

<https://helda.helsinki.fi>

---

## St1 Deep Heat Project : Geothermal energy to the district heating network in Espoo

Kukkonen, I. T.

2021-04-23

---

Kukkonen , I T & Pentti , M 2021 , ' St1 Deep Heat Project : Geothermal energy to the district heating network in Espoo ' , IOP Conference Series: Earth and Environmental Science , vol. 703 , no. 1 , 012035 . <https://doi.org/10.1088/1755-1315/703/1/012035>

---

<http://hdl.handle.net/10138/341118>

<https://doi.org/10.1088/1755-1315/703/1/012035>

---

cc\_by

publishedVersion

---

*Downloaded from Helda, University of Helsinki institutional repository.*

*This is an electronic reprint of the original article.*

*This reprint may differ from the original in pagination and typographic detail.*

*Please cite the original version.*

PAPER • OPEN ACCESS

## St1 Deep Heat Project: Geothermal energy to the district heating network in Espoo

To cite this article: I T Kukkonen and M Pentti 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **703** 012035

View the [article online](#) for updates and enhancements.

You may also like

- [THE PROPER MOTION OF THE MAGELLANIC CLOUDS. I. FIRST RESULTS AND DESCRIPTION OF THE PROGRAM](#)  
Edgardo Costa, René A. Méndez, Mario H. Pedreros et al.
- [Evaluation of the maturity level and critical success factors of the knowledge management implemented in state-owned construction company in Indonesia](#)  
A W Septari and Y Latief
- [GHRS Observations of Cool Low-Gravity Stars. III. Plasma Flows and Turbulence in the Outer Atmosphere of Orionis \(M2 lab\)](#)  
Kenneth G. Carpenter and Richard D. Robinson



The Electrochemical Society  
Advancing solid state & electrochemical science & technology

242nd ECS Meeting

Oct 9 – 13, 2022 • Atlanta, GA, US

Abstract submission deadline: **April 8, 2022**

Connect. Engage. Champion. Empower. Accelerate.

**MOVE SCIENCE FORWARD**



Submit your abstract



# St1 Deep Heat Project: Geothermal energy to the district heating network in Espoo

I T Kukkonen<sup>1</sup> and M Pentti<sup>2</sup>

<sup>1</sup>Department of Geosciences and Geography, University of Helsinki, Pietari Kalminkatu 5, P.O. BOX 68, 00140 University of Helsinki, Finland

<sup>2</sup>Firdonkatu 2, 00520 Helsinki, P.O. BOX 68, 00521 Helsinki, Finland

[ilmo.kukkonen@helsinki.fi](mailto:ilmo.kukkonen@helsinki.fi)

**Abstract.** St1 Deep Heat Project with its two deep wells extending to 6.2 - 6.4 km depth is the world's deepest industrial geothermal energy project. The aim is to build an EGS (enhanced geothermal system) at the depth of about 5 - 6 km. The project is a pilot aiming at exploring the technical and economic feasibility of geothermal energy in the crystalline rock conditions of Finland for production of thermal power to a district heating network. Due to the demands of the district heating, the aim is to produce hot fluid at about 100°C and re-inject it to the formation at 50°C. The 100°C goal requires to drill to about 6 km depth. The drill site is located in Espoo, next to the Fortum district heating plant on the Aalto University campus. So far (2020) the project has drilled a 2 km deep completely cored pilot hole (OTN-1), and two deep wells OTN-2 to 6.2 km and OTN-3 to 6.4 km. Hydraulic conductivity has been enhanced by hydraulic stimulation in both deep wells in 2018 and 2020. The extreme depth level sets significant challenges for drilling and hydraulic stimulation, as well as controlling of induced seismicity. At present, the project proceeds with the installation of production pumps in OTN-2 and OTN-3, and first test cross-hole pumpings are expected to start in January 2021. In the presentation we provide an insight to the project and its major achievements and challenges.

## 1. Introduction

St1 Deep Heat Project started in 2014. With its two deep wells extending to 6.2 - 6.4 km depth, it is the world's deepest industrial geothermal energy project. The aim is to build an EGS (enhanced geothermal system) at the depth of about 5 - 6 km. The project is a pilot aiming at exploring the technical and economic feasibility of geothermal energy in the crystalline rock conditions of Finland for production of thermal power to a district heating network. The drill site is located in Espoo, next to the Fortum district heating plant on the Aalto University campus (Figure 1). So far (2020) the project has drilled a 2 km deep completely cored pilot hole (OTN-1), and two deep wells OTN-2 to 6.2 km and OTN-3 to 6.4 km. Hydraulic conductivity has been enhanced by hydraulic stimulation in both deep wells in 2018 and 2020.

