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The thermal field of the Upper Rhine Graben – Temperature predictions based on a 3D model

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ABSTRACT

The Upper Rhine Graben (URG) is one of the regions in Germany with promising potentials for deep geothermal energy production. As part of the EU-funded project "IMAGE" (Integrated Methods for Advanced Geothermal Exploration), we aim to understand the processes and physical rock properties that control the temperature distribution in the deep subsurface of the URG.

Typically, numerical models of geothermal reservoirs are developed to predict the hydrothermal conditions and to reduce the risk of drilling non-productive geothermal wells. One major problem related to such reservoir-scale models is setting appropriate boundary conditions that define, for instance, how much heat enters the reservoir from greater depths. To address this problem, we first develop a lithospheric-scale 3D structural model that differentiates the main geological units of the lithosphere including the shallow sedimentary basin fill but also the configuration of the deeper crust and lithospheric mantle. Based on this model we solve the steady-state conductive heat equation to understand the first-order controlling factors of the regional thermal field. Furthermore, this regional thermal model provides the boundary conditions for smaller and higher resolved models of the basin fill, for which coupled heat and fluid transport is simulated in a next step.

1. INTRODUCTION

The Upper Rhine Graben (URG) developed as part of the European Cenozoic Rift System in the foreland of the Alpine Orogen in Eocene times (e.g. Dézes et al. 2004). The active rift comprises up to 5 km thick sediments of Permian to Quaternary age. These are underlain by a crystalline crust that is characterised by differently composed crustal domains of Paleozoic ages (Variscan zones; e.g. Kossmat 1927).

In general, subsurface temperatures are controlled by conductive and convective heat transport processes and thus lithology-dependent differences in (i) thermal conductivity, (ii) radiogenic heat production, and (iii) hydraulic conductivity.

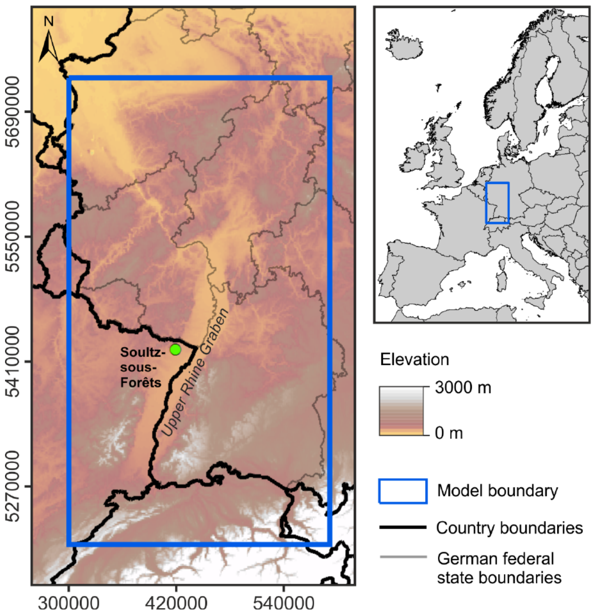

Figure 1: Location of the model area with topography (etopo1, Amante and Eakins 2009).

We want to determine in a first step the influence of the geological setting on the conductive thermal field and in a second step to better understand the coupled heat and fluid transport in the URG.

2. 3D STRUCTURAL MODEL

Therefore, we have built a lithospheric-scale 3D structural model of the URG and its surrounding areas that is based on published 3D structural models (Rupf and Nitsch 2008, Nitsch and Zedler 2009, Arndt et al. 2011, GeORG-Projektteam 2013, Maystrenko and Scheck-Wenderoth 2013, Freymark et al. 2015, Przybycin et al. 2015), published 2D surface and thickness maps, as well as reflection and refraction seismic profiles (e.g. Meissner and Bortfeld 1990). The upper boundary of the structural model is provided by the topography (Fig. 1) and the lower boundary by the seismological Lithosphere-Asthenosphere-Boundary (LAB) of Geissler et al. (2010).

The internal structure of the crystalline crust was constrained by seismic information and 3D gravity modelling.

The final 3D structural model differentiates 14 lithostratigraphic sedimentary and volcanic units, an upper crystalline crust divided into 7 domains, a lower crystalline crust and 2 domains of lithospheric mantle (Fig. 2; Freymark et al., in prep.).

