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Conditions for deep geothermal energy utilisation in southwest Latvia: Nīca case study

Ramūnas Povilanskas, Jonas Satkūnas, Egidijus Jurkus

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Abstract This paper focuses on the deep geothermal energy utilisation from the Lower Cambrian sandy siltstone aquifer as a potential supply to the district heating system in Nīca, a small municipality in southwest Latvia. Based on this case study, we argue that it is technically and economically feasible to develop efficient geothermal heat stations in small municipalities rich in geothermal resources under three key preconditions: - sufficient extractable heat resources of the aquifer; - ready availability of a nearby deep well; and – a plan for environmentally acceptable disposal of the cooled geothermal water to the surface waters. If these conditions are met, the deep geothermal energy utilisation in a small-scale district heating system might be economically viable and possibly more sustainable than a larger district heating system, where high-pressure re-injection of the cooled geothermal water into deep rock aquifers is necessary.

Keywords *• South Baltic Geothermal Region • Rural municipalities • Deep geothermal energy • Cooled brine disposal • Kriging • Deep well restoration*

✉ *Ramūnas Povilanskas (ramunas.povilanskas@gmail.com), Egidijus Jurkus, Klaipėda University, H. Manto g. 84, LT-92294 Klaipėda, Lithuania; Jonas Satkūnas, Lithuanian Geological Survey, S. Konarskio g. 35, LT-03123 Vilnius, Lithuania.*

INTRODUCTION

The cross-border region of Western Lithuania and Latvia is characterised by its special geological conditions within Precambrian crystalline bedrock, Cambrian and Devonian sedimentary strata. The rocks are anomalously hot at an average temperature of the Cambrian strata ranging from 38ºC in the northwest to over 120ºC in the southwest. The cause of this anomalous heat has been explained in terms of mantle processes and high heat generation of crustal lithologies (Šliaupa, Rastenienė 2000; Šliaupa, Kežun 2011). The heat extracted from these rocks, and, in particular, from the deep hot brine aquifers may be potentially beneficial for district heating systems in small rural municipalities and estates as one of the most sustainable energy resources. However, its use for district heating to-date is complicated, particularly in small rural municipalities due to implicitly high investment costs and lack of the proper experience in small scale deep geothermal energy use. To be able to provide the small municipalities with more plausible options regarding the use of the deep geothermal energy in small scale district heating systems of Western Lithuania and Latvia, it is vital to improve understanding of the essential differences between small, medium and large scale deep geothermal energy utilisation systems. Of particular relevance are the differences determined by local geological and environmental conditions and also by the geotechnical situation.

The Geothermal Energy for Rural Municipalities and Estates (GERME) project of the Latvia-Lithuania Cross-border Co-operation Programme 2007–2013 was aimed at building and providing this critically important knowledge. The fundamental goal of this project was to deliver the necessary information for the decision makers and community activists regarding geological, environmental and geotechnical conditions of the deep geothermal energy utilisation in small scale district heating systems. If the deep geothermal energy is used for electric power production, then 5

MW$_e$ nameplate capacity (technical full-load sustained output) is considered as a threshold separating small and medium scale power stations (Vimmerstedt 1998). For small scale geothermal heat stations and district heating systems this threshold should be lower due to higher efficiency of the heat production from the deep geothermal energy sources. The objective of the study was to assess the feasibility and conditions for the utilisation of the deep geothermal energy from the Lower Cambrian sandy siltstone aquifer to produce and supply the extracted heat to the district heating system in Nīca rural municipality located in southwest Latvia.

