

Use of Exploration Wells to Improve Geothermal Reservoir Models

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ABSTRACT

The large sedimentary basins and graben structures in Germany are regions of general interest for geothermal heat use. In our study we focus on two target areas: the eastern part of the Molasse Basin in Southern Germany and the southern and western part of North Rhine Westphalia (Niederrheinische Bucht / Rheinisches Schiefergebirge). A major obstacle in geothermal energy development lies in the high risk of failure due to the unknown thermal and hydraulic properties of the target rocks at depth.

In order to improve this situation, we systematically analyze data sets from different exploration wells (oil, gas, carbon and research boreholes) and core samples. Our aim is to develop methods for rock property mapping on the reservoir scale and thus to obtain better models for geothermal installations in the planning stage. For this purpose, we apply a combination of laboratory measurements and well log interpretation.

Petrophysical properties measured in the laboratory on a representative collection of samples obtained from boreholes and outcrops comprise thermal conductivity and specific heat capacity as well as porosity and permeability. Additionally, we consider the effects due to temperature and pressure increase with depth. Logging data add information with respect to spatial variations, on the one hand through relationships between core and wireline measurements, on the other hand by delineating regions of different petrophysical facies types.

1. INTRODUCTION

A major hindrance for the exploration of geothermal energy is the high risk of failure due to the unknown properties of the target rocks at depth. In general, the ranges of thermal and hydraulic properties given in compilations of rock properties (e. g. Haenel 1988, Clauser 1995) are too wide to be useful to constrain properties at a specific site.

To overcome the insufficient knowledge of rock properties at depth, a project funded by the German Federal Environment Ministry (FKZ 0327563) has been initiated to provide a database of thermal and hydraulic properties for the subsurface of Germany. An important aspect is the use of data from exploration wells (hydrocarbons, coal and lignite) that are largely untapped for the purpose of geothermal exploration. Goals of the work are defined as follows:

1. Determination of thermophysical and hydraulic data for the stratigraphic units based on laboratory and borehole measurements.

2. Consideration of the dependence of the properties on PT-conditions at target depth as well as of compaction, cementation and diagenesis.

2. SURVEY AREAS

Large sedimentary basins and graben structures in Germany are regions of general interest for geothermal heat use. In our study (project phase 2) we currently focus on two target areas: the eastern part of the Molasse Basin in Southern Germany and the southern and western part of North Rhine Westphalia (Lower Rhine Bay/ Rheinisches Schiefergebirge; see Figure 1). The former is a current target of geothermal exploration; the latter has a great demand for geothermal energy due to the high population density. In a previous stage (phase 1) we attended to the subsurface of the western part of the Molasse Basin and the adjacent Triassic and Jurassic landscapes north of the Molasse (Swabian Alp) representing the same Mesozoic sequence like in the deeper parts of the basin.

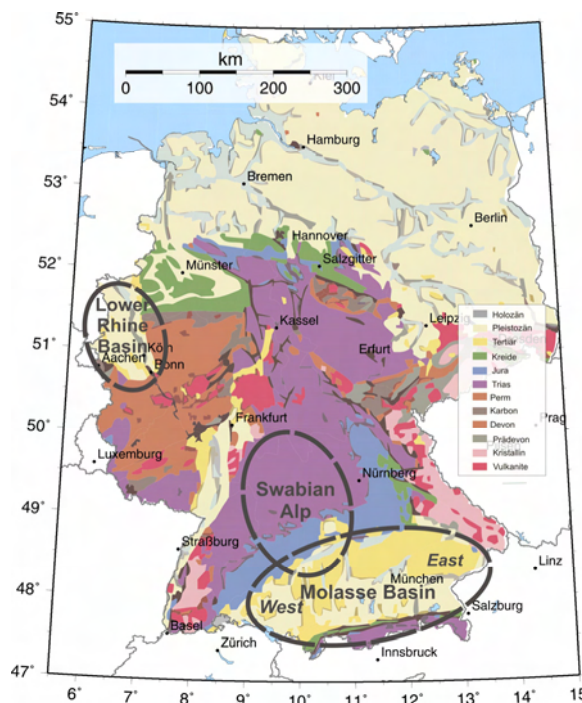


Figure 1: Geological overview map of Germany. The survey areas comprise the western part of the Molasse Basin and the Swabian Alp (phase 1) as well as the eastern part of the Molasse Basin and the Lower Rhine Basin (phase 2).

3. METHODS AND APPROACH

A combination of laboratory measurements and well log interpretation is used (Figure 2).

