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

First Steps in the Development of a New Geothermal Field in the Northern Part of the Upper Rhine Graben, Germany

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Keywords: Upper Rhine Graben, low-enthalpy geothermal systems, field development

ABSTRACT

The northern part of the Upper Rhine Graben (URG) is the geothermal province with the highest geothermal gradients in Germany. The geological setting of the URG is well known by hydrocarbon exploration. Over the last 50 years, the most productive oil and gas fields were developed in the central part of the graben around the cities of Landau and Karlsruhe and in the northern part around Stockstadt and Worms. The whole graben was and still is tectonically active. Exploration wells show geothermal gradients up to 7.7°C/100 m. The first geothermal power plant was built in Landau and started production in 2008 using ORC power generation. A second plant in Bruchsal will start operating in 2010.

The geological setting of the northern part of the URG is very different compared to the mid and southern part. The Mesozoic and early Paleogene is represented by a hiatus, therefore the sediments of a Permo-Carboniferous foreland-basin with a thickness up to 4000 m is underlying the Eocene. This setting demands a new exploration and development strategy. Because of this situation geothermal development has been slow compared to the central and southern part.

Exploration wells in the northern part show a geothermal gradient up to 5.6°C/100 m. To reach reservoir temperatures above 150°C a drilling depth of 2500 to 3000 m is necessary. The exploration concept depends on the reservoir rocks and the tectonic setting in this part of the graben. The first results of a reconnaissance study are based on seismic exploration data of the oil and gas industry acquired between 1974 and 1985 and outcrop analogue studies of the Saar-Nahe Basin. The Nahe Group of the Lower Rotliegend especially seems to contain a high prospective reservoir. However, high amplitude reflectors in the Paleogene anticipate an interpretation of the reservoir in old seismic data. Therefore, various attractive fault-zones were identified. Hence, new 2D-seismic data will be acquired.

1. INTRODUCTION

Besides the Molasse Basin and the North German Basin the URG is one of the three main geothermal provinces in Germany. The northern and the central part of the URG have an especially long history in hydrocarbon exploration and production, starting in the 18th century (Boigk, 1981). As a consequence of intensive hydrocarbon exploration and production activities during the 1950s to 1980s, the geological setting, hydrodynamic and geothermal conditions of the URG are well known today. A sketch of the URG with the main producing and depleted fields are shown in Figure 1.

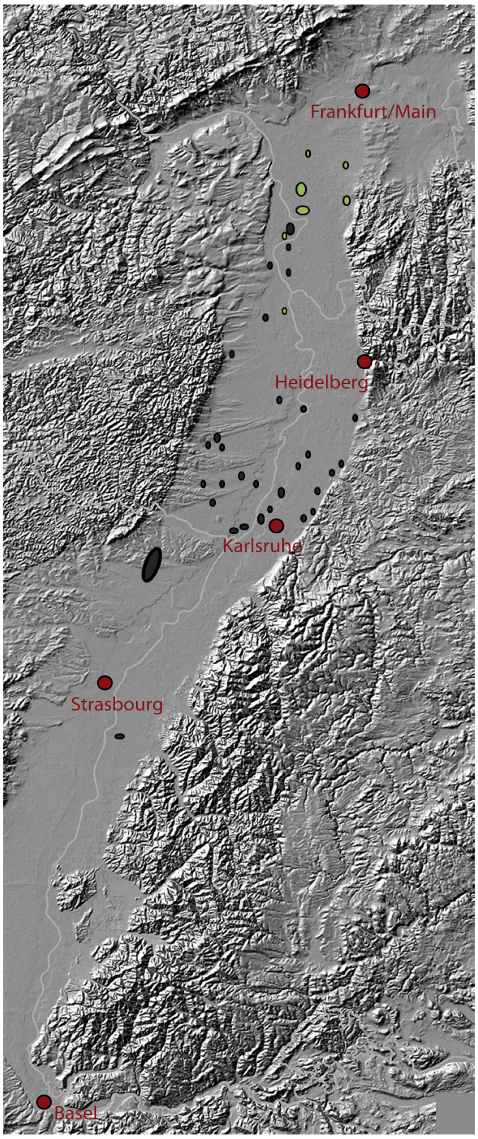

Figure 1: Image of the Upper Rhine Graben with recent and former oil (black) and gas (green) fields (after Boigk, 1981, image: Gabel, 2009).

