closely to the input data (Fig. 3b). (III) The normalized grids are calculated pairwisely against each other to obtain 10 sub-grids. (IV) The sub-grids are reconciled according to their lithofacies type inventory in order to create 0-isoenvelops, that clearly define the different lithofacies bodies (Fig. 3c). (V) The five lithofacies isoshell grids are assigned to each fault block of the initial structural reservoir model, enabling the calculation of a comprehensive 3D structural lithofacies model.

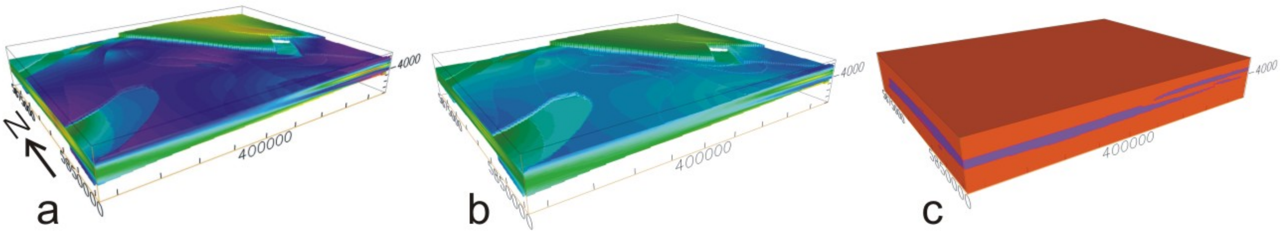

Fig. 3. (a) Faulted property grid, (b) normalized facies grid, (c) the pink facies body is defined by a 0-isoshell. All grids represent the facies type 3 (fine grained sandstone).

Results

Fig. 4 shows the lithology distribution and stratigraphic classification of the well Groß Schönebeck 3/90. The volcanic formation of the Lower Rotliegend consists of two different magmatic rock types. The upper series show higher thorium contents as the lower series and are suggested to be higher differentiated with a trachydacitic or –andesitic character. The lower series are characterised by geochemical properties of a more primitive source and are classified as basaltic andesite. Both of the volcanic rock suites are intersected by a crossbedded tuffaceous or tuffitic layer. The interbedded sediments consist of marls, marly limestones and mudstones, subordinatedly interstratified by thin anhydritic evaporite layers.

The sandstones and conglomerates of the Havel Subgroup show decreasing gamma ray values which are attributed to the depletion of mechanically unstable, chemically altered volcanic rock fragments within a fining-upward cycle of the siliciclastic sediments. The nearly clean sandstones of the Lower Dethlingen formation (4130-4175m/Lower Elbe Subgroup) show the lowest gamma ray emissions of all measured clastic sediments, owing to their low clay content. The gamma ray values increase continuously upward within the interval of interbedded silt-/sandstones and reaches a maximum value in the mudstones of the Upper Elbe Subgroup.

The petrophysical properties of the target horizons are important for the characterisation of the geothermal reservoir. Fig. 4 shows a composite log of the sandstones of interest. We used the neutron porosity measurement from the RST data (track TPHI RST) to estimate permeabilities (calc. permeability/logarithmic scale) using the empirical formula from Pape et al. (1999, eq. 22) and observed permeability values from 0.04 up to 110 mD. We repeated this procedure with porosity data calculated from density and sonic measurements and received transmissibilities in the range from 0.25 to 0.70 Dm for a 80m sandstone interval (4100-4180m).

The comparison of logging data (Tphi RST) with measured core porosities as well as a comparison of calculated permeabilities with core permeabilities is shown in tracks 3 and 4 (core porosity: n =290; core permeability: n=109). The results indicate a good correlation between logging data, permeability estimation and core data. The right-hand track illustrates a borehole temperature measurement representing the current state after the last stimulation experiment. Temperature logs record changes of the temperature field due to injection and production of brines during hydraulic experiments. The bright yellow areas mark the stimulated intervalls. Three temperature minima are recognized identifying productive zones. The upper two temperature signals prove the existence of pay sand horizons. The productivity of the lowermost reservoir horizon indicates a cumulative flow out of porous sandstones (Havel Subgroup) and of the naturally fractured volcanic formation (Lower Rotliegend).

