PUSH-IT

Piloting Underground Seasonal Heat Storage In geothermal reservoirs

D1.2 Commissioning report of installations Litoměřice
report of works, functioning of system, learnings from, integration, push-pull test

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ABI	Acoustic Borehole Televiewer
BTES	Borehole Thermal Energy Storage
CGS	Czech Geological Survey
CZ	Crack zone
DAS	Distributed Acoustic Sensing
DHN	District Heating Network
DTS	Distributed Temperature Sensing
DZ	Damaged zone
EGS	Enhanced Geothermal System
GRT	Geothermal Response Test
LCOE	Levelized Cost of Energy
OBI	Optical Borehole Televiewer
PQ	PQ drill string
PV	Photovoltaic
PVC	Polyvinyl Chloride
RINGEN	Research Infrastructure for Geothermal Energy
SYNERGYS	Systems for Energetic Synergy
TOC	Total Organic Carbon
UTES	Underground Thermal Energy Storage
UKR	Charles University (Univerzita Karlova)

1. Introduction

PUSH-IT aims to showcase full-scale application of high temperature heat storage (up to 90°C) in geothermal reservoirs using three different technologies, aquifers, boreholes and mines, at six different sites. The three technologies addressed in PUSH-IT are relevant for different subsurface conditions, reflecting the variety of subsurface environments found in European sub-surface. Key aspect of this project je presence of three demonstration a three follower sites, one for each type of heat storing technology. In PUSH-IT we are developing, deploying and testing our technologies for various configurations of heat sources, heat storage technologies, geological conditions, distribution systems, stakeholder populations and market and legal conditions. Hence, PUSH-IT provides a unique scope on demonstration, integration and advances for seasonal heat storage. These results will enhance the utilisation of sustainable energy and create a balanced system for sharing benefits and burdens tied to sustainable heat generation, storage and distribution activities.

PUSH-IT will reduce environmental impact, levelized cost of energy and risks and improve performance and robustness via development and demonstration of several enabling technologies, i.e., newly developed monitoring and water quality control and novel drilling and completion and novel control systems. Societal engagement is a key element and achieved via citizen engagement, analysing motivations and perceptions of heat storage, and investigating governance policies and business models that engage citizens in decision making regarding urban heating systems including storage. The PUSH-IT consortium combines heat suppliers, well drillers, public planning offices and academic partners. Through our transdisciplinary collaboration we will realise operational projects and use these to generate generic solutions and practices relevant across Europe. All activities will be monitored and reported, yielding a valuable comprehensive dataset on the technical and social real-world performance.

1.1. Goal of this Report

The goal of this report is to report the installation of boreholes and other facilities. Major drilling works and related activities were planned for late 2023, however drilling works were delayed due to the legal need to repeat the tender process and took longer than planned due to technical issues explained later in this document. In Q2/2025, all the drilling works are finished, and no further drilling investments are planned within the PUSH-IT project on the Litoměřice site. This report summarizes the results of the implementation of the boreholes, experience from the drilling process and partially also the data interpretation.

2. Site Description

The Litoměřice test site is a large research infrastructure of choice in the Czech Republic (RINGEN – Research Infrastructure for Geothermal Energy), focused on geothermal heat extraction and underground thermal energy storage. The Czech Geological Survey (CGS) and Charles University (UKR) is currently using RINGEN for the already approved SYNERGYS (Systems for Energetic Synergy) project focused on UTES (Underground Thermal Energy Storage) and EGS (Enhanced Geothermal System) development in 2023-2027.

The site itself is a geothermal area with deep and shallow drilling licences and permits already in place. The site can be connected to the nearby District Heating Network (DHN) that supplies about 70% of heat consumption of the town of Litoměřice, making a compelling case for positive distribution of benefits from the project. RINGEN has a long-term partnership with the local community, and the town management has strongly supported geothermal research activities since the early years of 21ST century. The site offers an interesting and unique opportunity to develop a series of thermal energy sources such as co-generation units, Photovoltaic (PV) panels and a hydrogen electrolyser, all concentrated in one place and connected in a single energy system. It allows testing of various Borehole Thermal Energy Storage (BTES) technologies (within three different depth BTES fields) under various operating conditions (different temperature input for each field) with a possibility of DHN connection. For the grid connection, a smart network controller will be designed within the SYNERGYS project.

For the purpose of exploration and gaining knowledge, two pilot wells were drilled within the PUSH-IT project. The obtained petrophysical and hydrogeological properties will be incorporated in numerical models, co-simulation of surface energy flows and the underground response following the findings of the Darmstadt BTES demo site in cooperation with the other consortium members. This information is crucial since there is an expectation of a major water reservoir in Cenomanian sandstones at ~140–180 m depth, which is very likely to have an impact on heat transfer in the environment in two deeper BTES fields (~200 and ~500 m depths). Another important interval is expected to be around ~460–500 m depth, which is likely to be a thermal insulation layer (rich in organic material) that could influence the deepest planned BTES field. Both these critical zones as well as knowledge of the rock physical properties in full depth profile are the main target for the pilot boreholes. Exploratory boreholes are equipped with double-ended fibre-optic cable to measure temperature (Distributed Temperature Sensing: DTS) and seismicity (Distributed Acoustic Sensing: DAS), which can be used to monitor potential water flow in the aquifer.

2.1. Location

The locality is a brownfield area in the former army barracks located on the eastern tip of Litoměřice city. District heating factory is placed ~500 m NW from the barracks, which makes it favourable for the future connection of the geothermal fields with the heating system. Figure 1 shows the position of drilled wells, which should surround the future BTES fields.

Figure 1: Wells drilled in the PUSH-IT project (1 to 3, red), old exploration borehole PVGT-LT1 (yellow), planned BTES fields in the SYNERGYS project (black) and potential connection to DHN (blue).

2.2. Objectives

Within the "Task 1.5 Litoměřice" of the PUSH-IT project, two pilot wells were planned to be drilled to investigate important geological and petrophysical information before drilling the system BTES wells within the parallel SYNERGYS project. In optimal case, one exploratory and one hydrogeological monitoring borehole were planned to be drilled with following parameters, as described in the Litoměřice Workplan (Peřestý et al., 2023, D1.1).

Well #1 – 550 m deep, fully cored, equipped with temperature and seismic monitoring, fully cemented after monitoring installation. The aim of this well is to gain basic information about the rock environment for future drilling works and to drill through the thermal insulant layer. The well is localised close to the future BTES fields and will be equipped by DTS and DAS fibre optics for long-term monitoring.

Well #2 – 200 m deep, several metres away from well #1, completed with screening at c. 170-200 m, for sampling, evaluation and continuous hydrogeological monitoring of the Cenomanian aquifer. Important goal of this well is to test the sufficiency of a cheap drilling technology (air-hammer drilling) and the possibility to keep the verticality of the future wells on site.

The PUSH-IT project should result in extended knowledge required to successfully realise three BTES fields of different depths and to learn good practice not only in implementation, but also in public engagement and dissemination activities.

2.3. Stakeholders

There are two main stakeholders in the area directly affected by the project activities as the whole area of the former army barracks, where the activities have been developed, is owned by the Litoměřice town (stakeholder No. 1). The RINGEN centre building located in this area, is owned and operated by the PUSH-IT partner, Faculty of Science, Charles University (stakeholder No. 2). Both institutions have been cooperating on the ongoing geothermal projects, therefore no complication in negotiations and planning with external stakeholders is expected. However, other stakeholders or target groups that might be indirectly affected by the planned activities have been identified:

Local community - general public - this target group is an important local actor and as such, needs to be approached by the implementation team; awareness raising events for local visitors (general public, schools, political leaders etc.) have been organised during drilling and post-drilling works to enhance acceptance and support to the project and its goals.

Industrial partners - one of the key stakeholders is also the private sector working in the geothermal area; the district heating company has been involved since the preparation of the project proposal and cooperation will continue in the course of the project - for this purpose regular working meetings will be organised and mainly technical aspects (with relation to other project sites) are being discussed; other target group in this sector is companies implementing geothermal installations - presentations and consulting days for this group have been organised in order to share information from both sides and thus increase impact of the project outputs.

Czech army - a Czech Army forces division is still present in one of the barracks buildings; the army representatives have been informed about the drilling works planned and consulted on the drilling rig specification and safety measures to be employed while drilling.

2.4. Status Q2 2025

Two pilot wells were drilled as part of the PUSH-IT project. However, after protracted tendering procedure during the realisation of the first well, technical issues showed up in the Cretaceous formations that lead to the collapse of the borehole (Fig. 1) and a necessity for a new tender procedure and a new contractor. Finally, in Q2/2025 the two planned boreholes have been finished, and the drilling works are completed for the Litoměřice site. Currently the works are being focused on the data interpretation, aquifer testing and sampling, modelling and long-term monitoring.

Tender #1:

- Q2/2024 - Collapsed borehole (cored to 162 m)

Tender #2:

- Q2/2025 - Monitoring well LT-M5-01 (516 m, cored, equipped with FO) - finished
- Q2/2025 - Hydrogeological well LT-H2-01 (202 m, screened in aquifer, equipped with FO) - finished

Currently, following boreholes present on site (Fig. 1) and major findings from their implementation are discussed below in detail.

3. Drilling and Completion

3.1. Methods for the core analysis

During the realisation of tender #1, the interval from the base of Quaternary at 32 m was cored down to 162 m, where the borehole collapsed. The tender #2 provided additional core from the completed well LT-M5-01 from the base of Quaternary (33 m) down to final depth of 516 m.

The core material provided detailed information about the geological profile, fracture locations and unstable horizons and provided in-situ material for further evaluation petrophysical properties. Both cores have been processed directly during the drilling works. The core was photographed (Fig. 2), scanned on a 3D scanner and then described by sedimentologists (Fig. 3). Finally, the core was sampled for measurement of porosity and thermal properties.

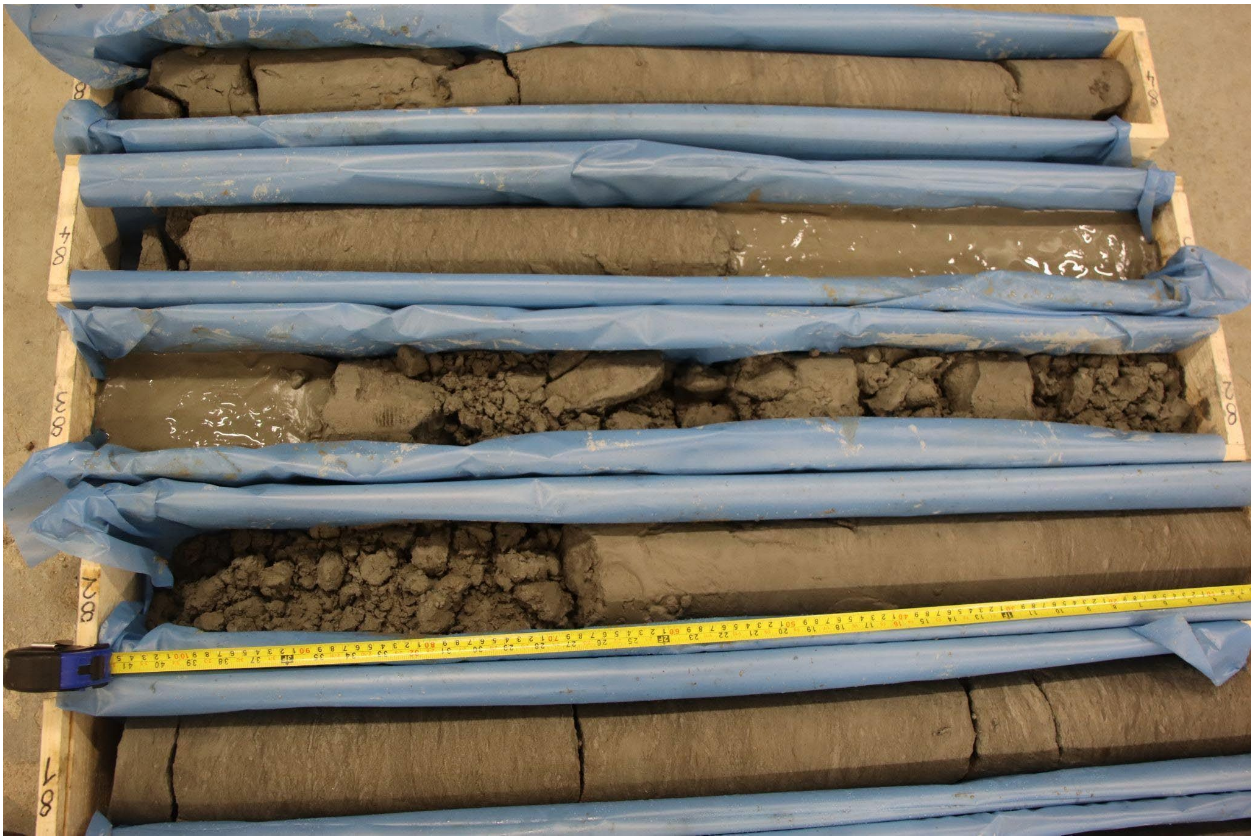


Figure 2: Photo of the core boxes (81-85 m depth) from the collapsed well.

