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# Low Temperature Systems in Kjalarnes Iceland, Exploration Using Gradient Wells

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**ABSTRACT**

Geothermal research and utilization near Kjalarnes in SW-Iceland have a long history, with drilling activity dating back to 1952. Geological mapping has identified two eroded central volcanoes, including the Viðey-Kjalarnes and Stardalur systems. Geophysical surveys have revealed a large low-resistivity zone south of Kjalarnes. Magnetic and gravity surveys support the presence of a volcanic center offshore Kjalarnes.

Several shallow geothermal wells were drilled between 1952 and the late 1970s, with limited success. Renewed interest in the area in 1978 led to drilling of a 637 m deep well in 1979, which showed a temperature gradient of 230°C/km and a peak temperature of 128°C. From 2022 to 2025, 28 temperature gradient wells were drilled across Kjalarnes by Reykjavik Energy, significantly expanding the geothermal knowledge and subsequently, two deeper production wells (~ 900 m) were drilled in a previously unknown system.

In 2025, six new gradient wells were drilled at Esjuberg, revealing unusually high temperature gradients—up to 430°C/km in EB-10, which does not align with results from earlier data. Measured temperatures reached nearly 90°C at just 200 m depth. These values strongly suggest an active geothermal system, likely controlled by fractures and dike intrusions observed in the nearby Esja mountain. Comparisons with other wells at Brimnes and Vallá indicate that Esjuberg shows the highest geothermal gradients in the region, with potential reservoir temperatures exceeding 100°C. Continued exploration and deep drilling are recommended to confirm the extent and capacity of this promising geothermal resource.

## 1 INTRODUCTION

Although surface signs of geothermal activity on Kjalarnes and its surroundings are limited today, several historical indications point to hidden potential. Warm springs were once active at Esjuberg (~26 °C) and Álfsneslaug, where in 1949 about 1–2 L/s of 24 °C water was self-flowing. Boreholes drilled in the 1950s at Arnarholt and Álfsnes produced little or no flow, yet temperature gradients were unusually high (150–240 °C/km) compared to a regional background of ~80 °C/km (Friðleifsson, 1974; Friðleifsson & Stefánsson, 1975; Sæmundsson & Jóhannesson, 2006).

Systematic exploration began in 1972 with resistivity surveys by Orkustofnun. Six lines across Kjalarnes revealed a low-resistivity anomaly in the east, near Norðurgröf, and a resistivity increase below 500 m at Vallá, interpreted as intrusive/metamorphosed rocks in the volcanic core (Georgsson, 1981). The bedrock, dominated by hyaloclastite and lava flows cut by intrusions and faults, suggests potential fracture-controlled aquifers. A denser survey network and shallow TG drilling were recommended (Friðleifsson, 1973). Subsequent surveys included magnetic profiling at Vallá (1978), which indicated a N30°E fault. Drilling there in 1979 to 637 m encountered impermeable formations, but bottom-hole temperatures reached ~128 °C with gradients of ~220 °C/km. A heat-exchange circulation test in 1980 proved unsuccessful, and the project was abandoned (Þórhallsson & Kjaran, 1980). On Álfsnes, a 370 m borehole (1951–52) recorded 88 °C at the bottom, and later surveys highlighted favorable strata and high gradients, recommending deeper wells (>1000 m) and step-out drilling in the south (Friðleifsson & Stefánsson, 1975; Tulinius, 1989). In Kollafjörður, wells drilled 1954–56 intercepted veins at 70–80 m, with Well III producing 7 L/s at ~67 °C. Chemical geothermometers indicated reservoir temperatures above 100 °C, leading to the drilling of KF-4 (1031 m) in 1978/81. This well reached ~116 °C, with silica geothermometry suggesting ~135 °C at depth (Bjarnason, 1983; Björnsson et al., 1999). KF-4 still delivers ~3 L/s at 68 °C, used today for fish farming. Additional evidence came during the construction of the Hvalfjarðar Tunnel, where north-facing fractures ~1 km offshore intersected ~60 °C water (Björnsson et al., 1999; Sæmundsson, 2014).

## 2 GEOTHERMAL IN THE VICINITY OF KJALARNES

Since the 1960s, temperature-gradient drilling has been a common method for geothermal exploration in Iceland. Shallow wells, typically 40–100 m deep, are drilled to investigate how temperature increases with depth (°C/km). This technique has yielded many successful results (Sæmundsson, 1977; Stefánsson et al., 1993; Pálmason, 2005). The highest gradients are generally found closest to volcanic belts, but several areas outside them also show anomalously high values. Notably, elevated gradients have been recorded north of Kollafjörður in Borgarfjörður and in the uplands of Árnessýsla (Pálmason et al., 1979).

