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Transition from hydrocarbon production to geothermal heat storage in the Upper Rhine Graben – the DeepStor project

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ABSTRACT

The subsurface condition of the Upper Rhine Graben is favorable for developing novel geothermal utilization concepts. In particular, they allow for an optimization of the energetic use for variable heat production and storage scenarios. The fact that former hydrocarbon reservoirs are involved, perfectly describes the transition to the future use of renewable CO_2-neutral energies.

The concept, which is tailored to the Campus North of the Karlsruhe Institute of Technology (KIT) that is located in the central-eastern Upper Rhine Graben. It includes multi-level utilization with heat recovery from the deep Mesozoic reservoirs (GeoHeat project) and seasonal heat storage in the Tertiary Sandstones above (DeepStor project). In the long term, the concept should cover a significant part of the basic heat load at the KIT Campus North in a climate-neutral way. The underground of the campus is characterized by the largest known heat anomaly in Germany, with temperatures of ≥ 100 °C at a depth of 2 km. In connection with the existing area-wide local heating network, the campus offers good conditions for the extraction, seasonal storage and distribution of heat from deep geothermal energy. The step-by-step development of deep geothermal energy at the KIT Campus North will include first the deep underground to Tertiary Basin is to be developed within the framework of the DeepStor storage project. The high temperature storage of renewable heat involves the same Tertiary strata from which hydrocarbons have been extracted until the 1990s and will be supplied in a first step with heat from cogeneration as well as current renewable waste heat from scientific infrastructure projects such as "bioliq".

The expected reduction of flow rates by seasonal storage in the later GeoHeat project should serve in particular to reduce induced seismicity, which is still one of the greatest obstacles for the industrial, deep geothermal development in the Rhine Graben.

DeepStor consists of three stages:

1) The establishment of a scientific demonstrator for high-temperature heat storage in the deep underground with the aim of validating the technical feasibility.
2) Coupling of the prototype to above-ground plants (e.g. CHP, bioliq) with feed into the local heat grid.
3) Integration into the regular operation of the KIT Campus Nord heat supply system.

1. INTRODUCTION

Located at KIT Campus North on one of the most prominent geothermal anomalies in central Europe, DeepStor will be used to investigate the capabilities of seasonal high-temperature thermal storage in a porous Tertiary sedimentary reservoir of the Upper Rhine Graben. It envisages to extend the current maximum storage temperatures from about 50-70°C heat recovery through technological innovations and to be a scientific demonstrator on high-temperature underground storage. High temperatures are defined by recovery temperatures of > 110°C representing common inlet temperatures for water-based district heating and for industrial processes. This facility should advance the technical and scientific topics necessary for seasonal, on-demand heat supply.

Its geoscientific and technological design represents a novel concept for thermal storage in former fossil reservoirs. This supports not only the energy transition, but also the technology transfer from hydrocarbon to geothermal utilization. In this context, seismic and other geophysical methods will support the planning of optimum borehole trajectories. DeepStor is challenged by the terrestrial to brackish origin of the reservoirs. Therefore, directional drilling, designing the length of the open hole, reservoir size or operation modes, as injectors and producers with a cycle-varying fluid composition and properties are key elements of the technological and scientific challenges. New developments in geophysical monitoring and numerical simulation will be applied accounting for multiphase and multicomponent processes in reservoir and boreholes. The DeepStor project will account for new strategies of public acceptance by engaging the public in a co-design process and even into data monitoring, and by supplying a continuous flow of information.

The geochemical composition and changing physical properties of the fluids affect and potentially harm high-value technical infrastructure in the borehole, heat exchanger or pump system, and the reservoir itself. Successful storage and extraction have to progress on reservoir technologies and on material research by accounting for the mutual interaction of the subsurface fluids with steel (e.g. corrosion), rock (e.g. scaling formation) or with fluids of different composition (e.g. borehole simulation). Geochemical characterization is therefore a prerequisite to modelling and prediction of scaling formation. Hydrochemical simulations for different materials under varying temperatures and flows will allow for characterizing the morphology and the corrosion and scaling rates.

