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Geldinganes Geothermal Field: Exploration of a Potential New Production Site for the Reykjavík District Heating System

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ABSTRACT

Geothermal water has been used for district heating in Reykjavík since 1930. To date, the water for the district heating system is supplied from geothermal fields located in the vicinity of and within the city limits, and from the two high temperature geothermal power plants at Nesjavellir and at Hellisheiði, about 30 km east of Reykjavík. The increasing heat demand for the capital area district heating system calls for new geothermal resources to supply the system for the future operations. One of the potential sites for added supply is located at the Geldinganes peninsula, an uninhabited area just north of the city center.

Plans to utilize the Geldinganes field for district heating date back to the 1990's when geothermal exploration in the area revealed a >100°C geothermal system and exceptionally high temperature gradient of 460°C/km. Following the exploration, a 1832 m deep production well was drilled which produced water with temperatures exceeding 100°C - but was less productive than anticipated. The plans for further drilling and utilization were subsequently abandoned due to changes in the urban planning of the city.

The increased demand of water supply for the district heating system has now put the focus back on the Geldinganes geothermal field. Here we report on the current exploration plans of this potential new resource. These include: i) a tracer test aimed to confirm that the system is isolated from a neighboring geothermal system currently utilized, ii) plans for stimulation of the existing production well in the area, and iii) construction of a geological model based on the existing data from the field that will facilitate decision making regarding future drilling of new wells.

1. INTRODUCTION

The Reykjavík District heating Utility was established in 1930, using low-temperature (<150°C) geothermal water from the geothermal areas surrounding and within the capital city Reykjavík. This new method of house heating became an instant success and in 1970 most houses in Reykjavík were connected to the district heating system (Gunnlaugsson et al., 2000). Today the water is supplied from two different sources: 1) Directly from the low temperature areas located within or nearby the city and, 2) as heated groundwater from the **high temperature geothermal power plants, Hellisheiði power plant and Nesjavellir power plant, located in the vicinity of the city (fig. 1-1). The low temperature fields can provide up to ~2,350 L/s and the high temperature fields up to ~2,500 L/s.**

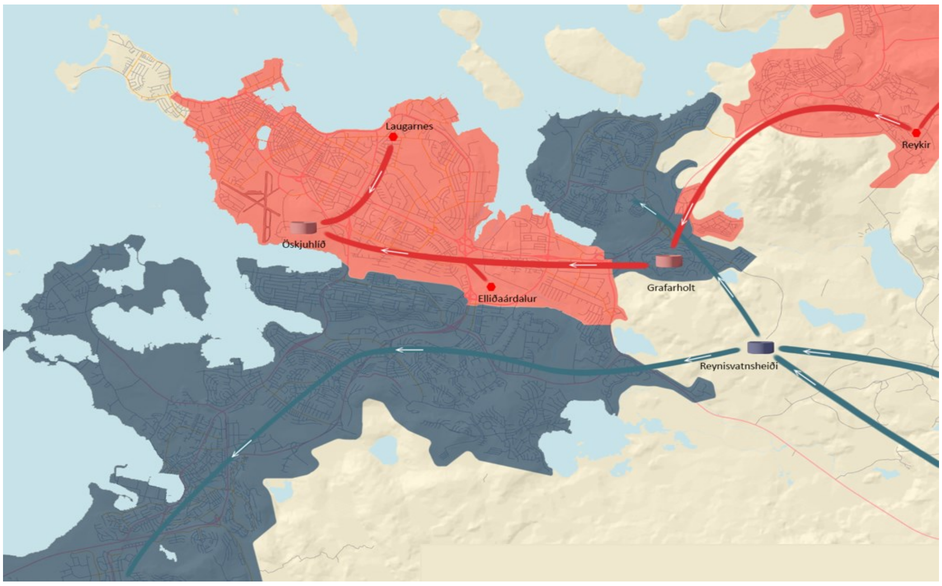

Figure 1-1: The distribution of low temperature geothermal water (red) and heated groundwater from the high temperature geothermal plants (grey) in Reykjavík and the neighboring municipalities.

