Proceedings World Geothermal Congress 2010
Bali, Indonesia, 25-29 April 2010

3D-Model of the Deep Geothermal Potentials of the Northern Rhine Rift Valley

Arne Buss, Kristian Baer, Ingo Sass

Institute of Applied Geosciences, Technische Universität Darmstadt

surename@geo.tu-darmstadt.de

Keywords: Rhine Rift Valley, 3D-Model, geothermal potential, thermal conductivity, permeability

ABSTRACT

Based on a 3D geological model of the geology and structure of the northern Rhine Rift Valley a geothermal model has been developed. Systematic measurements of permeabilities and thermal conductivities of relevant geologic formations have been combined with in situ temperature measurements, hydrothermal upwelling zones, characteristics of geological faults and added to the geological model. The model is an important tool for the planning of geothermal power plants because it will allow the geothermal potential to be easily determined at an early stage of the planning phase.

1. INTRODUCTION

For the planning of deep-geothermal installations, knowledge of the geological structure and the geothermal parameters of the potential reservoir rocks is indispensable. Therefore a 3D model of the deep geothermal potential of Hesse has been carried out (Arndt et al. 2009).

2. GEOLOGY

In the Hessian part of the Rhine Rift Valley the quarternary sediments with up to 340 m thickness (Haimberger et al., 2005) can be neglected from the deep geothermal model. These formations are underlain by 500 - 3000 m of Tertiary calcareous and clastic sediments. The Oligocene Pechelbronn group with a thickness of 160 - 370 m (Plein, 1992; Boigk, 1981) and permeabilities of $5 \cdot 10^{-13}$ m² is the only relevant geothermal reservoir rock at the base of this formation. Jurassic and Cretaceous rocks are not present due to an erosional hiatus. For the Triassic formations, regionally only the Buntsandstein with a maximum thickness up to 200 m is present (Boigk & Schoeneich, 1970, 1974). Due to its small thickness and only regional occurrence it is not relevant for direct geothermal use in Hesse. The Triassic Formations are underlain by the Permo-Carboniferous clastic and volcanic formation with a maximum thickness of up to 2500 m. Because of its depth, partially high permeabilities and temperature it is the formation that represents a potential geothermal reservoir. The uninvestigated crystalline basement has to be regarded as a petrothermal system because of high temperatures, low primary permeabilities and high thermal conductivities. It has to be assumed that the formation consists predominantly of granitic rocks.

3. GEOLOGICAL 3D-MODEL

The current state of the geological model (Baer, 2008) is based mainly on already interpreted seismic data, drilling results and geostructural maps. In the next steps of the project there will be further refinements of the model, particularly through the inclusion of additional seismic data. Layer thicknesses of the main geological units could be estimated based on the available/published information. As an example the thickness of the Permo-Carboniferous is shown in Figure 1, which is increasing towards the northwest and could reach up to 2000 m in the area west of Gross-Gerau (Boigk & Schoeneich, 1974). In addition, the depths of major geological horizons have been determined. As an example, the depth of the top of the crystalline basement is represented in Figure 2 with the maximum depth on the northwestern and southeastern edge of this part of the rift valley. These two depocenters are separated by an intervening NE-SW trend epirogene (Derer et al., 2005).

The quality and extension of the 3D-model depends on the available data. The building of the model with GoCAD has been mainly carried out based on a method described in Kaufmann and Martin (2009).

As input data, the digital SRTM model (version 3), 460 drillings, five geological cross sections and four interpreted seismic sections have been used. Furthermore seven isopachous and isoline maps for different horizons and five maps of subsurface temperatures have been taken into account. With this available data it was possible to carry out the top ground surface, the quaternary and tertiary basis, the basis of the mesozoikum and of the permo-carboniferious, the distribution of the main fault systems and the estimated temperature.

