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The Reykir Geothermal Area in Fnjóskadalur North-Iceland: District Heating in Rural Iceland

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ABSTRACT

Utilization of the geothermal resource at Reykir goes back to at least the mid nineteenth century. Runoff from a productive hot-spring with ~90°C hot water was used for washing and attempts to use the water for cultivation date back to at least the 1850's. Later recreational use of the water increased and since 1950 it has been used locally for space heating.

Systematic research on the field commenced in the 1970's. Initially it involved surface geophysical measurements, geological mapping and drilling of shallow exploratory wells. A low resistivity anomaly was recorded around the Reykir field and subsequent research was aimed at locating the hot water's main course of up-flow.

A second period of activity has been ongoing since 2005. Additional wells have been drilled in the area and the production well has been subjected to long term flow-testing. In all 13 boreholes have now been drilled in the area. The field is now utilized for space heating in the Fnjóska-dalur valley and hot water is piped to the village of Grenivík some 55 km north of the field.

1. INTRODUCTION

The Reykir low-temperature geothermal area is located at the head of the Fnjóskadalur valley, some 30 km southeast of Akureyri in North-Central Iceland (Figure1). The Fnjóskadalur valley is separated from the Eyjafjörður valley (and fjord) by a low flat mountain or moor, named Vaðlaheidi (highest point 854 m.a.s.). This moor is a formidable threshold when considering the possibility of pumping hot water from Reykir to market in the town of Akureyri (~17,000 inhabitants).

In the early years of prospecting for hot water for the town of Akureyri, the district heating service (now Norðurorka) purchased the land at Reykir and, with it, the rights to utilize the geothermal resource. At the time the field was considered a possible future candidate for providing hot water to the town of Akureyri in spite of its remote location.

Prior to drilling in the area, warm springs (Reykjalaug) produced an artesian flow of Q ≈ 5 l/s of over 90°C hot water which drained into the nearby Fnjóska river. Utilization of the geothermal resource goes back to at least the mid nineteenth century.

More recently the energy has been harnessed for space heating of farms and an increasing number of leisure or 2nd homes in the rural Fnjóskadalur valley and last but not least for space heating in Grenivík, a small fishing village (~300 inhabitants), some 55 km north of the Reykir field.

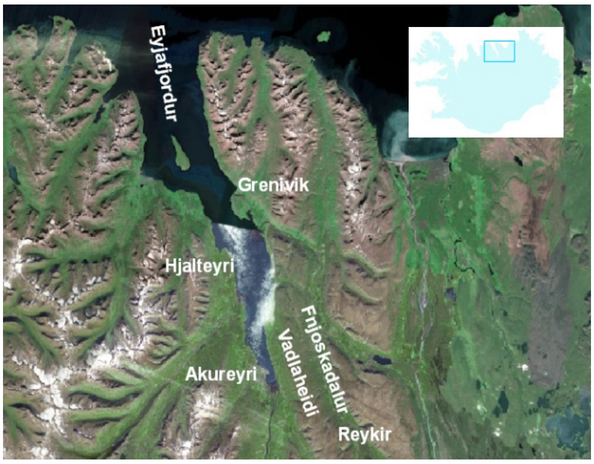

Figure 1: Overview of Eyjafjördur and Fnjóskadalur.

This paper reviews the history of geothermal utilization of the Reykir field. It describes the research carried out in the area over the past three decades, including geological mapping, geophysical surveys, logging temperature-logging subsurface mapping and the flow tests are discussed.

2. UTILIZATION OF THE RESOURCE AT REYKIR

The geothermal source at Reykir has been known for a long time. Its surface manifestation was a series of closely spaced hot springs rising from the gravel deposits covering the floor of Fnjóskadalur valley. According to contemporary source material, occupants of the closest farms used the largest of these springs (Reykjalaug) for washing early in the 19th century (Árnason, 1994). Potherbs have been cultivated in Reykir's lukewarm soil since around 1850 (Kristjánsson, 1963) and in the first half of the twentieth century flori-culture was practiced as well.

Around 1930, a small swimming pool was constructed by erecting a dam in Reykjalaug's effluent. By 1950 two green-houses, using geothermal energy, had been built near the hot springs. At this time a local farmer started using surface water for space heating at the Reykir farm. For this purpose, a simple heat exchanger was placed in Reykjalaug's effluent. Cold water was piped from the streams above the farm to the heat exchanger and then back to the farm house.