3.2. Lithological profile

From the lithological point of view (see simplified lithological profile of LT-M5-01 in Fig. 3), the top part of the profile are Quaternary sediments (down to c. 30.0 m) of terraces of the Elbe River, mainly composed of sand and clay at variable proportions with interbedded layers of gravel. The base of Quaternary contains pebbles several cm large. Below this level the borehole drilled the Upper Cretaceous (Cenomanian–Turonian) sedimentary rocks that continue down to 184.40 m. The topmost Jizera Formation was recorded between 32.00–60.30 m and is represented predominantly by siltstones (partly calcareous, 32.00–59.90 m), whereas the lower part of the formation is formed by calcareous fine-grained sandstones (59.90–60.30 m). The base of the Jizera formation is formed by c. 20 cm thick glauconitic sandstone. In the interval 60.30–137.10 m the borehole recorded Bílá Hora Formation consisting mainly of bioturbated silty sandstones, sometimes with glauconite. The Bílá Hora Formation contains two intervals with glauconitic sandstones, between ca. 60.30–86.00 m and 116.89–118.86 m. The basal calcareous siltstones that contain the Cenomanian-Turonian boundary between 136.20–137.10 m are glauconitic as well. The Cenomanian Peruc–Korycany Formation was recorded between 137.10–184.40 m. It is subdivided into two lithostratigraphic units: (1) informal Pecínov Member, and (2) Korycany Member. The Pecínov Member between 137.10–142.10 m is a lithological conspicuous interval formed by grey to dark grey calcareous sandstones, representing a counterpart to deposits of so called oceanic anoxic event 2. Korycany Member is typically represented by well-sorted medium- to coarse-grained sandstones (major aquifer A). The base of the Upper Cretaceous is formed by bimodal silty sandstone to sandy clay with basal breccia with up to 1 cm large quartz clasts.

Carboniferous continental deposits occur below the Cretaceous. Fluvial to alluvial clastic deposits of the Líňě Formation are 241.5 m thick (184.4 – 425.9 m) and consist of reddish-brown mostly massive mudstone to very fine-grained sandstone alternating with greenish grey medium grained sandstone to conglomerate. Based on variable proportion of coarse vs. fine clastics the depositional series of the Líně Formation can be divided into three intervals. The lowermost 41 m consists of floodplain fines made by massive poorly sorted mudstone to siltstone containing loosely dispersed fine calcite nodules. Thin, usually dm-thick beds of sandstone frequently interbed mudstones. The middle interval, 110 m thick, consists of vertically stacked cross-bedded conglomerates to sandstones with rather thin mudstone interbeds. Coarse clastics are arranged in to ~ 5–6 m thick fining upward successions that correspond to channel deposits. They can amalgamate into tens of meters thick sand bodies forming potential isolated aquifers. The uppermost interval, 90 m thick, resemble to the lowermost interval, it is dominated by fine grained deposits of mudstones to siltstones, rarely interbedded by dm-thick beds of sandstone.

Underlying lacustrine to alluvial plain fine-grained clastics of the Slaný Formation are 67 m thick (425.9 – 493.05 m). Despite of reduced thickness in this borehole (Slaný Formation commonly reaches about 150 – 200 m), all members can be defined based on lithology. The lowermost Jelenice Member (13 m) comprise heterolithic fine sandstone to siltstone arranged into coarsening and finning up series. The above sharply based Mšec Member (23 m) consists of dark grey carbonaceous mudstone with thin fine sandstone intercalations. These lacustrine deposits represent regional sealing. Above are heterolithic fine clastics of the Hředle Member (23 m) representing lake shallowing and prodelta lobes progradation. The above Ledec Member (5 m) consists of coarse sandstone of delta foresets. Heterolitic, carbonaceous and highly reduced Kounov Member (1.5 m) usually contain up to 1 m thick coal seam, is represented here by sub-cm coal laminae. The uppermost Kamenný Most Member (2.5 m) is formed by massive, reddish muddy sandstone with greenish-grey mottles representing condensed deposition accompanied by formation of paleosols.

Incomplete series of the lowermost Týnec Formation reaches only 23 m (493.05 – 516 m). It consists dominantly of massive reddish-brown siltstone disrupted by intense bioturbation interbedded by thin layers of fine to medium grained sandstones deposited in floodplain setting. The only coarse-grained channel deposits, ~3 m thick, occur near the base of the borehole.

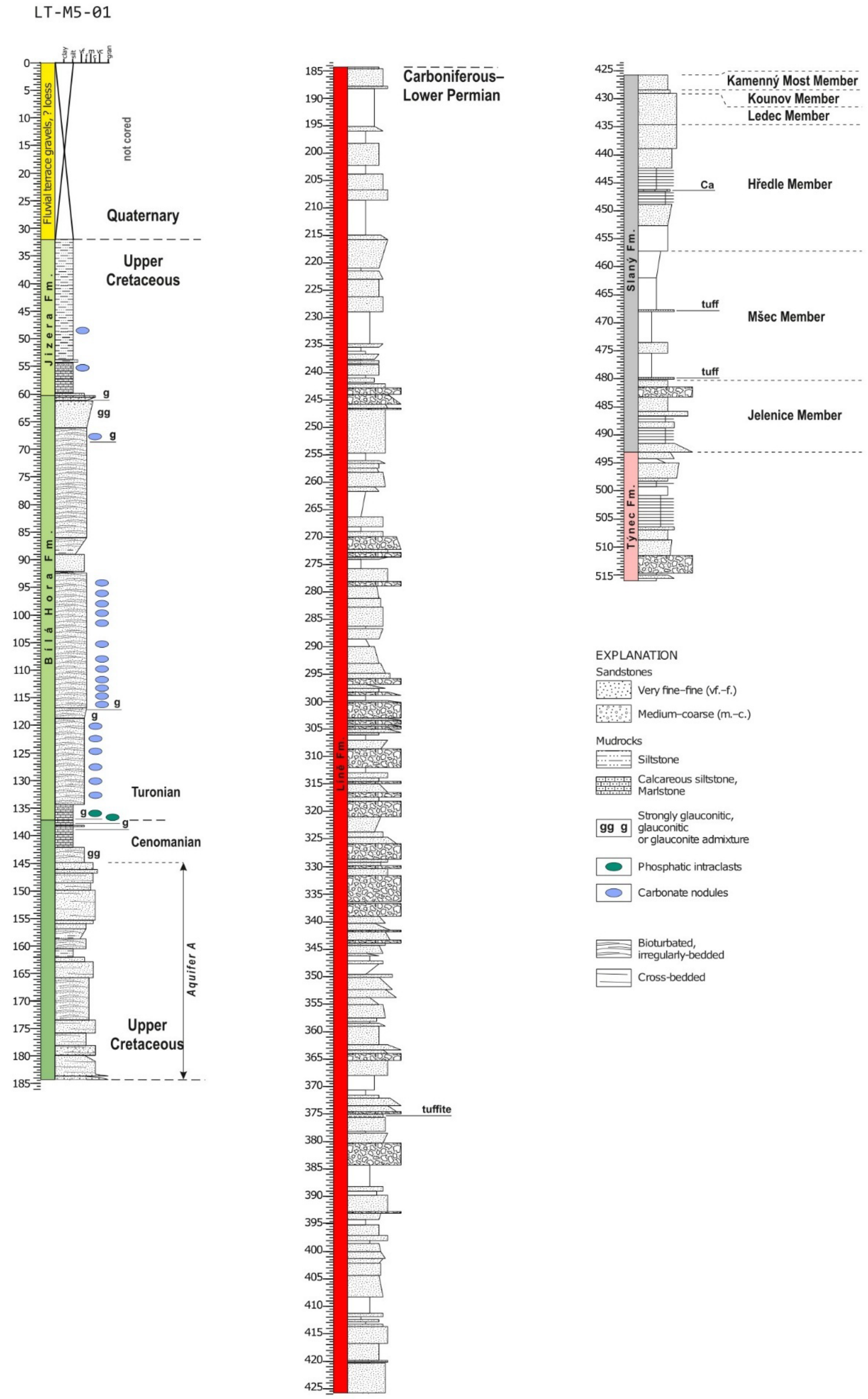


Figure 3: Simplified lithological profile of the borehole LT-M5-01. Full resolution images will be available at Zenodo.

3.3. Thermohydraulic properties

In the laboratory of RINGEN research centre, the thermal properties of acquired core samples are measured gradually, first after being collected and then after being dried in a furnace. The samples were taken immediately after drilling at 1 m intervals, weighed, their volume was measured, and then their thermal conductivity and thermal diffusivity inferred using optical scanning method. Before the measurement, the samples were cut lengthwise, and the measurements were performed in two perpendicular directions to determine the anisotropy of the thermal properties. Currently, the gradual drying and subsequent measurement of the samples is continuing. The Fig. 4—6 show the thermal properties of saturated samples perpendicular to the stratification planes and along these planes. In the Cretaceous sediments, differences due to rock lithology are clearly visible, as well as a local minimum at a depth of 120 m. In the Carboniferous sediments, the lowest values were measured in the Slaný formation, where dark, fine-grained lake sediments are found. Carboniferous sediments (below 190m) have quite homogenous thermal conductivity with some thin layers causing a local deviation. A large insulation layer appears at 455 m where the Slaný formation begins, and its top 25 meters have significantly lower thermal conductivity.