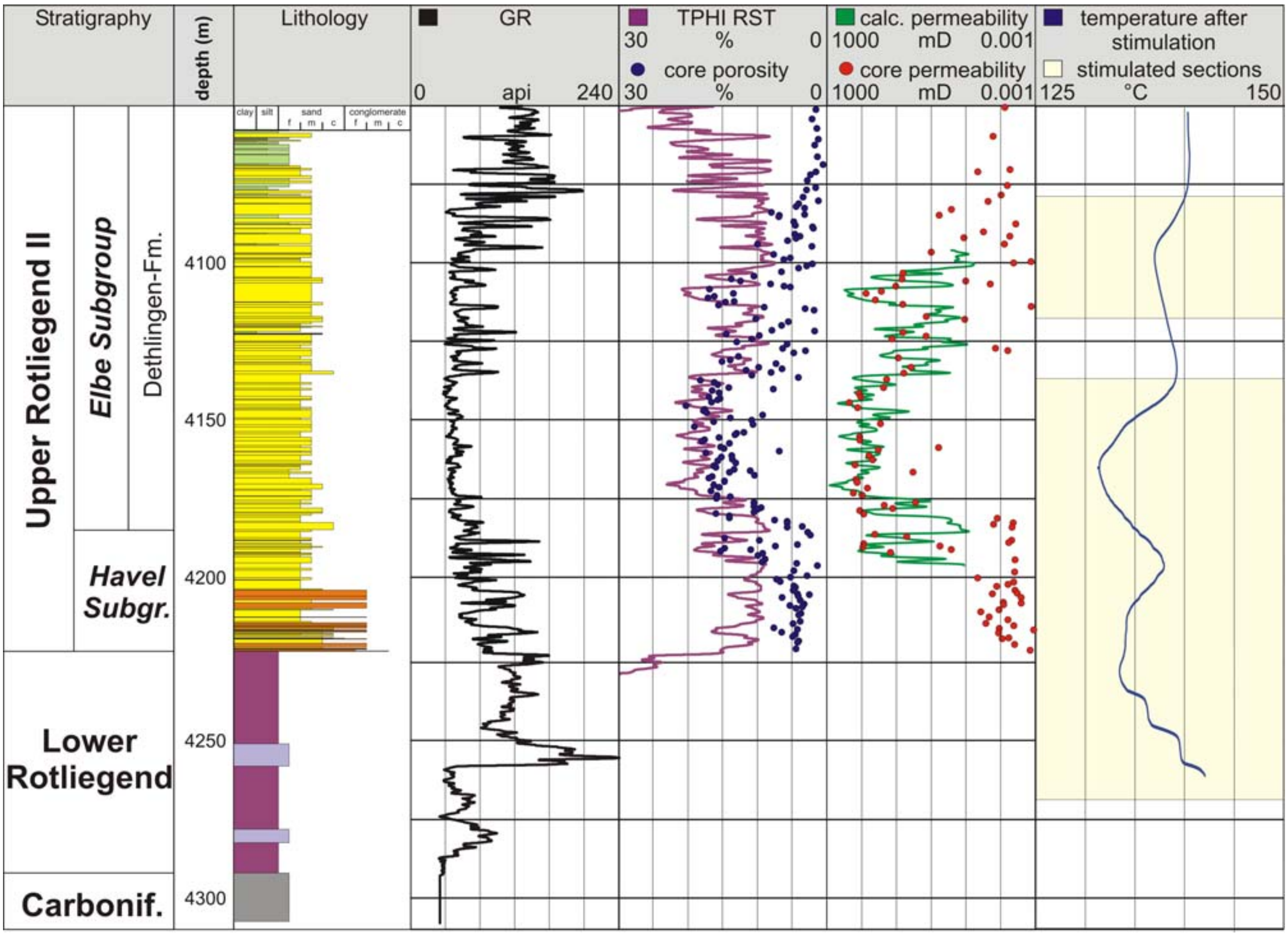

Fig. 4. Lithostratigraphic chart of the siliciclastic Rotliegend strata in the well Groß Schönebeck 3/90 and comparison of logging data (Tphi RST) with measured core porosities as well as calculated permeabilities (logarithmic scale) with core permeabilities (porosity: n =290; permeability: n=109). The right track illustrates a borehole temperature measurement after stimulation. Bright yellow areas show the stimulated intervalls.