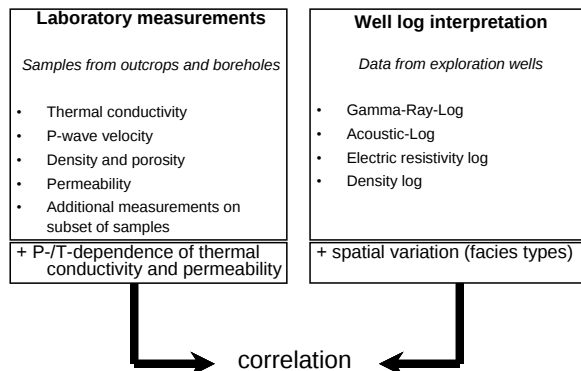


Figure 2: Schematic overview of the investigations performed.

3.1 Laboratory Analysis

Laboratory data present the basis of the study by providing petrophysical properties, measured on a representative collection of samples obtained from boreholes and outcrops in the working areas. Variations arising from temperature and pressure change with depth are additionally studied.

In the first project phase (March 2005 – October 2006), a large number of mesozoic rock samples from the South-West German Molasse basin was studied: About 280 core samples were tested by thermal and petrophysical core scanning yielding high resolution information on thermal conductivity, density, porosity and sonic velocity of the rocks in dry and saturated condition (see example in Figure 3). In addition, 100 core plugs were taken for measurements of specific heat capacity, hydraulic permeability, XRD and XRF analyses.

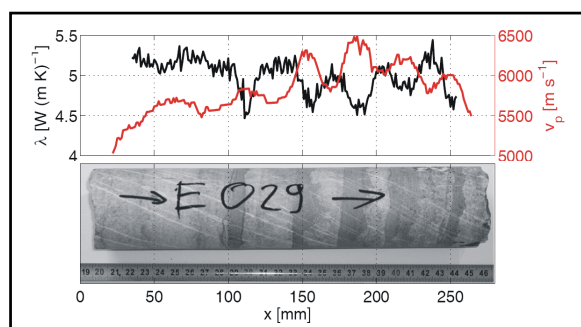


Figure 3: Example for the scanning measurement of petrophysical properties of core samples (here: thermal conductivity λ and sonic velocity v_p).

3.2 Well log Analysis

Logging data add knowledge by developing relationships linking core and wireline measurements. They comprise much better the variability of the petrophysical properties down hole since core data might be subject to preferential sampling. Moreover, a large number of boreholes allows a

better spatial characterisation of changes in facies and associated changes of petrophysical properties. For our purposes, we normally used gamma-ray log, acoustic log, electric resistivity log and density log.

3.3 Derivation of thermal properties from log data

Readings of wireline logs respond to the composition of the probed rock, its structure and environmental conditions. For the analysis of borehole geophysical data in terms of the quantitative description of the rock composition the assumption is made that a log reading responds mainly to the composition of the rock, given some appropriate mixing law. Using a standard inversion procedure (Doveton 1979; Hoppie 1996) the lithological composition can be computed. In turn this data can be used to compute a thermal conductivity profile (Hartmann and others 2005).

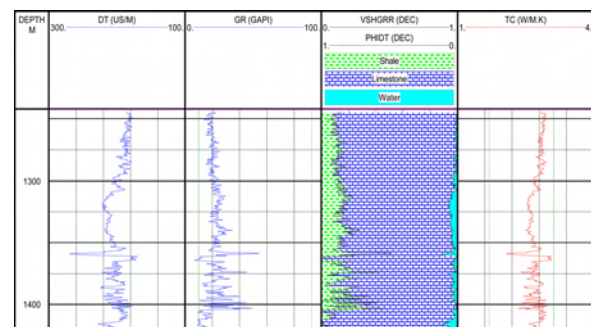


Figure 4: Example for the computation of a continuous thermal conductivity profile from wireline data, based on correlations derived from laboratory results. The lithology in track 3 results from input data DT (transit time in track 1) and GR (gamma-ray in track 2). Track 4 shows the computed thermal conductivity of this interbedded strata of marlstone and limestone of an Upper Jurassic borehole from the Southern German Molasse Basin.

4. RESULTS

In the first period of the project a total of almost 400 samples were investigated obtained from core archives of the Geological Survey of Baden-Württemberg, the University of Tübingen and Wintershall AG whose support is thankfully acknowledged. The geological sequence sampled ranges from Lower Triassic to Tertiary. A more detailed description of the laboratory work can be found in Pechnig and others (2007) in this volume.

Figure 5 gives an example of the P- and T-dependence of thermal conductivity simulating the burial depth of the samples down to 7 km. Increasing temperature is the most controlling factor for the decrease of thermal conductivity of most of the samples. Only two gypsum samples show a significant increase in the beginning that can be attributed to pressure effects.

The distribution and facies of a relevant rock unit is exemplarily shown in Figure 6. The Upper Jurassic in Southern Germany primarily consists of limestone with interspersed beds of marlstone. Figure 6 displays the reference profile of the sequence together with gamma-ray logs from boreholes in the survey area. Shown are both, boreholes in the central part of the Molasse basin as well as shallow boreholes from the northerly adjacent region. It is

apparent that the general sequence is similar for these two regions.

