Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Integrating deep, medium and shallow geothermal energy into district heating and cooling system as an energy transition approach for the Göttingen University Campus

Bernd Leiss[1, 2], Bianca Wagner[1, 2], Till Heinrichs[1], Dmitry Romanov[1, 2], David Tanner[3], Axel Vollbrecht[1], Klaus Wemmer[1]

[1]University of Göttingen, Goldschmidtstr. 3, 37077 Göttingen, Germany

[2]Universitätsenergie Göttingen GmbH, Hospitalstr. 3, 37073 Göttingen, Germany

[3]Leibniz Institute for Applied Geophysics, Stilleweg 2, 30655 Hannover, Germany

bleiss1@gwdg.de

Keywords: district heating and cooling, EGS, Variscan metasediments, energy transition, multi-faceted geothermal system, underground thermal energy storage

ABSTRACT

A subsurface exploration strategy of geothermal energy utilization for district heating and cooling system for the Göttingen campus in Germany – a demo site of the EU-Horizon 2020 project MEET – is presented. Preliminary geological investigations, including seismic profiles, are conducted, and the results demonstrate that the Göttingen geothermal project might be able to utilize two target horizons: the Variscan basement for a deep Enhanced Geothermal System (EGS) and the Zechstein salt layers for a medium deep underground thermal energy storage (UTES). Additionally, water-saturated sediments can be considered as a shallow geothermal system. In result, a possible concept of future district heating and cooling system for the Göttingen University campus based on multi-faceted geothermal system is suggested, and the key modules to accomplish it are identified. The current level of knowledge about the geological setting in Göttingen is still insufficient to suggest an economic exploitation strategy including reservoir stimulation actions. Therefore, the next step is to get financing for drilling a research well and to conduct subsequent investigations and experiments. If the considered geothermal system can be developed for the Göttingen demo site, an enormous geothermal potential can be exploited within Europe following the Göttingen example.

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 large parts of the city. Göttingen has 120000 residents, including more than 30000 students. In the 1970s, the University and the University Medical Centre merged their infrastructure and established a Northern and a Central campus area, as well as a new medical centre in between. Around 250 buildings are now connected by a roughly 13 km-long district heating network that is connected to a central, University-owned combined heat and power (CHP) plant. Originally, the heat and power production was based on heavy fuel oil, but it was replaced in the late 1990s by a gas-fired turbine, which allowed for a modern energy-efficient and strongly emission-reduced heat and power coupled system.

As a part of the upcoming refurbishment of the energy supply infrastructure as well as in the context of the long-term reconstruction of the medical centre's buildings, 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 maximum up to 20% and wood firing boilers – up to 65% of the total heat 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 in the best case scenario and being independent of market conditions.

While the surface infrastructure is already capable of integrating deep geothermal energy, the relatively complex and poorly known geological setting in the area of Göttingen is, on the one hand, quite challenging, but on the other hand, it offers an opportunity to explore 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 either locally deposited or not deposited all; 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 thrusted during the Variscan Orogeny in the late Carboniferous. On top of the Zechstein sequences follows a sedimentary 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 graben structure, which is around 5 to 8 km wide (Fig. 1). The boundary between the Variscan basement and the Zechstein layers is expected at about 1500 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 future consumers on the campus area as well as on the relatively complex – in view of a geothermal reservoir – and very little explored geological setting, an exploration program was set up. The components of this strategy are introduced in the following sections to eventually conclude on a harmonized subsurface-related exploitation and a surface-related infrastructure development also considering public funding policies and economic conditions.

The major component of the whole exploration and exploitation strategy is the development of Enhanced Geothermal Systems (EGS) for two target horizons:

(1) a deep geothermal system in the Variscan basement at a depth between 3000 to 5000 m for the needs of supplying heat to the district heating and cooling system

(2) a medium deep geothermal system in the Zechstein successions or the overlying sandstone layers at a depth between around 500 and 1300 m to realize a seasonal thermal energy storage (TES).

Additionally, a shallow geothermal system mainly for cooling purposes in the partly water-saturated quartenary alluvial sediments and karstified Mesozoic carbonates can be considered.

2. EXPLORATION STRATEGY

2.1 Seismic investigation

In 2015, a vibroseismic campaign acquired two seismic sections (Fig. 1). 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 5000 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 2500 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 spatial orientation of the sections allows for the development of a 3D geological-model, at least for 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. Not only was the seismic campaign itself well accepted, but also the geothermal project as a whole.