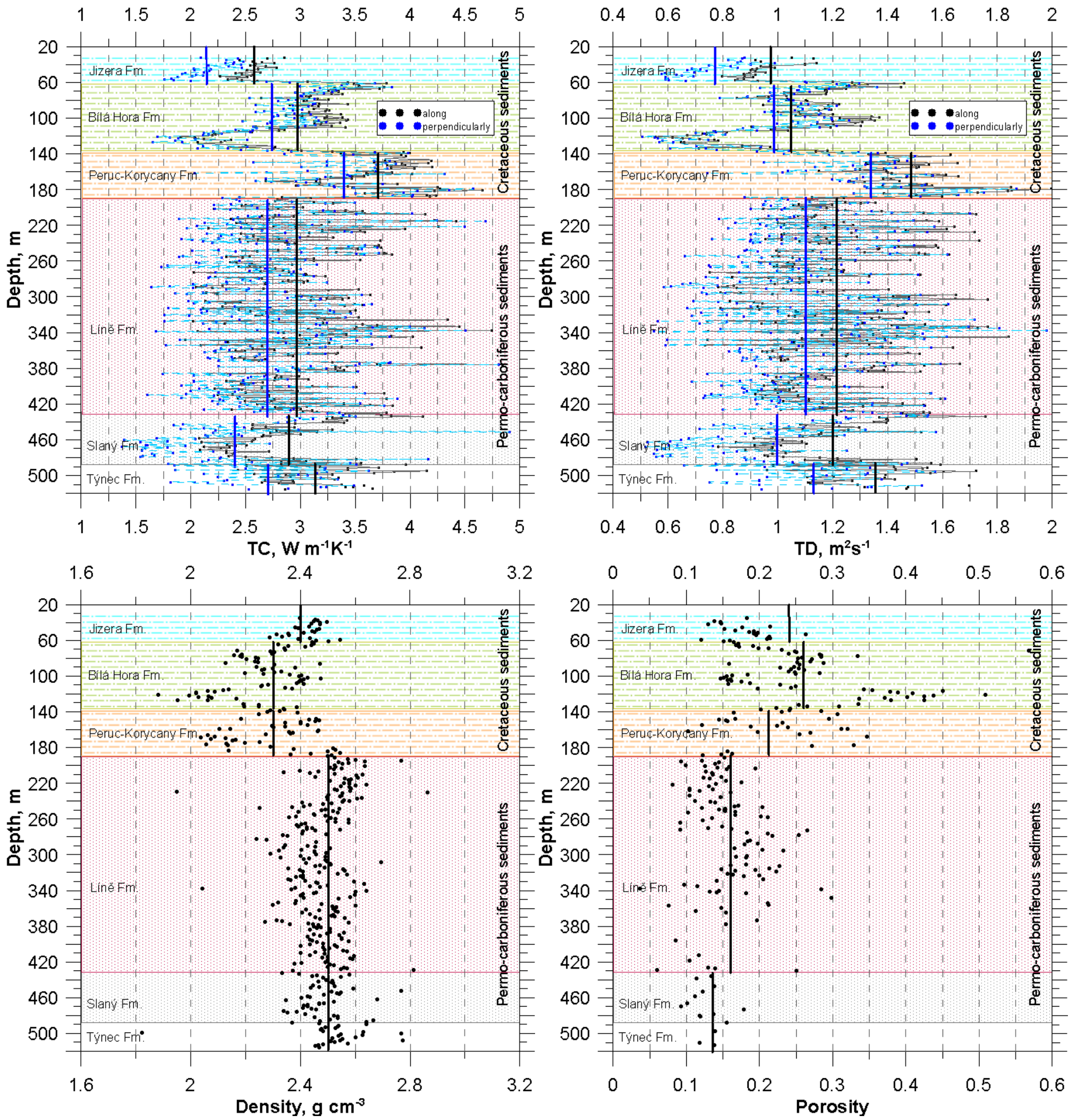


Figure 4: Thermal and petrophysical properties (thermal conductivity, thermal diffusivity, bulk density and porosity) of the Cretaceous and Carboniferous strata.

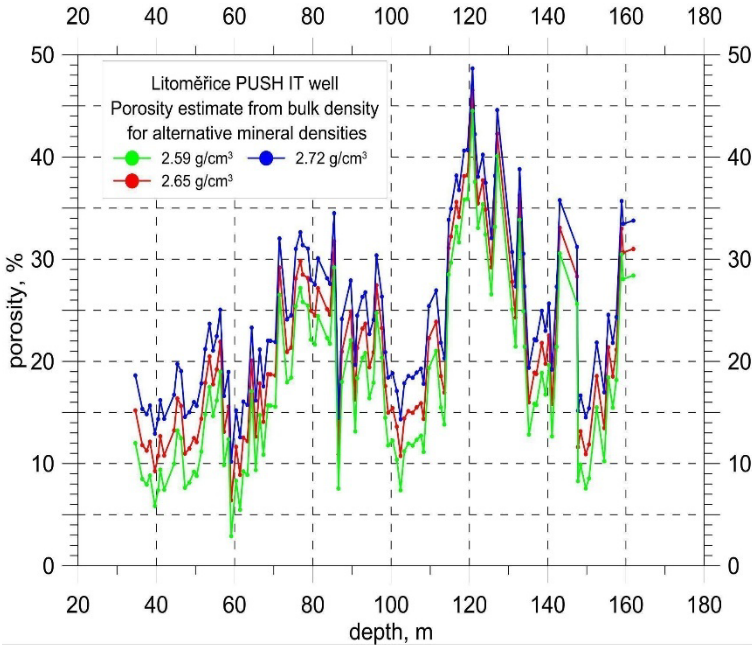


Figure 5: Porosity estimate from bulk density for three different values.

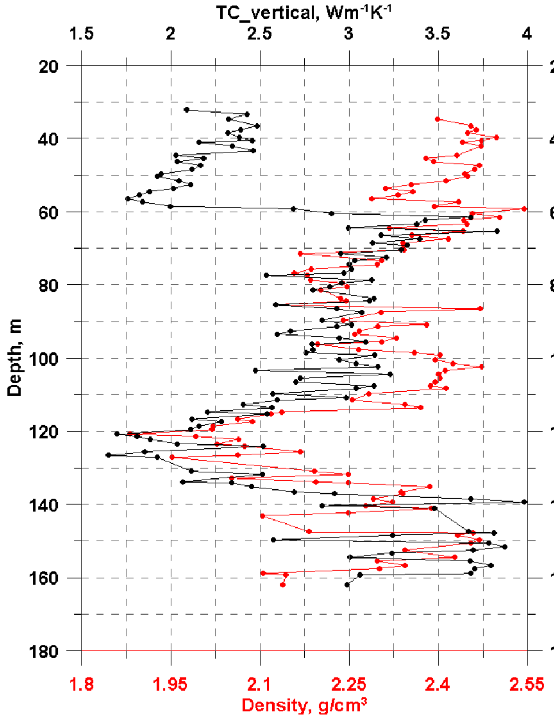


Figure 6: Preliminary measured values of thermal conductivity and bulk density.

Samples for hydraulic conductivity measurements were taken from the collapsed borehole following its lithological and stratigraphic description. Sampling focused on covering various lithological units, with an emphasis on identifying units with increased permeability (Fig. 7). The collection of representative samples from the Cenomanian unit was complicated by low core recovery, significant core damage, and the fact that the borehole intersected only about half the thickness of the Cenomanian, however additional samples from LT-M5-01 are being analysed. Permeability samples (Fig. 7 & Table 1) were analysed in the laboratories of SG Geotechnika in accordance with ČSN EN ISO 17892-11. The highest hydraulic conductivity, $K = 1.2 \cdot 10^{-5}\ \mathrm{m \cdot s^{-1}}$, was measured on a sample of grey Cenomanian sandstone from a depth of 159.12–159.2 m.

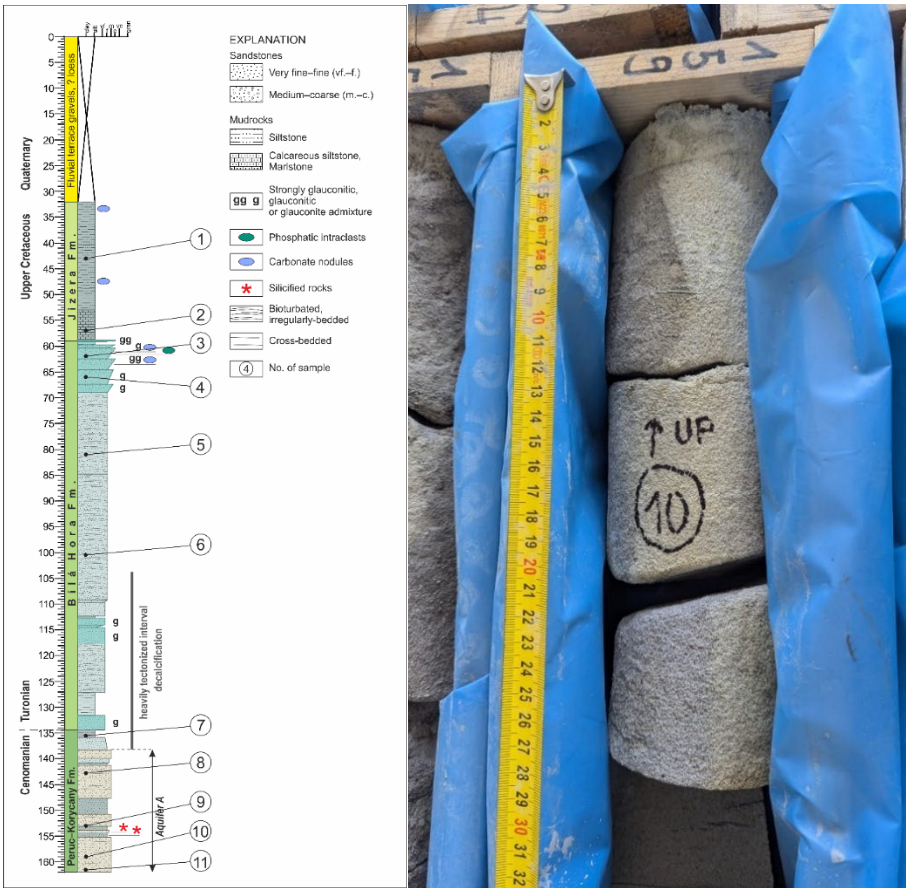


Figure 7: Stratigraphic profile of borehole LT-M2-01 showing sampling locations for hydraulic conductivity measurements. Picture of a core sample from borehole LT-M2-01 selected for hydraulic conductivity measurement.

Table 1: List of samples taken for permeability measurement in the laboratory.

Sample No.	Depth From (m)	Depth To (m)	Stratigraphy	Laboratory Description	CGS Description	K ($m \cdot s^{-1}$)
1	43.24	43.34	Jizera Formation	Grey siltstone	Calcareous grey siltstone, bioturbated	$3.0 \cdot 10^{-12}$
2	57.14	57.24	Jizera Formation	Light grey siltstone	Fine-grained calcareous sandstone	$1.3 \cdot 10^{-12}$
3	61.80	61.98	Bělohorská Formation	Light grey siltstone	Glauconitic sandstone	$2.4 \cdot 10^{-11}$
4	65.85	66.00	Bělohorská Formation	Light grey siltstone	Medium- to coarse-grained sandstone	$9.5 \cdot 10^{-11}$
5	81.00	81.10	Bělohorská Formation	Grey sandstone	Fine-grained streaky sandstone	$1.3 \cdot 10^{-9}$
6	100.50	100.57	Bělohorská Formation	Grey sandstone	Fine-grained grey sandstone, locally streaky, bioturbated	$1.3 \cdot 10^{-11}$
7	135.33	135.51	Bělohorská Formation	Grey siltstone	Siltstone, Upper Cenomanian, aquitard	$3.6 \cdot 10^{-10}$
8	142.77	142.85	Peruc-Korycany Formation	Grey sandstone with black layers	Light sandstone with siltstone laminations	$9.0 \cdot 10^{-8}$
9	152.90	153.00	Peruc-Korycany Formation	Light grey sandstone, dark streaky	Medium-grained dark sandstone, bioturbated	$4.2 \cdot 10^{-11}$
10	159.12	159.20	Peruc-Korycany Formation	Grey sandstone	Medium-grained light sandstone	$1.2 \cdot 10^{-5}$
11	161.78	161.88	Peruc-Korycany Formation	Grey sandstone, dark streaky	Medium- to coarse-grained streaky sandstone	$2.0 \cdot 10^{-6}$

3.4. 3D representation of the core and fracture network

Cores from the boreholes LT-M5-01 (33–516 m) and collapsed borehole (32–160 m) were scanned using the DMT CoreScan3 drill core scanner (Fig. 8a). Scanning was carried out in 1 m sections in 360° mode, resulting in an unwrapped image of the drill core (.jpg) in high resolution of 10 px/mm (Fig. 8b, top), an .obj file with a 3D visualization of the drill core (Fig. 8b, bottom), and metadata (.mtl). If 1 m sections could not be placed on the scanner in the full length (due to a damaged or missing beginning/end of the core), the beginning/end of the core was replaced with a sample of leucogranite, easily distinguishable from the scanned core (Fig. 8c). This helps to facilitate post-processing, but if the drill core was not sufficiently cohesive (parts with unconsolidated lithology), scanning was not possible. For documentation purposes, photographs of core boxes were taken along the entire borehole length using a camera. Borehole LT-M5-01 was structurally documented in detail in-situ, and this data was incorporated into the final borehole log (Fig. 8d, e) as “structure type, infill, infill thickness, damaged zone (DZ), crack zone (CZ), and optional remarks.” The collapsed borehole in the interval 32–160 m was not yet structurally documented. The data were subsequently processed using WellCAD software, resulting in two borehole logs, which contain data from the core scanner, structural data as described above (where documented), and for LT-M5-01 also logging data described in detail below.