Relatively little attention has been paid, both in academic research and in the technical literature, to analysing the technical and economic feasibility of the deep geothermal energy extraction and supply to small scale district heating systems. The most common reason for scepticism about such proposals are high investment costs for deep drilling combined with the relatively small market for energy supply and potentially high project failure risks (Merrick 2002, 2004, 2013). Two countries with the most advanced utilisation of the deep geothermal energy for small scale district heating are Iceland with 206 small scale heat stations and the United States with nine (Thorsteinsson, Tester 2010). The asseessment of geological conditions for the deep geothermal energy utilisation in small scale district heating systems of Central Lithuania, although without any analysis of economic feasibility, was carried out by Šliaupa and Kežun (2011). The essential role of geological and environmental conditions for the technical and economic feasibility of small scale deep geothermal district heating systems is informed by the surveys conducted in the United States by Thorsteinsson and Tester (2010) and Merrick (2002, 2004, 2013).

STUDY AREA AND METHODS

Study area

The study area covers the westernmost part of the Republic of Latvia, the Western Courland (Kurzeme) planning region with particular focus on two rural municipalities – Grobiņa and Nīca (Fig. 1). These two municipalities were identified as the most promising for the utilisation of the deep geothermal energy in small scale district heating systems in southwest Latvia. Nīca was chosen as the pilot area for further development of a detailed technical and economic feasibility study. Currently, the local district heating system delivers the heat from a biomass-fired heat station of 3.1 MW$_t$ capacity to 20 buildings producing 4 to 5 MWh of thermal energy annually during the heating season