In Kjósarhreppur, surface geothermal activity is visible in several places. In Brynjudalur, two warm sites are known. At Fremriháls, a 30 °C hot pool exists, and between 1991–1993 two production wells were drilled to 860 and 400 m depth. Bottom-hole temperatures reached 120 °C in the deeper well and 95 °C in the shallower. At Volgra, on the slope inside Möðruvellir in Kjós, a 15 °C warm spring is present. Exploration at Hvammsvík (1985–1991) included nine thermal-gradient wells, followed in 1991–1992 by a 1466 m deep production well. Although permeability was low, assessments suggested a long-term yield of 10–15 L/s of ~90 °C water. North of Hvalfjörður, on Hvalfjörðurströnd, drilling has been more successful: at Miðsandur, a 1513 m deep well recorded ~140 °C at the bottom, and at Hrafnabjörg, an 807 m well produces ~80 °C water by natural flow (Þórólfur H. Hafstað, 2015).

Further exploration in Kjós was carried out in 2008, combining re-measurement of older boreholes with new gradient drilling to close data gaps (Hafstað, 2015). Nearly 100 wells were surveyed, most of them shallow. The results revealed several anomalies suggesting underlying geothermal systems. Along a section from Hvalfjarðareyri in the west to Fremriháls in the east, five clear deviations from the regional gradient of 80–90 °C/km were identified, spaced about 4–5 km apart (Sæmundsson, 2014). The sharpest anomalies were at Möðruvellir, where gradients of 260–300 °C/km were recorded. A well drilled there in 2011 (MV-19) is estimated to be capable of producing ~20 L/s of 80 °C water, while a deeper well in 2014 (MV-24) reached 140 °C at 1700 m and flowed naturally at 20–25 L/s. In total, 19 wells have been drilled at Möðruvellir, confirming the area's strong geothermal potential.

The Reykir geothermal field in Mosfellsbær (often divided into Suður-Reykir and Reykjahlíð) is regarded as the most powerful low-temperature system in Iceland, with an estimated capacity of 367 MWth (based on water hotter than 35 °C). Drilling there began in 1933, eventually totaling 22 research wells and 122 production wells. Before drilling, natural springs discharged ~120 L/s of 83 °C water. By 1955, shallow boreholes increased output to 360 L/s at ~86 °C, and in 1959 deeper and wider wells—up to 2000 m—were introduced. Once pumping began, natural surface flows ceased. By 1975, production had reached ~850 L/s of 83.5 °C water from 20 wells, with drawdowns of 20–35 m. In 2015, average production was ~900 L/s at ~85 °C (Sveinbjörnsson, 2018).

Geothermal activity in Kjós and Mosfellssveit is thought to be linked to fissures and rock tunnels extending north from the Reykjanes Peninsula volcanic systems, particularly Krýsuvík (Sæmundsson, 2013, 2014). These tunnels provide permeability but not heat. According to a conceptual model for Mosfellsbær, a warm current (~100 °C) flows from the northeast, while a colder current from the Elliða River basin enters from the south. The cold-water travels deep through fractures, warms, and resurfaces at Suður-Reykir (formerly hot pools, now dry). Meanwhile, the hot NE current emerges at Norður-Reykir and enters porous strata at ~500 m depth, spreading south and west while partly mixing with the colder current. Inverted temperature profiles at Suður-Reykir support this model (Björnsson & Steingrímsson, 1995).

A later conceptual model for the capital area (Björnsson et al., 1999) described deep hot-water flow south of Kjalarnes, between Arnarholt and Vallá, inferred from high gradients in boreholes. Closer to Esja, vertical convection is weaker, though signs of agitation remain in Vallá and Kollafjörður wells. The authors proposed that the regional stress state may inhibit vertical fracture flow here. In contrast, Reykjavík's geothermal areas show strong vertical convection, linked to low horizontal stress. At the foot of Esja, however, horizontal stress dominates, possibly transferred from the mountain itself. As a result, thermal conditions are governed more by conduction (gradients of 80–100 °C/km) than by convective heat transfer. In figure 1 low geothermal systems around Reykjavik are shown on a geological map of Southwest Iceland (Seamundsson et.al 2016) and fracture pattern.