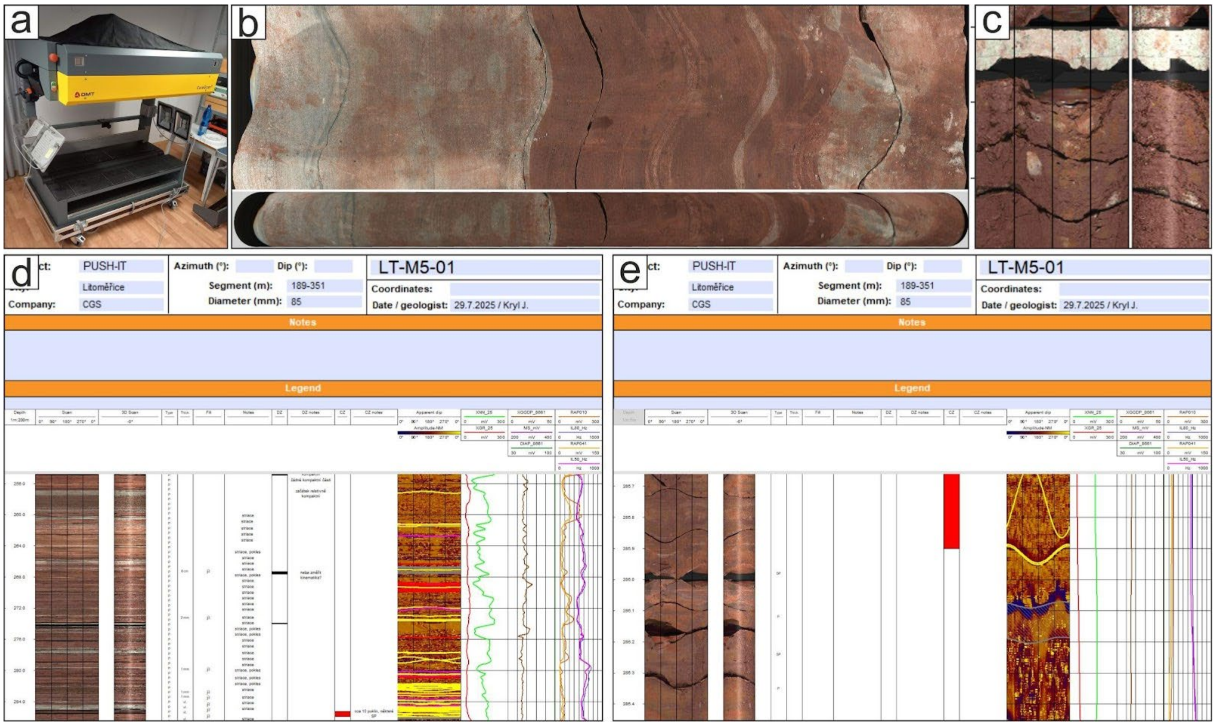


Figure 8: Preliminary measured values of thermal conductivity and bulk density. Example of borehole scanning and visualization using WellCAD software. Full scale images will be available at Zenodo.

Various logging and structural data can be implemented into the borehole log, with the ability to define structures on the scanned drill core using sinusoids characterizing azimuth, dip, and type of the given structure, among other features. The orientation azimuth of fractures cannot be interpreted, because the core was not oriented, only frequency and dip of fractures will be analysed. After processing and interpreting the acquired data, the borehole log will be expanded and serve as a visualization and interpretation of the results.

The final borehole logs (LT-M5-01 and collapsed borehole) are attached in PDF format. For borehole LT-M5-01, there are three PDF files labelled “segment1, segment2, and segment3,” corresponding to different borehole diameters. For collapsed borehole (here labelled LT-M2-01), there is only one PDF file with a single borehole diameter.

Fractures are usually steep or horizontal (bedding-parallel), sometimes filled by thin calcite (especially in Jizera marlstones), but mostly the fractures are open, without significant mineral infill. In two cases, c. 1 cm thick veins of sulphides have been documented.

3.5. Borehole logging

For thorough petrophysical and hydrogeological characterisation of the subsurface, full sets of wireline logs were attempted in all wells. The logging was carried out by an external commercial contractor and included a set of methods commonly used in the industry in the Czech Republic.

These methods include:

- Borehole deviation (azimuth and tilt) is vital for the design of the system fields and the interpretation of image logs. Azimuth cannot be determined in steel casing.
- Image logs (acoustic and optical imaging or televiewer, further mentioned as Acoustic Borehole Televiewer (ABI) provide detailed information on the orientation and thickness of structural features such as fractures or bedding planes and is used for orientation of the drill core. Image logs must be measured in open hole. Optical televiewer requires a clear fluid or air filled well, acoustic televiewer requires a water-based fluid.
- Caliper measures wellbore diameter and thus identifies fractures, mud cake, bulging clays and other features on the borehole wall. Caliper must be measured in open hole.
- Natural gamma is the primary method for identifying different lithologies, particularly distinguishing between pure sandstones and clay-rich formations such as mudstones. A large portion of the natural signal gets attenuated by casing and cement, but some relative differences may still be observed.
- Magnetic susceptibility complements natural gamma in distinguishing lithologies. Magnetic susceptibility cannot be measured in steel casing.
- Resistivity of the formation provides more information on the character of fluids in permeable formations and distinguishing between permeable and impermeable beds. Resistivity cannot be measured in steel casing. Resistivity may be measured in plastic casing using induction log.
- Density gamma-gamma log is a nuclear method for the determination of density of the formation. Results are affected by the presence of casing and cement, but some relative differences may still be observed. In a cased well, density log complements cement-bond log in the determination of the quality of cementation.

- Neutron-neutron log is a nuclear method for the determination of porosity of the formation (combined with density log) and the content of hydrogen (including in clays, water or hydrocarbons). Results are affected by the presence of casing and cement, but some relative differences may still be observed. In a cased well, neutron log complements cement-bond log in the determination of the quality of cementation.
- Cement-bond log is a special kind of sonic log used to determine the quality of cementation (primarily aimed at steel casing, may help assessing the quality of cementation behind a plastic casing).

Most wireline geophysical logs work best in an open hole filled with clear fluid. The presence of heavy mud, casing and cement attenuates the signal and, in case of steel casing, may thwart the measurement entirely (see above).

The high viscosity of the polymer mud used to mitigate mud losses and maintain wellbore stability resulted in some of the lighter tools floating and not reaching target depth.

Bulging clays in the deeper (Carboniferous) formations made the well inaccessible for most tools. Limited measurements were, hence, made through steel wireline casing, limiting the applicability of most methods and the resulting data. The available data are part of the Annex 1.

3.6. Logs from LT-H2-01

A standard set of logs commonly used for hydrogeological wells was measured, covering the interval from the anchor casing shoe to the final drilled depth. A cement bond log was measured after well completion to assess the quality of cementation. However, as the method is primarily designed for a steel casing cemented in place, the results from the perforated plastic casing and a gravel pack do not seem to reflect the actual situation. In Fig. 9, the cement bond (“zapažnicová cementace” as annotated in the figure) is interpreted in the context of other methods as well as the well design.

The borehole deviation was measured to the final drilled depth. The bottom of the hole is offset by approximately 3 m to the east-northeast.

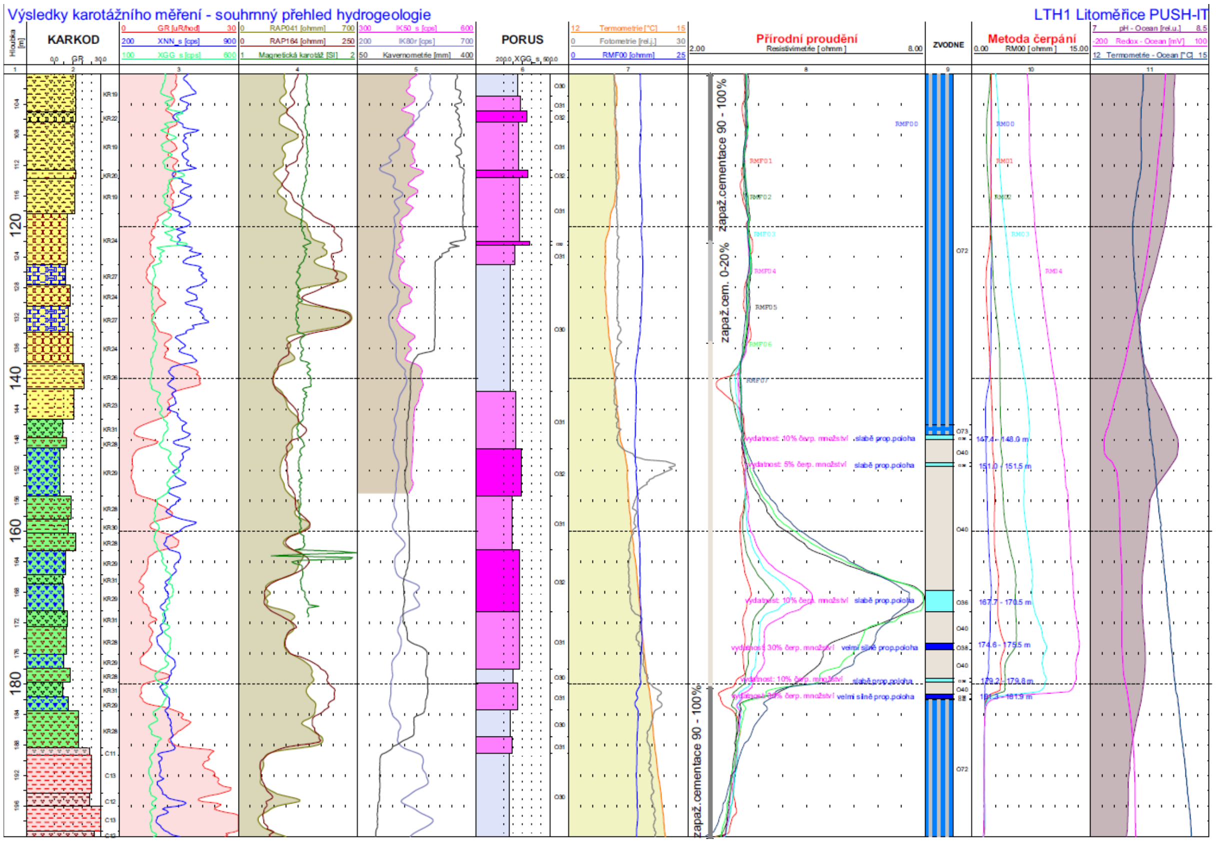


Figure 9: Example of interpreted set of logs from the 200 m hydrogeological monitoring well. Full-resolution log file will be available at Zenodo.

Logs measured in an open hole down to 200 m include: Normal resistivity and induction log (long and short), calliper, natural gamma, density and neutron. Magnetic susceptibility was measured, too, but failed to reach the bottom.

Natural gamma and resistivity correspond to major lithologies, with sandstones exhibiting low natural gamma activity and relatively high resistivity and mudstones exhibiting high natural gamma activity and low resistivity. The boundary between Cretaceous and Permian is particularly profound.

3.7. Logs from LT-M5-01

Challenges encountered during drilling this borehole affected the measured logs. The time and depth intervals when it was possible to maintain an open hole were limited. As a result, most logs had to be measured in a cased section or in a steel drill string. Thick polymer mud used for maintaining wellbore stability, and bulging Carboniferous mudstones, prevented some tools (temperature, magnetic susceptibility, resistivity, sonic, induction log) from reaching the final depth of 516 m MD. Data are still being processed, so only preliminary results are presented in this section. Logs successfully measured in open hole (below 30 m MD) are limited to the following (Table 2):

Table 2: List of well-logging methods and the depth ranges where data are recorded.

Log	Depth range (m MD)
natural gamma	30 - 188
neutron log	30 - 188
ABI	30 - 189
ABI	170 - 300
OBI	180 - 224
sonic	30 - 200
resistivity	180 - 347

An image log with an acoustic borehole televiewer (ABI) was first measured in an open hole between 189 m and anchor casing. Nevertheless, the logging run took place after the well had been reamed to the diameter of 178 mm, which is too large for this tool and, hence, the image quality is poor.

Another ABI run was performed in the depth interval between 300 m to 170 m MD. At the time, a PQ drill string was lowered to 170 m due to wellbore stability issues. Optical Borehole Televiewer (OBI) could only be used between 180 and 224 m. Due to thick mud, the image quality is poor.

