Multidisciplinary approach to assess the Cambrian geothermal potential in Brussels region with a focus on public buildings (GeoCamb project)

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Keywords: Geothermal Energy, Monitoring, Long term performance, Geophysical investigation, Geological and hydrogeological exploration, Environmental Impacts, Brabant Massif.

ABSTRACT

Below the Brussels Capital Region (Belgium) and the surrounding areas, Meso-Cenozoic soft sediments cover the hard and deformed Cambrian metasediments of the Brabant Massif. Traditionally, most of the existing shallow geothermal systems are installed in the sedimentary Mesozoic-Cenozoic cover, however, the depth of the Palaeozoic bedrock in this region (from 0 to 200 m) is adequate for the installation of both open- and closed-loop geothermal systems (Lagrou et al., 2019). Ongoing exploration drillings in Brussels demonstrated the high potential and efficiency of the Cambrian core of the Brabant Massif for geothermal systems. This high potential led to more feasibility studies for the exploitation of the Cambrian basement during the past years and more extensive research is currently conducted in the GeoCamb project with as aim to enhance the geothermal sector development and incorporate it in public buildings. Geological, hydrogeological and geophysical explorations are ongoing in public case-studies and several win-win cases. In this study we report on a multidisciplinary approach including many analyses conducted on lithology, mineralogy, and geophysical and thermal characteristics of the Cambrian basement and its weathered top.

1. INTRODUCTION

In 2019, the Belgian Science Policy approved the project “GeoCamb : Geothermal Energy potential in Cambrian rocks focusing on public buildings” (GeoCamb : https://www.belspo.be/belspo/brain2-be/project_p1_en.stm#GEOCAMB) which will run until 2024. The BRAIN-be 2.0 program (Belgian Research Action through Interdisciplinary Networks) funded a budget of 1 M€ for this project in order to support the sustainable exploitation of renewable natural resources and reduce CO_2 emissions. In Belgium, the heating and cooling sector counts for 52% of the total use of energy (165 TWh) (Heat Roadmap Europe, 2017). (Heat Roadmap, 2015). In this respect, the GeoCamb project focuses on investigating the geothermal potential of the Cambrian basement of the Brabant Massif (BM) in Brussels and its surroundings in order to advise the potential transformation of the main heating source of public buildings. A partner consortium was formed, including two federal institutes: the Geological Survey of Belgium (GSB) and the Royal Observatory of Brussels (ROB); the University of Brussels (ULB) and the University of Ghent (UGent-LTGH), and the Belgian Building Research Institute (BBRI).

In Belgium, shallow geothermal energy (SGE) systems are mainly installed in the Mesozoic-Cenozoic soft cover sediments up to a depth of 100 to 150 m. Considerable thicknesses of these soft sediments are only present in the northern part of the country. More south, their thickness quickly decreases and hard rocks like the Cambrian basement of the Brabant Massif are encountered closer to the surface. SGE projects in these older and harder geological layers are currently very limited in the northern part of the country, mainly due to a lack of knowledge and technical constraints. In southern and western part of Brussels, the thickness of the Mesozoic-Cenozoic sediments varies from 0 to about 60 meters. This means that for two-third of the territory, SGE systems have to be installed in the bedrock to fully exploit the SGE potential. On the other hand, there is a huge thermal energy demand in the Brussels region from office and residential buildings (3.525 TWh for heat demand and 1.419 TWh for cooling demand) (Lempereur et al., 2021). The overall heat needs (i.e. the total heat demand) (9.57 TWh) represent 60.6% of the total energy demand of the 3 sectors (industry, tertiary and residential sectors), all types of demand combined (Lempereur et al., 2021).

Geological, hydrogeological and geophysical explorations are ongoing in two public case studies and several win-win cases with external partners. The win-win approach consists of the execution of extra tests and analysis of the monitoring data of existing geothermal projects (both open and closed systems). Today, the GeoCamb project can rely on 20 sites: 2 piezometers, 2 case studies and 16 win-win cases. Among them, 3 win-win cases were studied in the framework of the Brugeo project (2016-2020) which was funded by the Brussels ERDF (European Regional Development Fund). The aim of Brugeo was to facilitate accessibility and the efficient use of shallow geothermal energy in the Brussels-Capital Region specifically for commercial and residential sectors (Petitclerc et al. 2021). A geoscientific and geothermal WebGis platform was developed: *BrugeoTool (2020)*. In the scope of Brugeo, an exploration drilling in Anderlecht, Brussels (Fig. 2) was conducted by the Geological Survey of Belgium in 2016 and confirmed that the hydrothermal potential of Cambrian core of the BM should certainly be emphasized (Petitclerc et al. 2019, 2020). From 2016, 18 private cases reaching the Palaeozoic basement followed and were closely investigated (17 open systems and 1 field of closed system).