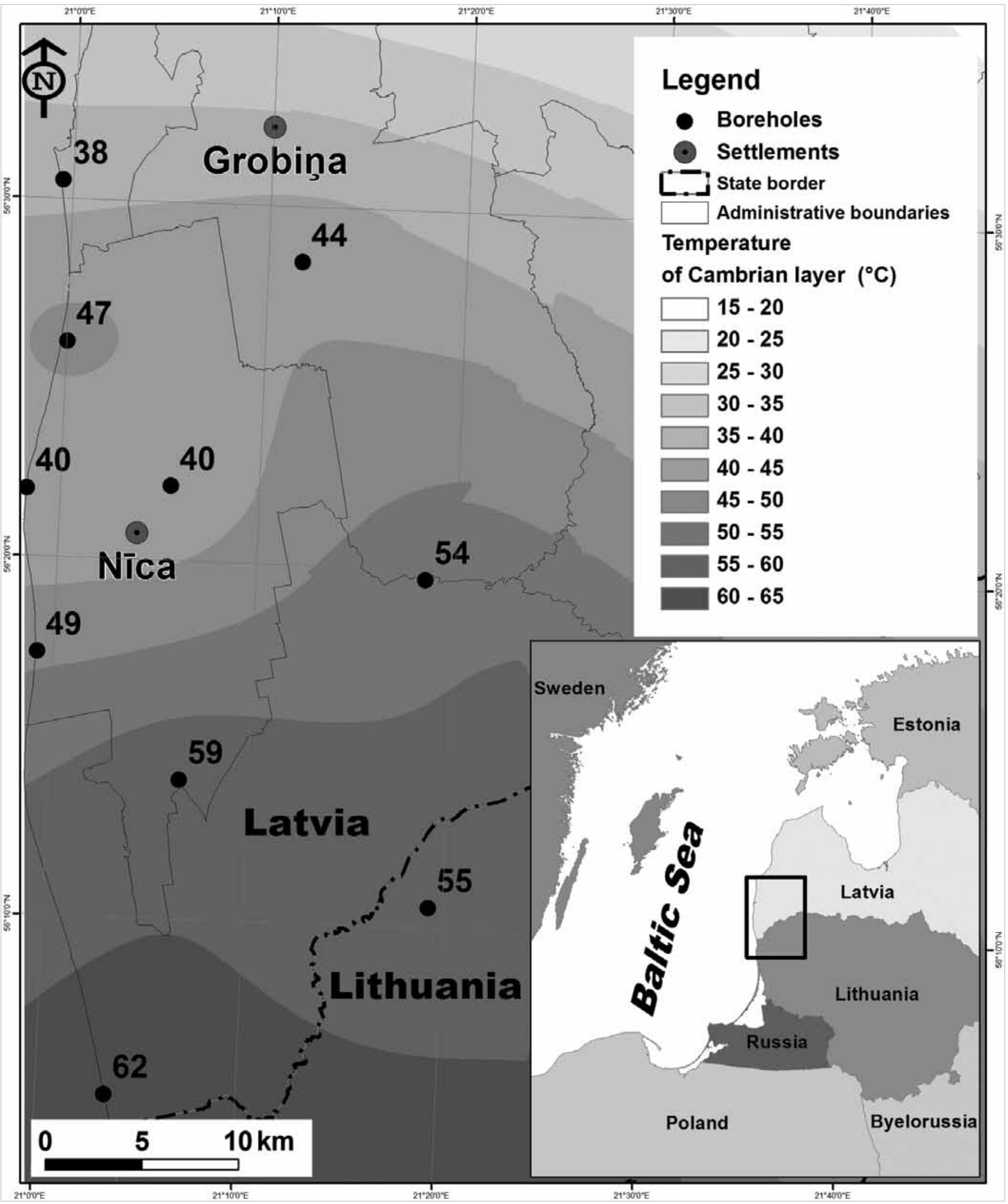

Fig. 1 Location of the study area and Cambrian aquifer temperatures. Compiled by E. Jurkus, 2013; deep well data courtesy of the Latvian Geological Survey.

(from October to May). The biomass-fired heat station is outdated and has low heat production efficiency. Its two boilers use unsorted timber as fuel.

Nīca is located within a geothermal anomaly known as the Western Lithuanian Geothermal Anomaly (Kepežinskas *et al.* 1996). However, the anomaly covers an area much larger than Western Lithuania, extending beyond the border at least into the neighbouring parts of Latvia and the Kaliningrad Region of Russia (Eihmanis 2000; Juodkazis *et al.* 1997; Zinevicius *et al.* 2003). Therefore, sometimes it is referred to as the Baltic Geothermal Anomaly. Numerous investigations have been completed to assess the bedrock geology of the Southern and Central Baltic Sea (Figs 2, 3) (Grigelis 2011). However, temperature maps of different deep bedrock strata underneath the sea floor are not yet available. Therefore, it is not clear, how far the geothermal anomaly extends westwards beneath the Baltic Sea. The extensive utilisation of the deep geothermal energy resources in many municipalities of the South Baltic Region (Thisted and Copenhagen in eastern Denmark, Lund in southern Sweden, Szczecin-Pyrzice in northwest Poland, as well as Neustadt-Glewe, Waren and Neubrandenburg in northeast Germany) may suggest that the entire South Baltic area comprises the South Baltic Geothermal Region, perhaps subdivided into smaller geothermal anomalies confined by diverse sub-regional tectonic conditions (Huenges 2013).

Methods

GERME project partners used a variety of methods to extract the best possible information from readily available results of previous geological surveys in southwest Latvia. In particular, sedimentary rock cores from the deep wells drilled in the region for oil exploration during the 1970s were examined. The key methods applied in the study comprised a comprehensive examination of archive materials and examples of the small scale geothermal district heating systems, use of analytical Geographical Information System (GIS) software, simulation of optimal district heating demand and cost-benefit analysis. Data on geophysical characteristics of the sediment rock cores from the deep wells in southwest Latvia were obtained from the Latvian Geological Survey while data on technical characteristics of the current district heating system in Nīca were obtained from the municipal administration.