Borehole deviation was measured in the steel drill string down to 515 m MD. Since the azimuth could only be measured by an acoustic televiewer in an open hole interval between 170 and 300 m MD, the azimuth below and above this section was only extrapolated. The maximum offset of the bottom of the hole from vertical is slightly below 3.5 m.

Natural gamma and neutron log were measured in the steel drill string to the depth of 515 m MD. Density was measured in two runs, covering the interval between 175 and 515 m MD. The results are indicative only. Resistivity was limited to open hole intervals.

The measured data had not been processed or interpreted at the time of writing this report.

3.8. Setbacks from the drilling of the wells

To keep the continuous circulation of the drilling fluid a cohesive unfractured rock with low porosity is required to have a low penetration rate of the drilling fluid into the formation. Such conditions are not met in the Litoměřice case. Additionally, water table is significantly below the surface, causing overpressure in the borehole compared to the surrounding rock enhancing potential for losses. Therefore, proper mud must be chosen to seal the porous environment, to stabilize the walls and all the encountered losses need to be carefully eliminated.

During the realisation of the tender #1, severe circumstances occurred that the borehole collapsed, and the drilling works stopped. The chosen wireline coring method was accompanied by notorious loss of the drilling fluid hindering successful realisation of the drilling works according to the original drilling works programme formation (typically mud loss <20% is acceptable).

After setting and cementing the conductor (standpipe) to the depth of 34.3 m, wireline coring started. Mud loss first occurred at depth of 36.4 m and reached critical level of 40% at depth around 45.5 m, in the marlstones of Turonian Jizera formation (Upper Cretaceous). The problematic horizon was cemented and re-drilled. The same situation repeated in the underlying sandstones of Jizera formation (Turonian, Upper Cretaceous), at depth 78.3 m mud loss reached unsustainable 100% and repeated cementations did not improve the situation.

Inability to keep drilling fluid circulation consequently led to a limited transport of cuttings to the surface, limited access of the mud to the drilling bit, resulting in a reduced rate of penetration and consequently a bit malfunction (increased wear of the bit, deterioration of the equipment). Reduced or absent return of the mud required its continuous refill to cool the bit. However, such approach did not solve the primary cause.

Other complications occurred at depth 138.6 m and below, in the well-sorted sandstones of the Cenomanian Peruc-Korycany formation. Sandstones lost cohesion and borehole walls became unstable and the borehole was repeatedly collapsing. The urgent need of string removal occurred at depth 162.2 m, where the swelling borehole led to the stuck drilling string. The drilling string was successfully retrieved to the surface and drilling works were stopped due to the risk of lost equipment.

If the drilling equipment got stuck in the borehole without any possibility of its retrieval, the borehole would be destroyed and would need to be sealed/plugged and abandoned, drilling tools would be lost in the hole, and the goals of the project would not be able to be reached. Additionally, the drilling showed that the air-hammer drilling planned for the second well is not a suitable method.

Despite prolonged negotiations, there were no other technical solutions to be applied to successfully reach the goals and outcomes with the available equipment on site and existing contractor. To fulfil the objectives, a significant change of the drilling technology and the design of the borehole needed to be considered. The contract was cancelled, and a new contractor was tendered.

The second tender #2 was successful and only several minor issues were encountered during its realisation, but overall result followed the proposed drilling plan. Both cored borehole LT-M5-01 and hydrogeological borehole LT1-H2-01 have been drilled simultaneously.

After drilling through the Quarternary, the borehole LT-M5-01 was drilled using similar wireline drilling setup (borehole 146 mm) and contrary to the previous attempt, it was drilled with polymer mud from the beginning to the final depth. Additionally, the drilling was continuous 24/7 and in case of technical breaks, the borehole was kept filled with polymer mud. As a result, the coring efficiency was almost 100% (see scanned core in Annex 1) and only one mud loss event occurred, which was eliminated by its clogging by the mud and cuttings. After drilling to the base of Cretaceous, the borehole was reamed to 178 mm and cased. In the next stage, the borehole was drilled with 122 mm to 350 m and cased (without sufficient cementing), the last portion was drilled with 96 mm diameter to the final depth. The swelling of the claystones and poor cementing of the permanent PQ casing led to vibrations, several drop-down event and consequently failure of the casing, which made continuation of the drilling works down to 550 m and subsequent logging too risky (increased risk of potentially inaccessible bottom part of the well). Therefore, the only noticeable change in the result is shortening of the exploratory borehole from planned 550 m to 516 m final measured depth, as the primary goal of the borehole to drill through the thermal insulant layer was achieved. After several logging attempts (with variable success, see above), the borehole was equipped with the fibre optic cable loop and cemented to the surface.

The hydrogeological borehole was drilled without any complications to the final depth of 202 m. It was drilled with the bentonite mud, without any mud loss event. It was completed with screened section between 140 and 182 m, cleaned and now it is in use for water level measurement, accessible for water sampling, aquifer testing and temperature measurements. The major problems were caused by using bentonite mud. Despite it perfectly prevented losses and kept the borehole stable, it hindered running of the logging tools (too heavy mud) and more importantly caused clogging of the aquifer and especially gravel pack. The installation of the gravel through the pipes was not successful, because the pipes got stuck and the gravel was installed from the surface. This led to a very poor control of the gravel pack level, which resulted in significantly higher level than planned (Fig. 10, in the insulant layers, as seen in fibre optic record of the subsequent cement job). The clogging of the filter required complicated cleaning approach to activate the well. Several airlift operations took place to induce natural inflow to the well, followed by mechanical cleaning of the perforations (controlled by camera inspections) and finally using c. 50 cm double-packer together with airlifting. In the end, the cleaning of the well was successful, and the well is now available for further investigations of the aquifer.

3.9. Completion

Wells were completed as shown in Fig. 10:

- Exploratory borehole, 516 m final depth – fibre optic cable (2x DAS, 2x DTS fibre) in double-ended setup, 2 thermistors for precise temperature measurement and DTS calibration, borehole fully cemented. The U-shaped loop of the double-ended cable configuration is interrupted on one borehole side around 300 m depth due to mechanical damage, nevertheless cable is still able to measure since both arms can be reached to this point, and data can be joined consequently.
- Hydrogeological borehole, 202 m final depth – double-ended fibre optic cable (DAS, DTS) behind the casing. Well completed with plastic casing (150 mm diameter), screened interval 140-182 m.

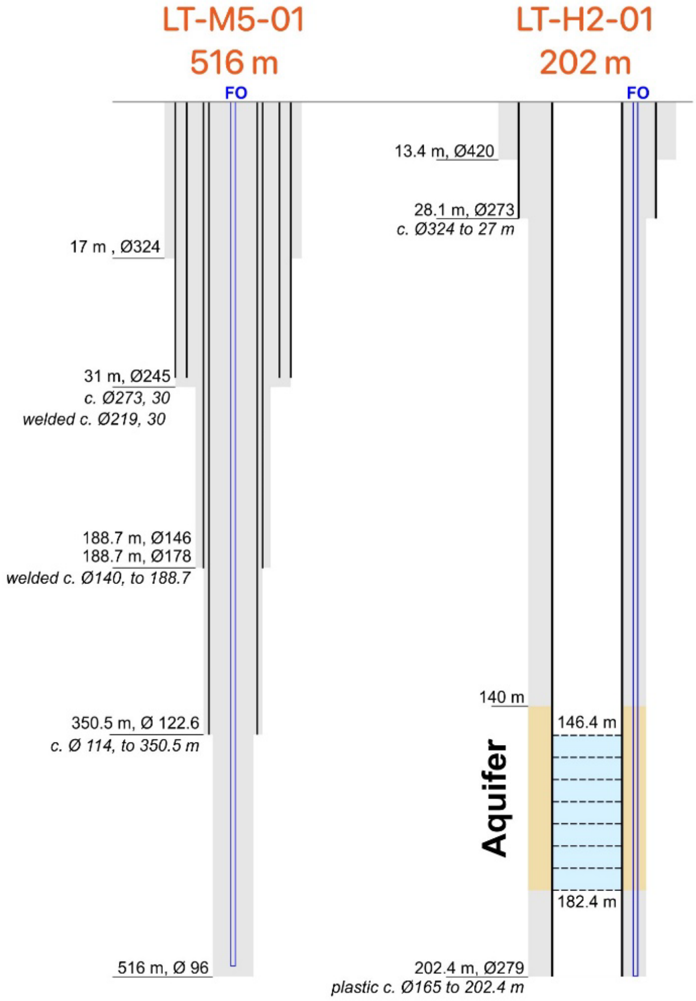


Figure 10: Final design of the wells LT-M5-01 and LT-H2-01.

3.10. Lessons learned from drilling

Key geological aspects of the Litoměřice site and related drilling risks and challenges

- thick Quaternary (~30 m) with swelling clays plus pebbles at the base–swelling + collapse slow down rate of penetration
- deep groundwater level (~25 m below surface) – increased potential for losses
- fractures and rock porosity (Cretaceous, ~30–180 m) – increased potential for losses
- poor cohesion of some sandstones (especially aquifer at ~140–180 m) – swelling
- swelling claystones (especially Carboniferous, below ~180 m) – swelling
- low potential for losses in the Carboniferous (below ~180 m)
- no dangerous gases encountered.

Altogether, our experience showed, that smooth realisation of the future drilling works can be achieved when simple rules are carefully followed:

- do not use water as a drilling fluid.
- do not leave the well without mud (reduces potential for collapse and swelling) or work 24/7.
- carefully eliminate all the potential losses to prevent future problems.
- mud additives to prevent swelling clays.
- carefully cement the permanent casing.
- do not use bentonite in the hydrogeological wells (at least in the screened interval).
- install gravel pack of hydrogeological well via pipe to the screened interval.
- carefully clean the hydrogeological well (airlift, mechanical cleaning, double-packer cleaning) and prove permeability of the screened section (pumping tests, sampling).
- logging is probably possible only in the temporary plastic casing (poor borehole stability).

3.11. Potential for vertical wells

Efficient BTES field requires numerous wells which are as vertical as possible, or at least as parallel as possible. The drill paths of the available boreholes at the Litoměřice site show, that despite none of them was intended to be as vertical as possible, all reached quite good verticality, with maximum deviation less than 3.5 m from vertical at depth of 200 m and 500 m respectively (Fig. 11). This is probably caused by sub horizontal bedding of the sedimentary rocks (horizontal in Cretaceous, less than 10° dip in Carboniferous), which does not cause natural deviation of the drilling string. This highlights a great potential to drill vertical wells reasonably well. Discussion of the know-how of the Bochum demo site team, who achieved vertical well, led to several tailor-made suggestions how such wells can be implemented in Litoměřice in the future.