Figure 1-2: The low temperature geothermal areas currently supplying water for the district heating system of the Reykjavík capital area.

Mixing of the low temperature geothermal water with the heated groundwater during the commencement of the hot water production at the Nesjavellir power plant caused severe magnesium silicate scaling within pipelines and the infrastructure of the distribution system (Hauksson et al., 1992). Since then, the two systems have been operated separately. Currently, four low temperature fields are utilized for the district heating system; Laugarnes, Elliðaárdalur, Reykir and Reykjahlíð geothermal fields (fig. Figure 1-2). The low temperature fields supply water for the Reykjavík centrum and Mosfellsbær, a nearby municipality in the vicinity of the Reykir and Reykjahlíð fields.

As a part of the sustainable planning policy of Reykjavík, the Reykjavík Municipality Plan for 2010-2030 highlights the need to densify urban areas (City of Reykjavík, 2008), resulting in growing population in the Reykjavík centrum. In addition to the urban densification, the blooming tourism in Iceland has called for the construction of numerous hotels in and nearby the city center. This increase in tourism and number of inhabitants in the part of the city that relies on the low temperature areas has resulted in increased demand for hot water supply. This has put the focus back on a geothermal field located north of Reykjavík city center, the Geldinganes geothermal field (fig 1-2).

1.1. The Geldinganes geothermal field

The Geldinganes geothermal field is located at the Geldinganes peninsula, north of Reykjavík city center. The geology of the Geldinganes peninsula is characterized by basaltic formations; lavas, breccias and pillow lavas. The top part of the peninsula consists of basaltic lavas that are underlain with breccias and pillow lavas indicating that the lava flow reached the sea. Compressed, fine-grained marine sediments are found below the basalts, at depths between 15-40 m, followed by sedimentary tuffs and basaltic lavas. The tuffs and especially the lavas are highly altered. The stratigraphy below about 200 m consists of lavas and intrusive rocks, mostly dolerites. The most common alteration minerals below 100 m are pyrite, calcite and laumontite which indicate a formation temperature of 120°C. Laumontite overprints high temperature alteration minerals such as epidote and chlorite (formation temperatures ~230°C) which indicates cooling of an ancient high temperature geothermal field (Steingrímsson et.al, 2001).

Here we review the past, present and future work on the geothermal exploration of the Geldinganes geothermal field, in connection with the increased demand for hot water supply for the Reykjavík district heating system.

2. PREVIOUS ACTIVITES AT THE GELDINGANES FIELD

Geothermal exploration wells have been drilled all over Reykjavík city in the last decades (e.g. Tómasson et al., 1994; Tulinius et al., 1996). The objective of these wells was to map the temperature gradient in Reykjavík and the surrounding area. Geothermal exploration in Geldinganes started in the late 1980's, followed by drilling of exploration wells in connection with the idea of developing a new neighborhood at the Geldinganes peninsula.

Although the idea of a new neighborhood was abandoned, 16 temperature gradient wells were drilled in the area in the period between 1992 and 1999 (Hafstað et al., 1999). These are mostly shallow wells (~100 m), but two of them, HS-33 and HS-44, are deeper, reaching 347 m depth and 1265 m depth, respectively (fig. 2-1). Drilling of well HS-33 revealed temperatures of about 100°C at 347 m depth. Few years later the high temperature gradient in Geldinganes was confirmed when well HS-44 was drilled to a depth of 1265 m, producing about 10 L/s of water with temperatures exceeding 100°C. The temperature gradient mapped in the Geldinganes revealed one of the highest temperature gradients measured in a low temperature field, or about 460°C/km (fig.Figure 2-2) (Steingrímsson et.al 2001). The results of the drilling survey in Geldinganes led to the drilling of a production well in the northern part of the peninsula.

Figure 2-1: The Geldinganes peninsula. The wells in the field are shown as red dots for the shallow (~100 m) exploration wells, and as orange dots for the deeper wells (>300 m).

