

Investigating ways to improve knowledge towards the implementation of geothermal systems to harness heat

C. Rivard¹, V. Gascuel^{1,2}, M. Des Roches^{1,2}, J. Raymond², S. Larmagnat¹, P. Francus², J.-S. Gosselin³, M. M. Rajaobelison¹, A. De Coninck¹, M. Blouin³, D. Lavoie¹

¹ Geological Survey of Canada, Natural Resources Canada (NRCan)

² Institut national de la recherche scientifique – Eau Terre Environnement (INRS-ETE)

³ Geostack

Summary

A two-part research project using both new and existing data collected over several decades from the Bécancour area (St. Lawrence Lowlands, QC, eastern Canada) is currently underway. The first component aims to design and model different types of intermediate-depth geothermal systems in order to identify the most suitable system(s) for heat extraction from this cold sedimentary basin. The second part aims to better understand the processes at play and identify the scale effect of key features of rock properties involved in fluid flow and heat transfer in deep geological units, based on core sample characterization (porosity, permeability and thermal conductivity), CT-scan image processing, machine-learning and numerical simulations. Each part is producing methodological developments applicable to other sedimentary basins with a low geothermal gradient.

Context and Rationale

As global energy demand is constantly increasing, particularly for electricity, improvements are needed for low-carbon technologies to either replace fossil fuels or save electricity for other uses. Relatively deep geothermal systems (1-3 km) can be used for heat production, even when the geothermal gradient is low, especially when combined with heat pumps. These systems have several advantages, including providing continuous energy with a low footprint, being resilient to major events linked to climate change (e.g., very high winds and storms) and occupying little space, but they have a high installation cost and their performance is dependent, to varying degrees, on the properties of the rock at depth. As a result, they currently appear less attractive to investors than other sources of energy such as wind and solar, even if the latter are intermittent. Improvements can take a variety of forms, including those presented here: the numerical modeling of various types and designs of geothermal systems and the study of the effect of heterogeneities at different scales on fluid flow and heat transfer. For this work, the Bécancour area, in the St. Lawrence Lowlands in Quebec, was selected because it comprises a growing industrial park with important energy needs and a number of abandoned gas wells, and it benefits from data from several studies conducted there over the last few decades.

Method

For the first project component, closed-loop (deep borehole heat exchanger, DBHE) and open-loop (doublet) systems were modeled with FEFLOW (Figure 1) to evaluate their heat production. To model geothermal systems in a fairly realistic manner, some functions were developed and

coupled to the numerical models, such as to account for the temperature dependence of the fluid properties and the use of one or several heat pumps at the surface to extract more heat. Two options were also considered: the repurposing of abandoned oil and gas wells and the drilling of new wells, with a larger diameter.