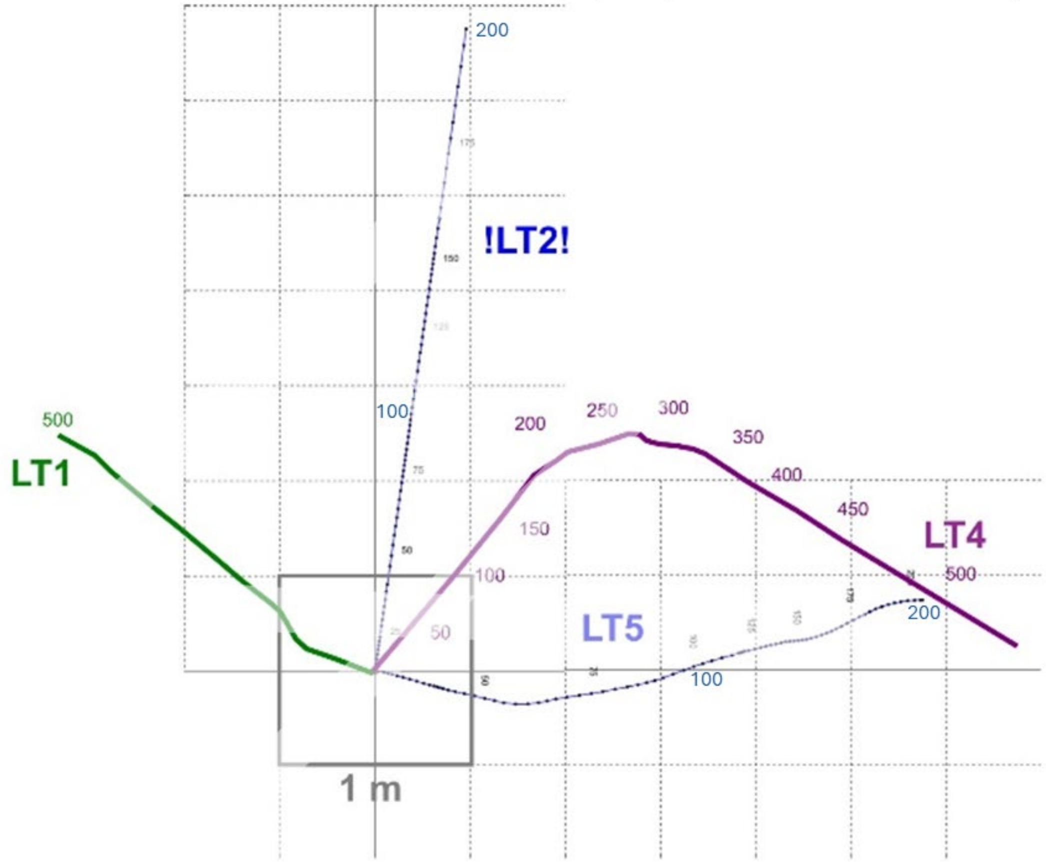


Figure 11: Drill paths of the available boreholes on the site. LT4 is equal to LT-M5-01 and LT5 is equal to LT-H2-01, LT1 is equal to PVGT-LT1 (see Fig.1 for detail positions). Rotary drilling was applied for LT1, air-hammer drilling was applied for LT2 (azimuth is extrapolated from the surface and kept constant due to steel casing of the well).

4. Performance Assessment and Optimisation

4.1. Hydrogeology of the Cenomanian Aquifer

The heat losses of the planned BTES fields are significantly increased by significant ground water flow. In the sedimentary strata present in Litoměřice, this aspect is even more important, compared to e.g. crystalline environment. In the PUSH-IT project, we aimed to investigate the most permeable rock formation, the Cenomanian aquifer, as the proxy for the upper estimate of the possible groundwater flow.

After drilling the borehole LT-H2-01, casing installation, and placement of a gravel pack, borehole logging was carried out, including resistivity logging under natural flow conditions to determine inflows into the well (Fig. 12). The water column in the borehole was salted along the entire profile using NaCl. Subsequent resistivity logging was conducted with a probe measuring the electrical resistance of the salt solution in the borehole.

Natural flow in the Cenomanian aquifer was monitored in the borehole between 4th March and 5th March 2025, overnight, for a total duration of 25.5 hours during the measurement of other logging methods. The groundwater table was recorded at a depth of 23.0 m and remained almost stable during the measurements.

During the monitoring of natural flow, natural groundwater flow was observed in the interval 147.4–181.9 m (the casing was perforated below the water table in the section 146.0–182.0 m, and casing was solid in the remaining section). According to the drilling crew, the solid casing was cemented in the intervals 30.0–130.0 m and 178.0–200.0 m. Logging confirmed cementation of varying quality in the intervals 26.25–137.20 m and 180.4–201.6 m, based on cement log and density logging, in agreement with the drilling crew's report.

A total of six permeable zones were identified. The main inflow occurred in the interval 167.7–170.5 m. Under stable hydrodynamic conditions, this zone contributed a total inflow of 600 L/day. From this interval, water flowed both upwards and downwards (300 L/day in each direction).

Water flowing downwards was lost into three permeable zones: 174.6–175.5 m (loss of 50 L/day), 179.2–179.8 m (loss of 150 L/day), 181.3–181.9 m (loss of 100 L/day).

Water flowing upward was lost into two permeable zones: 151.1–151.5 m (loss of 200 L/day) and 147.4–148.0 m (loss of 100 L/day). Interval of perforated Polyvinyl Chloride (PVC) casing 165/10 mm: 146.0–182.0 m. The water movement in the borehole under stable conditions can be summarized in the Table 3, see below:

Table 3: Description of water flow in the screened section of the borehole.

Permeable Interval	Flow Type	Note
147.4–148.0 m	Loss of 100 L/day	Water flows upward (100 L/day) and is lost at this interval
151.0–151.5 m	Loss of 200 L/day	200 L/day flows from the lower part of the borehole
167.7–170.5 m	Inflow of 600 L/day	300 L/day flows upward; 300 L/day flows deeper
174.6–175.5 m	Loss of 50 L/day	A total of 300 L/day flows in from the upper section, 250 L/day continues deeper
179.2–179.8 m	Loss of 150 L/day	A total of 250 L/day flows in from the upper section, 100 L/day continues deeper
181.3–181.9 m	Loss of 100 L/day	A total of 100 L/day flows in from the upper section, no groundwater flow occurs deeper

The natural movement of groundwater is associated with the perforated section of the PVC casing between 146.6–182.0 m.

Following the resistivity logging under natural flow conditions, resistivity logging was also carried out during simultaneous pumping of the borehole. Pumping was conducted at a discharge rate of Q = 0.5 L/s using a Grundfos SQ85 pump for a duration of 100 minutes. The water level stabilized quickly (after just 40 minutes of pumping) at a depth of 23.95 m (from a static water level of 23.00 m).

Most of the water entered the borehole from the three lower permeable zones:

- 174.6–175.5 m – inflow 30% of the pumped volume (dominant inflow)
- 179.2–179.8 m – inflow 10% of the pumped volume
- 181.3–181.9 m – inflow 35% of the pumped volume (strongest inflow during pumping)

From the other, higher-situated permeable zones, inflows accounted for 5–10% of the pumped volume. The inflows from each zone are listed in Table 4 below.

Table 4: List of permeable zones in the screened zone of the borehole and its water inflow.

Permeable Interval	Inflow (% of pumped volume)
147.4–148.0 m	10%
151.0–151.5 m	5%
167.7–170.5 m	10%
174.6–175.5 m	30% (dominant inflow)

Permeable Interval	Inflow (% of pumped volume)
179.2–179.8 m	10%
181.3–181.9 m	35% (dominant inflow)

The total hydraulic conductivity for the permeable zones within the perforated section 147.4–181.9 m (thickness 34.5 m) at a pumping rate of 0.5 L/s and a constant drawdown of 0.95 m to the stabilized level of 23.95 m is $K\_total = 1.53 \cdot 10^{-5}$ m/s.

If the pumped volumes and drawdown are related to the smaller thickness of individual permeable zones, the partial hydraulic conductivities range from $1.88 \cdot 10^{-5}$ m/s to $3.70 \cdot 10^{-4}$ m/s.

The obtained data for the permeable zones are summarized in the Table 5 below.

Table 5: Obtained hydraulic parameters for permeable zones in the borehole.

Hydraulic Conductivity (K)	Interval	Thickness	% of Discharge
$K_1 = 8.77 \cdot 10^{-5}$ m/s	147.4–148.0 m	0.6 m	10%
$K_2 = 5.26 \cdot 10^{-5}$ m/s	151.0–151.5 m	0.5 m	5%
$K_3 = 1.88 \cdot 10^{-5}$ m/s	167.7–170.5 m	2.8 m	10%
$K_4 = 1.75 \cdot 10^{-4}$ m/s	174.6–175.5 m	0.9 m	30%
$K_5 = 8.77 \cdot 10^{-5}$ m/s	179.2–179.8 m	0.6 m	10%
$K_6 = 3.07 \cdot 10^{-4}$ m/s	181.3–181.9 m	0.6 m	35%

During the final stage of drilling operations—cleaning by the airlift method—two short pumping tests were carried out on borehole LT-H2-01 to verify the efficiency of cleaning the gravel filter pack in the borehole. The inner diameter borehole casing of LT-H2-01 is 150 mm, with perforations located at a depth of 146.4–182.4 m over a length of 36 m, intersecting the Cenomanian aquifer. The static water level in the borehole was recorded at 22.69 m. The first pumping test was conducted on 4 April 2025 and lasted 2.4 hours. Pumping was performed at a rate of 0.9 L/s and by the end of the test, the water level had dropped by 2.64 m to 25.33 m. This was followed by cleaning the gravel pack of the hydrogeological borehole using a modified airlift method. The second pumping test was conducted on the same day (4 April 2025) and lasted 2.3 hours. Pumping was again at a rate of 0.9 L/s, and by the end of the test, the water level had dropped by 1.84 m to 22.53 m. From the drawdown (s) versus logarithmic time graph (Fig. 13), it is evident that after the cleaning, the borehole skin effect was reduced. The pumping test was evaluated using the Cooper-Jacob method. After the second cleaning, transmissivity was calculated as $1.24 \cdot 10^{-3}$ $m^2 \cdot s^{-1}$, and the hydraulic conductivity of the Cenomanian aquifer within the perforated interval corresponds to $3.44 \cdot 10^{-5}$ $m \cdot s^{-1}$. These pumping tests were, however, very short and should be considered only as indicative. Proper long-term pumping tests are planned for LT-H2-01 in the autumn of 2025.

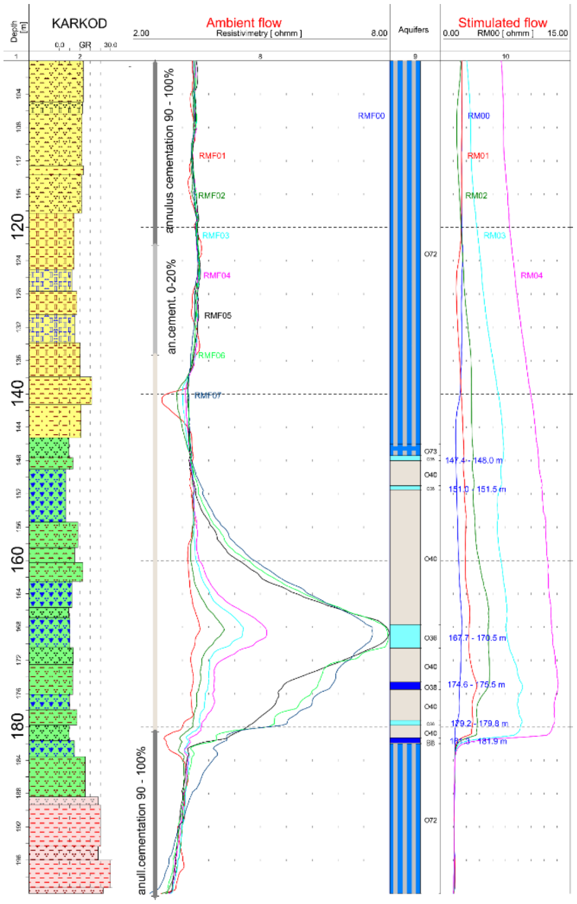


Figure 12: Graph showing borehole logging measurements in borehole LT-H2-01.

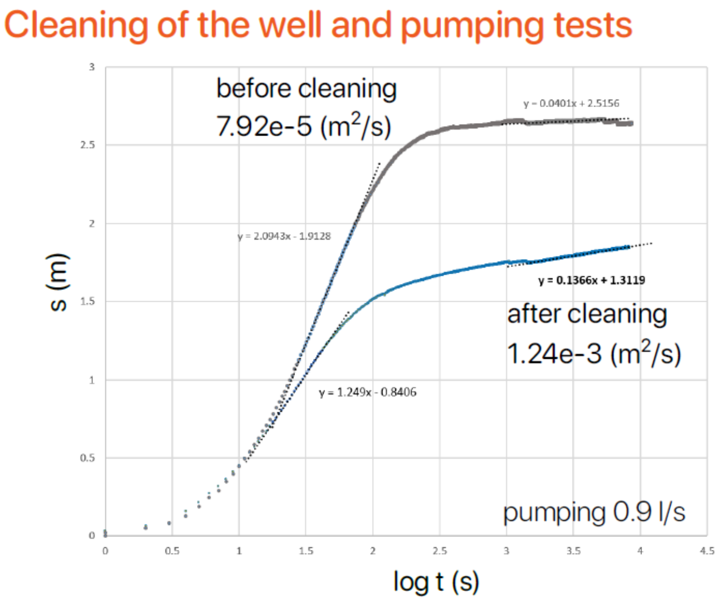


Figure 13: Pumping tests on borehole LT-H2-01. Drawdown versus log t graph, evaluation according to the Cooper-Jacob method. Grey curve – pumping test before airlift, blue curve – pumping test after airlift.