The prediction of the Cambrian aquifer temperatures in Nīca from the available deep well data was car-

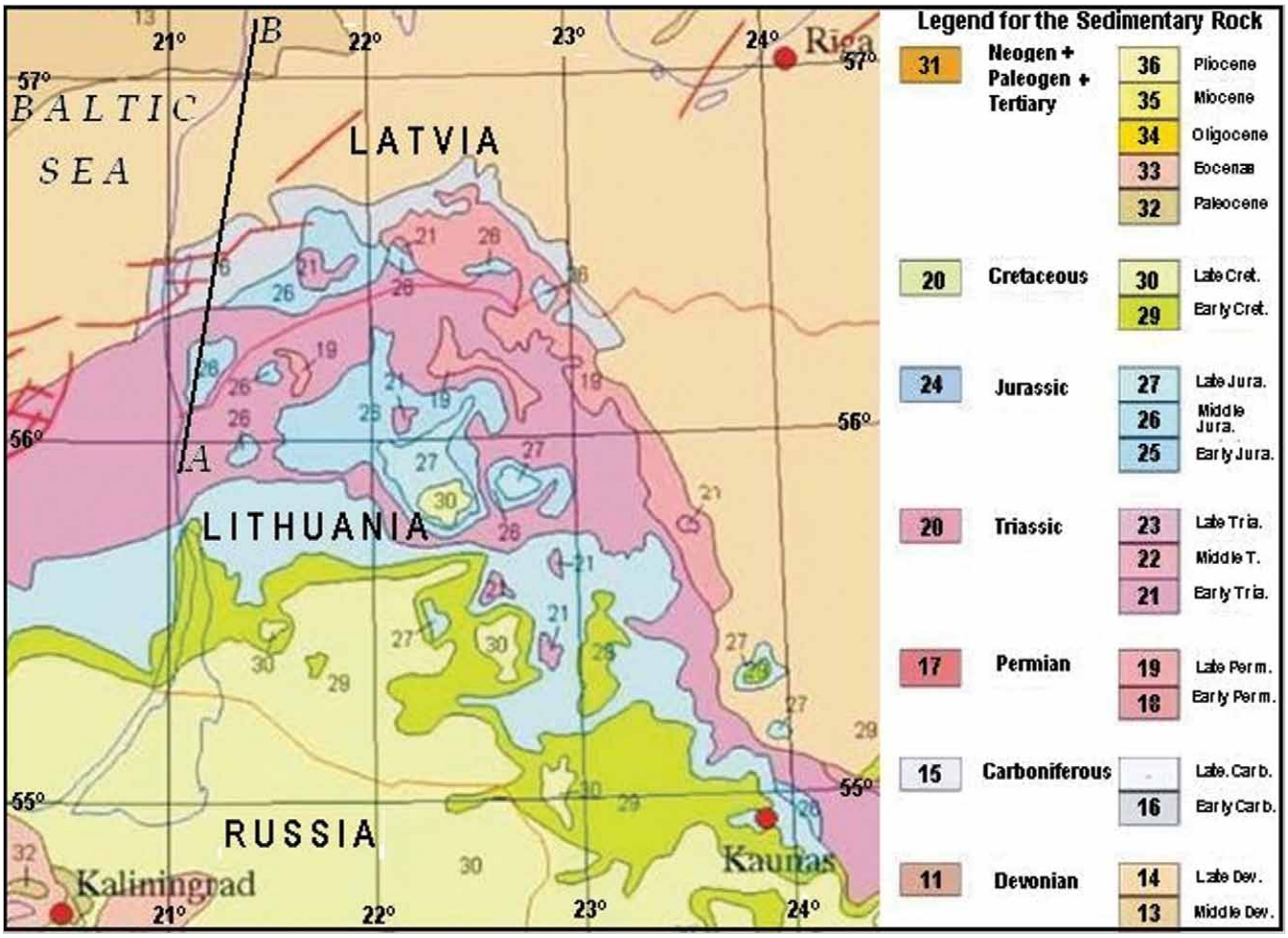

Fig. 2 Geological map of the south-eastern Baltic region; A–B identifies line of the cross-section of the study area (see