This heating utility was in use until harnessing of free-flow from one of the boreholes (RF-7) commenced in 1982. The artesian flow was utilized for residence heating and culti-vation by the local farms at Reykir. Since 2006 the well has been harnessed for space heating of an increasing number of leisure homes in the rural Fnjóskadalur valley, and additionally for space heating in Grenivík since 2007. Grenivík is a small fishing village some 55 km north of the Reykir field. The well RF-9 drilled 2008 serves as an emergency backup well for RF-7.

3. RESEARCH AT THE REYKIR FIELD

As mentioned above, research on Reykir geothermal field commenced in the 1970’s. At that time prospecting for hot water for Akureyri’s heating utility was ongoing. It was focused mainly on fields 10 to 15 km south of Akureyri but also included the Reykir field, which was considered to be particularly promising (Sæmundsson and Ragnars 1974).

The initial research effort from 1975 to 1982, included basic geological mapping, surface geophysical measurements (resistivity, magnetic anomaly, seismic refraction and VLF), exploratory drilling and temperature logging.

The more recent research effort, which is still ongoing, started in earnest in 2005, has included more detailed geological mapping, drilling of exploratory wells and long term flow testing of production wells.

3.1 Geological Mapping

Sæmundsson produced the first geological maps of the area (Björnsson and Sæmundsson 1975, Flóvenz et. al 1982). Later Hjartarson and Jónsdóttir added to and expanded on the earlier work (Hjartarson and Jónsdóttir 2001, Axelsson et al. 2006).

Formations from two different geological stages are among the key features in the area. The lava flows that form the mountains to east of Reykir belong to a Pliocene rock formation (Kinnarfjalla-basalt). This Kinnarfjalla-basalt formation lies discordantly on top of the Miocene Eyja-fjardar-basalt formation (7-10 million years old) which forms the bedrock in Eyjafjörður. Here an unconformity is recorded, covering 1-2 million years, which is believed to represent the relocation of the northern volcanic zone to its present position, some 6-7 million years ago.

These two lava formations are separated by a sedimentary sequence, up to 50 m thick, typically comprised of fine-grained and medium-grained sediments (siltstones and sandstones). In some areas these sediments contain lignite horizons.

The Eyjafjardarbasalt is a typical Miocene rock formation, principally formed of simple lava sheets intercalated with thin intrabasaltic beds. The Kinnarfjallabasalt formation is principally formed of shield lava flows, forming thick sequences of relatively thin flows. The shield lava sequences are intercalated with thick beds of sandstone and conglomerates.

The sedimentary sequence, representing the hiatus in volcanism, can be traced in the gullies to the north and west of Reykir (Figure 2). However, in the Fnjóskadalur valley, the boundary between the two basalt formations is concealed by thick sediments covering the valley floor. In addition substantial rock-slides have occurred in the valley and Reykjalaug is situated close to the edge of just such a rock-slide from the Reykjafjall mountain. The thick sediments formed at the end of the Quaternary period and beginning of Holecene.

The Reykir field is situated at the northern periphery of an extinct central volcano belonging to the Pliocene rock sequence. Siliceous rocks (andesites, dacites and rhyolites) belonging to this centre are exposed in the mountains to the southwest of Reykir (Figure 2).

