District Heating Conversion from a Fossil to an Integrated Geothermal Energy-Based System – the Göttingen University Campus (Germany) as a Demo Site

Bernd Leiss1, Bianca Wagner1, Christian Gemm1, Till Heinrichs1, David Tanner2, Axel Vollbrecht1, Klaus Wemmer1

1University of Göttingen, Goldschmidtstr. 3, 37077 Göttingen, Germany
2Leibniz Institute for Applied Geophysics, Stilleweg 2, 30655 Hannover, Germany
bleiss1@gwdg.de

Keywords: district heating, EGS, Variscan metasediments, energy conversion, integrated geothermal systems, seasonal thermal storage systems

ABSTRACT

At present, the university campus of Göttingen in Germany operates its own central power station to meet the power, heating, steam, and cooling demands. It is composed of a natural gas-fired turbine for a combined power and heat production, as well as oil-fired generators and boilers for backup and peak load. The conversion of such an existing conventional energy supply system into a renewable energy based system, especially with the focus on integrating different geothermal concepts, faces diverse hurdles in such a market demand-driven project. This is particularly true for Göttingen, which is not situated in one of the classical areas that are ideally suited for deep geothermal utilization. Therefore, a development of Enhanced Geothermal System (EGS), in a very general and broad sense, must be considered. The targeted horizons, at around 4.000 m depth, comprise folded and thrust metasediments (dominated by slates and greywackes), which are covered by a Permo-Triassic suite of around 1.500 m thickness and are overprinted by Cretaceous to Tertiary extensional tectonics. The development of exploration and exploitation strategies of the Variscan basement is currently supported by the EU-Horizon2020 project MEET (Multidisciplinary and multi-context demonstration of EGS exploration and exploitation Techniques and potentials), which focuses, with regards to the Göttingen demo site, on analogue studies in the Western Harz mountains to generate a conceptual 3D structure model. Lab experiments on the physical and chemical properties allow the parametrization of the model’s geological bodies and thus deliver a reservoir model. In addition, the overlying rock salt layers of the Zechstein, as well as the sandstone and carbonate lithologies possess the further potential to develop medium-deep geothermal systems for seasonal thermal energy storage. This technology requires a supplementary low-temperature district-heating system, which is already targeted, in combination with decentralized, smaller, combined power- and heat-plants as a part of the energy conversion strategy. The possibility of excess heat storage can extend the runtime of the power plants and therefore increase the efficiency of the whole system. Large-scale, shallow geothermal systems for cooling are already implemented in some buildings. Beside the focus on the geological potential, our contribution also aims to construct a strategy for the conversion of the district heating system, the adoption and integration of existing and new buildings, the integration of all partners on the campus, the economical aspects of the conversion and, of course, the political and social acceptance. In combination with the already completed seismic investigation and an aspired research well of ca. 2.000 m depth, the Göttingen demo site will significantly contribute to the learning curve of establishing integrative geothermal systems in existing energy supply systems, including EGS strategies.

1. INTRODUCTION

The city of Göttingen is situated in the centre of Germany and is renowned for its Georg August University, which was founded in the year 1734. Because the University was relocated several times, the buildings of the faculties are dispersed over the whole city. The city has 120.000 residents, including more than 30.000 students. In the 70ties, the University and the University Medical Centre amalgamated their infrastructure, and they established a Northern and a Central campus area, as well as building a new medical centre in between. Around 250, mostly new buildings are now connected by a roughly 13 km-long heating-pipe system that supplies hot water from a central, University-owned combined power and heat station. This station, with a total thermal capacity of around 192 MW, and a capacity for district heating of around 60 MW, also produces substantial quantities of cold water and steam, mainly for the medical centre (for quantities, see Figure 1). Originally, the heat and power production was based on heavy fuel oil, but this was replaced in the late 80ties by a gas-fired turbine, which allowed a modern energy-efficient and strongly emission-reduced heat-power-coupling system.

In the upcoming refurbishment of the energy-supplying infrastructure as well as in the context of the long-term reconstruction of the complete medical centre building, the University and the University Medical Centre aim to maximize the integration of renewable energies. Internal studies focusing on heat production have shown that the production of biogas could cover up to a maximum of 20% and wood firing ovens up to a maximum of 65% of the total demand, which, however, strongly depends on the fluctuating availability. Therefore, geothermal energy, including the option of seasonal heat storage, is seen as having the largest potential of the renewable energies, covering up to 70% of the recent heat demand and being independent of market conditions.

While the surface infrastructure is already in a well developed state to integrate deep geothermal energy, the geological setting in the area of Göttingen is on one hand extremely challenging, but on the other hand offers promising new approaches.