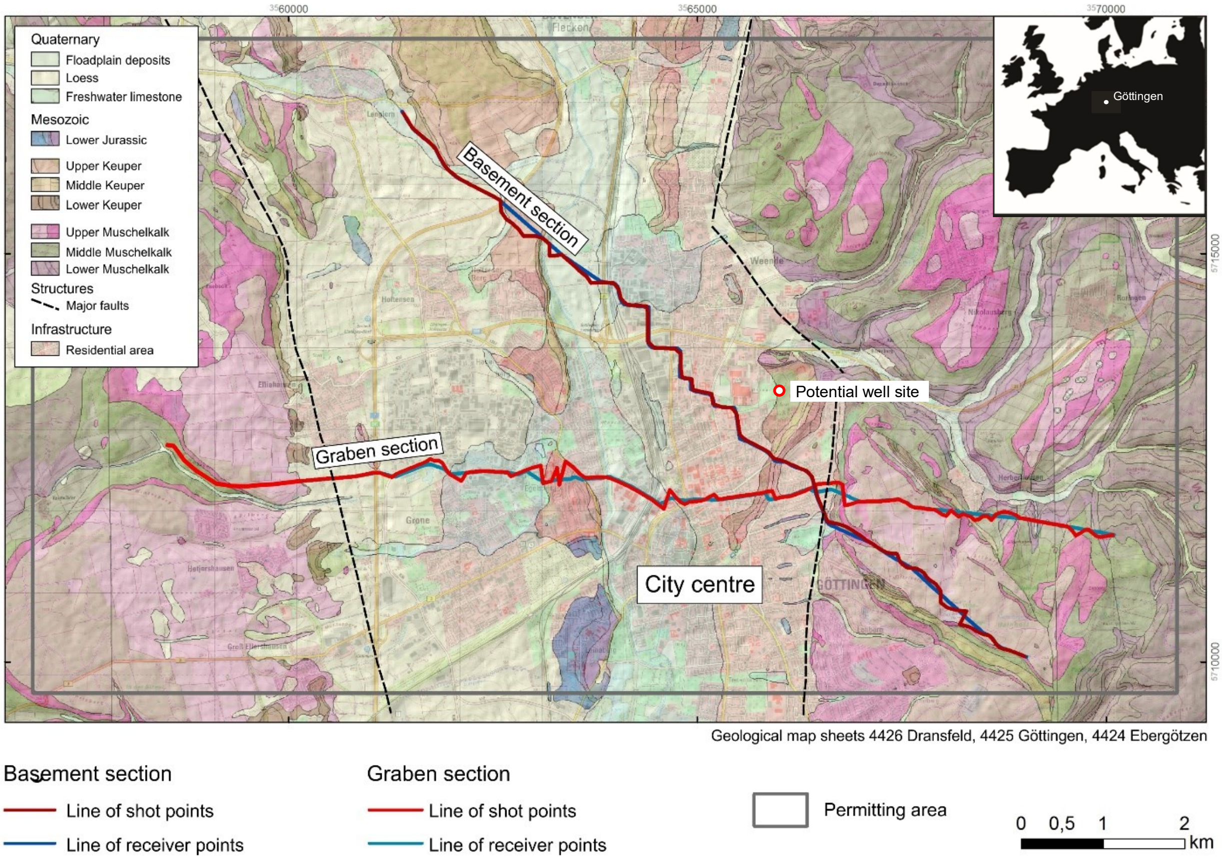

Figure 1: Location of the seismic sections crossing the northern part of the city of Göttingen, Germany (mixed colours for the geological units are due to a semi-transparent geological map on top of a topographic map).

Note: 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 in the area of 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 lasting 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 far-field analogue sites related to different geological settings were selected within the project MEET (Fig. 2 and 3) (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

- (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 supply system (CHP plant and district heating system) in Göttingen, Germany
  Outcrop analogues: Western Harz Mountains, Germany