The Cambrian bedrock is (i) highly heterogeneous, (ii) strongly folded and faulted, and (iii) the intense weathering and deformation episodes have affected the upper part of the basement. Before encountering the unweathered bedrock, a weathered layer of a few meters up to more than 60 meters in thickness is observed in almost all sites. This weathering zone consists of clay, silt, sand, weathered siltstone and sandstone, quartz veins, faults and cavities which can have serious implications on the design, budget and risks of exploration drillings. To have a better understanding of the Cambrian basement and to de-risk geothermal feasibility studies in the future, currently not only the top of the basement, but also the thickness and lithology of the weathered zone are investigated with lithological, hydrogeological and geophysical methods. On the scale of a potential geothermal borehole, alternation of beds, lithology, stratigraphy, permeability, depth and fracturing are unknown or have a large uncertainty, even though the basement is relatively close to the surface along the southern part of the Brabant Massif. In parallel of the geothermal reservoir evaluation, the energy demand of specific public buildings is incorporated in the case-studies to maximise the efficiency of the system.

In this paper, the status, the actual conclusions and the perspectives of the two public case-studies (European Paul Henry Spaak (PHS) building and Molenbeek social buildings) and the successful installation (2020) of the open geothermal system of the Gare Maritime (Fig. 2) are described.

2. GEOLOGICAL AND HYDROGEOLOGICAL BEDROCK INVESTIGATION

2.1 Geological investigations

The Anglo-Brabant slate belt (further referred to as the Brabant Massif; BM) is a Lower Palaeozoic deformation that extends from central Belgium, below the North Sea, to the center of the UK. In its southern rim, the BM is exposed along the flanks of incised river valleys. The top of the BM dips to the North (Figure 1) and reaches a depth of 1000 m at the Belgian-Dutch border.

In Belgium, the core of the Brabant Massif is composed of Cambrian heterogeneous metasedimentary formations flanked by Ordovician and Silurian rocks. Boreholes, outcrops and potential field data (Figure 1) allowed to map the BM. A few magmatic intrusions are present along the BM's southern flank. Chalk (Cretaceous), sands, silts and clays (Neogene/Paleogene), and loess (Quaternary) cover the Lower Palaeozoic units. In Brussels, the Cambrian series are represented by the Tubize Formation, i.e., alternating quartzites and slates, and the Blanmont Formation, which predominantly consists of series of medium-grained quartzites. The Cambrian bedrock is highly heterogeneous, strongly folded and faulted. Successive intense weathering and deformation episodes have affected the upper part of the basement. The paleorelief of the BM was shaped by the combined effect of the Brabantian deformation and repetitive phases of uplift following the erosive phase during the end of the Late Cretaceous-Early Cenozoic (Danian) (Van Noten et al. 2022). In the central and northern part of Brussels, a Cretaceous chalk is present above the Palaeozoic basement. Most of it was eroded during the Middle Paleocene uplift of the BM (Deckers & Matthijs, 2017). In the Brussels capital region, 50 to 150 m Cenozoic soft sediments overlie hard and massive rocks (Devleeschouwer et al., 2018). **Erreur ! Source du renvoi introuvable.** illustrates that the Hannut (upper Paleocene) and Kortrijk Formation (early Eocene) entirely cover the Palaeozoic basement with gravel and clayey silt sediments, respectively. The topography of the eastern part of Brussels is explained by the succession of the sandy Brussels Formation, the sandy to clayey of Sint-Huibrechts-Hern Formation (late Eocene–early Oligocene), the clayey sandy Maldegem Formation (late Eocene) and the sandy Lede Formation (middle Eocene) (Van Noten et al. 2022).

The location of the 3 cases described in this paper is illustrated in Figure 2. The cases are briefly presented in the next paragraphs.