4. GEOTHERMAL CHARACTERISATION OF THE PERMO-CARBONIFEROUS

The lithostratigraphy of the Permo-Carboniferous in the Hessian part of the Rhine Rift Valley could be structured with respect to the classification of the Saar-Nahe-Basin. The focus here is on the Upper Nahe-Group, the Lower Nahe Group and the Kusel- to Tholey-Group at the bottom (Henk, 1993; Marell, 1989; Mueller, 1996). Measurements of the thermal conductivity and the permeability were conducted on all sedimentary units of the Permo-Carboniferous both on drill core samples and at samples taken from neighbouring outcrops as described by Sass et al. (2008).

The conglomerates and sandstones of the Upper Nahe – Group, which occur mostly in the lower part of this unit, show the highest thermal conductivities of the Permo-Carboniferous rocks: up to 3.4 W/(m·K). The permeabilities of the sandstones lie around $1 \cdot 10^{-14}$ m², while those of the conglomerates are distributed around approximately two orders of magnitude. The upper part of this unit is dominated by silt and clay stones which show lower permeabilities in the order of $1 \cdot 10^{-15}$ to $1 \cdot 10^{-14}$ m² and substantially lower thermal conductivities of around 1.5 W/(m·K) (Figure 3).

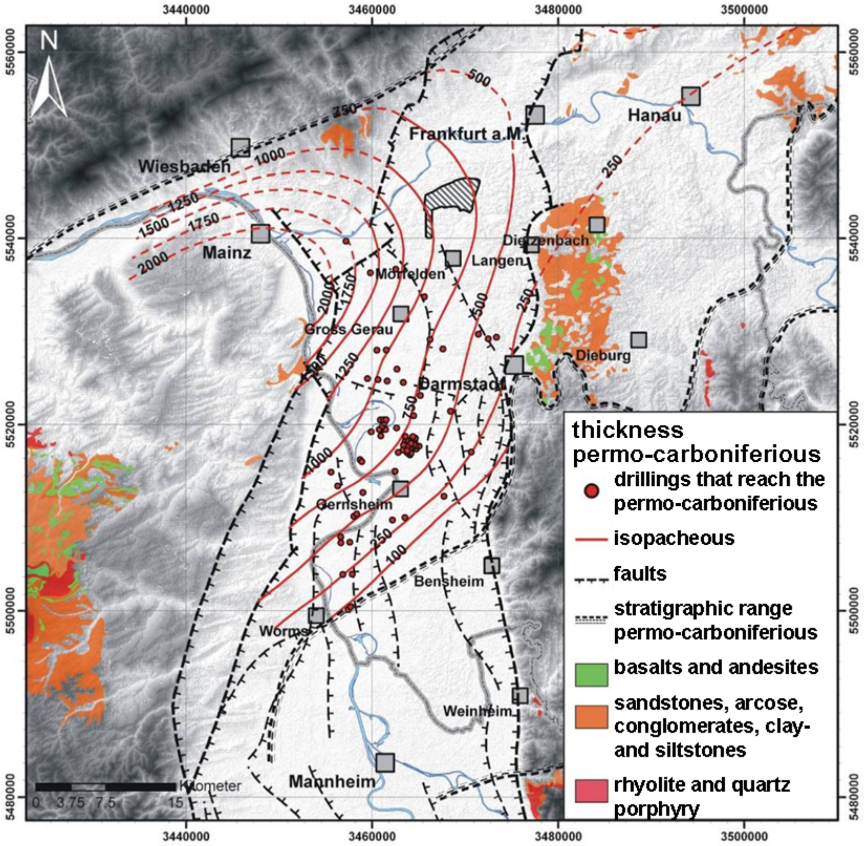

Figure 1: Thickness of the Permo-Carboniferous in the northern part of the Rhine Rift Valley