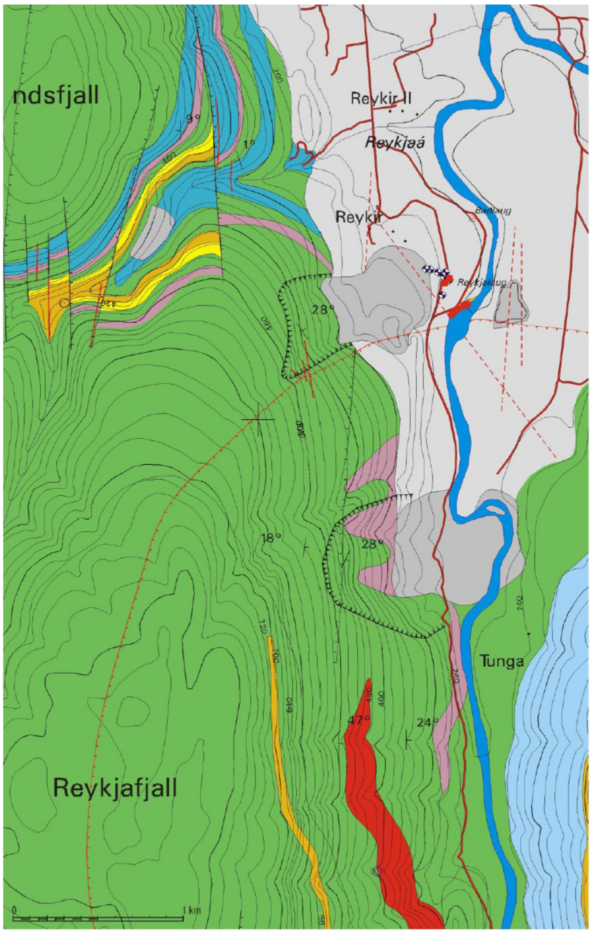

Figure 2: Simplified geological map of the Reykir area Bedrock; olivine-tholeiite (green), tholeiite (blue), rhyolite (yellow), intrusive siliceous rocks (red), andesite (purple) sediment (orange). Sediments; valley-fill (light grey), rock-slide deposits (dark grey). Also shown are faults and dikes in bedrock are indicated by red stippled lines. The outline of the silicic centre is indicated by the red continuous line with hash marks.

3.2 Surface Geophysical Measurements

The initial research effort in Reykir included resistivity mapping, magnetic surveys, seismic refraction and VLF-surveys. The main objective was to try to locate structures (dikes, faults) associated with the up flow of hot water feeding the springs.

A resistivity map of the area revealed that a low-resistivity anomaly is associated with the geothermal field at Reykir (Flóvenz, 1984). The anomaly has an elongated almost elliptical shape with a N-S oriented long axis (Figure 3).

The results showed unusually low resistivity, considering the lithology, often less than 20 Ωm, and that the up-flow from the bedrock was on a N-S trend.

A later study on the resistivity structure of the bedrock formation in the Fnjóskadalur valley, using TEM measurements confirmed this, in that a profile along the valley showed a low resistivity anomaly, concave upwards, with the shallow-most point underneath Reykir (Árnason and Hjartarson, 1997).

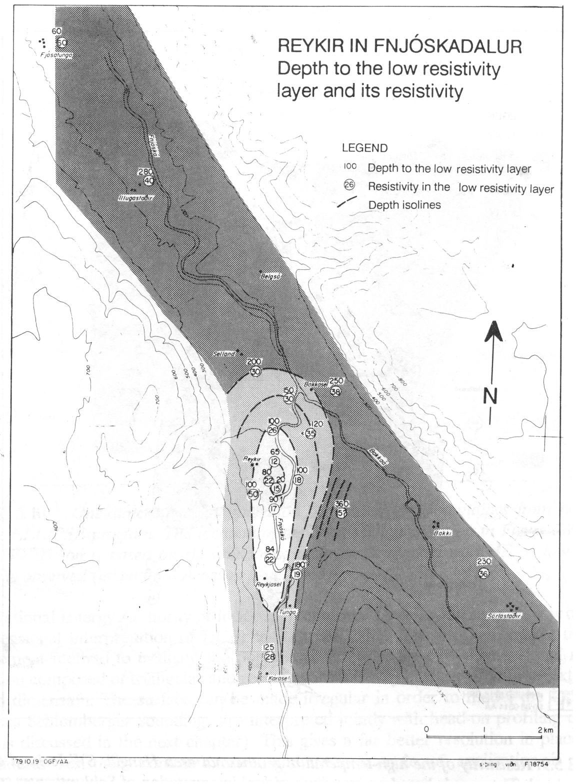

Figure 3: Resitivity map of Reykir and surrounding areas based on Schlumberge soundings (Flóvenz 1984).

Magnetic field measurements indicated a N45°V dyke close to the hot springs. Furthermore the magnetic measurements showed two closely spaced dikes with a N-S trend a little bit east of Reykjalaug and possibly a single dike immediately west of the spring. Traces showing the location of these presumed dikes may be seen on the geological map (Figure 2).

3.3 Exploratory Drilling

Prospecting for geothermal energy by drilling of shallow wells for temperature gradient observation has been quite successful in Iceland in recent years. The purpose of drilling such wells is to observe variations in geothermal gradient in the field relative to the regional gradient due to heat flow from the mantle. The regional gradient is steep in the volcanic zones of Iceland but decreases with increasing age of bedrock, crustal thickness and distance from the active volcanic zones. Deviations from the expected regional gradient are related either to the flow of hot water towards the surface from greater depths, or possibly to local recharge of cold water. From a relatively closely spaced grid of shallow boreholes the shape and orientation of the geo-thermal anomaly may be mapped out. Ideally the anomaly can then be linked with key geological and tectonic features inferred from mapping and geophysical surveys.