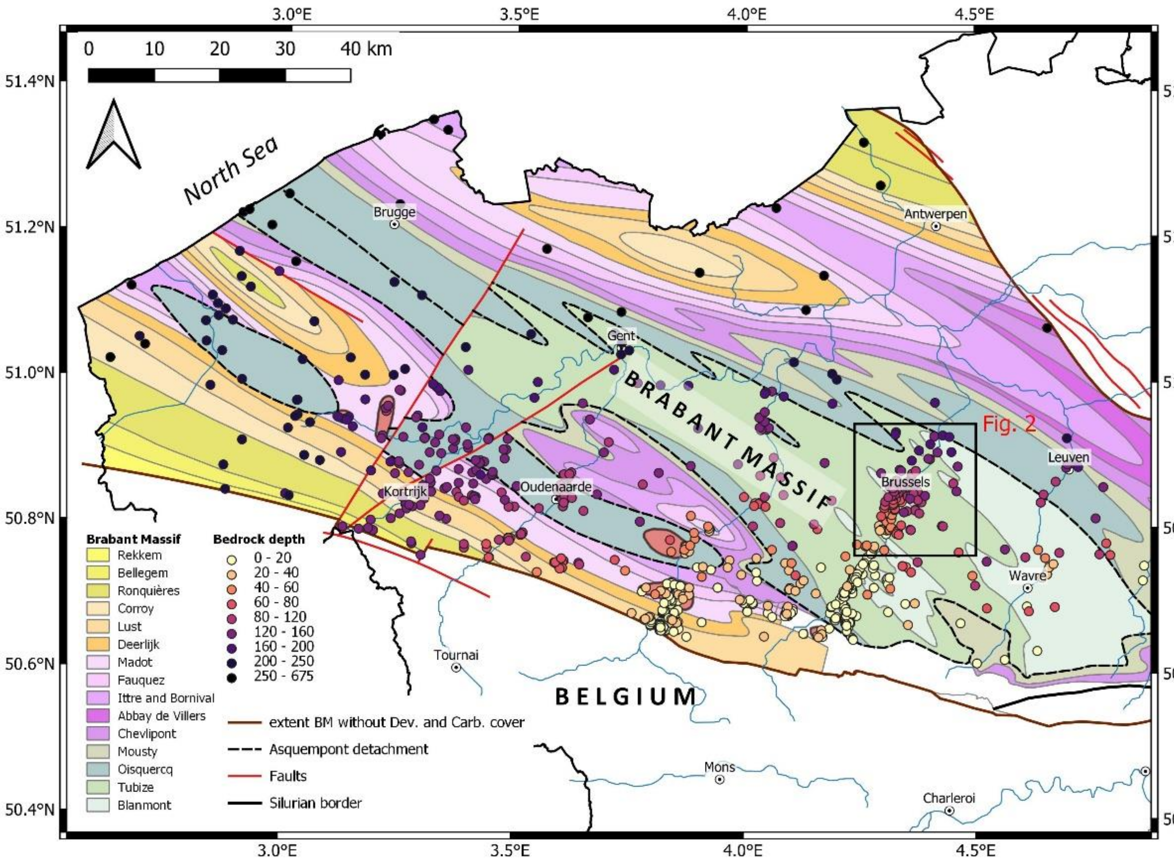

Figure 1 : Geological subcrop map of the Brabant Massif (BM) with main lithologies and the localization of boreholes (dots) from which the main bedrock depth is derived (Van Noten et al. 2019 after Piessens et al. 2006). In the GeoCamb project, the Brussels region is targeted (see square) where the Cambrian Tubize and Blanmont formations are mainly present in the subsurface.

Gare Maritime, Brussels

In 2020, an open geothermal system was installed at the Gare Maritime, located on the Tour & Taxi site North of the center of Brussels. The system is composed of 5 doublets installed in the Cambrian bedrock, making it the first open geothermal system in the Palaeozoic basement in Brussels. The top of the BM bedrock varies in a unpredictably way as it is reached between 82 and 100 m (Fig. 8B) depth depending on the location. The flow rate observed at the wells ranges from 15 to 75 m^3 per hour, but the total flowrate of the 5 doublets reaches 180 m^3 per hour. One of the boreholes was deepened from 150 to 200 m depth by the Geological Survey of Belgium in order to analyze the evolution of the flow rate. No increase of the flow rate was observed. Recently, data loggers were installed in each well to monitor both the hydraulic head and the water temperature. This project was a win-win case in the Brugeo project and the monitoring data of the geothermal system will be analyzed during the GeoCamb project. 2 other geothermal open systems are installed in the sedimentary Mesozoic-Cenozoic cover, 300m away from the Gare Maritime site. Monitoring through the dataloggers will help to evaluate the possible inference between the 3 close located geothermal installations.

Paul Henri Spaak Building, Brussels

The first case study in the GeoCamb project is the Paul Henri Spaak (PHS) building located in the center of Brussels (Fig. 2). Four wells were drilled between 2020 and 2021. The aim is to study the geothermal potential for the decarbonization of the heating system of the building. The boreholes reach a depth of 190 to 210 m, with the BM bedrock encountered at 120 m depth. An Enhanced Thermal Response Test (ETRT), carried out by means of a hybrid cable consisting of copper heating wires and an optical fiber temperature sensing cable, was realized in one of the boreholes in order to determine the soil thermal conductivity, the soil undisturbed temperature and the thermal gradient. The results of this test are shown in figure 3. Between 50 and 200 m depth, the temperature evolves from 12.5 to 13.5°C. The thermal conductivity is about 2 W/m.K in the Cenozoic upper layers and increases in the Cretaceous layer up to 3 W/m.K. A peak of almost 4 W/m.K is reached in the upper part of the weathered Cambrian around 125m depth. Below that depth, the values range from 2 to 4 W/m.K. One of the boreholes was deepened to 301 m, becoming the deepest borehole in Brussels. This operation was done in the search for zones with higher permeability and thus to increase the geothermal potential. Nevertheless, 13 m^3 per hour is