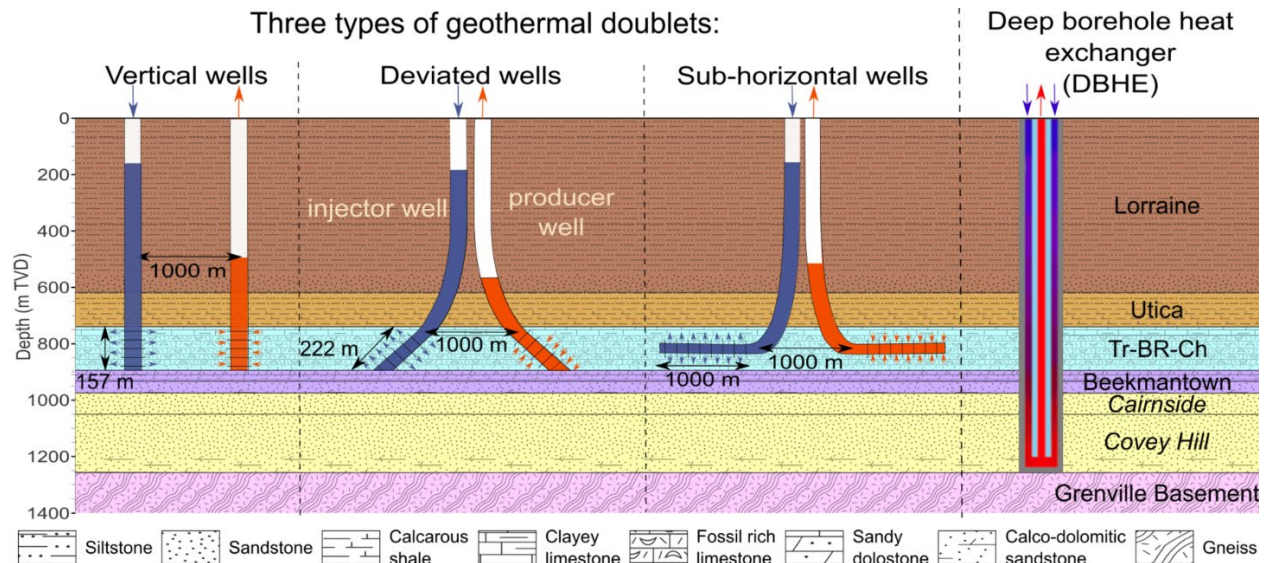


Figure 1: Schematics of the three types of doublets and coaxial DBHE modeled, as well as the geological units present in the Bécancour area (taken from Gascuel et al., 2024).

For the second project component, a variety of core samples (reference and site-specific samples, both intact and fractured) were imaged by tomography (CT-scans) using dry and saturated conditions (Larmagnat et al., 2019). A protocol is currently being developed to process these images to obtain 3D porosity networks that can be used in COMSOL to simulate fluid flow and heat transfer. Upscaling from micrometric, to centimetric and then to metric scales to integrate heterogeneities will be achieved by training machine-learning (ML) models to predict the spatial distribution of the properties studied. Validation of the upscaled predictions will be carried out using standard laboratory measurements (e.g. measurements of bulk gas porosity versus predicted bulk porosity, the later obtained using ML models trained on CT images at different scales). The generalization of the ML models will be assessed by applying the protocol developed using relatively homogeneous reference samples on cores from the Bécancour area. Heterogeneities, such as natural property variations, will influence the response of the trained models. The magnitude of tuning/adaption of the hyperparameters will serve as an indicator of the model generalization.

Results

Simulation results and a preliminary cost analysis covering a 30-y period have shown that the repurposing of idle wells into DBHEs appears promising, even for Quebec where electricity is cheap, because of the savings that can be made on drilling (the main cost) with this type of system (Gascuel et al., 2022). Doublets, especially those with more costly sub-horizontal wells, are particularly efficient in the presence of a permeable unit and remain the best option in terms of heat production, even when this production is weighted by the drilled length.

To date, images of very permeable cores have been processed and used for simulations to initiate the development of the protocol, but the latter needs to be adapted to more complex and less porous / permeable rocks, such as those of the Bécancour area, and to integrate fractures as well. As part of this project, ML is also being used to evaluate if 3D CT images, either in gray scale or in relative density in Hounsfield (HU) units (a rescaled linear attenuation measure, with air at -1000 HU and water at 0 HU) can be used to produce predictive 3D matrices representing thermal conductivity, as this parameter can currently only be measured in 2D (i.e. as profiles along the outer surface of cores).

Conclusions

For a given project and location, the optimum geothermal system must be selected carefully. Doublets can produce more energy than DBHEs, but since they require the presence of a permeable unit, can suffer from geochemical issues and could simultaneously release gas, they may not necessarily be the best choice. Moreover, doublets are highly dependent on uncertainty in lateral variability of rock properties (unlike DBHEs), which is often a problem since deep units are commonly poorly characterized, particularly in eastern Canada. This is precisely why numerical models that allow comparison of geothermal system types and designs, taking into account uncertainties, are a critical step towards the future implementation of these renewable yet costly energy systems.

The study involving CT-scan images is still in its early stage, but the idea behind this more fundamental work aimed at integrating heterogeneity at different scales is to eventually embed these results into the numerical models of geothermal systems. The results will provide valuable information that will help reduce uncertainties, improve performance predictions (hence the design of geothermal systems), and consequently reduce technical and financial risks.

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