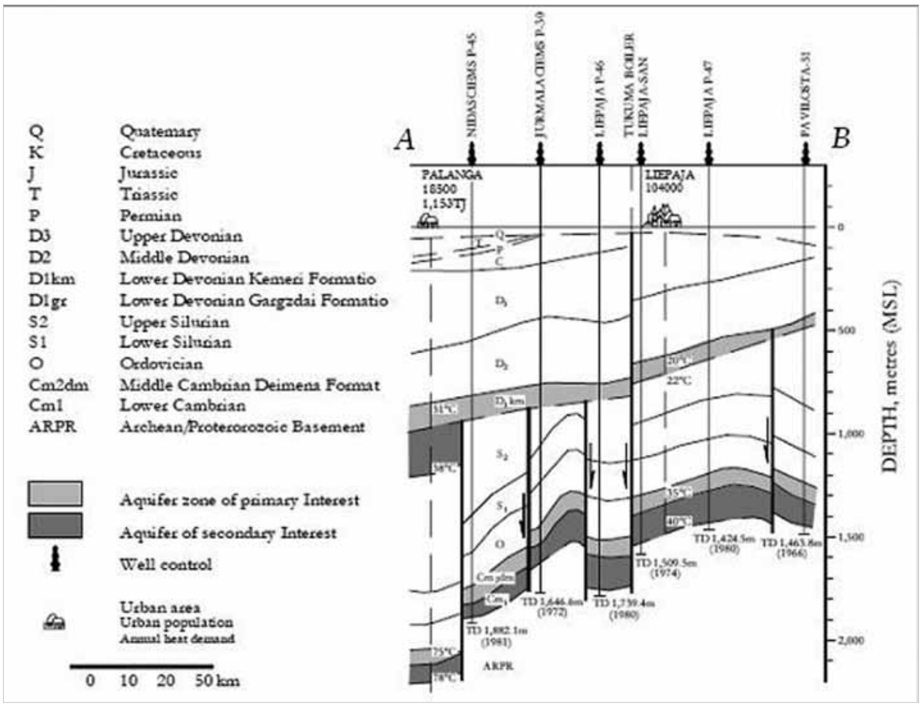

Fig. 3 Cross-section (A–B) of the study area. Compiled by E. Jurkus (after E. Eihmanis, 2000).

ried out by generating the prediction surface GIS map of the Cambrian aquifer temperatures for southwest Latvia using kriging as an analytical tool (see Fig. 1). The ordinary kriging method and a spherical simulation model have been applied for this purpose (Lesauskienė, Dučinskas 2003). The simulation of optimal district heating demand in Nīca was undertaken using EnergyPRO v.5 energy demand simulation software (EnergySoft, 2011). The cost-benefit analysis of the construction and operation of a small scale geothermal heat station in Nīca was completed according to the Technical and Economic Feasibility Study Guidelines for the municipal infrastructure projects financed by the European Union (EU) Structural Funds (Ekoncepti 2011).

RESULTS

Feasibility of the deep geothermal energy utilisation in Nīca

The resulting prediction surface GIS map of the Cambrian aquifer temperatures of southwest Latvia allowed us to conclude, that the Cambrian aquifer temperatures in the Nīca area may be in the range of 42–44ºC, which is sufficient for the extraction of heat from the hot brine using a heat pump and delivery to the district heating system. Application of the heat pump, of either the compressor or absorption types, for the extraction of the geothermal heat is the only option in the case of low enthalpy deep geothermal energy anomalies (Table 1). Since there is already a biomass-fired heat station in Nīca, apparently the most cost-efficient option is to apply an absorption heat pump in the existing geothermal heat station using the high-enthalpy energy provided by the biomass-fired heat station.

The prediction of the Cambrian aquifer temperatures in Nīca may not be accurate due to spatial variability of the geophysical characteristics of the Cambrian sedimentary strata and water aquifers (Eihmanis 2000). This uncertainty could lead to a

Table 1 Applicability of different geothermal heat extraction technologies in various geological conditions. Compiled by R. Povilanskas, 2013.