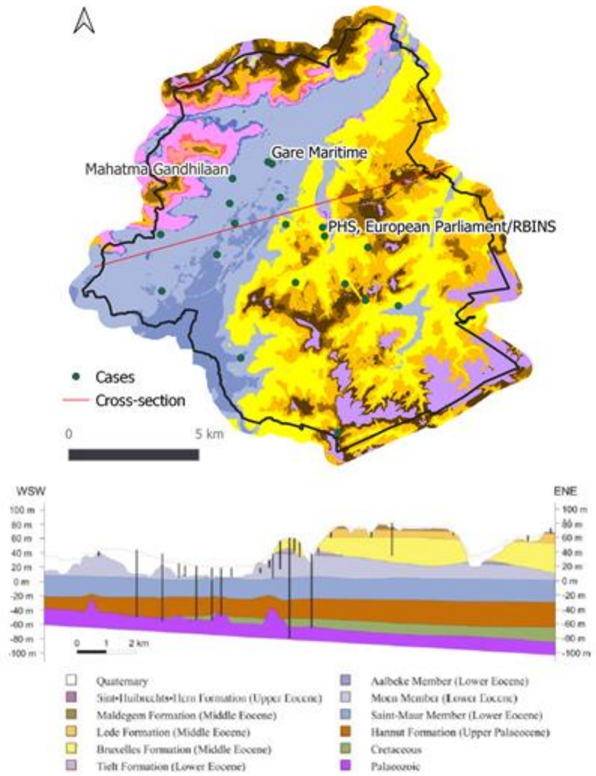

Figure 2 : Geological map of the Brussels-Capital Region with the location of the case studies. The 3 cases detailed in this paper are labeled on the map. The boreholes located on the geological section are illustrated by vertical bars (modified after Buffel & Matthijs, 2002; Devleeschouwer et al., 2018).

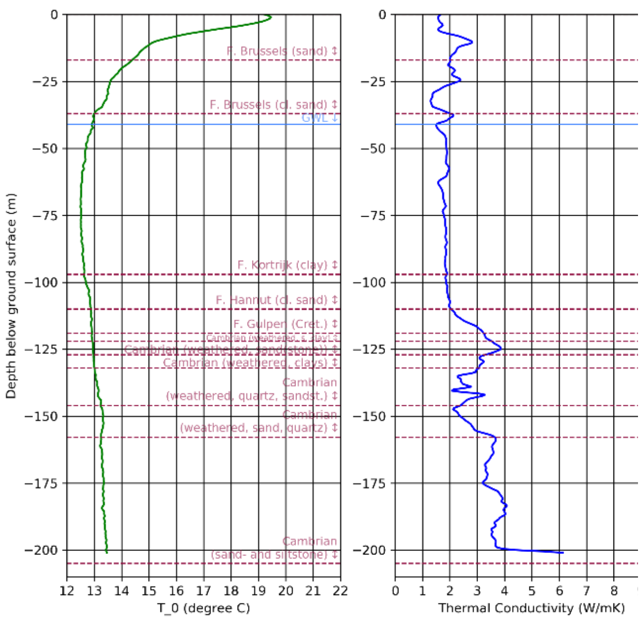

Figure 3: Results of the ETRT measurement at the Paul Henri Spaak building. The interface between the different formations is illustrated by the red dotes lines. Left: evolution of the temperature with depth. Right: evolution of the thermal conductivity with depth.

the maximum flow rate obtained on this site after all the hydrogeological investigation (pumping, injection and tracing tests). Compared to the average yield found in the Cambrian of Brussels, the results will not be able to cover the needs of the building. To illustrate this, up to now only 3 geothermal projects out of 21 conducted in and around Brussels did not reach the expectations. More efforts have to be conducted to decrease geological uncertainty of this fractured reservoir.

Mahatma Gandhilaan, Molenbeek, Brussels

The second case study of the GeoCamb project focuses on a social housing complex of Molenbeek. It is planned to carry out in 2022 a core drilling during the exploration operation in the Palaeozoic basement. The geological and geothermal exploration borehole will be equipped with a piezometer with a filter element at the base. A hybrid cable consisting of copper heating cables and an optical fiber temperature sensing cable will be installed in order to carry out an ETRT.

Perspectives

A few drilling site follow up are still planned in the scope of this project. The nature and the composition of the collected samples are currently being described and the borehole description is entered in the borehole database of the Geological Survey of Belgium. The mineralogy characterization (X-Ray diffraction and EBSD, electron backscatter diffraction) will also be conducted to investigate the Tubize formation properties. These analyses will also allow to understand the thermal properties variability of the different lithologies (quartzites and sandstones) in relation with their silica content and texture.