The location of the production well was based on the temperature gradient map, and a magnetic measurement survey that was carried out on- and offshore Geldinganes and its vicinity in 1997-2000 (Gunnarsson, 1997, 1999, 2001; Gunnarsson and Lindman 2000). The magnetic survey revealed a negative anomaly north-east of the peninsula, indicating an intrusive body. The target of the well, named RV-43, was this intrusive body and a NA-fault mapped by the temperature gradient revealing a temperature maximum in the northern part of the peninsula (fig 2-2).

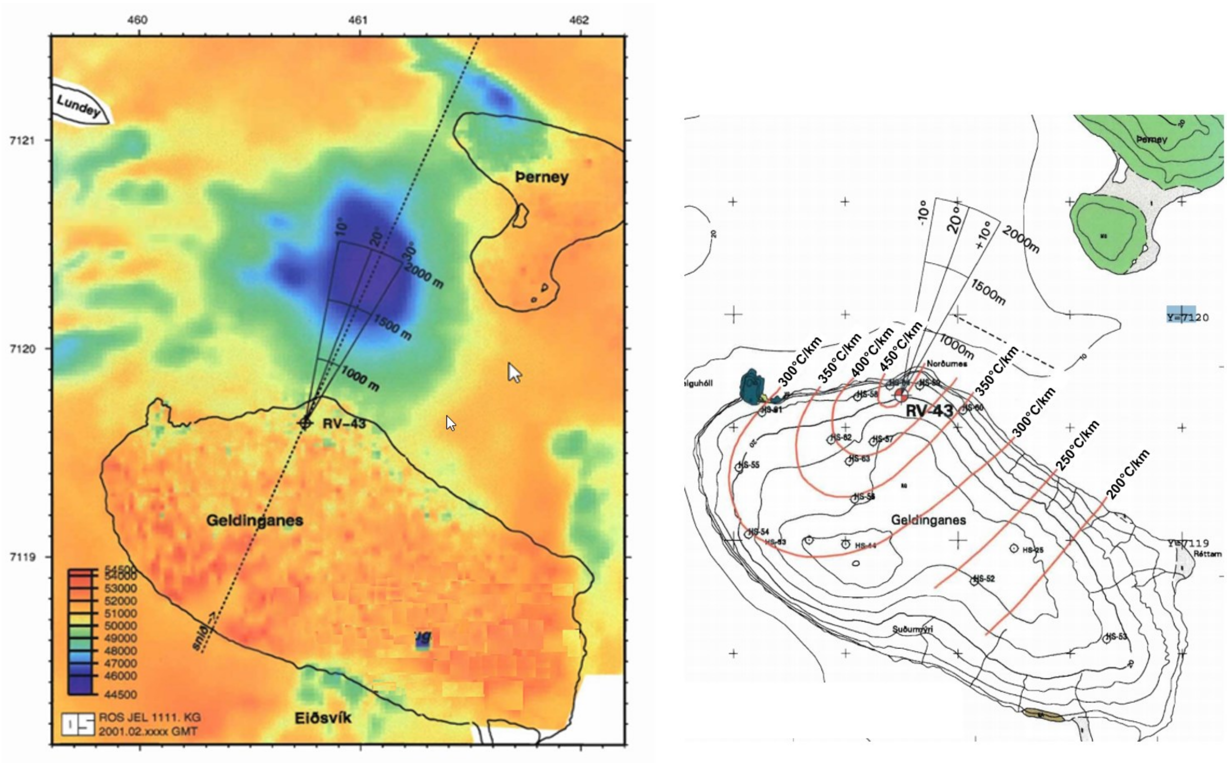

Figure 2-2: The results of the magnetic surveys carried out on- and offshore Geldinganes (Gunnarsson, 2001) and the measured temperature gradient of the Geldinganes peninsula (Steingrímsson et.al, 2001).