Aspects	Direct heating	Heat pump	Enhanced Geothermal System (EGS)
Geothermal	Shallow well depth (<1000 m), high water temperature (>65ºC)	Medium well depth (1000-2000 m), tepid water temperature (<65ºC)	Deep well depth (>2000 m), high bedrock temperature (>90ºC)
Technological	Simple heat extraction, but the technology is not directly applicable to electricity co-generation	Anti-corrosive submersible water pumps and heat pumps are necessary, as well as second heat source	Sophisticated technologies including highly heat-resistant pumps and instruments are necessary
Social and economical	Most suitable for buildings with air heating systems	Most suitable for buildings with water heating systems	Suitable for various heating systems but, so far, too expensive
Financial	Small investments needed to convert water heating systems into air heating ones	Large investments needed to drill the geothermal water extraction and injection wells	Extremely large investments needed to develop the entire EGS
Application range	Suitable even for one large building or a small district	Suitable for variously sized districts, but for small areas only in exceptional cases	Applicable only for large-scale district heating systems

significant increase in project costs. Thus, according to Merrick (2002), in Canby municipality, northeast California, the initial survey showed that the vertical temperature gradient was similar to geothermal wells 30 km away being 7ºF/100 ft (12.8ºC/100 m). It was estimated that at 500 m of depth, the available geothermal water resource would be 9.5–12.5 l/s at 64–70ºC. A hot spring two miles away discharged 31.5 l/s and the assumption was that the well in Canby would intersect the same aquifer not far from the surface. In reality, the drilling intersected the aquifer at the 640 m depth and the bottom-hole temperature was 106ºC while the estimated geothermal water flow was app. 12.5–19 l/s. As a result of the miscalculation, a USD 192,000 project increased to USD 450,000. At the Klaipėda Geothermal Demonstration Plant, in Lithuania, the theoretically anticipated 43ºC temperature of the Lower Devonian aquifer proved to be lower, reaching just 38ºC (Zinevicius *et al.* 2003).

Sustainability conditions of small scale deep geothermal heat stations

The unpredictability of the aquifer temperature, porosity and permeability conditions, relatively expensive drilling of deep wells and the associated financial risks make any small scale deep geothermal energy utilisation projects unsustainable from the economic point of view, unless deep well drilling can be avoided. Deep well drilling could potentially be avoided under two preconditions. The first precondition is the ready availability of a deep well in the vicinity. The ready availability of a well makes it possible to install a geothermal water extraction system just for 10 % of the cost necessary for drilling a new well (S. Šliaupa *et al.* 2008). The second precondition is the