The extreme depth of the planned EGS is due to low geothermal gradient in the study area (ancient Precambrian bedrock) and the technical requirements of the district heating system. The reservoir temperature should be at least 100°C, and the re-injected fluid should be about 40 – 50 °C. The project aims in production of space heating energy only, and no power (electricity) production is planned. With a typical geothermal gradient of about 15-17 °C/km, the 100°C temperatures require drilling to about 6 km depth.





**Figure 1.** The St1 Deep Heat drill site in Espoo in 2019. Photo by St1.

The theoretical energy resource of bedrock is huge. For instance, assuming the temperature decrease in an EGS reservoir during production is 50°C, and the volume of the reservoir is one km<sup>3</sup> and the specific heat capacity of rock is 800 J/kg/K, the total theoretical energy content is 30·10<sup>6</sup> MWh. The most important challenge related to exploiting such an energy resource is how the heat can be extracted from the rock. In EGS it is done by circulating water as a heat transfer fluid in the formation between two deep boreholes. Natural level of hydraulic conductivity is very low at depths of several km, and provided by natural fractures of the rock. In most cases, the natural hydraulic conductivity is too low for EGS production, and must be improved. It is done by hydraulic stimulation. In stimulation, large amounts of fluid are injected into rock which widens the natural fractures and enhances the conductivity. Under the high tectonic stress of bedrock, stimulation generates slipping of fracture surfaces, meaning micro-earthquakes. In an EGS project, stimulation must be carried out sustainably without generating hazardous seismicity to the surrounding society. In the present paper, we provide an insight to the project and its major achievements and challenges.

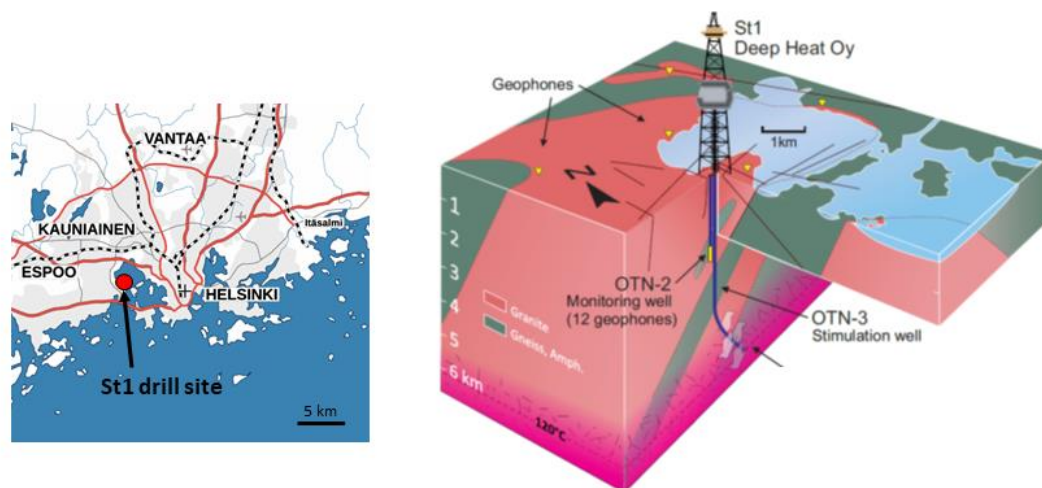
## **2. Drill site geology and geothermal conditions**

The drill site geology is typical for southern Finland. The Precambrian bedrock is overlain by a thin layer (0-20 m) of Quaternary sediments. The bedrock comprises about 1.8 – 1.9 Ga age migmatitic rocks, i.e. mixtures of veined gneiss, mica and hornblende gneiss, amphibolite and granitic intrusions. The lithological boundaries are mostly steep and subvertical (Fig. 2). Due to thorough deformation and migmatization during the geological history of the area, the target formation structure is complex. Intact



crystalline rock has very low porosity, less than 0.5 vol-%. Therefore, practically all fluid flow is constrained to brittle deformation structures, i.e., fracture and shear zones. At the surface level, such structures are revealed by several km long linear structures on topographic, geophysical and geological maps.