RV-43 is deviated by 16° to the north east with maximum 36°C inclination at the bottom of the well. The measured depth of the well is 1832 m. The well intersects lavas, tuffs and breccias, and below 250 m intrusive doleritic rocks become dominant along with highly altered basalts. The alteration mineralogy is like the mineralogy of the previously drilled wells in the area, with laumontite overprinting high temperature minerals such as epidote and chlorite. Pyrite and calcite are also common. At about 1700 m measured depth a gabbro intrusion was intersected identified as the targeted intrusive body (Richter et al., 2002).

The outcome of the drilling was unsuccessful as described in detail by Richter et al. (2002). No large feed-zones were intersected during the drilling of the well, but temperature logs revealed some small ones at ~780 m, ~830 m, ~1030 m, ~ 1100 m, ~ 1135 m, ~1250 m, ~ 1330 m and ~1720 m (fig 2-3). The well was air-lifted directly after drilling and started flowing at 19 bar. The flow was measured about 2-3 L/s. Following the airlift, the well was stimulated via pumping of 40-60 L/s through the drill string at 230 m depth. After three days of stimulation the well was airlifted again, and the flow had now increased to about 10 L/s of about 100°C hot water. Temperature log revealed that during the stimulation most of the water had flowed through feed zones located right beneath the casing, and a small fraction through feed zone at ~1250 m. No water reached the deeper parts of the well. The well was closed off after drilling and has since then remained closed.

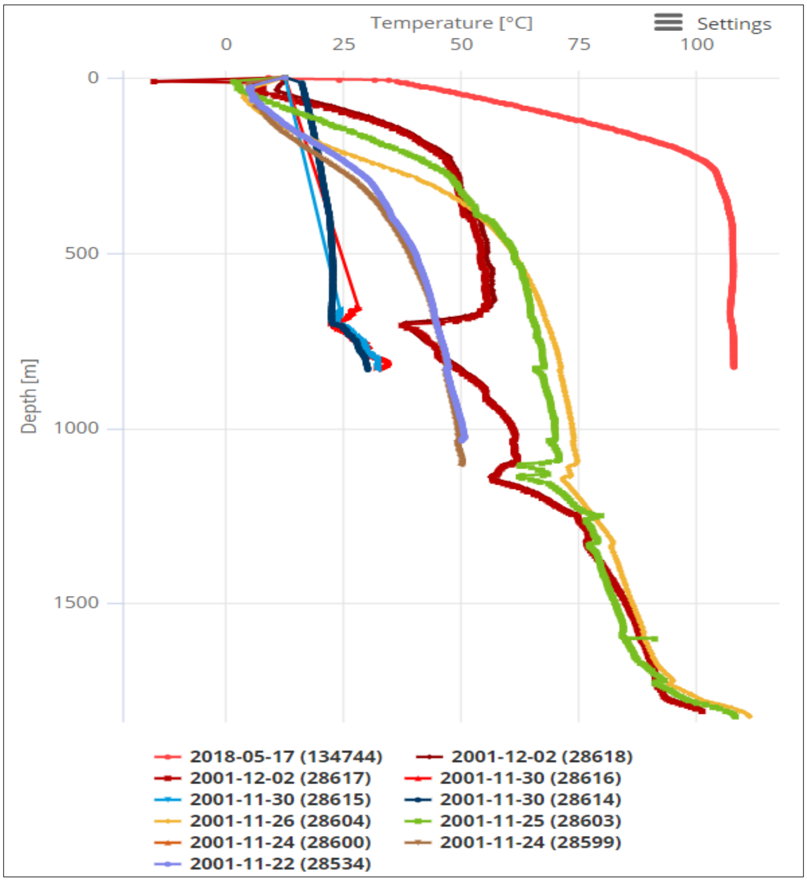

Figure 2-3: Temperature logs from well RV-43. No large feed-zones are intersected in the well, but several smaller ones have been located.

3. CURRENT ACTIVITIES AT THE GELDINGANES FIELD

Due to the increased demand for hot water supplied from the low temperature areas the Geldinganes field is now being reassessed as a potential addition to the district heating system in Reykjavík. The following activities are ongoing or in the pipeline for this assessment: 1) water table monitoring of wells HS-33 and HS-44 and a tracer test in well RV-43; 2) construction of a geological model of the area using Leapfrog; 3) stimulation of well RV-43; 4) drilling of well RV-44.