2.2 HYDROGEOLOGICAL INVESTIGATION

Hydraulic characterisation of the Cambrian aquifer

Hydraulic characterization of aquifers is a key point for estimating their potential for operating open geothermal systems. Indeed, aquifer transmissivities control the amounts of water that can be pumped from and injected into aquifers. The best way of deriving in situ hydraulic parameters is by means of pumping tests, and preferably in configurations that also include observation wells at different distances, but these facilities are expensive and rare. More often pumping tests are followed up in the pumping well only. The problem is that drawdowns in the pumping wells do not depend only on the hydraulic parameters, but also on the well efficiency. More often static (pre-pumped) and dynamic (during pumping) water levels are available after drilling wells, when a test pumping is performed, just to check the yield of the drilled well. As pumping tests always give local transmissivity values, regional patterns and trends in transmissivity should be based on more than a few pumping test results. An important question is the spatial correlation scale of transmissivities in the Cambrian aquifer as this defines the distance over which individual point values can be interpolated. Static and dynamic water levels were collected in the study region and used to calculate specific well yield. Specific well yield can be used as a proxy for transmissivity as both show a correlation using a power law relation, with equation coefficients dependent on lithology (Alfarrah et al., 2013). The obtained specific well yields were plotted on a map (Fig. 4). There is wide range in the transmissivities between only a few m^2/day to nearly 250 m^2/day, but spatial correlation may be rather limited.

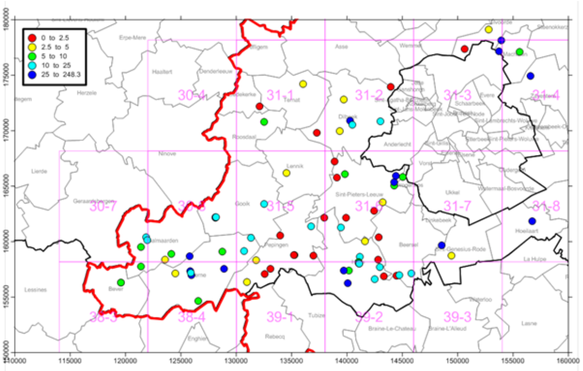

Figure 4 : Values of the specific well capacity (in m^2/day) derived from static and dynamic water levels in pumping wells as an indicator of the transmissivity of the Cambrian aquifer.

Groundwater flow and hydrodynamics

Piezometric time series were collected and analyzed to investigate groundwater flow and hydrodynamic response of the Cambrian aquifer. Special attention was given to the hydraulic connection between the basement aquifer and the overlying tertiary layers. Recharge of the deep aquifer depends on the vertical water fluxes that exist between the shallow and the deep layers. Most interesting are observation wells that have screens in multiple aquifers. These monitoring wells allow to compare water level variations in the Cambrian aquifer with fluctuations in the overlying tertiary layers. Differences in water levels and response of the deep aquifer to the seasonal cycle in the shallow aquifer give an indication of the vertical hydraulic connection between the different layers.

One series (Fig. 5) is located in Bierbeek (near Leuven, SE of Brussels) and shows that the piezometric levels in the overlying aquifers in the Hannut and Brusselian formations are significantly higher than the piezometric level in the Cambrian, suggesting the Cambrian may here be recharged with a water flux coming from above. The highest piezometric levels occur in the upper aquifer, which is the Brusselian sands. Levels in the Landenian (Hannut) aquifer are a few meters lower while there is a difference of more than 50 m with the Cambrian basement aquifer. The hydraulic connection is apparently good enough to allow the propagation of seasonal fluctuations into the Cambrian, although the seasonal signal is damped and superposed on a multi-year variation. Remarkable is the declining trend since 2017. The summers of 2007 to 2010 were very hot and dry, resulting in generally low piezometric levels in phreatic layers. Apparently, this trend has also propagated from the shallow layers into the Cambrian basement layer. It proves there is a significantly good hydraulic connection between the Cambrian and overlying layers.