The existence of HC-mature beds is caused by a high geothermal gradient in the URG with a maximum of more than 7.7°C/100 m in the south of Landau. This is the highest gradient in Germany (Illies and Fuchs, 1974). Reservoir temperatures between 130°C and 170°C define the URG as a low enthalpy geothermal region. To produce electric power at such reservoir temperatures, available concepts are binary power plants. The use of heat for power production in the URG was first envisaged in the 1960s. The first geothermal well for hydrothermal power production was drilled in 1983 in the city of Bruchsal reaching the Lower Triassic Buntsandstein in a depth of 2.500 m. After completion of a second well and an implementation of circulation tests, the project was stopped in 1987. Corrosion phenomena in the casing caused by the pumped brine and economical aspects led to this decision. With the implementation of a new feed-in tariff by the German government for electric power generated by geothermal energy, the project was reanimated in the year 2002 (Schröder, 2007), and completed in 2009. A flow rate of 24 l/s and a brine temperature of 130°C allow a power capacity of 550 kW generated by an Organic Rankine Cycle-(ORC) system.

Between 1987 and 2007, the development of a petrothermal reservoir was realized in Soultz-sous-Forêts employing Enhanced Geothermal Systems (EGS). After the drilling of three wells, a synthetic heat exchanger was fractured into the crystalline basement in a depth of 5.000 m. At the moment, a power capacity of 1.5 MW is installed and will be extended up to 6 MW in the future (Genter, 2008).

Further successful geothermal projects in the URG are situated in Landau and Insheim. All projects are located in the central URG (Figure 2) with developed reservoirs in the Lower Triassic Buntsandstein and/or the crystalline basement.

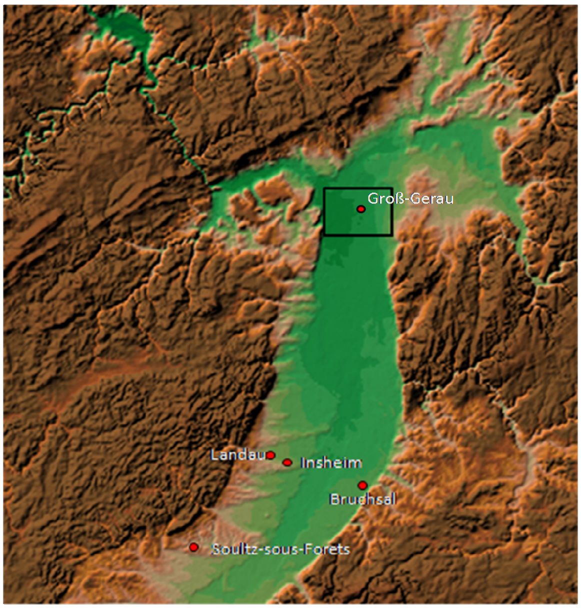

Figure 2: Position of recently successful geothermal wells in the URG (red dots) and the study area (Map: Roehr, 2009).

In 2007, a local energy supplier started to develop a geothermal field in the northern part of the URG near the city of Groß Gerau (Figure 2). Comparing the Paleogene to Neogene evolution of the northern URG with the central part, the geological environment of the reservoir area in the northern URG has a totally different history of development and belongs to a Permo-Carboniferous strike-slip basin (Schäfer and Korsch, 1998).

For a first reconnaissance of the interest area, key methodologies include i) information research, ii) evaluation of available well data, iii) interpretation of available 2D-seismic data, iv) outcrop-reservoir analogue studies.

This paper shows first results and conclusions of the reconnaissance study.

2. MATERIALS AND METHODS

Literature data, geological maps and published transects have been evaluated to understand the regional geological context. Well data of different quality and quantity are available for 6 wells in the interest area. For one well, a synthetic seismogram that integrates well top data into the seismic dataset does exist. 6 seismic transects are available as SEG-Y files and two interpreted lines from literature data. A database based on SEG-Y files and well information has been set up. The uploaded seismics were acquired between 1974 and 1985 by explosive seismic (5 lines) and vibroseismic (1 line) sources and reprocessed during the last year. Figure 3 shows a basemap of evaluated subsurface data. A lithofacial mapping of outcrop-analogues in the Saar-Nahe-Basin (SNB) is in progress.