The first seven wells at Reykir were drilled in the time period from 1980 to 1982 (Flóvenz et. al 1982, Flóvenz 1990) Six of these wells were shallow research wells, five were 80 m to 110 m deep but one (RF-4) was 197 m deep. Based on the data gathered a seventh (RF-7) well was drilled to 650 m depth in 1982. It intersected a productive aquifer at 257 m depth. Temperature logs showed a reversed gradient below the aquifer, clearly indicating lateral flow to the well.

After drilling RF-7 artesian flow from the well was used for space heating and cultivation. Furthermore the Reykjahver hot-spring more or less disappeared indicating that the well had intersected its feed zone. After the completion of well RF-7 little research was done in the area for several years. The artesian flow from the well more than satisfied the local need and due to its location, harnessing of the field for the town of Akureyri would prove to be very costly.

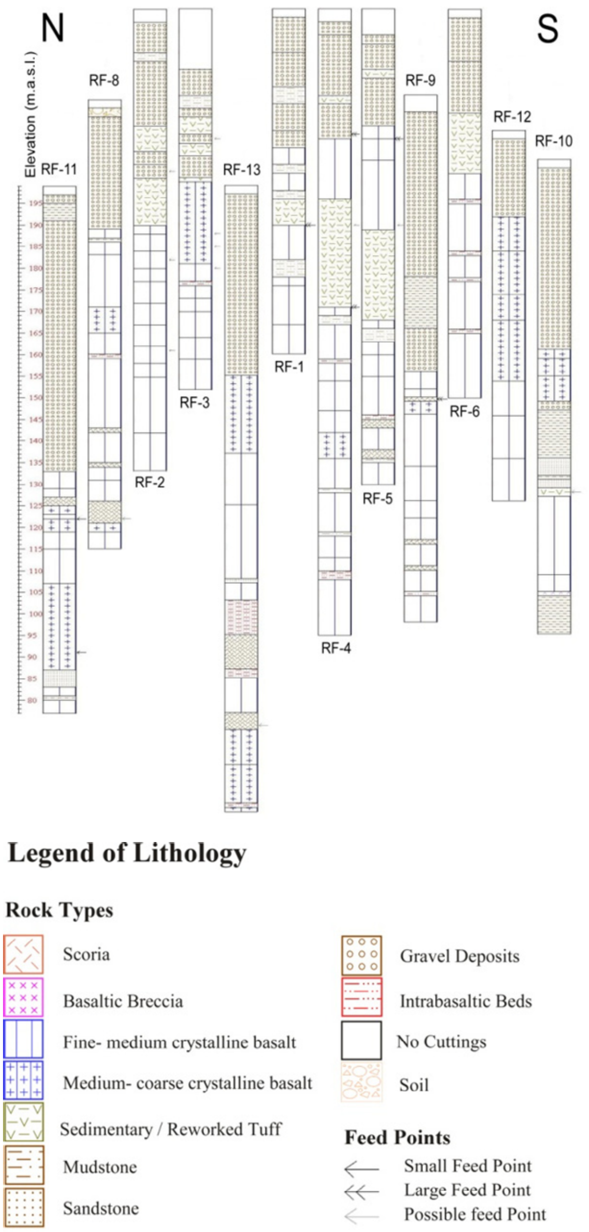

Figure 4: Lithology based on analysis of cuttings from shallow exploration wells. Also shown are feed points in the wells at Reykir.

In the past two to three decades there has been a phenomenal growth in leisure homes in Iceland. The Fnjóskadalur valley has seen its fair share of this growth. Thus a market for hot-water has slowly developed in the vicinity of the, once remote, Reykir field. In addition attempts to find hot water for the town of Grenivík located at the mouth of Fnjóska-dalur have been unsuccessful. Therefore Norðurorka, the district heating company in Akureyri, decided to test the feasibility of building a district heating system for the Fnjóskadalur valley and the village of Grenivík. Hence studies on the Reykir field recommenced.

In 2008 five shallow wells were drilled for temperature gradient studies. These wells were located farther away from the original hot-spring than the wells drilled previously. The purpose was to define better the size and shape of the thermal anomaly associated with the field.

Figure 5: Measured temperature 130 m.a.s. in boreholes in Reykir and a 20°C isotherm.

The outline of the geothermal anomaly is shown in Figure5 as a 20 C isotherm at 130 m.a.s. The Reykir geothermal field is at ~220 m.a.s. so the isotherm shown is at ~90 m below surface on average. The thermal anomaly associated with is surprisingly large. The area inside the 20°C isotherm is characterized by a thermal gradient in excess of 180 C/km which is substantially above the expected background gradient (~80 C/km). It is interesting to note the striking similarity of the thermal anomaly and the resistivity anomaly (Figure3). Both are nearly elliptical with a long axis striking ~N-S. The anomalies are broader towards the north end and seem to terminate more abruptly to the north of the Reykjahver hot-spring. The similarity strongly suggests that the resistivity anomaly is due to present day geothermal activity.