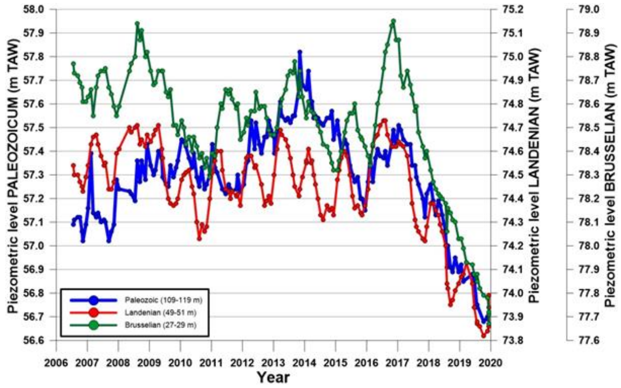

Figure 5 : Evolution of piezometric levels in the Cambrian basement aquifer and the overlying tertiary layers (from 2006 to 2020) in Bierbeek (near Leuven, SW of Brussels)

A second series (Fig. 6) in Hoegaarden (near Tienen, SE of Brussels) has two well screens at different depths in the Cambrian aquifer. Between the two screens is a depth difference of around 30 m, but both wells have nearly the same piezometric level. This series is around 24 years long and can be used to see long time trends. In the basement aquifer levels have risen between 1996 and 2017, only the last dry years have introduced a recent decline. The rising trend may be due to decreasing exploitation in this region. The overlying tertiary layers have nearly the same piezometric level, but do not show the same trend. In all 4 wells screens, seasonal fluctuations can clearly be recognized.

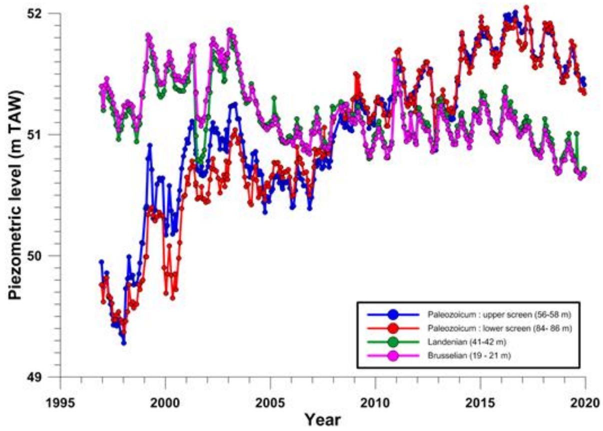

Figure 6 : Evolution of piezometric levels in the Cambrian basement aquifer and the overlying tertiary layers (from 1996 to 2020) in Hoegaarden (near Tienen, SW of Brussels)

To create piezometric maps and derive regional flow patterns, a monitoring network is needed. In the Flemish part of the study region the Flemish administration has a number of observation wells in the Palaeozoic basement, which are measured biweekly. In the capital (Brussels) itself, only a few deep wells exist.

Groundwater flow models are important tools as they produce piezometric distribution over the whole model area. In the western part of Flanders, a regional groundwater flow model of the deep aquifers system, including the aquifers in the Palaeozoic basement, Cretaceous and Hannut formations, has already been implemented around the year 2000. The model includes the western part of the Flemish-Brabant province. It was used to simulate the predevelopment situation and the whole history of exploitation since 1920 (Van Camp et al., 2000) and some recovery scenarios (Van Camp and Walraevens, 2009). More recently, the Brussels Capital Region has started the development of three separate groundwater flow models, which also include the surrounding region of the capital. The BPSM model (Aquale, 2016), already finished in 2016, includes the upper tertiary deposits which are mainly phreatic. A separate model (Agniel, 2020) was made for the Landenian (Hannut) aquifer (finished in 2000) and another one (BCSM) including the semi-confined deeper layers, including the Cambrian aquifer, is planned for the near future.

3. IDENTIFICATION OF THE BEDROCK DEPTH USING PASSIVE SEISMOLOGY

In the geophysical part of GeoCamb, non-invasive geophysical methods are used (i) to predict the local bedrock depth to the Brabant Massif below buildings of interest, and (ii) to laterally extrapolate geological information received from the newly-drilled geothermal wells. We rely on ambient seismic noise measurements recorded by three-component geophones (SmartSolo® IGU-16HR seismic nodes). These sensors are beneficial in dense urbanized areas as their modular design allows node installation in a variety of sites both with soft and sealed surfaces.

To predict bedrock depth, we investigate horizontal-to-vertical spectral ratios (HVSR) of ambient seismic noise recorded at sites where drillings are already in place or next to public buildings where people have an interest in installing a geothermal system. The HVSR method consists of applying a Fourier transformation of seismic vibrations recorded in three dimensions by each component of the geophones and computing the ratio of the horizontal (H) over the vertical (V) spectrum. When soft sediments cover the bedrock, the difference in seismic velocity of vibrations between soft sediments (slow) and bedrock (fast) causes an acoustic impedance contrast that is detected by HVSR. HVSR analysis results in a frequency – amplitude diagram in which the impedance contrast is shown by the large amplitude peak at the resonance frequency (Fig. 7B). At each GeoCamb site, converting resonance frequency to depth using an empirical scaling law specifically developed for Brussels (Van Noten et al. 2022) provides a first-order, cost-efficient approach to determine bedrock depth prior to drilling. The depths obtained by HVSR correspond well to depths obtained from co-located wells, with depth uncertainties below 10 m. This information is valuable for other GeoCamb partners focusing on the hydrogeology of the Brabant Massif and interpreting measured flow rates.