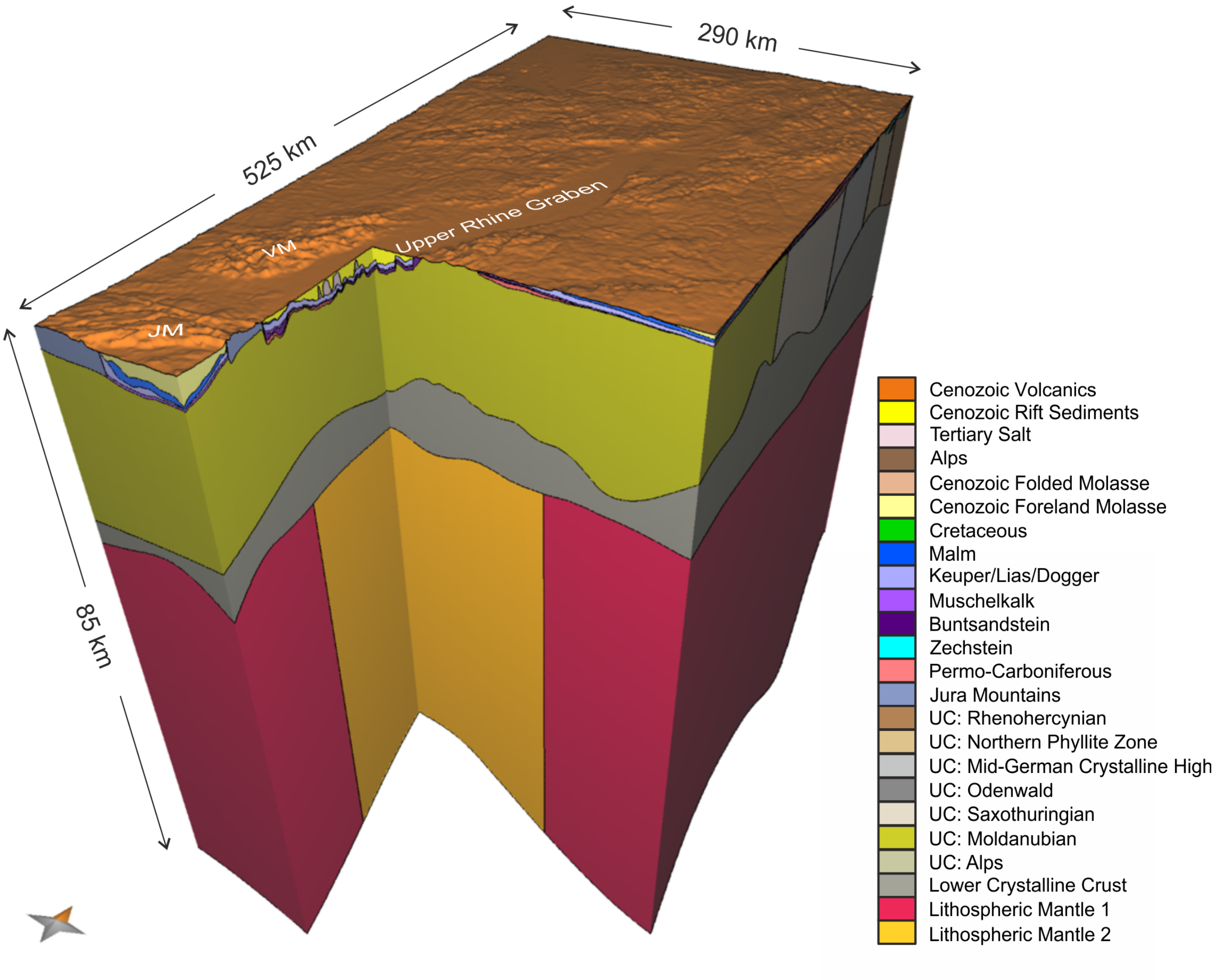

Figure 2: Lithospheric-scale 3D structural model of the Upper Rhine Graben and surrounding areas (Freymark et al., in prep.; UC = Upper crust, VM = Vosges Mountains, JM = Jura Mountains; vertical exaggeration 1:5)

3. 3D CONDUCTIVE THERMAL MODEL

Based on the lithospheric-scale 3D structural model and a finite element method the conductive thermal field was calculated. Therefore, we solved the conductive heat equation for steady-state conditions [1] with thermal conductivity λ, temperature gradient gradT and radiogenic heat production S after Bayer et al. (1997).

$$0 = \mathrm{div}(\lambda * \mathrm{grad}T) + S \qquad [1]$$

An average value of thermal conductivity and radiogenic heat production was assigned to each model unit. For most of the units published lab measurements were used (Freymark et al., in prep.).

As upper boundary condition the annual average surface temperature was used and for the lower boundary condition the seismological LAB was defined as 1300°C isotherm (Goes et al. 2000).

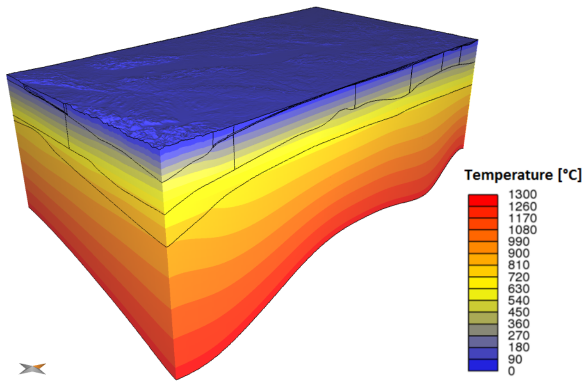

Figure 3: Lithospheric-scale 3D conductive thermal model (Freymark et al., in prep.; vertical exaggeration 1:2).

The 3D thermal model (Fig. 3) was validated by comparing the calculated temperatures with 2633 temperature measurements from 355 wells. Areas with a reasonably good fit are interpreted as being dominated by conductive heat transport. Misfits, especially in the URG, indicate an additional influence of fluid flow (Freymark et al., in prep.).

4. OUTLOOK: 3D COUPLED FLUID AND HEAT TRANSPORT

In the next step, we will assess the influence of coupled fluid and heat transport by performing 3D numerical simulations to selected parts of the northern URG.

The 3D conductive thermal model will provide the thermal boundary conditions for these smaller-scaled and higher resolved, coupled models (cf. Scheck-Wenderoth et al. 2014).

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