A major obstacle for acceptance of deep geothermal energy utilization is induced seismicity. Its occurrence and intensity are mainly linked to the operational flow rates in the deep fractured reservoirs. Scalable seasonal heat storage in porous media may allow for reducing the overall flow rate in the individual system and will thus strongly impact the acceptability of the technology.

2. DEEPSTOR DESIGN

DeepStor benefits strongly from the large number of boreholes from earlier oil production in the vicinity of the KIT Campus North as well as large-scale geophysical mapping data. Although targeting principally the area below the campus, the project will be placed at the most promising location. The design of DeepStor includes two drill holes to develop the Tertiary Sandstones (Figure 1).

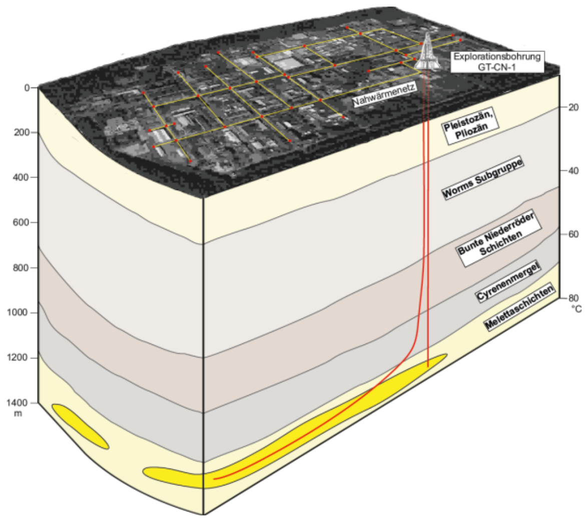

Figure 1: Conceptual design of the DeepStor project for high-temperature heat storage.

It is envisaged to drill a first exploration well investigate the three possible target horizons for geothermal utilization, which so far had been studied for oil production (Figure 2):

1) Bunte Niederrödern strata (BNS) and Oligocene
2) Cyrene marls (CyM), Oligocene
3) Meletta layers (MS) Oligocene

According to current knowledge, the upper edge of the Meletta layers at KIT Campus North is at a depth of approx. 1'085 m below sea level (i.e. 1'190 m below ground level). In the Tertiary strata a temperature gradient of about 50-58 °C/km prevails. The porosity and permeability values in the Meletta strata are between 4 and 32% and 0.01 to 140 mD (Bruss, 2000). The formation waters are highly saline Na-Cl fluids with salt contents of 60-150 g/l (Stober and Bucher, 2014).

The second borehole is to open up the target horizon via a vertical section in order to allow as high an inflow as possible to the borehole or outflow from the borehole into the reservoir.

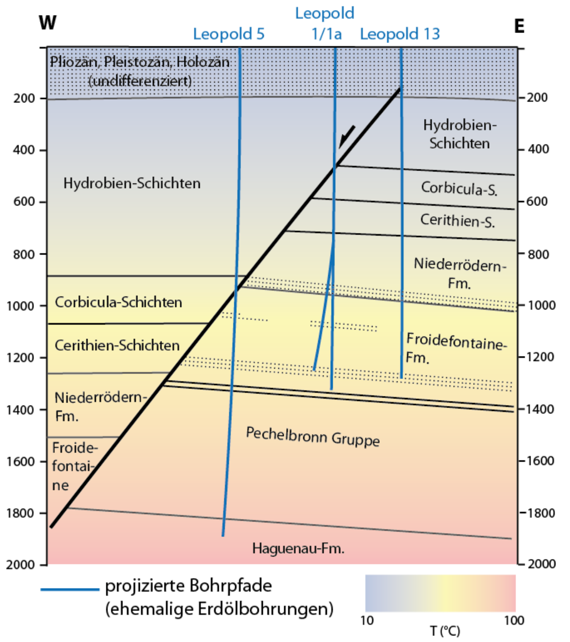

Figure 2: Geological section west of the campus (modified after Wirth, 1962). The blue lines mark the projected drilling paths of the holes Leopoldshafen 1/1a, Leopoldshafen 5 and Leopoldshafen 13 into the profile plane. The campus is located a few tens of meters east of the Leopoldshafen 13 well. Point signatures in the stratigraphic units mark sandstone

reservoir rocks. There were oil inflows from the sands of the Niederröder Formation and the Froidefontaine Formation (Cyrene marls and Meletta layers). The temperatures (Sauer, 1981) are presented her as linear interpolation.