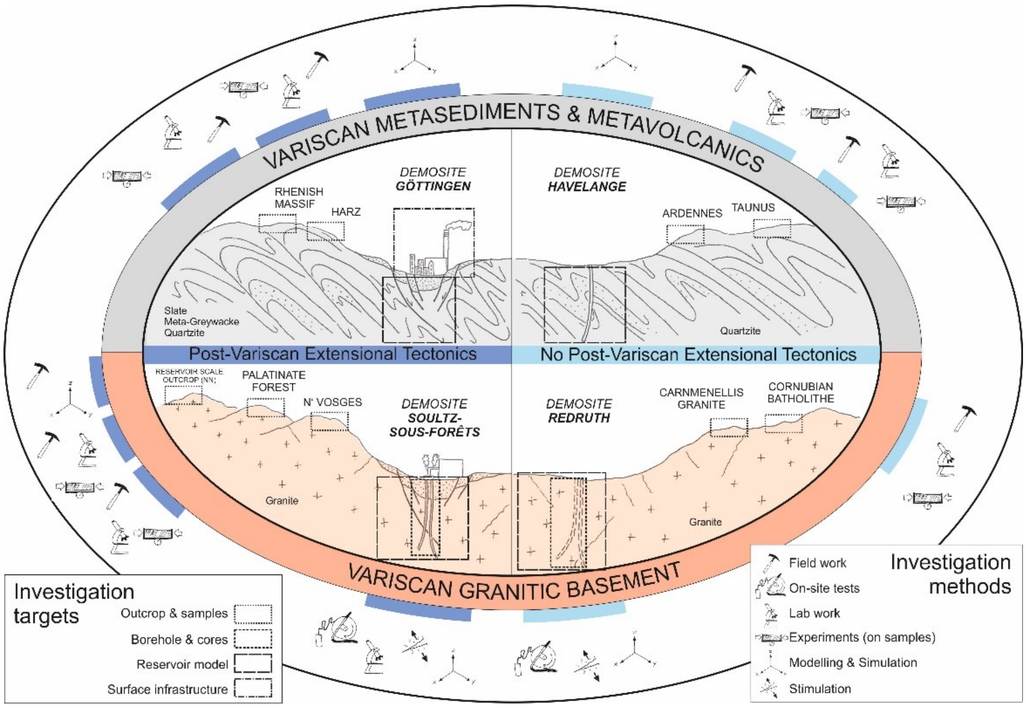

Figure 2: The position of Göttingen within the assemblage of demo sites and associated outcrop analogues of the EU-project MEET. The assemblage represents four characteristic geological settings within the Variscides as well as different "Technology Readiness Levels" of the demo sites (compare with Fig. 3).

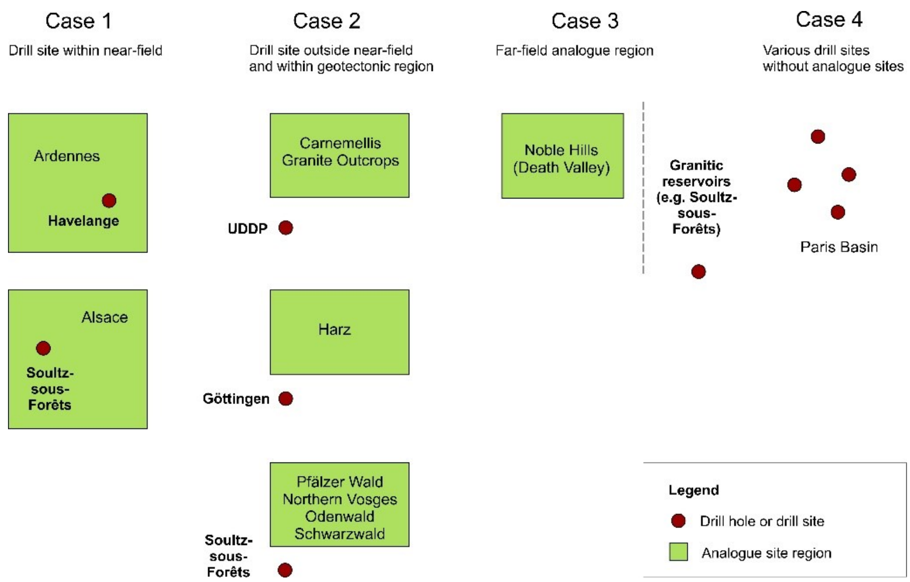

Figure 3: The Göttingen site within the constellation of demo-sites and far- and near-field outcrop analogues as one element of the EU-project MEET (compare with Fig. 2).

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 will allow for 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 4 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 can encounter below Göttingen, they primarily get highest priority for our reservoir characterization. Figure 5 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 1000 m.