Geologically, Göttingen is situated at the southern rim of the Central European Basin System, where sedimentation started within the Permian (e.g. Doornbal and Stevenson 2010). Because it is the rim of the basin, Permian Rotliegend sequences were not or only locally deposited; though the rock salt, potash salt, anhydrite, dolomite and clay-dominated layers of the Permian Zechstein age reach a thickness up to several hundred metres. They were deposited on a low-grade metamorphic basement, consisting mainly of Devonian and Carboniferous metasedimentary and metavolcanic successions (greywackes, slates, quartzites, cherts, diabase) that have been folded and thrust during the Variscan Orogeny in the late Carboniferous. On top of the Zechstein sequences follows a sedimentary...
Leiss et al.

cover of 500 to 800 m thickness made up mainly of sandstones, clay rocks and limestones of Triassic age (Buntsandstein, Muschelkalk and Keuper). The whole sequence is tectonically overprinted by a north-south striking graben structure that developed during Mesozoic to Cenozoic times. The main fault system forming the graben structure consists of en echelon arranged sets of faults trending NNE-SSW and separated by cross faults. The main fault system shows a maximum slip of 800 m. Göttingen is situated on the eastern side of this around 5 to 8 km wide graben structure (Fig. 2). The boundary between the Variscan basement and the Zechstein layers is expected at about 1,500 m depth below Göttingen. Whether the faults continue into the Variscan basement or they are mechanically-decoupled by the Zechstein successions and possibly located elsewhere is not known. There are only a very few deep wells that reach the top of the Variscan basement in the wider surrounding area of Göttingen. No exploitable high-resolution seismic profiles existed at the start of our exploration campaign.

Based on the high heat and cooling demand of the existing and improvable consumption infrastructure as well as on the relative– in view of a geothermal reservoir - complex and very little explored geological setting, an exploration program was set up. The components of this strategy are introduced in the following to eventually conclude on a harmonized subsurface-related exploitation and a surface-related infrastructure development (conversion strategy).

One major component of the whole exploration and exploitation strategy is the exploration on two target horizons for which both of them an Enhanced Geothermal System (EGS) has to be developed:

1. a deep geothermal system in the Variscan basement at a depth between 3,000 to 5,000 m for the needs of supplying heat to the district heating system
2. a medium deep geothermal system in the Zechstein successions or the overlying sandstone layers at a depth between around 500 and 1,300 m to realize a seasonal heat storage system

Figure 1: Energy balance of the Göttingen University campus illustrating (1) quantities of heat, cold, steam and power as well as (2) the modularized system. Flow temperature of the district heating: 70 to 120°C depending on the outdoor temperature.

2. EXPLORATION STRATEGY

2.1 Seismic investigation

In 2015 a Vibroseismic campaign acquired two seismic sections (Fig. 2). A 10 km-long basement section was oriented NW-SE, i.e., it is normal to the strike of the Variscan fold and thrust structures. Measurements were conducted for an exploration depth down to 5,000 m. An 11.5 km-graben section was oriented E-W, i.e., normal to the graben structure. Measurements in this section were conducted for an exploration depth of around 2,500 m. The area around intersection point of the two sections covers the region of potential drilling sites and a possible geothermal power plant in the northern part of the city. The perpendicular orientation of the sections allowed the development a 3D geological-model, at least of the sedimentary cover.

In regard to the further geothermal exploration strategy, these are the main results of the seismic investigation:

- the top of the basement as well as the Zechstein layers can be well identified
- the main fault system can be well identified within the sedimentary cover
- within the graben structure, the sedimentary cover is strongly fragmented, which suggests high permeability
- not all seismic reflectors can be clearly allocated to lithological boundaries. Complex deformation features as well as hiatuses can be interpreted
- the Variscan basement appears relatively homogenous, so no limestone reef complexes or granitic bodies are expected.
faults in the Variscan basement can be interpreted, but further structural interpretation does not make sense at this stage without having more information from a research well.
- based on the results of the seismic data, it was decided that the next step would be a research well instead of a high resolution 3D-seismic
- the seismic campaign within the city of Göttingen was accompanied by public relations activities. The seismic campaign itself, but also the geothermal project itself was well accepted in the public.

Figure 2: Location of the seismic sections crossing the northern part of the city of Göttingen, Germany (mixed colours for the geological units are due to a semi-transparent geological map on top of a topographic map). The directions of the lines have been chosen normal to the Variscan strike as well as normal to the strike of the graben structure. The geothermal research well is planned to be located close to the intersection point.