3.1. Water table monitoring and tracer test

Water table monitoring has been ongoing in Geldinganes since early 2018. The aim of the monitoring is to monitor potential pressure relationship between the Geldinganes field and the nearby Laugarnes field which is in utilization. So far, no connection has been noted between the two fields, indicating that production from the Geldinganes should not affect the production in Laugarnes.

To further establish the hydrology at the Geldinganes field a tracer test has been taking place in the field since May 2019. 75 kg of 1,6 napthalenesulfonic acid disodium salt was dissolved into 1000 L of water and injected as a slug into well RV-43 where it was anticipated to flow into the geothermal reservoir at depths between 700-1500 m depth. Wells HS-33 and HS-44 in the field are sampled regularly along with production wells in the Laugarnes field. No results are yet to report on from the tracer test.

The results from the water table monitoring and the tracer test will help to establish the hydrology of the field and will feed into existing reservoir models of the production fields of the Reykjavík district heating system in order to access the size and production potential of the field.

3.2. Geological modelling

A geological model of the Geldinganes field is currently being constructed by ISOR (Iceland GeoSurvey) using Leapfrog Geothermal modelling software. The idea behind the model is to compile all existing data and integrate it into a 2D and a 3D model. This allows for easier access and multi-disciplinary analysis of the existing data.

The biggest task of the modelling work is the quality control of the data incorporated in the modeling, including collecting and digitizing of all relevant data. The locations of wells in the field will be imported along with all well data available, such as pressure- and temperature logs, locations of feed zones, formation temperatures and analysis of geological properties such as stratigraphy and alteration mineralogy. Existing maps and models from the field will be integrated as well including geological maps, aerial photographs, contour maps, map of faults and fissures, mapped resistance and magnetic measurements.

The first version of the geological model of the Geldinganes field is predicted to be ready during the latter half of the 2019. The model will be an important tool in locating well RV-44 that is planned to be drilled in Geldinganes in the winter of 2020-2021.