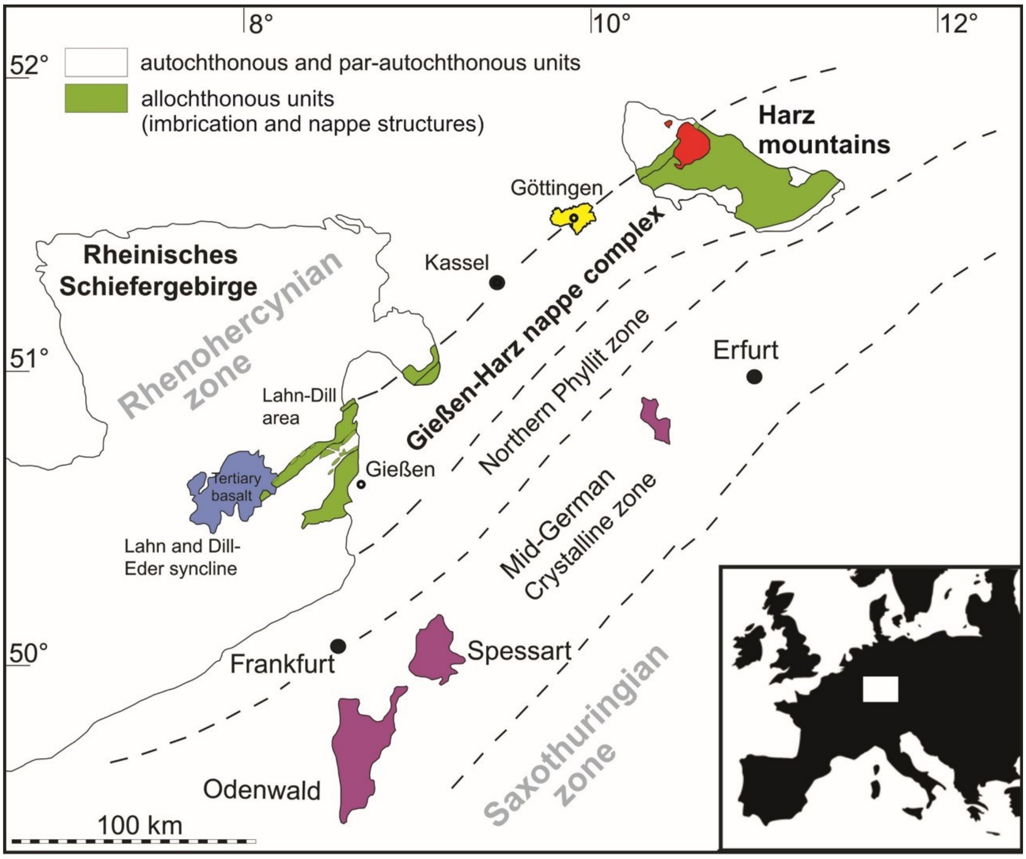

Figure 4: Location of Göttingen (Göttingen area in yellow) located along the Rhenohercynian strike between the outcrop areas of the Rhenish massif and the Harz Mountains part of the Gießen-Harz nappe complex (modified after Eckelmann et al. 2014).

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).