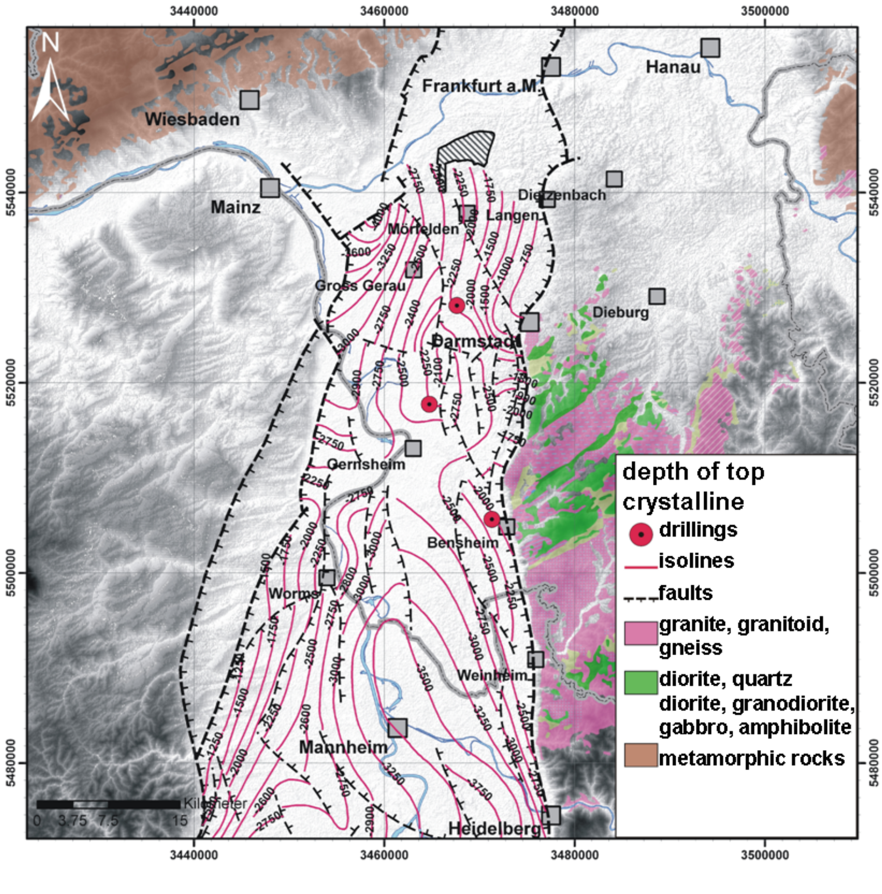

Figure 2: Depth of the top of the crystalline in the northern part of the Rhine Rift Valley