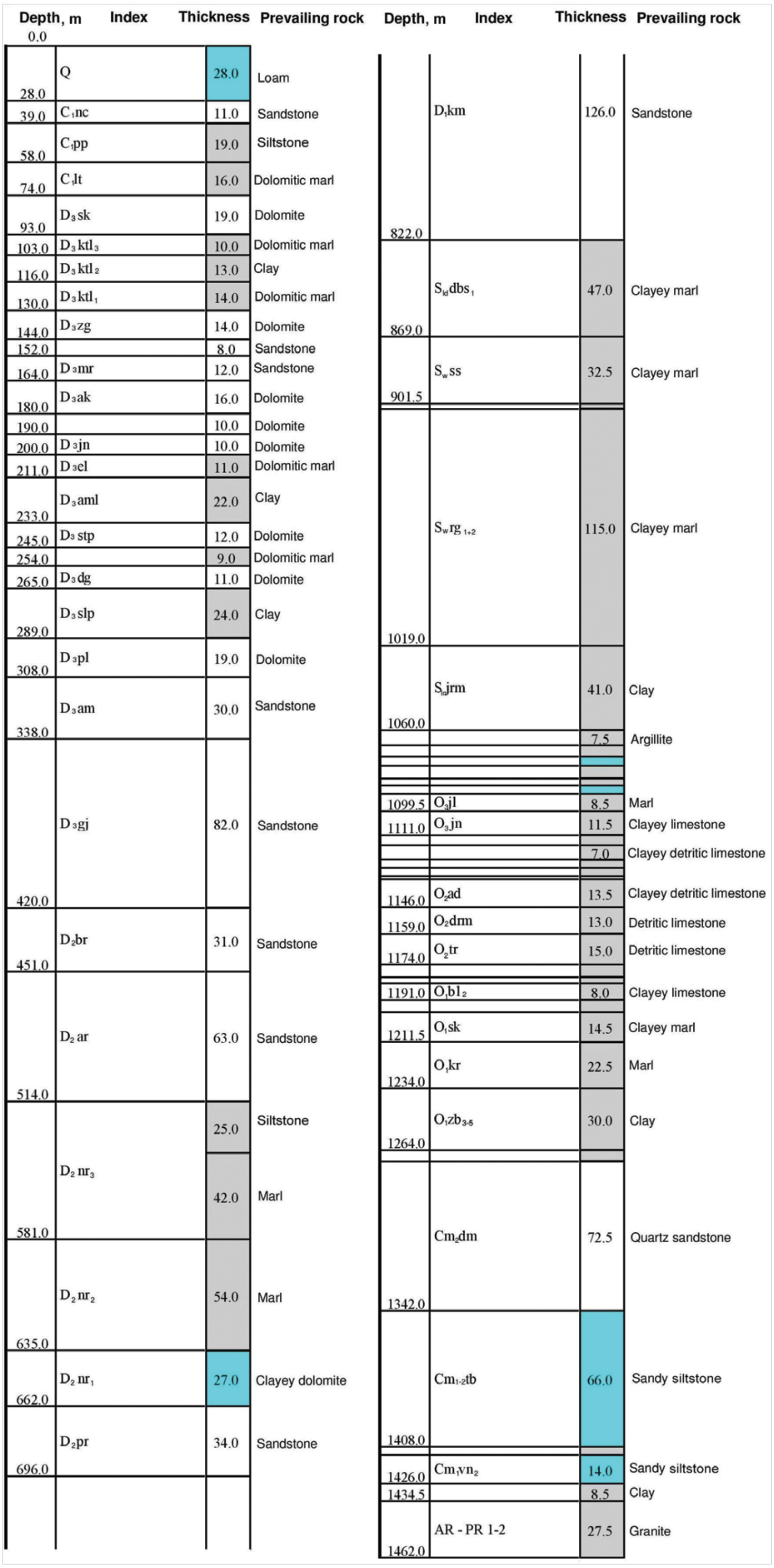

Fig. 4 Sediment strata and aquifers in Bernāti-22 well. Compiled by E. Jurkus, 2013; deep well data courtesy of the Latvian Geological Survey.

Table 2 Lower Cambrian sandy siltstone aquifer characteristics in the Nīca area. Compiled R. Povilanskas, 2013 (after E. Eihmanis, 2000 and from the data provided by the Latvian Geological Survey).

Characteristics	Parameter
Thickness of the overlying strata above the target horizon, m	1434.5
Thickness of the geothermal aquifer, m	152.5
Net-to-gross ratio of the geothermal aquifer	0.53
Temperature, °C	42–44
Porosity, %	15–20
Permeability, mD	30–100
Brine mineralization, ‰	100–120

possibility for disposal of the cooled geothermal water directly to surface waters (Merrick 2002, 2004, 2013). The possibility for disposal of the cooled geothermal water directly to surface waters eliminates the need to drill an injection well and to purchase and maintain costly high-pressure pumps and other specially tailored equipment for circulating hot brine under high pressure within the closed geothermal loop. In such situation, the small scale of a geothermal heat station becomes an advantage compared to the larger ones, where drilling of the injection well and circulating hot brine under high pressure within the closed geothermal loop is necessary (Zinevicius *et al.* 2003).

The first precondition for the economic sustainability and the overall feasibility of a geothermal heat station at Nīca is met by the availability of the Bernāti-22 well, which was drilled in the 1970s for oil exploration purposes. The sedimentary stratigraphy and the measured or predicted characteristics of the Bernāti-22 well are given in Fig. 4 and Table 2. The well is located about 1.5 km from the Nīca heat station therefore some heat losses would occur between the well and the heat station. Technical conditions and integrity of the Bernāti-22 well yet have to be thoroughly tested applying geophysical logging and hydrogeological pumping test.