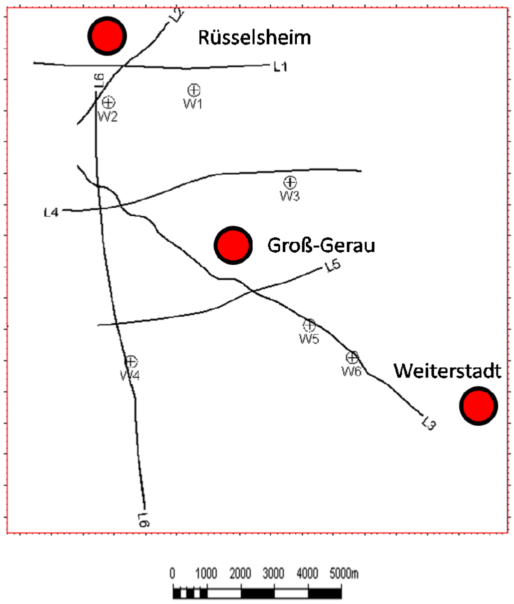

Figure 3: Basemap of evaluated seismic and well data.

3. RESULTS

3.1 Geological Setting

As a part of a major extensional rift system in Central Europe reaching from the North Sea to the Mediterranean Sea, the structure of the URG shows pronounced fault-block architecture. The tectonic history can be divided in two phases. An extensional rift phase with σ_1 in NNE-SSW direction caused by collision events in the Alpine region started in the Eocene and ended in the Lower Neogene (Aquitanian). After a reorientation of the stress field, a phase with a strike-slip regime with σ_1 in NW-SE direction started in the Lower Neogene (Illies, 1975; Buchner, 1981; Michon et al., 2003; Schwarz, 2005). The strain regime is predominantly extensive in the E-W direction (Tesauro et al., 2005).

In the central URG, pre-rift sedimentation is represented by early to middle Triassic deposits of the fluvial Buntsandstein and marine Muschelkalk formations, which are overlying the crystalline basement. These formations are actually the main geothermal reservoirs in this region.

The northern URG is overlying the Permo-Carboniferous Saar-Nahe-Basin (SNB), which in the past has not been a focus of geothermal exploration. Mesozoic strata were not deposited or were eroded in this area. The SNB is an intramontane basin dominated by clastic continental sediments of alluvial fans, braided and meandering rivers, deltaic and lacustrine facies (Korsch and Schäfer, 1995). As a part of the greater Nancy-Pirmasens-Basin, the SNB extends from the city of Saarbrücken in the SW to the Sprendlinger Horst in the south of Frankfurt. The basin has an asymmetric geometry perpendicular to the South Hunsrück Fault (Rhenish Massif) while the depocenter is located close to this fault zone (Korsch and Schäfer, 1995). The SNB is characterized by dextral strike-slip faulting of synsedimentary origin (Stollhofen, 1998).

In the area of the URG, the SNB is sagged with an offset of up to 3.500 m at the western master fault. At the eastern graben fault, the offset is about 1.500 m (Derer, 2003). As a consequence, the sedimentary beds dip downward to the west.

The basement of the SNB is built by three units of the German Variscan Fold Belt: the Rhenish massif in the NW, the Northern Phyllite Zone in the centre and the Mid German High in the SE. The lithological composition of the basement varies from low to medium metamorphic shales, schists or slates in the north over low metamorphic phyllites in the depocenter and crystalline rocks in the south (Thews, 1996; Peters, 2007; Figure 4).

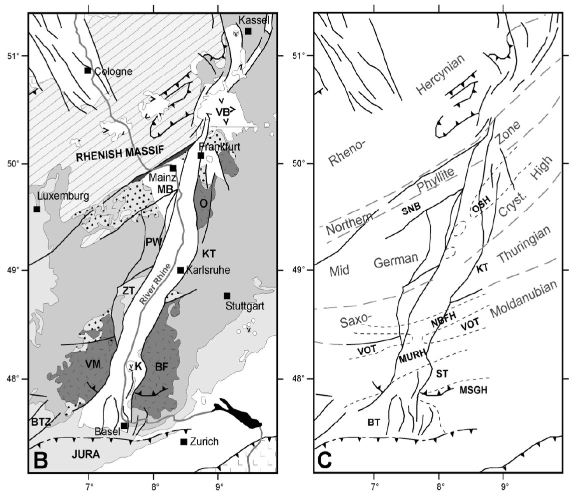

Figure 4: Structural units of the URG and surrounding area (Peters, 2007). The genesis of the Mid German High, the Northern Phyllite Zone and the Rhenish Massif define the rock composition of the basement.