2.2 Analogue studies and reservoir model

The MEET Project (Multidisciplinary and multi-context demonstration of EGS exploration and Exploitation Techniques and potential) aims to boost the utilization of deep geothermal energy across Europe in various geological settings (sedimentary, volcanic, metamorphic and crystalline settings) by using different approaches (Trullenque et al. 2018, Dalmais et al. 2019, Leiss & Wagner 2019, Dalmais et al. 2020). This project, funded under the EU Horizon 2020 grant program, started in May 2018 and will last until October 2021. One specific approach within the MEET-project is the assessment of different Variscan orogen-related geological settings, i.e. granitic terrains in general, as well as metasedimentary and metavolcanic rocks within the fold-and thrust-belt. Since such Variscan rocks cover large areas of Europe, this is an important component for quantifying the general geothermal potential (Wagner et al. 2020) and, in the case of successful explorations, to exploit these areas using EGS on a large scale. Four demo sites and associated near- and farfield analogue sites related to different geological settings were selected within the project MEET (Fig. 3 and 4) (Trullenque et al. 2018, Dalmais et al. 2019, Leiss & Wagner 2019, Dalmais et al. 2020). These are:

- (1) Variscan crystalline basement overprinted by post-Variscan extensional faults. Target horizon: fractured granites below a post-Paleozoic sedimentary cover: Demo site: the operating geothermal system in Soultz-sous-Forêts in France (e.g. Genter et al. 2010, Koelbel and Genter 2017, Ravier et al. 2019) Outcrop analogue sites: Alsace, Pfälzer Wald, Northern Vosges and Schwarzwald, Death Valley
- (2) Variscan basement not overprinted by late extensional faults. Target horizon: granites Demo site: United Downs Geothermal Power Project in Cornwall, UK, which is at present in the exploitation phase (two wells completed, www.uniteddownsgeothermal.co.uk) Outcrop analogues: Carnmenellis granite in Cornwall, UK
Leiss et al.

- (3) Variscan metasedimentary (and metavolcanic) successions not overprinted by younger extensional tectonics
  Demo site: existing bore hole Havelange, Belgium (Graulich et al. 1989). Target horizon: quartzite
  Outcrop analogues: Ardennes, Belgium

- (4) Variscan metasedimentary (and metavolcanic) successions overprinted by younger extensional tectonics (fault and graben systems)
  Demo site: operating energy supplying system (power station and district heating system) in Göttingen, Germany
  Outcrop analogues: Western Harz Mountains, Germany

Figure 3: The position of Göttingen within the assemblage of demo sites and associated outcrop analogues of the EU-project MEET. The assemblage represents four characteristic geological settings within the Variscides as well as different “Technology Readiness Levels” of the demo sites (compare with Fig. 4).

Figure 4: The Göttingen site within the constellation of demo-sites and far- and near-field outcrop analogues as one element of the EU-project MEET (compare with Fig. 3).
The general goal for all four sites is to develop or to refine reservoir models, also incorporating advanced thermal, hydrological, mechanical and chemical (THMC) simulations, which later on allow an assessment of the efficiency of stimulation operations and their sustainability at the different test sites. Based on these simulations as well as on experiences of in-situ operations at some of the different geological settings, strategies and operational recommendations (guidelines) for stimulation actions of Variscan reservoirs will be developed. Input for the models are data from field surveys including mapping and quantitative structural analyses at various scales in the outcrop analogue areas. For mapping and 3D-structural analyses also terrestrial and aerial photogrammetry (drones, aeroplanes) and laser scanning methods are applied. To parameterize the models, representative samples are collected for quantitative petrophysical characterisation and fluid-rock interaction experiments in the lab (Trullenque et al. 2018, Dalmais et al. 2019, Leiss & Wagner 2019, Dalmais et al. 2020).

For the demo site in Göttingen, the Western Harz Mountains were chosen as an analogue site. As Figure 5 shows, the closest outcrop areas along the Variscan strike are the Rhenish massif to the Southwest and the Harz Mountains to the Northeast of Göttingen. The figure shows that the Göttingen area correlates with the basis of the Gießen-Harz nappe. Due to the shallow dip of the nappe boundary to the Southeast, we can expect to hit the sequences underlying the nappe. Therefore, our investigations on the lithological and structural characterization of possible reservoir rocks focus on the units of the Western Harz Mountains. The main target horizons for developing geothermal systems are the Devonian and Carboniferous slates, slaty silt- and sandstones as well as Lower Carboniferous greywacke-successions because these units can show thicknesses of up to several hundred meters. This means that these units provide rock volumes relevant at reservoir scale. Since we expect that these rock units are the most probable deep reservoir rocks that we would encounter below Göttingen, they primarily get highest priority for our reservoir characterization. Figure 6 shows the locations where samples have been collected for laboratory analysis. Slates and slaty siltstones from surface outcrops are usually not suitable for lab experiments; due to weathering the cleavage planes are already opened. Therefore, we obtained access to the drill core samples of the Bundesbohrgramm (Brinckmann and Brüning 1986) of the “Federal Institute for Geosciences and Natural Resources” (BGR) at the archive in Grubenhagen, Germany to collect samples from a depth partly more than 1.000 m.