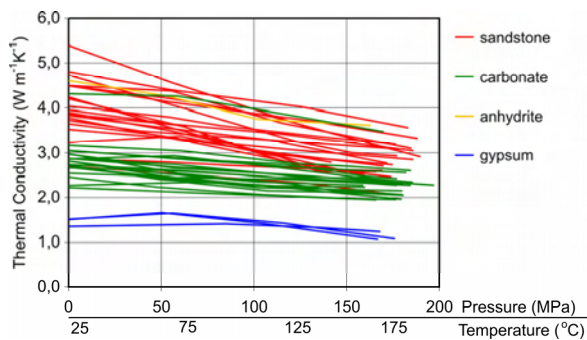


Figure 5: Dependence of thermal conductivity on pressure and temperature of sandstones, carbonates and sulphates from Mesozoic rocks from the survey areas in Southern Germany.

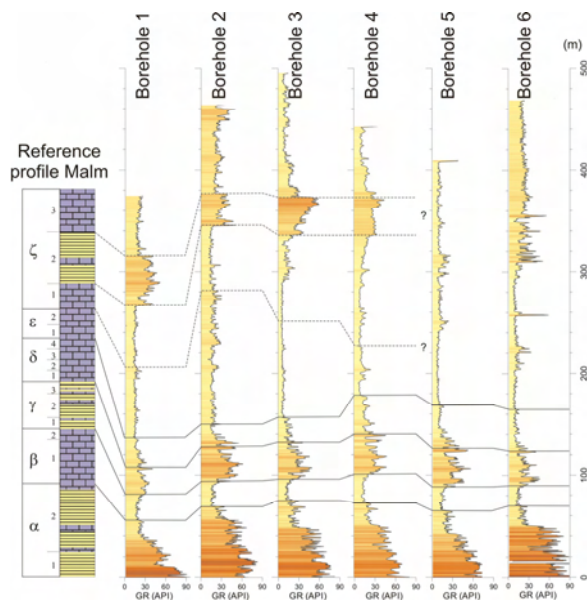


Figure 6: Reference profile of the Upper Jurassic (Malm) in Southern Germany compared with gamma-ray logs from hydrocarbon exploration wells. Unit alpha to delta can be well correlated, whereas units epsilon and zeta show considerable variability. The six boreholes cover a west-east distance of more than 100 km in the western part of the Molasse Basin.

For porosity and permeability the use of data from hydrocarbon exploration wells is particularly important. A large body of data exists that has been compiled in this and a previous study. The data have been used to calibrate a k - ϕ relationship for the sandstones of the western South German Molasse Basin (Figure 7) in order to be able to compute permeability with low effort from porosity data.

5. CONCLUSIONS AND OUTLOOK

The results of the combined analysis of laboratory measurements and wireline data provide base petrophysical properties for rocks from the Buntsandstein to the Miocene epoch in South Germany. In addition to the statistics our work also provides information on the main controlling factors for the variation of these properties. This information is particularly important because it will allow a more rational choice of rock properties in the design phase of a geothermal installation. Information on the site-specific geologic situation can be translated into constraints that narrow the possible bounds for petrophysical properties of the rock.

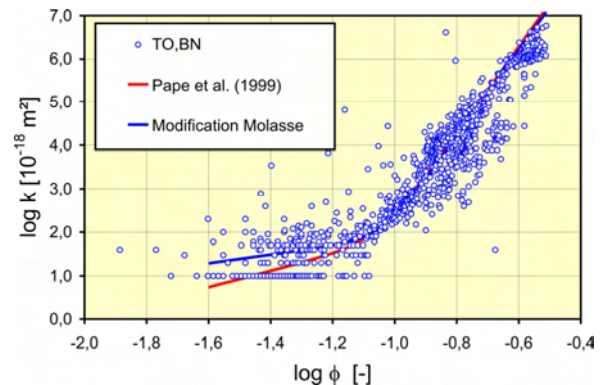


Figure 7: Example of k - ϕ relationship for Molasse Basin sandstones (here: a Tertiary subunit). The relationship was originally derived for the North German Basin (Pape et al. 1999, red curve). The dataset for the Molasse Basin incorporates over 1000 porosity and permeability measurements performed on Tertiary and Mesozoic sandstones in the course of hydrocarbon exploration (modified according to Hartmann and others 2006).

Currently, we perform a sampling and measuring campaign in the Lower Rhine Basin collecting core samples from weakly consolidated Tertiary sediments (clay, silt, sand, partly gravel, lignite) of a bore near the open pit “Hambach”, supported by RWE Power AG whose aid is thankfully acknowledged. The borehole reaches a depth of more than 800 m down to the subjacent Paleozoic rocks and provides both core and log data which is a good opportunity to calibrate the rock models needed for the derivation of thermal properties of the Tertiary sequence.

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