Based on the expectation of a brine temperature of 150°C and a geothermal gradient of 5.6°C/100 m, a potential reservoir is located at a minimum depth of 2.500 m. Due to the fact that the base of the Paleogene in the Northern URG is at depths of 1.500 to 2.500 m, a potential reservoir has to be found in Permo-Carboniferous rocks or in the basement.

3.2 Evaluation of Well Data

The most comprehensive dataset is available for the well W6. It was drilled through the whole Carboniferous to recent sedimentary cover and ends in the crystalline basement of the Mid German Crystalline High. The well report contains detailed information about lithofacial and biostratigraphic composition and physical parameters of the drilled formations. An interpretation of depositional environments is replicable.

The Pre-Paleogene is represented by sand- and siltstones of Upper Rotliegend (Guadalupium) flood plain sedimentation (Marell, 1989). The Upper Rotliegend is divided from the Lower Rotliegend (Cisuralium) by porous andesitic to basaltic volcanic rocks with a thickness of up to 100 m. Siltstones interbedded with sandstones and conglomerates form the basal section.

All other wells have their final depth in the top of the Rotliegend so that information from these wells were only useful to create a depth map of the Top Rotliegend. Hence, subsurface reservoir information is just available for well W6. Relevant parameters for geothermal reservoir characterization of the Rotliegend from cores and outcrop-anaologues were measured at the University of Darmstadt (TU).

The results show intermediate to good thermal conductivity between 1.5 and 3.5 W/(m·K) and permeability values ranging from 1.4E-15 to 1,7E-12 m² (Sass and Bär, 2008, Figure 5). Outcrop analogue studies in the SNB verified the presence of well developed flow units in the Lower Rotliegend.

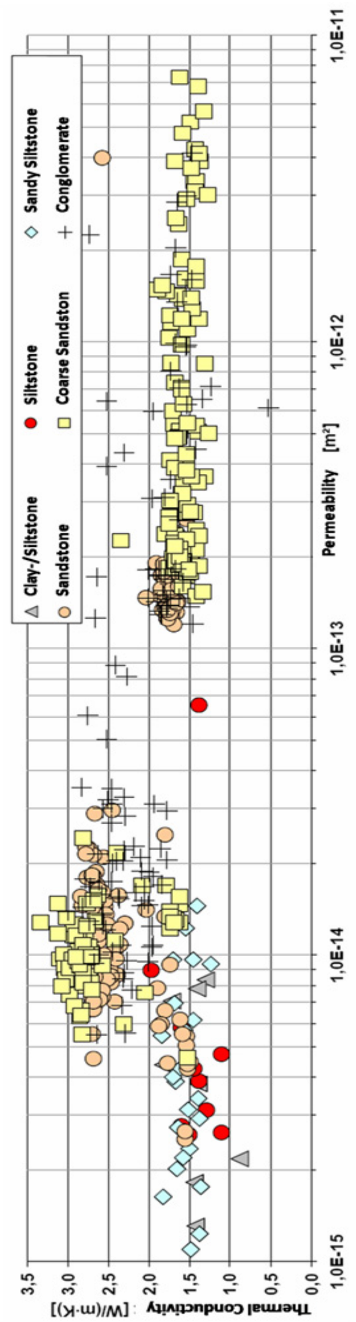

Figure 5: Thermal conductivity vs permeability of Rotliegend clastics (Sass and Bär, 2008).

Temperature data is available for the wells W1 and W6 and varies between 4.7 and 5.7°C/100 m. Information about hydrodynamics and hydrogeochemistry is not available.

3.3 Seismic Interpretation

Based on the VSP data from well W6 and approximate interval velocity estimation for well W2, five main reflectors of the Paleogene and Neogene and the top Rotliegend could be picked (Figure 6 and 7).