The HVSR results are illustrated by three examples (introduced in chapter 2.1) showing predicted bedrock depths below the Gandhilaan social buildings (Fig. 7), PHS European Parliament building (Fig. 8A), and the Gare Maritime (Fig. 8B). For each of these sites, the figures show the frequency-amplitude diagram and a virtual borehole that translates resonance frequencies into bedrock depths using the aforementioned scaling law, including their depth uncertainty.

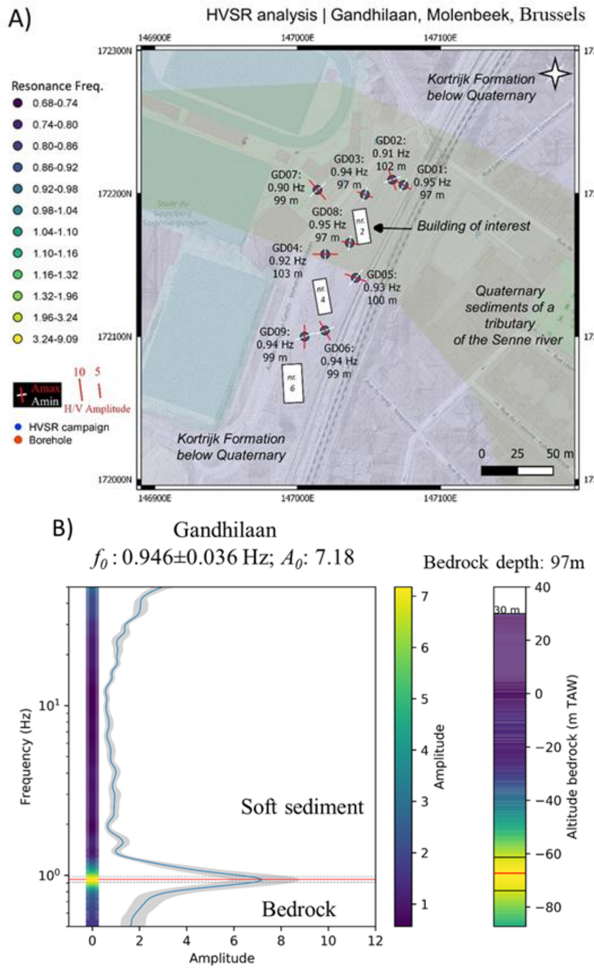

Figure 7 : A) Map showing bedrock depth variability, detected by HVSR, around the social buildings of the Gandhilaan. B) Detail of an HVSR frequency-amplitude curve showing resonance frequency (f0) at the large amplitude peak. The entire curve is converted to depth resulting in a virtual borehole (right) with the red line indicating the transition from soft sediment to bedrock.

The transition between the soft Cenozoic sediment layers and the metamorphic Lower Palaeozoic bedrock is marked by a strong impedance contrast that is sharp along its erosional surface. The thickness of the weathered top of the Brabant Massif bedrock can reach up to several tens of meters, making this weathered layer of particular interest for geothermal purposes because of its higher hydraulic conductivity relative to the unweathered bedrock. Correlating resonance frequency and well data shows that the H/V reflector corresponds to the interface between sediment and top weathered layer, rather than to the base of the weathered layer and the intact bedrock. The reason for this observation is that the strongly-fractured weathered layer has a much higher density than the overlying sediments, causing the clear impedance contrast seen by HVSR. This conclusion complicates the interpretation of the thickness of the weathered layer from single-station, non-invasive geophysical data alone. Future efforts will focus on array seismology to create velocity profiles at those places where the geothermal test wells indicate a thick weathered layer to strengthen our single point H/V observations.