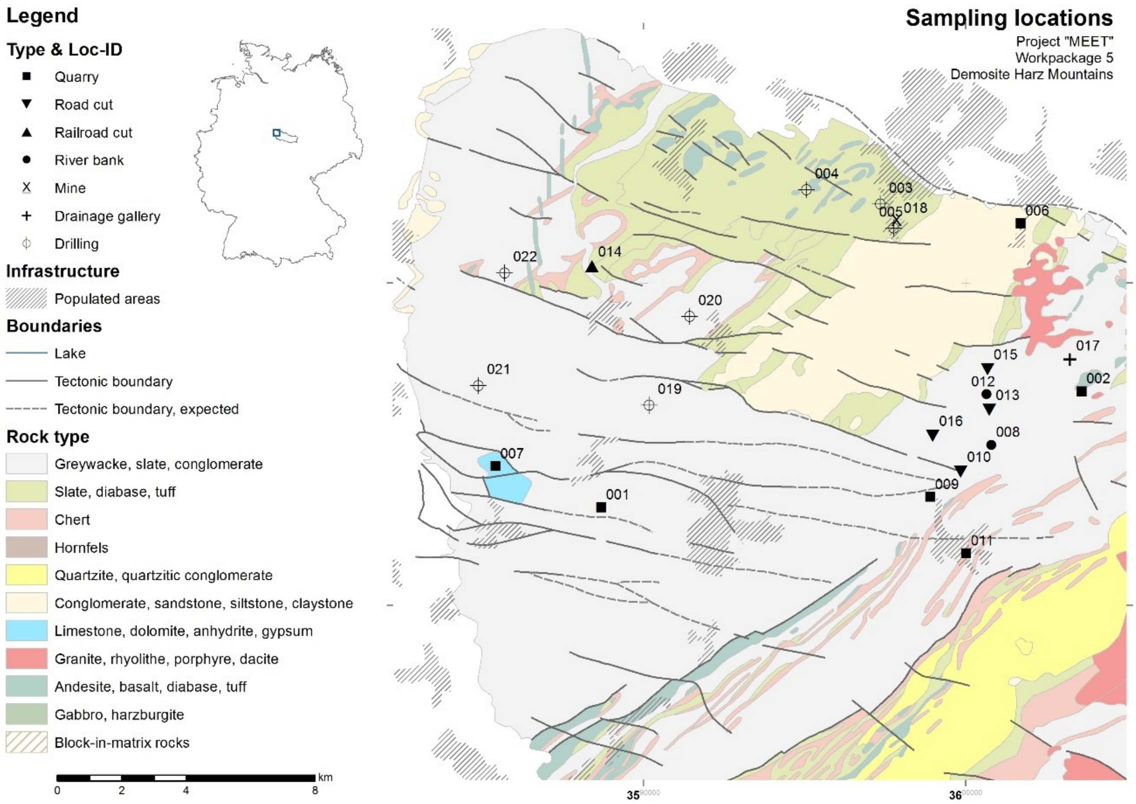

Figure 5: Geological map of the Western Harz Mountains as the outcrop analogue area for the demo site at Göttingen. Sampling locations are indicated including the drill sites of the sampled drill cores.

2.3. Research well

The next step in the exploration procedure is to realize a research well. A drilling concept and a well site have already been suggested. The research well is planned to reach up to 5000 m depth. 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 for the subsequent exploitation wells;
- getting data on the stratigraphic levels, metamorphic grade and structural units of the Variscan basement that will be reached below Göttingen. Only this information allows for 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 establishing different EGSs;
- providing a much better vertical seismic profiling at the exploitation well and to monitor stimulation experiments;
- proving and showcasing safety and sustainability of EGS to induce public acceptance;
- 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. ENERGY TRANSITION STRATEGY

Fig. 6 sketches the existing district heating and cooling system of the campus in 2020. The system consists of different fossil fuel-based supply facilities, high temperature district heating (HTDH) network and energy intensive buildings of the campus. The combined heat and power (CHP) plant includes a gas turbine, which is expected to be put out of operation in the nearest future, and several steam and hot water boilers consuming in total about 350 GWh/a of natural gas (Energiebericht 2018, Leiss et al., 2020). Small-scale decentralized CHP plants serve as peak load and backup options. The base cooling load for the medical centre is covered by absorption chillers, and the peak load – by vapor compression (electric) chillers.

For a geothermal–based energy transition strategy, the crucial next step is to get a research well financed. Since in Germany, the public-funding strategy focuses on the support of system changes rather than of single components (e.g. Wärmenetze 4.0), the authors suggest a vision on how the system could look like by the expected end of the partial campus renovation in about 15 to 20 years (Fig. 7). It includes deep geothermal system embedded in a multi-faceted geothermal system for the energy transition of the campus. According to the preliminary plans, new energy efficient buildings, a new low temperature district heating network (LTDH) and a replacement of the steam absorption chillers by hot water absorption chillers are expected at the campus. For a holistic approach, those parts could be coupled with additional components (or modules):

- deep geothermal energy taking over the base heat load of the campus;
- biomass boilers replacing small-scale fossil fuel-based CHP plants;
- green electricity from power generating companies;
- utilization of waste heat of the campus with the help of seasonal TES in the medium geothermal horizon and heat pumps;
- utilization of shallow geothermal energy for direct cooling and supplying LTDH via heat pumps.

Following these suggestions, it might be possible for the University campus to achieve green and sustainable energy supply in the next 15-20 years. Taking into account such prolonged period of the renovation and transition, a modularized approach can be applied. This means that different parts (modules) of the transition concept in Fig. 7 can be implemented step by step following the progress of the buildings' renovation. The benefits of such approach are schedule time flexibility, reduction of the risks associated with EGS development and allocation of capital expenditures per many years instead of immediate high investments.