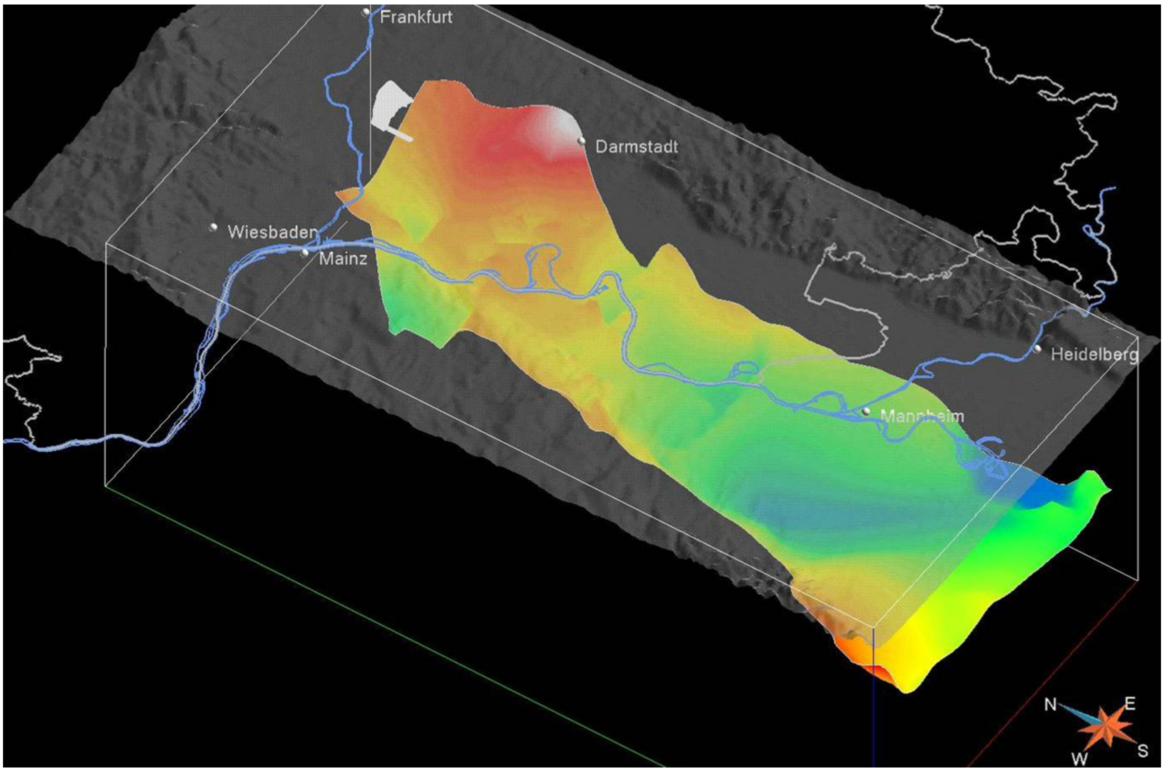

Figure 3: Pane of the geological 3D-Model. Top ground surface (grey), top of the permo-carboniferious (colour by depth). In addition the border of the state Hesse, the rivers Rhein, Main and Neckar and some important cities are shown

The Lower Nahe-Group (Figure 4) shows in all samples without any significant correlation to the lithology a relatively low and almost continuous thermal conductivity between 1.5 and 2 W/(m·K). The permeabilities of the sandstones and conglomerates vary over a large range with predominantly high permeabilities between $1 \cdot 10^{-13}$ and $1 \cdot 10^{-11}$ m². Beside the sedimentary rocks there are regionally additional relevant occurrences of rhyolite and melaphyre (Mueller, 1996; Kowalczyk, 2003; Lippolt et al. 1990). The lateral extend and thickness as well as the geothermal properties of these rocks are the scope of current investigations.

The sedimentary rocks of the Kusel- to Tholey-Group (Figure 5) show despite the different lithology only a small distribution within the permeabilities over one magnitude around 10^{-14} m² and have to be classified as rather low permeable. The thermal conductivities of this unit typically have values between 1.5 and 2.5 W/(m·K), slightly higher than in the Lower Nahe-Group, and tend to increase with grain size. Fine grained granular sedimentary rocks were underrepresented in the available drill cores and could not been sampled in outcrops due to the high degree of weathering. They will be the focus of further sampling and measuring in the future.