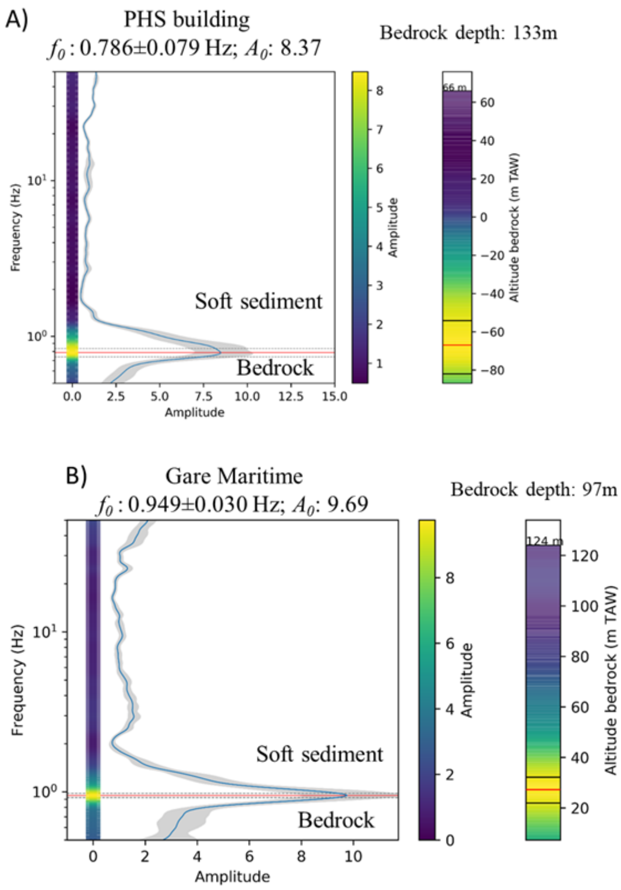

Figure 8 : Virtual boreholes obtained from HVSR analysis near the A) PHS European building and B) Gare Maritime case studies.

4. POTENTIAL AND PERFORMANCE OF GEOTHERMAL SYSTEMS

GeoCamb also aims to investigate the geothermal potential for a series of case studies, starting from the building heating (and cooling) needs, but focusing on the potential for the geothermal systems. Two of the case studies were presented in paragraph 2.1 (PHS office building and a social housing complex in Molenbeek). For the social housing complex dynamic simulations are performed to model the heating needs over the year. This is done for the current situation (so the model could be fit to energy measurements) and 2 levels of renovation, resulting in different temperature levels for the emitters and leading towards different performances of the heat pumps. For all the selected cases an evaluation of the geothermal potential will be executed and the potential of both open and closed systems will be addressed, as well as the benefit of drilling into the bedrock. These case studies will be described in detail during the project so that they can serve as a guide for future projects.

Apart from the case studies, GeoCamb also wants to assess the performance of existing geothermal systems in the Brussels region, especially those exploiting the Cambrian basement. In this respect, the Tour and Taxis site in the north of Brussels is a very interesting site to focus, as three open geothermal systems are operating close to each other. Two systems are installed in the Hannut Formation (i.e. the Brussels Environment building and the Herman Teirlinck building). The most recent system is the one of Gare Maritime with 10 wells in the bedrock (see also Section 2.1). Collection of monitoring data is still ongoing. This data will be analyzed later in the project and the insights will be reported.

Another interesting case is about an office building in the center of Brussels. The heat and cold production of the building is partly supplied by a closed geothermal system installed in the bedrock, which is reached at a depth of about 110 m. A first analysis of the available monitoring data (2018-2021) showed that the average annual heat production of the geothermal system was about 412 MWh for a design heat load of 600 MWh/year, while the average cool load was only 2.4 MWh for a design cool load of 300 MWh/year. Nevertheless, during this period (2018-2021) the average annual cooling demand of the building accounted for more than 850 MWh. The limited cooling supply by the geothermal system appears to be caused by the control settings, bypassing the free geocooling when the fluid return temperature is higher than 14°C. Moreover, the fluid temperature in the beginning of the cooling season is higher than in the design calculations, as the actual heating load is about 30% lower than designed. These factors drastically reduce the free geocooling capacity. Several proposals have been done towards the asset manager of the building in order to maximize the use of the available geothermal capacity, amongst others:

- Adapt the control settings and increase the fluid return temperature limit from 14°C to 16°C before bypassing the free geocooling.
- Investigate if the geothermal source can be deliver heat to other parts of the building in order to increase the heat load. This will also have a positive influence on the cooling capacity, as fluid temperatures will be lower in the beginning of the cooling season.

This case and the effects of the proposed measures will be further investigated. However, it illustrates the importance of a good monitoring system of geothermal and in particular a hybrid system (combining different heat and/or cool production units), a good understanding of its functioning and regular follow-up, especially during the first years of operation.

5. CONCLUSIONS

The ongoing work in the GeoCamb project is supporting the shallow geothermal sector deployment in Brussels (Belgium) by providing more geological and hydrogeological data by enhancing geophysical methods to identify the bedrock top and by demonstrating the efficiency of geothermal systems. The success rate of the projects of the last two years is very promising: 79% of the boreholes drilled in the BM would allow an open system installation. Nevertheless, the Cambrian fractured reservoir still presents a lot of uncertainty concerning its transmissivity and potential. Increasing the understanding of the structural context of the Brabant Massif in order to manage effectively the exploitation of this renewable natural resource and reduce CO_2 emissions is essential. The GeoCamb research project will help reducing investment risk, allowing better planning of subsurface resources at policy level and in the end lead to a more secure, carbon-lean and affordable energy cost for the end-users.

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Acknowledgements

This research has been achieved in the framework of the GeoCamb research project (B2/191/P1/GEOCAMB), thanks to the financial support of the Belgian Scientific Policy (BELSPO).