The second precondition for the feasibility of the small scale geothermal heat station in Nīca is met by the estuarine situation of the municipality. Nīca is situated in the estuary of the Bārta River. The river discharges to the coastal Lake Liepājas having a direct link to the Baltic Sea, hence the entire aquatic system is adjusted to the influx of the brackish water from the sea during frequent storm surge events. Therefore, the disposal of small quantities of the cooled brine into the river might not be detrimental to the water quality and aquatic ecosystems. In order to meet the environmental quality standards for the discharged brine, it is necessary to mix it with treated municipal wastewater before disposing of the diluted mixture to the Bārta River. In this way, a 'win-win' situation could be achieved, since mixing the treated municipal wastewater with the brine will help to reduce the nutrient concentration in the wastewater discharge from the municipal treatment facilities to the Bārta River, which is currently too high.

DISCUSSION

Simulation of the optimum district heating demand in Nīca and the cost-benefit analysis of the construction and operation of a small scale geothermal heat station in Nīca has shown, that if the above two preconditions are met, and if the temperature of the Lower Cambrian sandy siltstone aquifer is indeed proved to be not less than 43°C, then it is sufficient to extract approximately 2 l/s of the hot brine to supply enough heat to the district heating system of Nīca all year round. If a newly constructed geothermal heat station is built this should include a modern high-efficiency absorption heat pump working in combination with the biomass-fired boiler according to five different heating loads: base summer load, three regular winter heating loads and peak winter load.

Unlike the current facilities, the geothermal heat station could potentially deliver to the end users heat during the colder winter months, and hot water all year round. Once the optimum operation mode of the entire geothermal heating system in Nīca is achieved and maintained, then the total cost of geothermal heat production over the 15 years of the project lifecycle might be half of that using the current inefficient way of heat production from the burning of unsorted timber. Furthermore, the total cost of geothermal heat production over the 15 years of the project lifecycle has been estimated to be approximately 50% less if investments were made into the replacement of the outdated biomass-fired boilers with the new, more efficient and updated models.

CONCLUSIONS

Summing up the results of the comprehensive investigation into the Nīca case study we conclude that it is technically and economically feasible to develop and efficiently operate small scale geothermal heat stations in small municipalities of the South Baltic Geothermal Region. Although, these require three principal conditions for this to be viable. These include: (a) sufficient extractable heat resources in the aquifer, (b) the ready availability of a deep well in the vicinity, and (c) the possibility of the environmentally acceptable discharge of the cooled geothermal water into the surface waters. If these three preconditions are met, then the deep geothermal energy utilisation in a small scale district heating system may be more economically sustainable than in larger districts, where there is the need to reinject the cooled geothermal water under high pressure into deep rock aquifers via additional boreholes.

Despite these new and encouraging findings of the GERME project, several matters need to be studied further before the commencement of the geothermal heat station construction in Nīca. These include the measurement and monitoring of the Cambrian aquifer temperature in the Bernāti-22 deep well, more accurate calculations of the hydrogeological characteristics of the Lower Cambrian sandy siltstone aquifer and a detailed evaluation of the geotechnical properties of the aquifer and hydrogeological potential for the hot brine to flow from the well. One of the findings of the GERME project was that the disposal of the cooled brine into the Bārta river estuary should not be detrimental to the river water quality.

There is no precise information on the geochemistry of the brine from the Bernāti-22 well. Therefore we recommend geochemical investigation as the first step of further research. Additionally, a comprehensive system of environmental quality monitoring programme should be developed and implemented. The aim of the regular environmental monitoring will be to monitor the environmental impact of the treated, mixed and disposed municipal wastewater with the brine on how these may influence the aquatic environment of the Bārta River and Lake Liepājas.

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