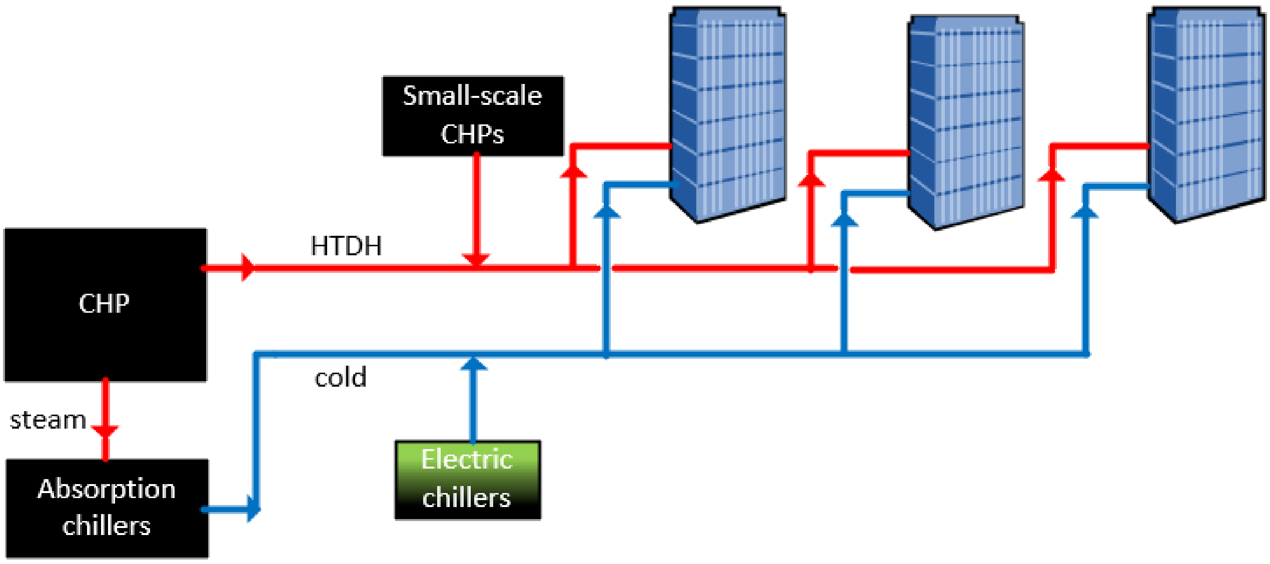

Figure 6: Existing district heating and cooling system of the campus in 2020.

Note: HTDH – high temperature district heating; CHP – combined heat and power plant; return lines are not shown.

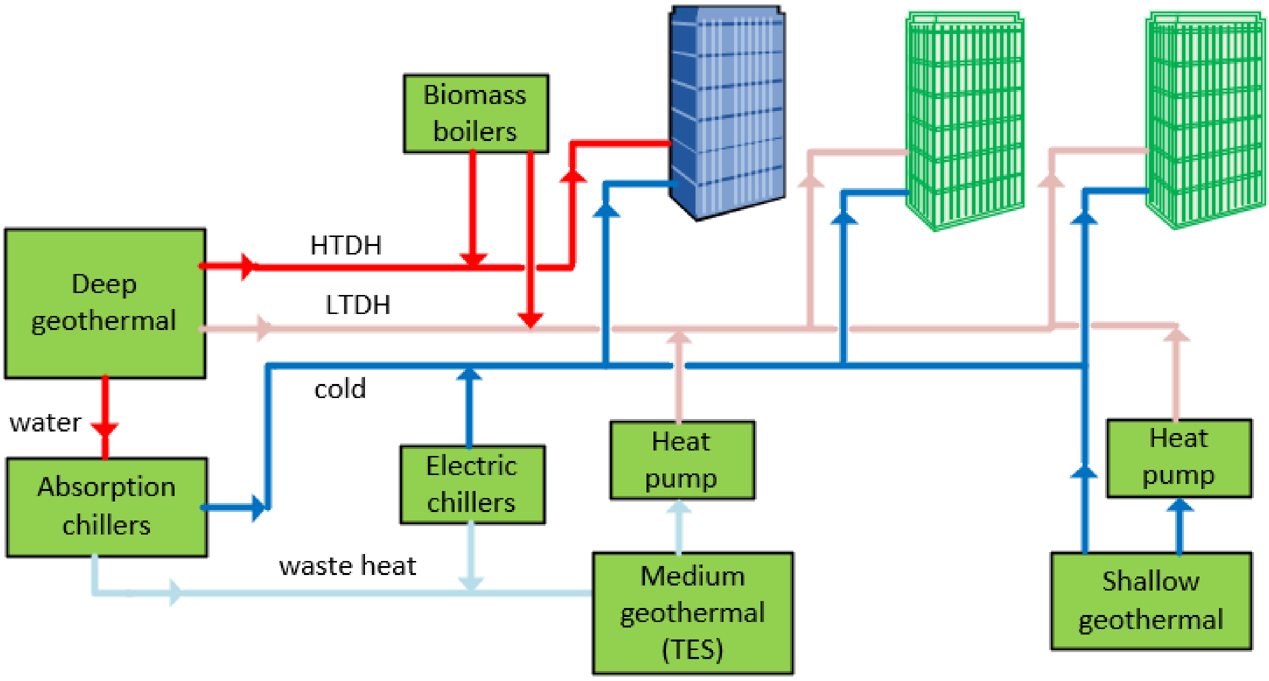

Figure 7: Suggested district heating and cooling system of the campus for the future.