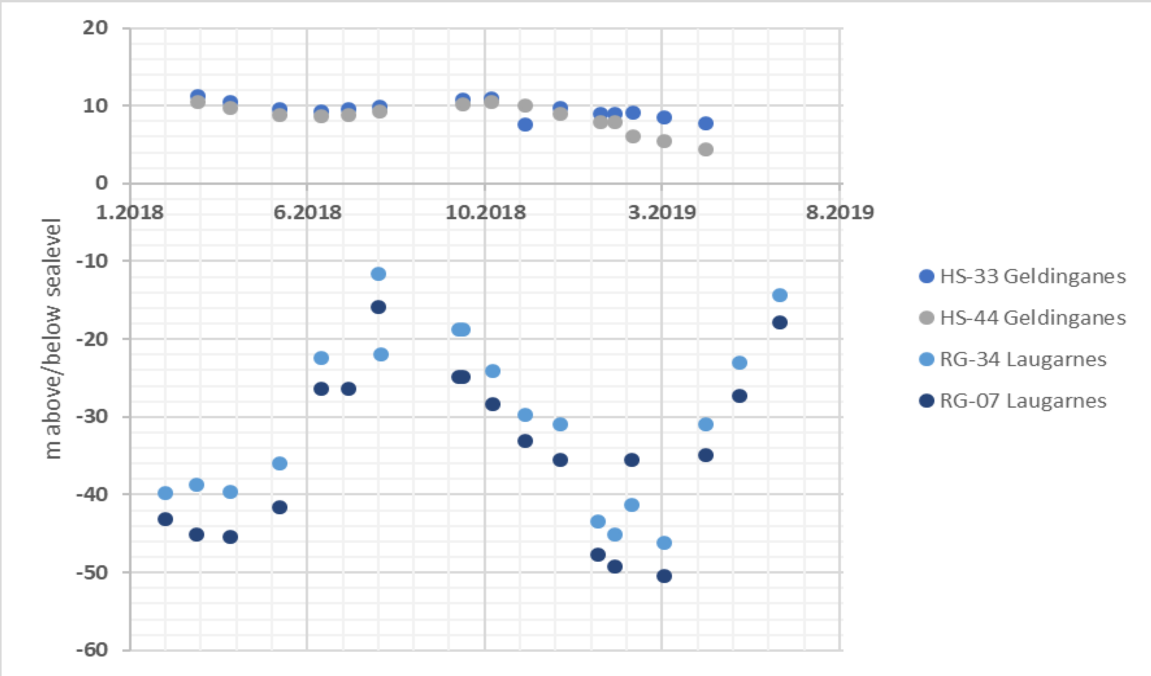

Figure 3-1: Water table monitoring of the Geldinganes and the Laugarnes geothermal fields.

3.3. Stimulation of well RV-43

During the period between 1970 and 1990, 45 production wells were drilled for the district heating system in Reykjavík. All of them were stimulated using injection packers. The process starts by cleaning the well by pumping compressed air into it; the pumping is continued until the water is free from suspended matter and the temperature becomes steady. Next an inflatable packer is located at a predetermined depth and water injected beneath the packer. The number of packers used in each well depends on the number of feed zones encountered. The rate of pumping varies with wells, well location and the location of the packer in the well and can range from 15-100 L/s. Stimulation as described above proved successful in most geological settings. Stimulation in quaternary rocks provided good results in four out of five settings outside of Reykjavík. In Tertiary rock the results varied from no improvements to 50% improvement of productivity. For the Reykjahlíð and Reykir wells, up to 40-fold improvement in productivity was detected compared to the loss of circulation at the end of drilling in the wells (Tomasson and Thorsteinsson, 1978). A successful stimulation in a well makes it possible to increase production from the wells that are already in the area, instead of drilling new ones, significantly decreasing cost of developing new production fields.

Plans are to stimulate well RV-43 using a packing system, as a part of the H2020 backed DESTRESS project. The stimulation project is described in detail by Hoffman et al. (this issue). The aim of the stimulation is to reach the deeper parts of the well in attempt to increase the permeability and hence the production rate of the well. Considering how well the low permeability zones responded to the previous stimulation it is likely that it could lead to a more productive well.

3.4. Drilling of well RV-44

Drilling of a new production well in Geldinganes is estimated in 2020. The exact location of that well has not yet been decided but will build on the past work in the field as well as new information gained from the on-going activities at Geldinganes.

The results from the drilling will be vital for assessing the potential for further development of the Geldinganes field for production for the Reykjavík district heating system. If the outcome is satisfactory, this new well could make the connection of the peninsula to the district heating system economically feasible. In this case wells HS-44 and RV-43 could we utilized as well. The stimulation of well RV-43 also feeds into the economical aspect, even though the results are not expected to be significant for the future of the Geldinganes geothermal area.

4. DISCUSSION AND FINAL REMARKS

Here we have reported on the past, present and future activities in connection with geothermal exploration of the Geldinganes field. Exploration drilling in the 1990's has revealed an exceptionally high temperature gradient in the field, but the permeability of the wells has been low. The field was abandoned after the unsuccessful results of the drilling of well RV-43.

The increased demand for hot water supply from the low temperature areas within and nearby Reykjavík has put the focus back on the Geldinganes field. Ongoing research activities and proposed stimulation of well RV-43, in addition to the drilling of a new production well in the area in 2020 aim to gain an increased understanding of the nature and extent of the geothermal field for potential utilisation in the near future. This is not only the case for Geldinganes, but other fields in the vicinity of the city are also being further explored as potential options for geothermal utilisation. In addition to the exploration of new fields, an emphasis has been placed on exploring methods to enable mixing of waters from the two systems; the low temperature fields and the heated groundwater from the power plants.

The outcome of the ongoing activities at the Geldinganes peninsula will be used directly for the assessment of the potential for further development of the Geldinganes and hopefully result in a successful expansion of the Reykjavík district heating system.

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