3. FIRST RESULTS FROM EXPLORATION

Most of the numerous oil wells (Figure 3) drilled in the 1950s and 1960s targeted the Cenozoic graben fillings. Thus, the underground model is well documented down to the stratigraphic level of the Froidefontaine formation (approx. 31 Ma to 28 Ma) - especially in the vicinity of the former Leopoldshafen oil field. On the basis of published geological 2D sections (Figure 4), a first underground model of the KIT Campus North was obtained (Figure 5) using PETREL©. The general structural picture in the Cenozoic sequences is characterized by almost graben-parallel NNE-striking as well as obliquely oriented NW-striking faults, of which the offsets decrease with strike. The offsets of the graben-parallel displacements were transferred via internally complex accommodation zones to other subparallel structures. The most prominent of these NNE-striking faults is the Leopoldshafen fault, which is located directly west of the campus and is cut off by the Pliocene unconformity. This observation indicates - within the stratigraphic resolution of the sequences - that the Leopoldshafen fault has not been active since the Pliocene times. The high-resolution digital terrain model shows two S-N-oriented meandering channels immediately west of the campus, which cut into the older gravel surface. No further tectonic lineaments could be detected. A systematic and detailed analysis of the Plio Pleisto Holocene sedimentary sequences in the vicinity of the campus is therefore recommended for the identification and characterization of possible neo-tectonic movements.

The Leopoldshafen fault was mainly active during the early Miocene time (about 25-18 Ma), when the Hydrobia, Corbicula and Cerithian layers were deposited. The vertical offset of the Leopoldshafen fault increases from 300 m to 600 m from south to north and decreases slightly to 550 m further north (Schad 1964). This variation is documented by ESE dipping open syn- and anti-forms in the hanging wall of the Leopoldshafen fault. In the footwall, a basin structure occurs southeast of the campus, which is bounded by a NNW-striking fault to the southwest, which extends between the Leopoldshafen fault in the west and the so-called Stutensee fault in the east. The accumulation of oil occurred in the footwall in the sandy layers of the Froidefontaine and Niederrödern Formations along the Leopoldshafen fault. The former Leopoldshafen oil field was able to recover oil inflow from several horizons into the well and is therefore referred to as a stacked reservoir. With a field size of 2000 x 500 m and a total oil production of 187,600 tons, this field was the seventh largest oil field in the Upper Rhine Graben (Böcker, 2015).

The Bunte Niederröderner strata, which occur below the campus at a depth of approx. 700±50 m, dip at low angle to the NE. They include fluviatile sandstones at their base. Further potential storage horizons are formed by sandstones of the Froidefontaine formation occurring in the Cyrenean marls deposited under brackish conditions and the Meletta layers deposited under marine conditions.

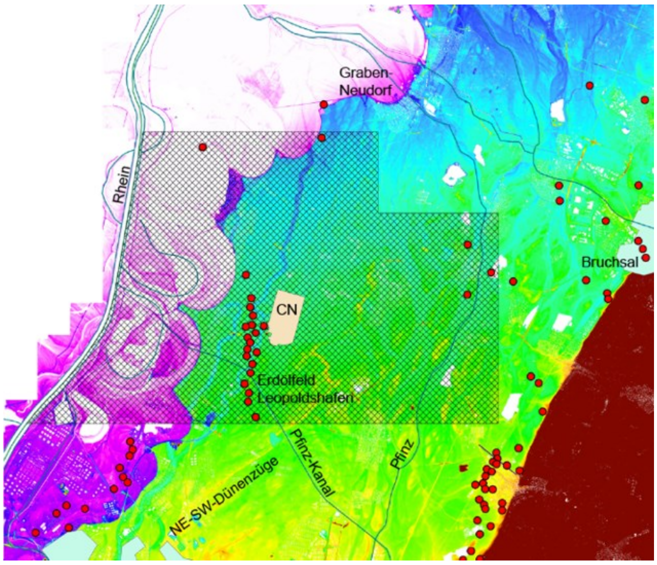

Figure 3: Digital terrain model of the KIT Campus-North area with the drill holes indicated by red dots. The elevation interval ranges between 100 m in the NW and 120 m above sea level in the S. The exploration area is hatched area. CN indicates the area of the campus.