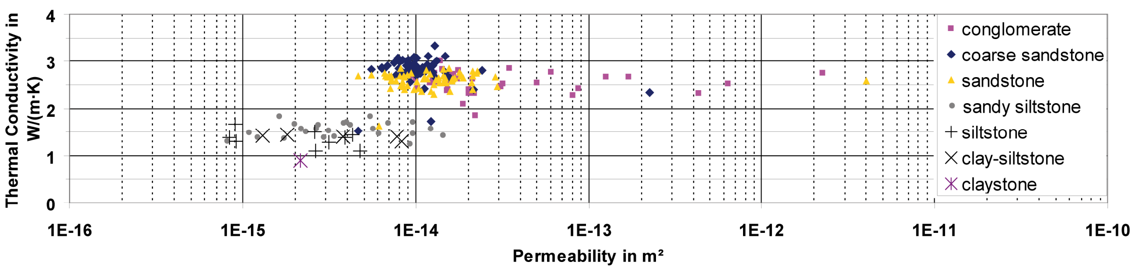

Figure 4: Thermal conductivity and permeability of the Upper Nahe-Group

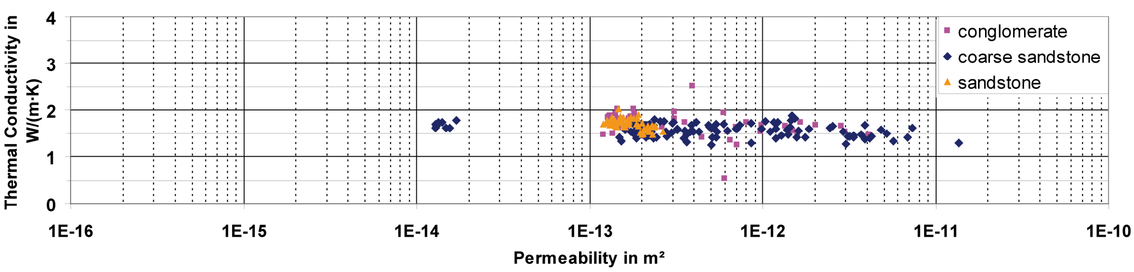

Figure 5: Thermal conductivity and permeability of the Lower Nahe-Group

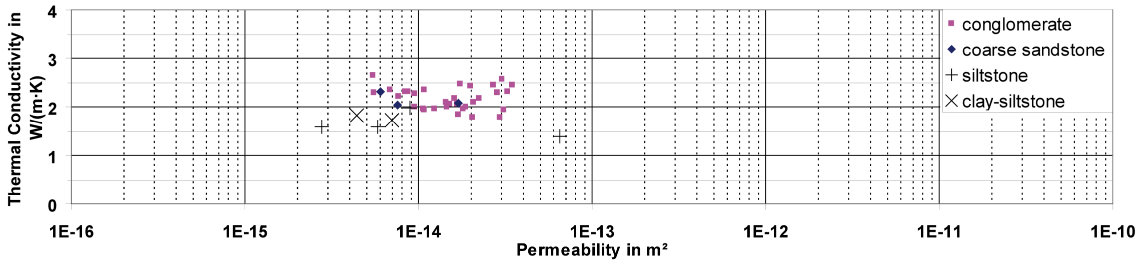

Figure 6: Thermal conductivity and permeability of the Kusel- to Tholey-Group

CONCLUSION

Investigations of permeabilities and thermal conductivities of the geothermally relevant Permo-Carboniferous rocks could not demonstrate any significant relationship between the thermal conductivity and the permeability. It seems that the sedimentary facies properties are controlling the thermal charactieristics of the Permo-Carboniferous more strongly than the petrological composition. The presented results show that the geothermally relevant rock properties of the Permo-Carboniferous subunits of different geological age are not necessarily the same. Due to the increased permeabilities of the Lower Nahe-Group, this unit is potentially the most suitable as a hydrothermal reservoir.

The developed 3D-model is a significant improvement of the previous model and allows a more detailed view into the northern part of the Rhine Rift Valley and its extension, especially in terms of the thickness of geothermal relevant horizons.

PROSPECTS

For the refinement of the model further data must still be interpreted and implemented. With this refinement the classification of detailed volume bodies of the individual geothermally relevant layers for the northern Rhine Rift Valley should become possible. Furthermore, during further study, thermal conductivities and permeabilities will be determined, particularly for the Permo-Carboniferous volcanic rocks and the fine-grained sedimentary rocks of the Kusel- to Tholey-Group. On the basis of this relationship and additional available data a further goal is the estimation of distinctive geothermal reservoirs.

ACKNOWLEDGEMENT

The authors thank the Hessian Ministry for Economics, Transport, Urban and Regional Development for founding the project and the Hessian Agency for Environment and Geology for the co-operation. In particular we thank Dr. Fritsche, Dr. Kracht and their colleagues for supporting the project.