Geothermal gradient (rate of temperature increase with depth) is about 17 mK/m in the 2 km deep OTN-1 well, and corresponding heat flow is about 52 mWm<sup>-2</sup>. It implies drill holes should be about 6 km deep to meet the 100°C temperature level.



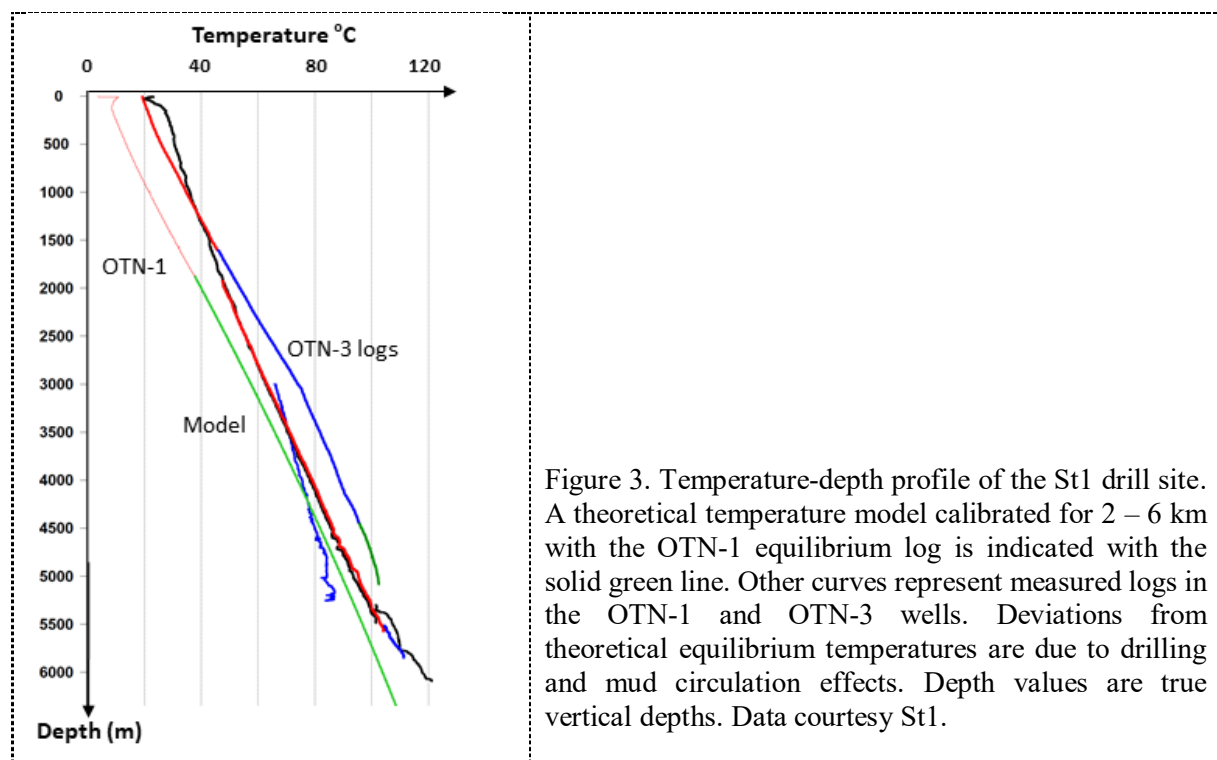
**Figure 2.** Location map of the St1 Deep Heat drill site (left panel), and a 3D diagram of the deep wells and simplified geology in the uppermost 6 km (right panel). Pink represents granitic rocks whereas green represents gneisses and amphibolites, respectively. Modified from [1].

### 3. Hydraulic stimulation and controlling of induced seismicity

According to geophysical downhole logs in OTN-3 the measured temperature at 6 km depth is 100–110 °C (Fig. 3). Thus, the required reservoir temperature level was attained in drilling, and the thermal predictions based on temperature logs in the 2 km deep OTN-1 well proved to be correct. Temperature logs in the deep wells OTN-2 and OTN-3 indicate mostly a conductive heat transfer regime, and a steady temperature gradient of 17°C/km. However, at the depth of the EGS reservoir, in a ca. 400 m thick fractured zone of rock, also flow-induced effects could be detected, suggesting increased hydraulic conductivity of the structure. The zone was imaged with vertical seismic profiling (VSP) in OTN-3 (see below).