The 3D lithofacies model reveals the spatial distribution of the five lithofacies types, that are part of the Rotliegend II siliciclastics (Fig. 5). The conglomerates and the middle grained sand were only deposited south of a NW-SE striking strike slip fault and in NE-SW trending graben structures. The thickness of these facies types increases towards the S to SW. The fine grained sand type is distributed over the whole model area and shows increasing thickness towards the WSW. The facies type mudstone shows increasing thickness towards the NW and SSW.

The target horizon is in the fine and middle grained facies type in average 4150 m TVD due to its efficient porosity.

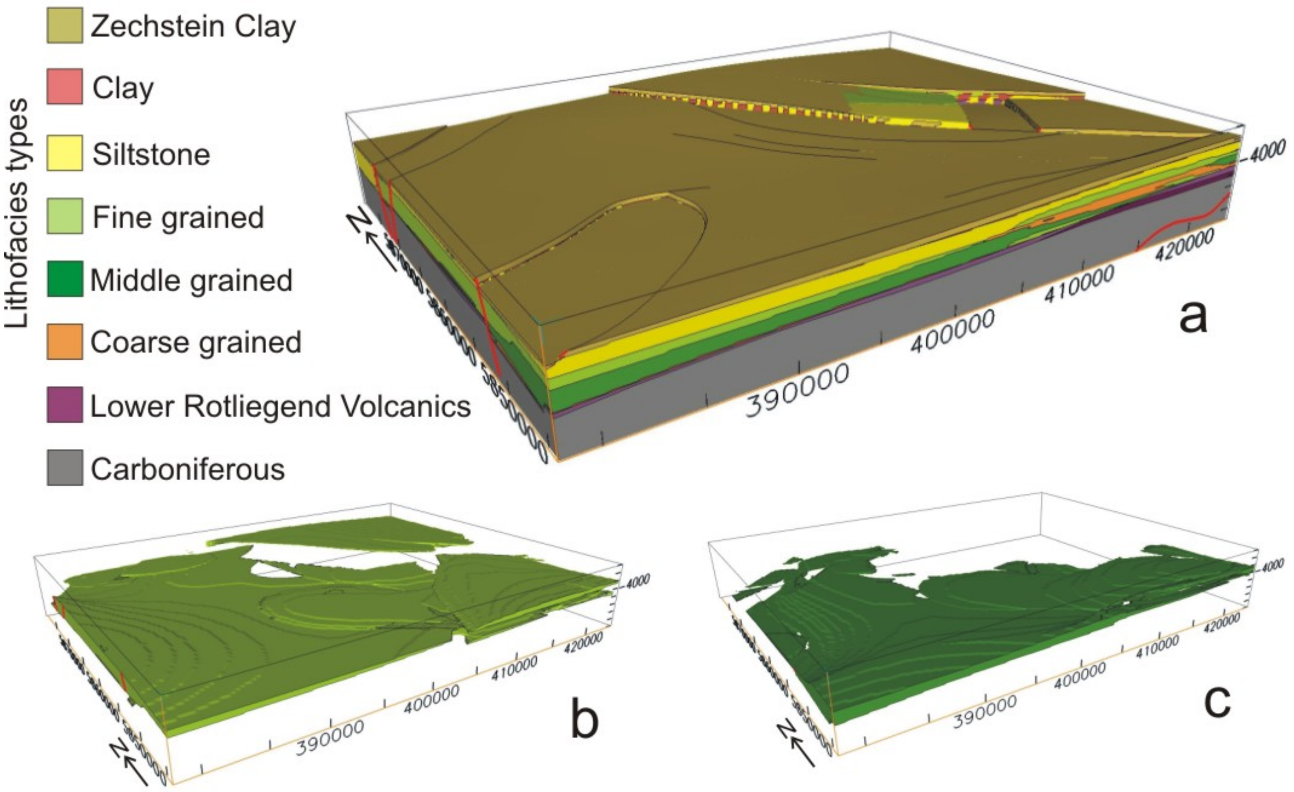

Fig. 5. (a) Structural lithofacies 3D model of the reservoir horizon. (b) and (c) demonstrate the spatial extend of fine grained and middle grained facies types.