Following the second pumping test (cleaning of the gravel pack using the modified airlift method), resistivity logging was performed in borehole LT-H2-01 to verify the cleaning effect and determine the horizontal flow velocity (Fig. 14). The water column in the borehole was salted along the entire profile with NaCl. Subsequent repeated resistivity logging was carried out using a probe measuring the electrical resistance of the salt solution in the borehole. The curves of electrical conductivity in the borehole are shown in Fig. 14. The apparent horizontal flow velocity v_a was determined using the equation (Mareš & Valtr, 1987):

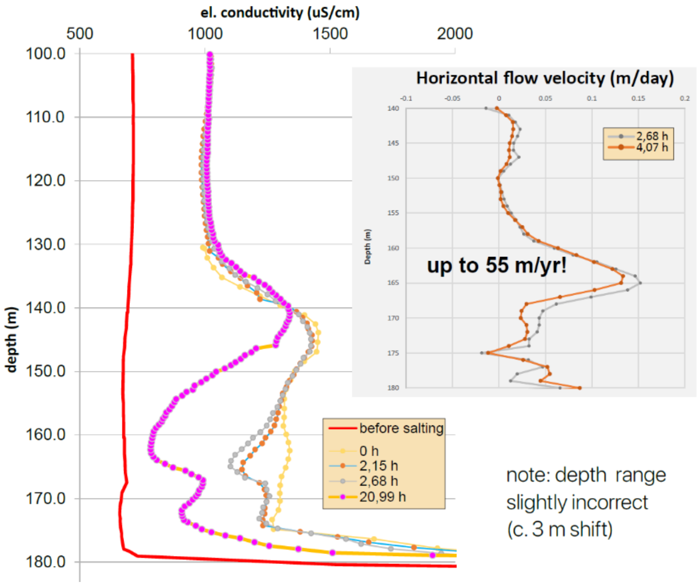
$$v_a = \left(\frac{3{,}62 * \mathrm{r}}{\Delta \mathrm{t}}\right) * \log \frac{C_1 - C_0}{C_t - C_0}$$

Where:

- $\Delta t = t_i - t_1$ – time difference between the moment when the concentration C_t was measured in the borehole and the moment immediately after the adjustment, when concentration C_1 was recorded
- C_0, C_1 – concentrations of the tracer in the borehole under natural conditions and immediately after adjustment
- C_t – tracer concentration at time C_t
- r – borehole radius

The flow velocity was evaluated considering the drainage effect of the borehole. A borehole is generally more permeable than the surrounding formation, causing groundwater flow to be concentrated into it. A generally accepted drainage coefficient is two, meaning that water flows in from a width twice the borehole diameter. The apparent horizontal velocity is therefore divided by the drainage coefficient (Pitrak et al., 2007).

The resulting profile of horizontal natural flow velocity in the borehole is shown in Fig. 14. The average velocity in the entire perforated interval of the borehole is 0.054 m/day. The average velocity in the depth interval with the highest flow intensity (163–167 m) is 0.15 m/day.



note: depth range slightly incorrect (c. 3 m shift)

Figure 14: Electrical conductivity profiles in the borehole after salinization and profile of horizontal velocity of natural flow in borehole LT-H2-01.

In the future, at least 5 more hydrogeological monitoring wells will be drilled during the related SYNERGYS project (targeting Cretaceous aquifers). Tracer tests among the boreholes are planned. Together with evaluation of water tables (to determine site-scale hydraulic gradient), this should confirm velocity and direction of the water flow in the reservoir.

4.2. Hot Push-Pull Test and Geothermal Response Tests

Despite the Hot Push-Pull Test is not necessary for the BTES site development, the exploratory work done in the PUSH-IT project revealed that the Cretaceous strata have a significant potential for feasible ATES. Following the site development within the SYNERGYS project, the Hot Push-Pull Test is now planned for detailed evaluation of the ATES potential. Results of this test will be shared with the PUSH-IT consortium.

Following our colleagues from the Darmstadt BTES demonstration site where Geothermal Response Test (GRT) has been done, we will perform GRT once relevant system BTES wells are completed within the SYNERGYS project. Results of these tests will be shared with the PUSH-IT consortium.

4.3. Connection Plan

Connection of the BTES system is planned for the very end of the project and depends largely on the parallel project SYNERGYS that should provide the budget and main results. SYNERGYS project has been approved in Q2/2024 and is ongoing. Connection of BTES1 to the RINGEN building is planned for 2026. Connection to DHS is planned for the second half of the SYNERGYS project (probably 2027).

4.4. Control

Control mechanisms are planned to be designed and tested in the associated project SYNERGYS in cooperation with PUSH-IT project, once the underground installations are ready. It is momentarily planned for 2026 for the RINGEN building and for the DHN probably for 2027.

5. Monitoring System

Monitoring systems were installed in both existing boreholes according to the initial plan. Exploratory borehole LT-M5-01 is now cemented and equipped for DTS/DAS monitoring for long-term monitoring of the future BTES3 field. Hydrogeological borehole LT-H2-01 is also ready for possible well-logging campaigns during pump tests, water sampling and long-term monitoring of the BTES3 field.

5.1. Long-Term Monitoring

A fibre optic cable (enabling both DTS and DAS measurements) was installed in double-ended configuration in the full length of the exploratory borehole LT-M5-01 (down to c. ~510 m). One part of the cable was probably damaged during cementation of the borehole, so the loop is not accessible, but still the cable can be used for DTS and DAS monitoring. Two precise thermistors were also installed in both boreholes for better calibration of the DTS data. The same cable is installed behind the casing in the hydrogeological monitoring borehole LT-H2-01 (200 m).

Both boreholes and its cables are now running test measurements and are being prepared for long-term monitoring. First results from DTS monitoring are from the observed cementation of the exploratory borehole, as presented in Fig. 15.

Once completed, an optical cable loop was installed for DTS and DAS measurements up to a depth of 510 m, along with three temperature sensors at depths of 30 m, 260 m and 484 m in the borehole LT-M5-01. Finally, the borehole was cemented and sealed. Fig. 15 shows the temperature record of the cementation process in April 2025. After the borehole was flushed on April 12, cementation followed until reaching the Cretaceous sediments which were permanently cased to a depth of 189 m.

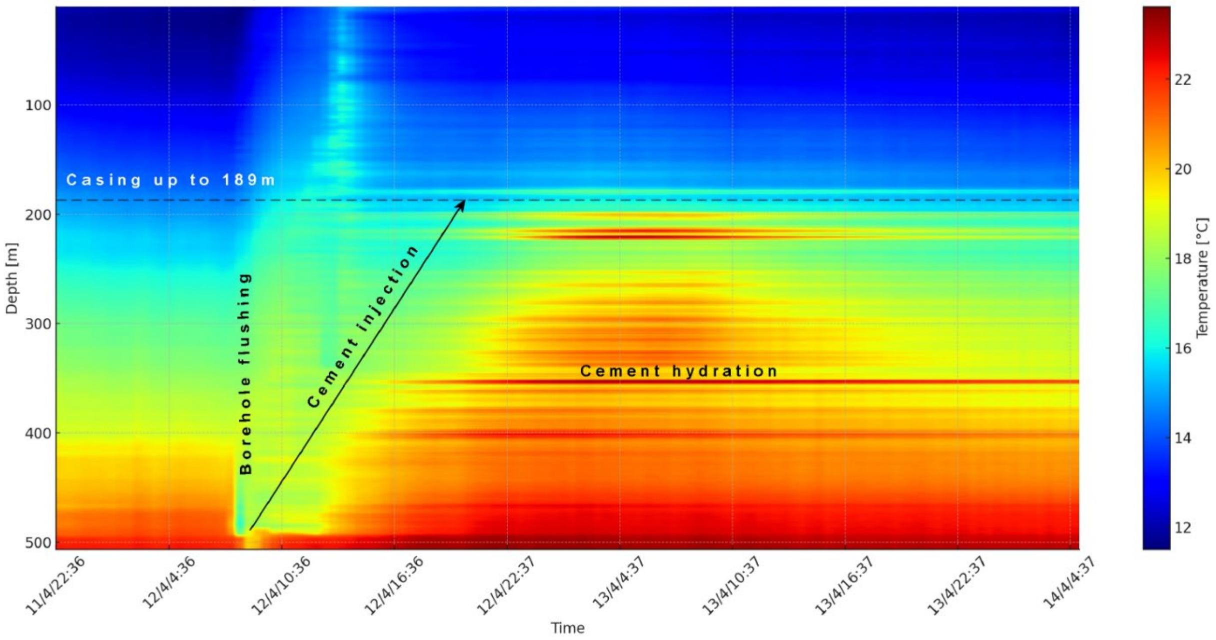


Figure 15: DTS record of the cementation of the LT-M5-01 borehole.

The 202 m deep hydrogeological borehole LT-H2-01 has a permanent plastic casing which is perforated at 140–182 m. An optical cable loop is installed behind the casing together with two temperature sensors. Cementing took place in several stages, as can be seen in Fig. 16.

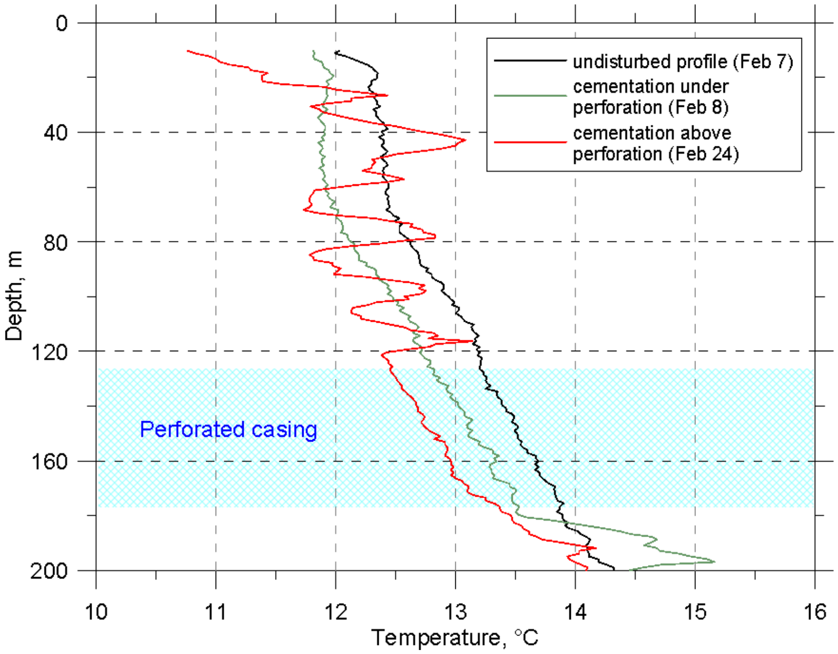


Figure 16: DTS record of the cementation of the LT-H2-01 borehole.

5.2. Hydrogeological Monitoring, Water Quality

As a part of the PUSH-IT project, even before the drilling operations at borehole LT-H2-01 began, suitable accessible sites for groundwater level monitoring were identified within approximately 1 km of the pilot location. From the Geofond ČGS database, four hydrogeological boreholes (HLN-1, HV-3, LI-1B, and LV-2) and one deep borehole (PVGT-LT1) were selected. These were supplemented by a well located in the premises of the former barracks in the immediate vicinity of the pilot site (“barracks well”) and a shallow geothermal borehole at the HENNLICH company site (HLH-1), which were not listed in the Geofond database. At these points, repeated inspections of groundwater levels were carried out between 4 September 2023 and 1 March 2024, and on 29 January 2024 they were equipped with automatic probes to record fluctuations of the water column in the boreholes. Since the probes measure the absolute pressure of the water column, a Solinst Barologger barometric probe was installed at the RINGEN facility to record atmospheric pressure for the purpose of compensating the Solinst Levelogger readings. The locations of the monitored boreholes are shown on the map in Fig. 18. Detailed information on the monitored sites is provided in Table 6.