Note: HTDH – high temperature district heating; LTDH – low temperature district heating; TES – thermal energy storage; return lines are not shown.

4. CONCLUSIONS AND OUTLOOK

At present, the Göttingen University campus in Germany operates its own fossil fuel-based CHP plant to meet the power, heating, steam, and cooling demands. The transition of the existing conventional energy supply system to a renewable energy-based one, especially with the focus on integrating different geothermal concepts, faces diverse hurdles. This is particularly true for Göttingen, which is not situated in one of the classical geological settings that are well suited for deep geothermal utilization.

The target horizons, at around 3000 to 5000 m depth, comprise folded and thrusted metasediments (dominated by slates and greywackes), which are covered by a Permo-Triassic suite of around 1500 m thickness and are overprinted by Cretaceous to Tertiary extensional tectonics. Analogue studies in the Western Harz mountains are being conducted to generate a conceptual 3D structure model. Moreover, lab experiments on the physical and chemical properties are supposed to provide the parametrization of the model's geological bodies, and thus to facilitate a reservoir model's development. These are the main parts of the EGS exploration strategy at Göttingen demo site.

Preliminary geological investigations, including the seismic ones, have shown that there are two target horizons: the Variscan basement for a deep EGS and the Zechstein salt (and possibly Buntsandstein layers) for a medium deep seasonal TES. Additionally, surface near water saturated sediments offers an additional option for the integration of shallow geothermal systems. In result, the concept of future district heating and cooling system for the Göttingen University campus based on multi-faceted geothermal system is suggested, and the key modules to accomplish it are identified. Even though some of the modules are already in progress, a lot of coordination work is to be done by all stakeholders of the project; and the most relevant one is to get financing for the research well drilling and to conduct subsequent investigations.

Beside focusing on the geological potential, future works on the geothermal project for Göttingen should aim at economic, ecological, political and social aspects of the transition of the existing district heating and cooling system to the renewable-based one. The questions of the schedule for implementation of different modules and integrating them with the existing and to-be-built buildings, effective cooperation between all partners on the campus and risk mitigation strategy should be also considered.

In combination with the already completed seismic investigation and an aspired research well of up to 5000 m depth, the Göttingen demo site will significantly contribute to the learning curve of establishing complex geothermal systems for sustainable district heating and cooling systems. If the considered geothermal system can be developed for the Göttingen demo site, an enormous geothermal potential can be exploited within Europe following the Göttingen example.

ACKNOWLEDGEMENTS

The development of this geothermal concept for Göttingen has gained support from many colleagues in science, engineering and administration within different disciplines, whose feedback and comments are greatly acknowledged. This project has received funding from the European Union's Horizon 2020 research and innovation programme and 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).

Dalmais, E., Genter, A., Trullenque, G., Leoutre E., Leiss, B., Wagner, B., Mintsa, A. C., Bär, K., and Rajsl, I.: MEET Project: Toward the spreading of EGS across Europe, *Proceedings*, European Geothermal Congress, Den Haag (2019).

Dalmais, E., Genter, A., Trullenque, G., Leoutre E., Leiss, B., Wagner, B., Mintsa, A. C., Rajsl, I. and Marot, M.: Meet Project: Toward large scale deployment of deep geothermal energy in Europe, *Proceedings*, World Geothermal Congress 2020, Reykjavik, Iceland, (2020), this volume.

Doornbal, H. & Stevenson, A. (Eds): Petroleum geological atlas of the Southern Permian Basin area. EAGE Publications, Houten (2010).

Eckelmann, K, Nesbor, H.-D., Königshof, P., Linnemann, U., Hofmann, M., Lange, J.-M. & Sagawe, A.: Plate interactions of Laurussia and Gondwana during the formation of Pangaea – Constraints from U–Pb LA–SF–ICP–MS detrital zircon ages of Devonian and Early Carboniferous siliciclastics of the Rhenohercynian zone, Central European Variscides. *Gondwana Research* **25**, (2014), 1484-150.