Conclusions

Recent investigations on the state of stress in the NEGB have revealed a constant ± N-S trend of the direction of the maximum horizontal stress S_H in the area north of Berlin (Röckel and Lempp, 2003). The mean direction of S_H was determined in the open-hole section of Groß Schönebeck from borehole breakouts and vertical hydraulically induced fractures to 18.5° ± 3.7° (Holl et al., 2004). Thus only a small acute angle exists between S_H and the NNE-trending faults. Röckel and Lempp (2003) have shown, that the current state of stress in the NGB is generally a normal faulting state, however transitions to strike-slip faulting states may not be excluded.

The recent stress regime in the Groß Schönebeck area is not fully known, however in both possible cases ($S_H = \sigma_1$ or $S_V = \sigma_1$) the potential kinematic behaviour of the NNE-trending faults is transtensional, whereas the NW-trending faults may suffer frictional blockade. The N to NNE trending faults are considered to be hydraulically conductive due to its shear stresses and resulting high tendency of transtensional slip (see also Zoback & Healy, 1992). Based on this knowledge, a 3D hydrotectonic model is developed for the reservoir (Fig. 6), indicating hydraulically conductive structures. This should be taken into account when new potential drilling sites are going to be localized.

The combined use of pre-existing and newly generated data sets provides new understanding for the characteristics of the geothermal reservoir in the Lower Rotliegend formation of the North East German Basin. The multidisciplinary approach included implementation of existing well data, reprocessing of pre-existing 2D seismic sections, interpretation of various newly generated well log data and reconciliation of all data to a coherent 3D geological model.

The petrophysical properties of the target, the depositional environment and the reservoir geometry are now well known. These data are crucial for modelling the thermo-hydraulic conditions within the geothermal reservoir during production. Future work will focus on the use of geostatistical models, combining porosity and permeability distributions with sedimentary facies architecture.

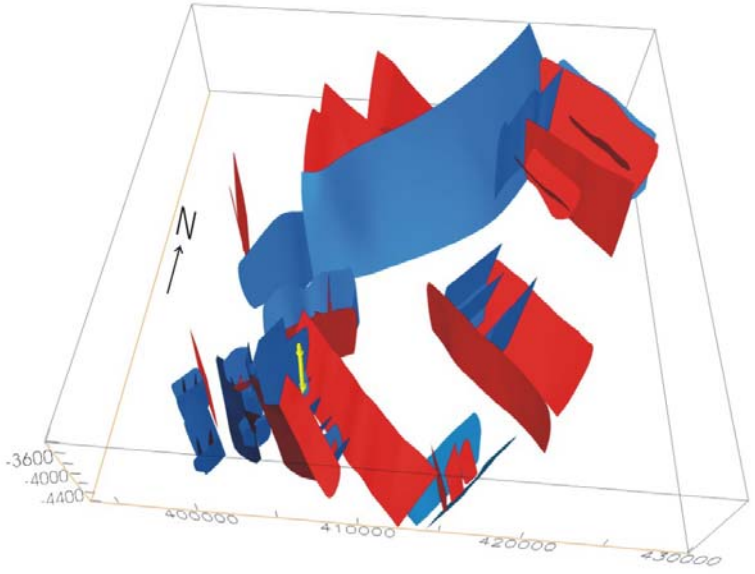

Fig. 6. Hydrotectonic model indicating the hydraulic conductivity of the faults with respect to their kinematic behaviour within the current in-situ stress field. Red faults: frictional blockade, acting as seals; Blue faults: transtensional, serving as conduits. Yellow tube represents the research borehole GrSk 3/90.

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