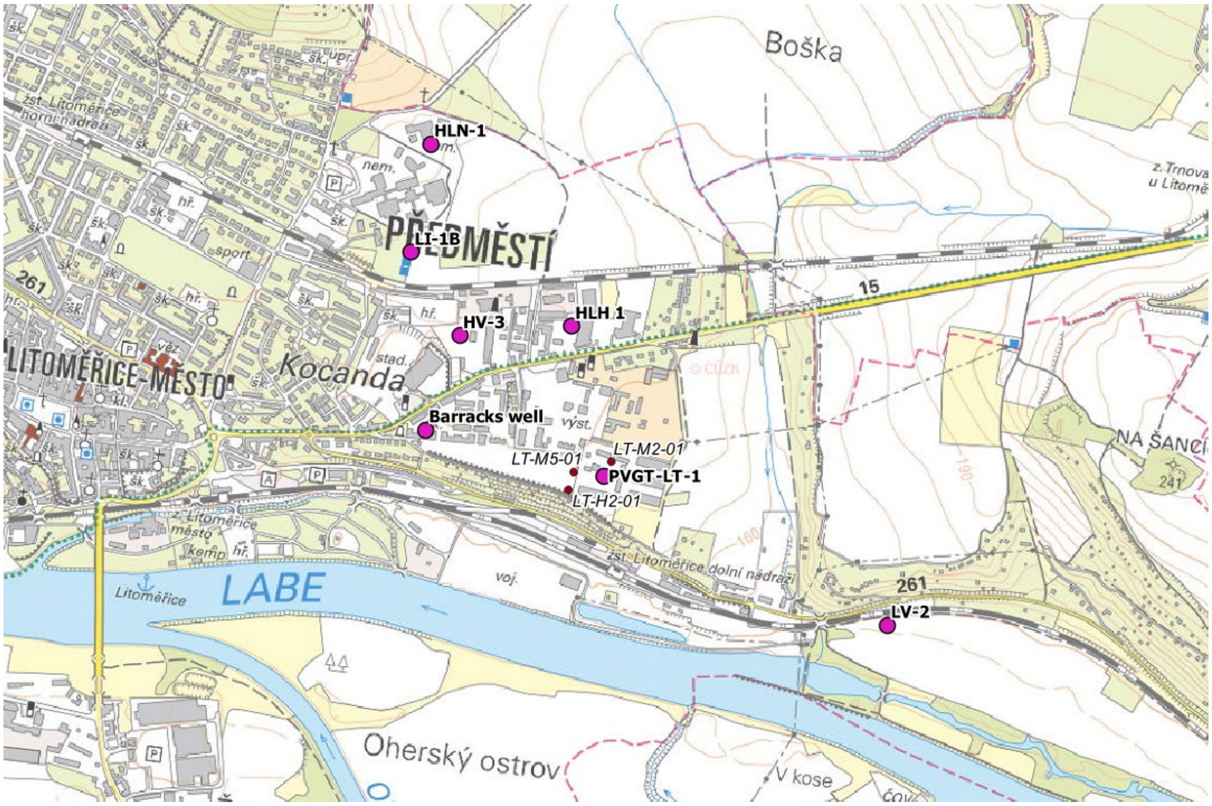


Figure 17: Spatial arrangement of the monitored wells in the vicinity of RINGEN site.

Table 6: Monitored wells in the vicinity of the pilot location. Aquifer: Q – Quaternary, T – Turonian, C – Cenomanian, PC – Permo-Carboniferous, Crystalline – Crystalline basement.

Name	X	Y	Z	Type	Depth	Inspection of groundwater level (m.a.s.l.)					Automatic levelogger type	Aquifer,Note
			m.a.s.l.		m	04.09.23	25.01.24	29.01.24	20.02.24	01.03.24		
HLN-1	990218	755298	191,71	Drilled well	131	163,60	163,56	163,61	NA	NA	Solinst	T
HV-3	990752	755217	182,77	Drilled well	165	149,67	150,02	NA	NA	NA	Solinst	T, pumped
LI-1B	990520	755353	187,6	Drilled well	186	148,81	148,90	NA	NA	NA	Solinst	T + C
HLH 1	990726	754904	178,23	Drilled well	120	145,92	144,06	144,13	NA	NA	Solinst	T, pumped
LV-2	991560	754023	146,9	Drilled well	171	144,50	144,29	144,27	NA	144,05	Solinst	C
PVGT-LT-1	991144	754815	173,45	Borehole	2111	NA	152,34	152,29	152,42	152,53	Fiedler	PC+crystaline
"Barracks well"	991015	755312	174	Dug well	29	145,35	146,44	146,45	146,45	NA	Solinst	Q + T

Samples of water will be regularly taken to monitor changes in water quality. The physical and chemical properties (electrical conductivity, pH, Eh, O_2 content and temperature) will be monitored during this operation and groundwater for chemical analyses will be sampled and interpreted together with PUSH-IT partners in the next stages of the project. Following analysis are planned:

1. chemical composition of water (will be done by CGS): major elements (Na, Ca, Mg, K, SO4, Cl, HCO3, NO3, NO2) and trace elements (Fe, Mn, Al, Si, total sulphur, …). Total Organic Carbon (TOC) and phosphate concentration will be determined.
2. chemical analyses of dissolved gas (if present in groundwater) in a sufficient amount allowing to collect the gas sample.
3. microbiological characterization: sampling of waters and analysis.
4. scaling potential

6. Public Engagement, Social Benefits and Risks

6.1. Public Engagement

The public engagement activities have followed a well-established communication and general setup from the previous years. During the early phase in 2023, several internal meetings with local politicians were carried out and preparation of the drilling works, and other activities of the project were presented.

At the end of February 2024, a press conference took place at Litoměřice RINGEN site, as the drilling of the PUSH-IT exploratory borehole was officially launched. This event led to opportunity to invite local stakeholders and presentation of the geothermal projects not only to the audience present onsite, but also via TV, newspaper, radio and Czech News Agency. The event was covered by national, regional as well as local media and provided a great visibility to the project, its goals and activities but also problems and obstacles that the geothermal sector faces in Czechia and other parts of Europe.

One of the most visible scientific events was the PUSH-IT General Assembly organised in December 2023. The meeting took place in Prague and Litoměřice and created a great opportunity to share experience among this broad scientific team. About 40 members of the PUSH-IT team visited the RINGEN research centre in Litoměřice and the drilling site and had the opportunity to see the future BTES location.

Drilling works and the area of geothermal projects in Litoměřice were also presented in two separate student excursions during March 2024 to geoscience students of the Faculty of Science, Charles University. Group of students from TU Delft arrived at the Litoměřice site to work on their “Geoenergy project” for 2 months in autumn 2023. They worked on various measurements (geophysical survey, hydraulic tests, thermal properties of rock samples) and compiled the final report, which was successfully defended.

After the restart of drilling operations in January 2025, several excursions were organised at the RINGEN for representatives of the various target groups. In March 2025, a field trip for students of geology of Charles University, excursion for representatives of local municipal politics and for representatives of the business community took place. From January to April 2025, four school groups visited the site.

Each time a lecture on the PUSH-IT project was followed by a tour of the laboratory of geothermic and the drill site, to inform visitors not only about the principles and advantages of UTES, but to show them the scientific and practical context of its implementation.

In May 2025, an Open Day was organised at RINGEN - the most important event of this year for the general public. More than 100 visitors were informed about the PUSH-IT project and about news on the site, including the drilling of two pilot PUSH-IT boreholes. Apart from the presentation on the project and the visit to the geothermal laboratory, the samples of the newly extracted core were shown and commented on by the members of the research team.

In May 2025, a PUSH-IT online webinar on "Co-creating the PUSH-IT engagement catalogue" was held, where we shared our experiences with organizing public events and with creating content for the web and social media in cooperation with the scientific team.

In June 2025, we participated at the Geology Day at the Czech Geological Survey. During the event, a roll-up and flyers of the PUSH-IT project were exhibited in the CGS area. For next year, we are planning more active participation at this event, including face-to-face interaction with visitors. The same model of dissemination was chosen for the Night of Scientists – event held at UJEP Ústí n. L. in September 2024. The information about these events (the Geological Day and the Night of Scientists) was spread through our web and social media channels.

Alongside these activities, the PUSH-IT project was promoted in several types of media, from articles and videos on the web and social networks to articles and reports in traditional media. During spring 2025, the entire drilling process and geothermic analysis of the core were documented in three video reports. These reports were shared on LinkedIn and YouTube channel, having approximately 500 views in July 2025.

In June 2025, two articles including information about the PUSH-IT project were published in the magazines Panorama of the 21st Century and Přírodovědci.cz. Four reports were also published on regional radio and TV, documenting the progress of the drilling operations, its successful completion and laboratory analysis of the core.

6.2. Regulation and governance

The PUSH-IT and SYNERGYS projects are ongoing and do not have any direct impact on the regulation processes yet. We have done interview with regulatory stakeholders and conduct policy analysis as described in the Litoměřice Workplan (Peřestý et al., 2023, D1.1). However, we will continue to evaluate and attempt to reduce the potential regulatory barriers.

6.3. Finances

The PUSH-IT project provided budget for the drilling of the two pilot wells. Despite of the issues with the tendering procedure and during the realisation, leading to the need to change the contractor, the planned boreholes have been drilled and the overall costs of drilling works stayed in the planned budget.

The main BTES activities (especially drilling of the BTES field of c. 16 wells 500 m deep) will be funded from ongoing project SYNERGYS, which was approved for funding in Q2/2024. Cost data provided during implementation of the pilot wells as well as the other planned system wells can serve as an input in the LCOE (Levelized Cost of Energy) analysis that will be implemented within SYNERGYS project and shared with the PUSH-IT consortium.

7. Conclusions

Drilling of two pilot boreholes in Litoměřice was the main task for this site within the PUSH-IT project. The drilling works have been and successfully completed in May 2025, after long-term tendering process and necessary change of drilling contractor. Currently, we obtained detailed information on the properties of rock formations down to depth of future BTES3 field (500 m), borehole stability potential, fracture densities and thermohydraulic properties. The hydrogeological properties of the main Cretaceous aquifer have been studied, and its long-term monitoring and testing is granted through the successfully implemented and accessible hydrogeological well. The PUSH-IT and the RINGEN site in general, as well as the PUSH-IT parts in Litoměřice more specifically, were presented in the media and the results have been used in students’ education and in scientific output. Further research will focus on additional data processing and interpretation, as planned in the next stages of the PUSH-IT project. The above presented installation report, commissioning, data and lessons learned from the borehole implementation represent a fundamental knowledge for de-risking of future Litoměřice follower BTES site development, which is the key target of the PUSH-IT project.

8. References

Peřestý et al. (2023), D1.1 - Litoměřice Workplan, PUSH-IT project.

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The EU aims to have a net-zero greenhouse gas (GHG) economy by 2050, with 55% reduction on 1990 levels by 2030. At present, heating and cooling represent around 50% of the final energy demand in Europe and are mainly supplied by fossil fuel derived energy. It is therefore essential for heating and cooling to decarbonise to achieve EU ambitions.

A challenge for decarbonizing heat systems is the size of the seasonal mismatch between demand for heat and heat generation from sustainable sources – this mismatch is much larger than the equivalent intermittency in electricity supply and demand. The two main solutions to address this mismatch are: (i) to install a large capacity, so that peak demands can be met even at low production levels; or (ii) to store energy for later use if it is not needed at time of conversion. Many sustainable heat supply systems are characterised by high capital expenditure and low operational costs. Therefore, an installed capacity tailored at peak demand is not cost effective, while extending the annual operation period is advantageous for meeting energy needs, reducing levelised cost of energy (LCOE) and decarbonisation. Optimal utilisation of sustainable heat requires storing large amounts of heat to account for seasonal supply and demand fluctuations. Various technologies have been proposed for large-scale heat storage in geothermal reservoirs and low temperature storage is routinely applied. PUSH-IT focuses on extending storage temperature ranges to high temperatures. We will tackle remaining barriers, demonstrate applicability, increase public engagement, and optimise and de-risk operations. We will showcase three technology options that are fit for a wide variety of geological conditions covering most locations in Europe.

PUSH IT

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