Energiebericht 2018 [2019]. Georg-August-Universität Stiftung Öffentlichen Rechts (ed.). Annual report. https://www.umg.eu/fileadmin/Redaktion/Dachportal/006_Ueber_uns/id143_Vorstand/id798_Geschaeftsbereiche/id801_G3-3_Gebaeudemanagement/Energiebericht_2018.pdf. (Accessed: 25 June 2020).

Ford, K., Wagner, B., Leiss, B., Zeuner, M., Floch, J., De Céris, L., Sosa, G.: Applying Variscan Metasediments as an EGS Reservoir - A Conceptual 3D-Structural Model as a First Approach, *Proceedings*, World Geothermal Congress 2020, Reykjavik, Iceland, (2020), this volume.

Genter, A., Evans, K., Cuenot, N., Fritsch, D., and Sanjuan, B.: Contribution of the exploration of deep crystalline fractured reservoir of Soultz to the knowledge of Enhanced Geothermal Systems (EGS). *Comptes Rendus Geosciences* **342**, (2010) 502-516.

Graulich, J.-M., Leclercq, V., and Hance, L.: Le sondage d'Havelange - Principales données et aspects techniques. *Memoirs of the Geological Survey of Belgium* (1989) 72 p.

Koelbel, T., and Genter, A.: Enhanced Geothermal Systems: The Soultz-sous-Forêts Project. In: Uyar, T. S. (Ed.): *Towards 100% Renewable Energy*, Springer International Publishing (2017) 243-248.

Leiss, B., Friedel, C.-H., Heinrichs, T., Tanner, D.C., Vollbrecht, A., Wagner, B., and Wemmer, K.: Das Rhenohercynikum als geothermischer Erkundungshorizont im Raum Göttingen.- In: Friedel, C.-H. & Leiss, B. (Ed.): Harzgeologie 2016. 5. Workshop Harzgeologie – Kurzfassungen und Exkursionsführer, *Göttingen Contributions to Geosciences* **78**, (2016) 31.

Leiss, B., Romanov, D., and Wagner B.: Risks and Challenges of the Transition to an Integrated Geothermal Concept for the Göttingen University Campus, *Proceedings*, 1st Geoscience & Engineering in Energy Transition Conference 2020, (2020), 1-5.

Leiss, B., Vollbrecht, A., Tanner, D., and Wemmer, K.: Tiefengeothermisches Potential in der Region Göttingen – geologische Rahmenbedingungen.- In: Leiss, B., Vollbrecht, A., Tanner, D., Arp, G.: Neue Untersuchungen zur Geologie der Leinetalgrabenstruktur - Bausteine zur Erkundung des geothermischen Nutzungspotentials in der Region Göttingen, *Universitätsdrucke Göttingen*, (2011) 163 – 170.

Leiss, B., and Wagner, B.: EU-Projekt MEET: neue Ansätze "Enhanced Geothermal Systems (EGS)" – Göttinger Unicampus als Demoprojekt.- *Geothermische Energie* **91**, (2019), 26-28.

Ravier, G., Seibel, O., Pratiwi, A.S., Mouchot, J., Genter, A., Ragnarsdóttir, K. R., Sengelen, X.: Towards an optimized operation of the EGS Soultz-sous-Forêts power plant (Upper Rhine Graben, France), *Proceedings*, European Geothermal Congress, Den Haag (2019).

Trullenque, G., Genter, A., Leiss, B., Wagner, B., Bouchet, R., Léoutre, E., Malnar, B., Bär, K., and Rajšl, I.: Upscaling of EGS in different geological conditions: a European perspective, *Proceedings*, 43rd Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, CA (2018).

Wagner, B., Günther, S., Ford, K. Sosa, G., and Leiss, B.: The "Hexagon concept": A fundamental approach for the Geoscientific Spatial Data Compilation and Analysis at European Scale to Define the Geothermal Potential of Variscan and Pre-Variscan low- to high-grade Metamorphic and Intrusive Rocks, *Proceedings*, World Geothermal Congress 2020, Reykjavik, Iceland, (2020), this volume.

Wärmenetze 4.0: Bundesförderung für effiziente Wärmenetze, Bundesamt für Wirtschaft und Ausfuhrkontrolle, https://www.bafa.de/DE/Energie/Energieeffizienz/Waermenetze/waermenetze_node.html (Accessed: 30 September 2020).