REFERENCES

Bär, K.: 3D-Modellierung des geothermischen Tiefenpotenzials des nördlichen Oberrheingrabens und Untersuchung der geothermischen Eigenschaften des Rotliegenden. unpublished *diploma thesis*, Technische Universität Darmstadt, Institute of Applied Geociences, (2008)

Boigk, H.: Erdöl und Erdölgas in der Bundesrepublik Deutschland. Stuttgart,. (1981), 330 pp

Arndt, D., Buss, A., Fritsche, J.-G., Kracht, M., Sass, I.: Forschungs- und Entwicklungsprojekt „3D-Modell der geothermischen Tiefenpotenziale von Hessen“. unpublished *project report* (2009)

Boigk, H., Schöneich, H.: Die Tiefenlage der Permbasis im nördlichen Teil des Oberrheingrabens. In: Illies, J.H. & Mueller, S. [Eds.]. Graben Problems. *Proceedings* of an International Rift Symposium held in Karlsruhe, 10-12 October 1968, Stuttgart (Schweizerbart), (1970), 48-55

Boigk, H., Schöneich, H.: The Rhinegraben: geologic history and neotectonic activity. Perm, Trias und älterer Jura im Bereich der südlichen Mittelmeer-Mjösen-Zone und des Rheingrabens. In: Illies, J.H. & Fuchs, K. [Eds]: Approaches to Taphrogenesis. *Proceedings* of an International Rift Symposium held in Karlsruhe, 13-15 April, 1972: Stuttgart (Schweizerbart), (1974), 60-72

Derer, C.E., Schumacher, M.E. & Schäfer, A.: The northern Upper Rhine Graben: basin geometry and early syn-rift tectono-sedimentary evolution. In: Behrmann, J.H., Ziegler, P.A., Schmid, S.M., Heck, B. &Granet, M. (eds.): EUCOR-URGENT Upper Rhine Graben Evolution and Neotectonics. *Int. J. Earth Sci.* (Geol. Rundsch), Berlin, **94**, (2005), 640-656

Haimberger, R., Hoppe, A. & Schäfer, A.: High-resolution seimic survey on the Rhine River in the northern Upper Rhine Graben. In: Behrmann, J.H., Ziegler, P.A., Schmid, S.M., Heck, B. &Granet, M. (eds.): EUCOR-URGENT Upper Rhine Graben Evolution and Neotectonics. *Int. J. Earth Sci.* (Geol. Rundsch), Berlin. **94**, (2005), 657-668

Henk, A., 1993. Subsidenz und Tektonik des Saar-Nahe-Beckens (SW-Deutschland). *Geol. Rundschau* **82,** 3-19

Hurter, S. & Schellschmidt, R. (eds): Atlas of geothermal resources in Europe. Luxembourg, European Communities (2002), 92 pp.

Kaufmann, O. Martin, T.: Reprint of ‘‘3D geological modelling from boreholes, cross-sections and geological maps, application over former natural gas storages in coal mines’’. *Computers & Geosciences,* **35,** (2009), 70-82

Kowalczyk, G.: Permokarbon des Sprendlinger Horstes und der westlichen Wetterau (Exkursion I am 20. April 2001). *Jber. Mitt. Oberrhein. geol. Ver.*, N.F. Stuttgart, **83**, (2001) 211-236

Lippolt, H.J., Kirsch, H. & Plein, E.: Karbonische und permische Vulkanite aus dem Untergrund des nördlichen Oberrheingrabens: Art, Altersbestimmung und Konsequenz. *Jber. Mitt. Oberrhein. Geol. Ver.*, N. F., **72**, (1990), 227-242

Marell, D.: Das Rotliegende zwischen Odenwald und Taunus. *Geol. Abh. Hessen,* Wiesbaden, **89**, (1989) 128 pp

Müller, H.: Das Permokarbon im nördlichen Oberrheingraben – Paläogeographische und strukturelle Entwicklung des permokarbonen Saar-Nahe-Beckens im nördlichen Oberrheingraben. *Geol. Abh. Hessen*, Wiesbaden, **99**, (1996), 85 pp

Plein, E.: Das Erdölfeld Eich-Königsgarten. *Jber. Mitt. Oberrhein. Geol. Ver*. N.F., **74**,: (1992), 41-54

Sass, I., Buß, A. & Homuth, S.: Permeabilität und Wärmeleitfähigkeit anisotroper Festgesteine als Kennwerte für die geothermische Erkundung. *Baugrundtagung*, 24.9.-27.9.2008 in Dortmund, (2008)