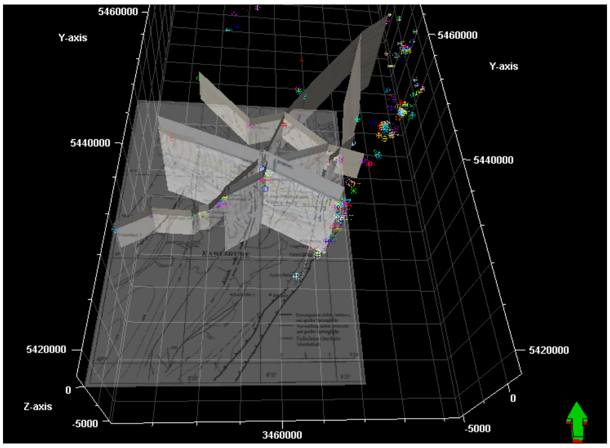

Figure 4: Data basis for 3D underground modelling. Profiles (Sauer, 1981, Schad, 1962, Schad, 1964, Wirth, 1962) were compiled and georeferenced and adopted. Colored dots mark drill start points of former exploration and production drilling on the earth's surface. The KIT Campus North is located at the intersection of three profiles. To the west of the north campus lies the Leopoldshafen oil field, which has been well developed by drilling.

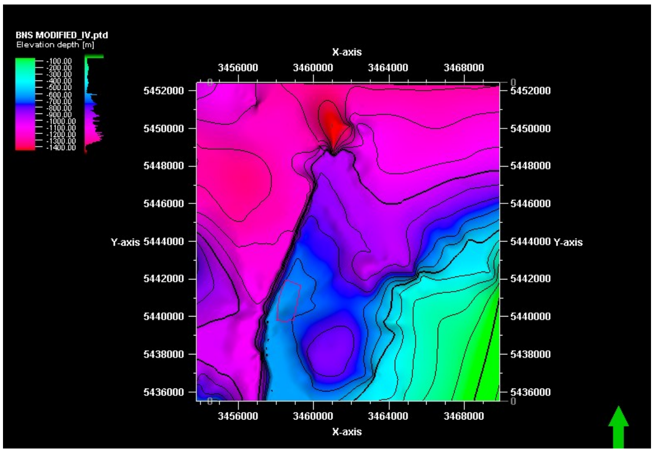

Figure 5: 3-D model of the Niederrödern Formation. The location of the KIT Campus North is marked by the red polygon. The surface of the Niederrödern Formation is about 700 m deep. The sandy layers of the Niederrödern Formation are located at the base of the formation at a depth of approx. 900 m. Immediately to the west, the prominent NNE-stroking Leopoldshafen fault is clearly indicated.

4. INTERACTION WITH PUBLIC

For the interaction with public DeepStor will implement an inter- and transdisciplinary co-design. This represents a paradigm shift in the definition of the development concept and the operation of geothermal power plants. This innovative approach makes it possible to integrate civil society already in the concept development phase. In this way, constructive impulses from society can be made fruitful at an early stage in order to identify the challenges of deep geothermal energy and thus also of the local "heat transition" and to develop solution options.

The "GECKO" project of the Karlsruhe Institute of Technology (KIT) consists of two sub-projects, one of which has a natural and engineering science focus and the other a social science approach. Both subprojects work together on an interdisciplinary basis. The transdisciplinary approach refers to the concept development of the use of deep geothermal energy on KIT Campus North with the local population. In the GECKO project, criteria and scenarios for the use of deep geothermal energy at the KIT Campus North are developed on the basis of laboratory tests, as well as geological and thermo-hydraulic-mechanically coupled numerical models based on scientific and technical knowledge in co-design. The results obtained in GECKO can, however, also extend beyond the use of deep geothermal energy for the KIT Campus North and include the surrounding communities. This citizen knowledge can be used to advance the regional heat transformation.

The development of the implementation concept in co-design is a first step on the way to improving the transparency demanded by society in the planning and implementation of long-term infrastructure projects for the heat transition an provides a new geo-ethical concept for geothermal energy development.

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