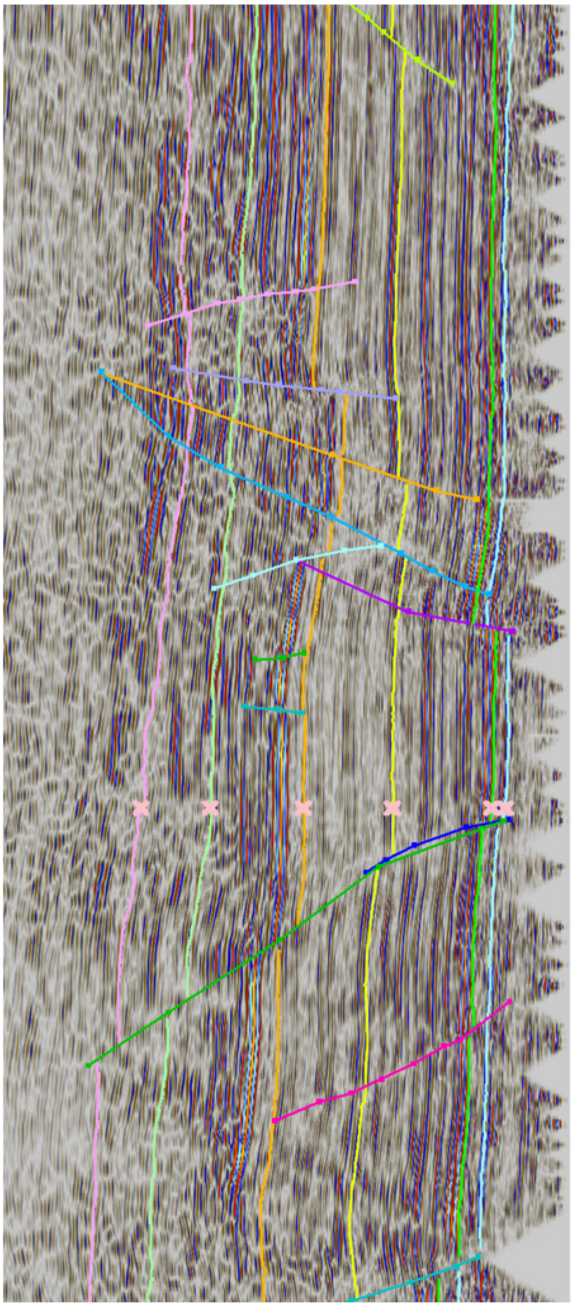

Figure 6: Preliminary sedimentary and structural model of L1. The current 2D seismic coverage and resolution does not allow a sufficiently reliable interpretation for reservoir assessment. Nevertheless, based on the underlying data, it is possible to locate areas of higher geothermal potential. The results themselves are the basis for further exploratory campaigns.

Especially in the Paleogene and Lower Neogene, rift phase faults are obvious and, if active, also visible in the Neogene.

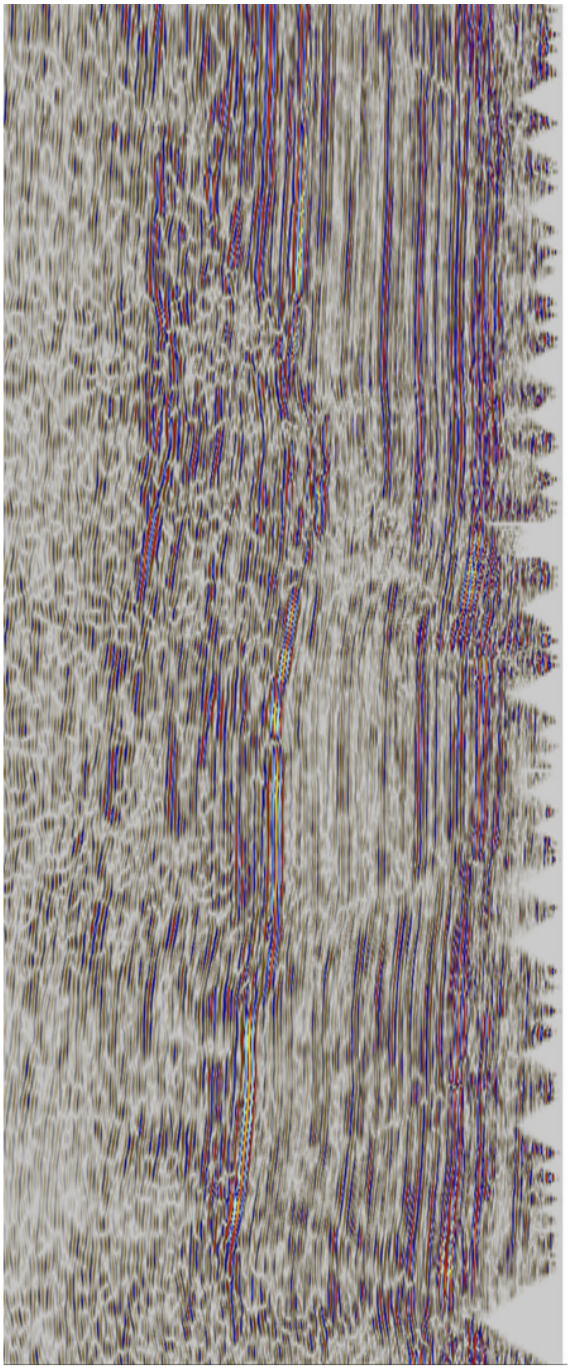

Figure 7: Uninterpreted seismic section (L1).