In addition an alternate shallow production well (RF-9) was drilled for potential harnessing in case RF-7 would fail, The well, like RF-7, is fed from horizontal flow off the main course of up-flow, yet its feed is from a shallower depth. Nonetheless, flow testing by the end of drilling showed that RF-9 is comparable to well RF-7.

3.4. Subsurface Mapping from Drill Cuttings

Analysis of drill cuttings from wells 1-6 and 8-13 (Flóvenz et. al 1982, Árnadóttir et. al 2009) revealed that gravel deposits characterize the uppermost 20-65 meters of the boreholes. Below the sediments are sequences of thin basaltic lava flows (Figure 4). These Miocene flows belong to the Eyjafjardar-basalt sequence. The lava flows are separated by thin beds comprised of oxidized scoria and thin fine grained sediments.

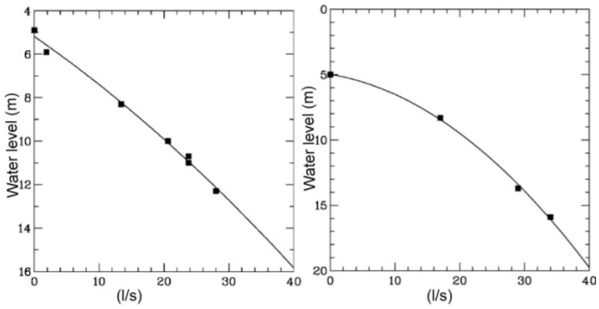

Figure 6: Results of flow-tests in wells RF-7 (left) and RF-9 (right). Depression of water level (m) is presented as a function of flow (l/s).

The stratigraphy of well RF-10 is nonetheless quite distinct from the other wells, being principally characterized by fine grained sediment deposited in calm water. A dyke was observed in well RF-3 at ca. 40 m - 60 m depth. The principal alteration minerals found in the drill cuttings are clay, chalcedony and zeolites (e.g. chabazite and scolecite).

3.5. Short Flow Tests

In 2005 research on Reykir geothermal field recommenced with a ~3 month long flow test in RF-7 (Axelsson et. al 2006). The results showed that the well would produce the required average of 16 l/s with only minor draw-down in the field (Figure 6). Moreover, the geothermal area is considered to allow exploitation at a rate of at least 50 l/s as a long-term annual average. This is considerably more than can be obtained from well RF-7 (Axelsson et. al 2006). Since the feed zone in RF-7 is shallow influx of colder water is a real concern and a temperature decrease of up to 10°C in twenty years is possible (Axelsson et. al 2006). In spite of this possibility the results of the flow tests were so encouraging that Norðurorka went ahead with building a district heating system for Fnjóskadalur and Grenivík.

Well RF-9 was flow-tested by air-lifting in August 2008 (Árnadóttir et. al 2009). The results indicate a fairly open well (Figure 6), somewhat resembling well RF-7 (Árnadóttir et. al 2009) in terms of production characteristics.

The Reykir geothermal field appears to be among the more powerful of the low-temperature geothermal systems in Iceland Reykir is considered to sustain long term production of at least 50 l/s on average (Axelsson et al. 2005, Axelsson et al. 2006). With the exception of the Hjalteyri field, it is the most productive field that Norðurorka currently operates.

4. CONCLUSIONS

A pronounced thermal anomaly is associated with the Reykir low-temperature field. Flow testing indicates that the field is among the more powerful low-temperature geothermal systems in Iceland. Reykir is considered to sustain long term average production of 50 l/s.

The geothermal resource at Reykir has had a long history of use for cultivation and local space heating. Currently it is utilized for space heating in the rural Fnjóskadalur and the village of Grenivík.

Present day utilization of the field is in part due to an increase in leisure or 2nd homes in the rural Fnjóskadalur valley. This growth helped in making a district heating system economically viable.

Future research at Reykir geothermal field will focus on locating the main up-flow accurately. This has been the goal since the start of research in the area, but it has remained elusive.

In the long term the plan is to site and drill a production well that intersects the up-flow at a depth of 800 m to 1200 m. This may not be realized until after a traffic-tunnel is dug through the Vaðlaheiði moor, providing a less expensive route to pipe hot water to market in Akureyri, or market conditions become favorable to running a pipeline across Vaðlaheiði.

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