Figure 5: Location of Göttingen (Göttingen area in yellow) located along the Rhenohercynian strike between the outcrop areas of the Rhenish massif and the Harz Mountains part of the Gießen-Harz nappe complex (modified after Eckelmann et al. 2014).

In the Silbernaal-Valley to the West of Clausthal-Zellerfeld typical fold-and-thrust-structures at various scales are relatively well exposed. The structures are developed in Lower Carboniferous greywacke-dominated intercalations of greywacke and slates. Therefore, this area has been chosen to carry out detailed structural analyses and to develop a conceptual model in view of the fold-and-thrust features as well as in view of the fracture systems. First approaches for such analyses, as well as first results, are presented in Ford et al. (2020).
2.3. Research well

The next step in the exploration procedure is to realize a research well. A drilling concept as well as a well site have already been defined. While the subsequent exploration/exploitation well is planned to reach 4000 m depth, this first research well is intended to reach 2000 m. This depth guarantees not only to reach the Variscan basement, but it is with its lowermost around 500 m far enough in the basement to perform stimulation experiments.

The main goals of the research well are:

- getting a lithological profile to correlate lithological boundaries with the seismic reflectors; this will enable a reprocessing of the seismic data
- reducing drilling risks during the subsequent deep exploration well by a well-known lithology, especially in the sedimentary cover with the salt layers,
- getting data on the stratigraphic levels, metamorphic grade and structural units of the Variscan basement will be reached below Göttingen. Only these informations allow the realization of an exploitation well in a cost-effective way and with reduced risks.
- reaching two geothermal target horizons (Zechstein layers and Variscan basement) to perform stimulation experiments at a low risk level in regard to establish different EGSs
- allowing a much better vertical seismic profiling at the exploitation well and to monitor stimulation experiments
- gaining experience on the acceptance of EGS in the public
- having the option to subsequently use the research well for a medium deep geothermal system also in the case the deep geothermal system cannot be realized

3. INFRASTRUCTURE CONVERSION STRATEGY

For the development of the Göttingen campus, several measures help to keep the surface development as far as possible independent from the geothermal production risk:

- the supplementary installation of several decentralized heat and power stations allows a smart harmonization with the effective supply of the geothermal sources, covers peak loads and allow, at best, the replacement of the central power station

Figure 6: Geological map of the Western Harz Mountains as the outcrop analogue area for the demo site at Göttingen. Sampling locations are indicated including the drill sites of the sampled drill cores.
- the new construction of the medical center is planned over a time of the next 15 years. A modularized planning of the different building complexes allow in respect to the time schedule a flexible integration of seasonal heat storage systems related to the medium deep system as well as the deep geothermal system

- the preventive installation of a low temperature pipeline system in addition to the new high temperature district heating parts to keep the option for a subsequent integration of the seasonal underground heat storage systems

4. CONCLUSIONS AND OUTLOOK

The Göttingen geothermal project aims to explore two target horizons: the Variscan basement for a deep EGS and the Zechstein salt layers for medium deep seasonal heat storage EGSs. During the long lasting exploration period, the surface structure is - also on a long-term basis - optimized (converted) for a harmonized integration of both systems. This multifaceted and therefore complex approach is a specific attribute of the Göttingen geothermal project, for which it is currently a demo site within the EU-project MEET as well as in the new EU-COST-Action "Integration of geothermal technologies into heating and cooling grids across Europe (Geothermal-DHC)". Even if there is a promising general setting to realize such ambitious targets at the Göttingen site, the key passage is the weakly known geological framework for which, next to all the above introduced research activities, a research well is indispensable as the next step. If a geothermal system can be developed for the Göttingen site, an enormous geothermal potential can be exploited within Europe following the Göttingen strategy.

ACKNOWLEDGEMENTS

The development of the geothermal project of Göttingen has gained from support, discussions and feedback from many colleagues in science, engineering and administration within different disciplines, which is greatly acknowledged. We deeply appreciate to be a part of the MEET-consortium. This project has received cofunding from the European Union’s Horizon 2020 research and innovation programme und grant agreement No 792037 (MEET-project).

REFERENCES

Brinckmann, J., Brüning, U. (Eds.): Das Bundesbohrprogramm im West-Harz, paläogeographische Ergebnisse (The federal drilling program in the Western Harz Mountains: paleogeographic results and five additional contributions to the geology of the Western Harz Mountains), Geologisches Jahrbuch Reihe D, Band D, (1986).


Leiss et al.