In 2018 about 18,000 m<sup>3</sup> of fresh (tap) water was injected into OTN-3 in five 100 – 200 m long stimulation stages at 6.0 – 6.4 km depth. Seismicity was monitored with 12 satellite seismic stations installed in 300 m deep shallow wells and two seismic downhole arrays in 2 km and 1 km deep monitoring wells [1, 2].

Regulating authorities required a traffic light (TLS) system had to be applied in controlling the stimulation and seismicity. The TLS red light limit was set at magnitude M2.1, meaning that occurrence of events bigger than this would imply stopping the stimulation. The injection induced seismicity which comprised more than 50,000 micro earthquakes with magnitudes below M1.9, most of them below M0.0 [1, 2]. Ground velocities were monitored in eastern Espoo and western Helsinki with up to 17 peak ground velocity (PGV) instruments installed in basements of buildings. The highest recorded PGV value was only 0.7 m/s. The stimulation produced three earthquake hypocenter swarms above the stimulated part of OTN-3.



Geological structures, i.e. hydraulically conductive fracture zones and lithological contacts of the reservoir were mapped with drill bit seismics (DSB) during hammer drilling of the deep wells and a VSP survey (vertical seismic profiling) in OTN-3 as well as downhole geophysical logging of the wells. These studies revealed a major natural fracture/shear zone ('VSP reflector') dipping about 44° to ENE. The structure was then utilized in the design of the reservoir when OTN-2 was deepened to final depth of 6.2 km. The deepest part of OTN-2 was deviated to run along the fracture zone for about 1 km length. Finally, OTN-2 was stimulated in 2020 by injecting about 7000 m<sup>3</sup> of fresh water to the 1.3 km long open hole section of the well.

During stimulation, wellhead pressures, flow rates and induced seismicity were continuously monitored and recorded. Hydraulic conductivity of the reservoir was estimated from stimulation pressure and flow rate data. A major observation is that conductivity is pressure dependent due to elastic response of the fractured medium on increased pore pressure. At the highest applied wellhead pressures of 70 – 90 MPa conductivity increased to about 10<sup>-9</sup> ... 10<sup>-8</sup> m/s. Leak-off pressure of fractures is about 52 MPa at 6 km. However, when the wellhead pressure was relaxed by about 20-30 MPa, conductivity decreased by about one order of magnitude according to the stimulation pressure data. Pre-stimulation leak-off test data and post-stimulation long-term monitoring of shut-in pressures in OTN-3 allowed estimation of the low-pressure conductivity, which appears to be of the order of 5·10<sup>-11</sup> m/s. It is considered to represent the natural level of hydraulic conductivity in the reservoir.

The achieved EGS reservoir consists of the volumes stimulated from OTN-3 and the natural fracture zone intersected by OTN-3 and OTN-2. At present, the project proceeds with the installation of production pumps in OTN-2 and OTN-3, and first test pumpings are expected to start in January 2021. The final thermal power is to be evaluated after the circulations tests have been completed during 2021, but will not reach the optimistic original estimate of 40 MW<sub>t</sub>.

#### 4. Discussion and conclusions

The St1 Deep Heat project has successfully drilled deep wells to 6 km depth level in crystalline rock. The project demonstrated that rock temperatures high enough for district heating purposes can be attained at the depth of 6 km. Further, the project achieved hydraulically stimulating natural fractures at depth with considerable volumes of injection fluid. Stimulation was carried out without seismic events exceeding the earthquake magnitude limits set by regulating authorities. This is an encouraging signal for developing EGS methods and technologies for sustainable thermal power production, also in other areas of normal continental crust. The project generated extensive experience and data sets of the continental crust, deep drilling, hydrogeological properties and seismic response of the crystalline rock to stimulation.

#### References

- [1] Kwiatek G, Saarno T, Ader T, Bluemle F, Bohnhoff M, Chendorain M, Dresen G, Heikkinen P, Kukkonen I, Leary P, Leonhardt M, Malin P, Martínez-Garzón P, Passmore K, Passmore P, Valenzuela S, Wollin C. 2019. *Science Advances*, 5: eaav7224, doi.org/10.1126/sciadv.aav7224
- [2] Leonhardt M, Kwiatek G, Martínez-Garzón P, Bohnhoff M, Saarno T, Heikkinen P, Dresen G. 2020 *Solid Earth Discussions* <https://doi.org/10.5194/se-2020-139>