The Pechelbronn and Niederrödern beds of the Paleogene in the URG are known for their high amplitude reflectance. As a consequence the energy of the seismic signal during data acquisition was not high enough to interpret sediment geometric architecture and structures in the reservoir. To get an image of the geometry and basin fill of the SNB, presently only proximate models based on literature data can be created. Important publications are Boigk and Schöneich (1970), Marell (1989) and Müller (1996).

The main geological results for now, based on seismic interpretation, are a depth map of the top of the reservoir and a Cenozoic fault model (Figure 8).

The top Rotliegend is placed at 1450 m depth in well W5. Considering a thickness of 200-450 m for the Upper Rotliegend, the reservoir in the lower Rotliegend may be located between 1600 to 1850 m depth. Brine temperatures of 85°C to 115°C in this interval are insufficient for electric power generation.

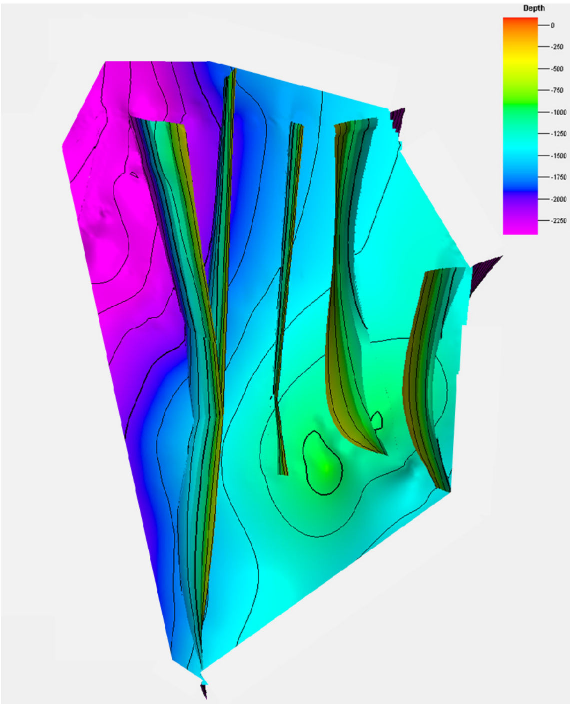

Figure 8: Depth map of top Rotliegend with fault model. Major faults are oriented in N-S perpendicular to the recent extensional regime. Depth in meters.

In northwest direction the Rotliegend top reaches a depth of 2000 m near a fault-zone. A Reservoir depth of about 2500 m and brine temperatures of 150°C are reasonable to expect. Porous volcanic rocks and permeable Rotliegend sandstones of the Nahe-Group provide a continuous flow of hydrothermal brine from the regional environment, while fault structures in this superior extensional system promise a high prospectivity. Based on the experiences of Landau and Insheim, flow rates about 75 l/s seem to be possible. These conditions will allow an economic geothermal power generation.

4. DISCUSSION

The Rotliegend seems to be a high potential geothermal reservoir in the northern URG, in particular the coarse clastic sediments of the Nahe-Group. It is characterized by permeable sandstones and volcanic rocks which allow water supply from surrounding formations. Three major tectonic events suggest a brine saturated intense faulted reservoir.

In order to get more information about the architecture and fault orientation in the reservoir, new 2D-seismic surveys have to be accomplished. Additionally, the energy of the induced seismic signal has to be high enough to receive reflections from the Pre-Paleogene. A seismic campaign with a frequency range between 12 to 72 Hz, a sweeplength of 15 s induced by four moving seismic vibrators is therefore planned. The actual model is the basis to develop further exploration strategies.

ACKNOWLEDGEMENTS

The presented results are based on seismic and borehole data which were made available within a data trade agreement. We like to thank Exxon Mobile Production Germany for permission.

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