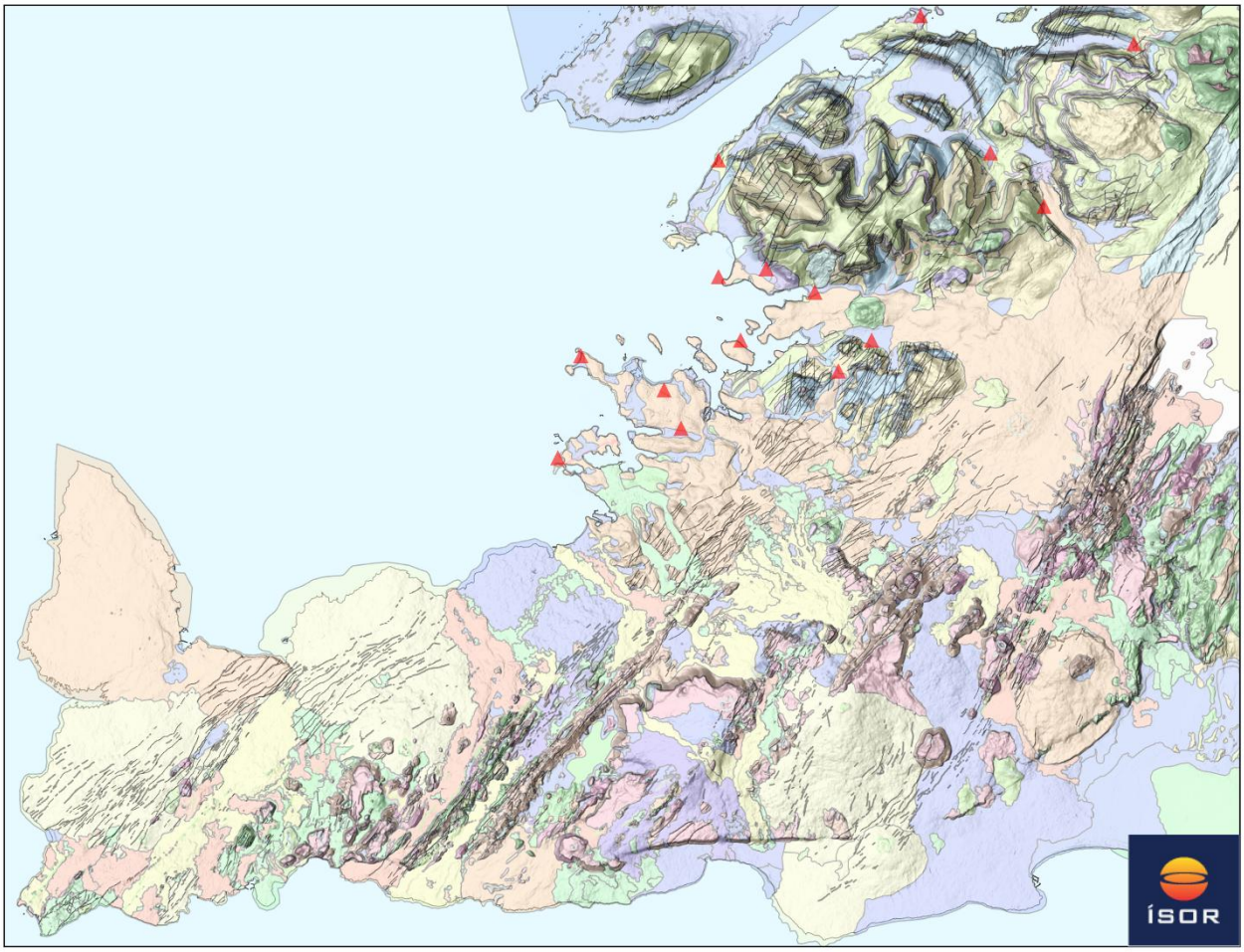



**Figure 1. A geothermal map of Southwest Iceland and low geothermal systems around Reykjavík.**

## 3 DISCOVERING NEW SYSTEMS

### 3.1 Field Observations in Kollafjörður, Hofsvík, and Brimnes

Before starting the gradient survey, a field excursion was done to focus on identifying open fractures along the shoreline in northern Kollafjörður, Brimnes and recording their main orientations. The shoreline hosts a dense network of open and filled fractures, numerous dikes, and altered bedrock. The most common orientation of dikes is northeast (excluding cone sheets), with many fault fractures following the same trend. Faults and fractures are widespread; many are filled with secondary minerals, but open fractures are also present. Several of these open fractures trend west to north. Many of the closed fractures are related to tectonic activity during the active or cooling stages of the local central volcanoes, whereas the active open fractures belong to the fissure swarms of the Reykjanes Peninsula and to transverse faults of the South Iceland Seismic Zone, both of which influence the Reykjavík area (.

### 3.2 Temperature-Gradient Results

As noted above, most of the wells drilled were tight and therefore provided excellent temperature-gradient conditions. Convincing gradients were obtained from all 17 new wells, ranging from the background value of 90–100 °C/km up to 380 °C/km. In addition to these new wells, measurements from six older boreholes on Kjalarnes were also incorporated, giving a total dataset of 23 wells across the area, from Kollafjörður to the Hvalfjörður Tunnel. The wells are not evenly distributed, and during the later drilling phase most were concentrated at Brimnes, where the highest gradients had already been recorded in the earlier phase, see figure 2 (Kristinsson et.al 2023).

The orientation of the two main anomalies—the Tíðaskarð anomaly and the Brimnes anomaly—is not entirely clear, and in both cases, interpretation is complicated by the influence of the sea. The Tíðaskarð anomaly appears to trend northward, or even north-northwest if connected from the northern Kjalarnes wells to the

geothermal manifestations in the Hvalfjörður Tunnel. Such a connection, however, is uncertain, as no three-dimensional data is available.

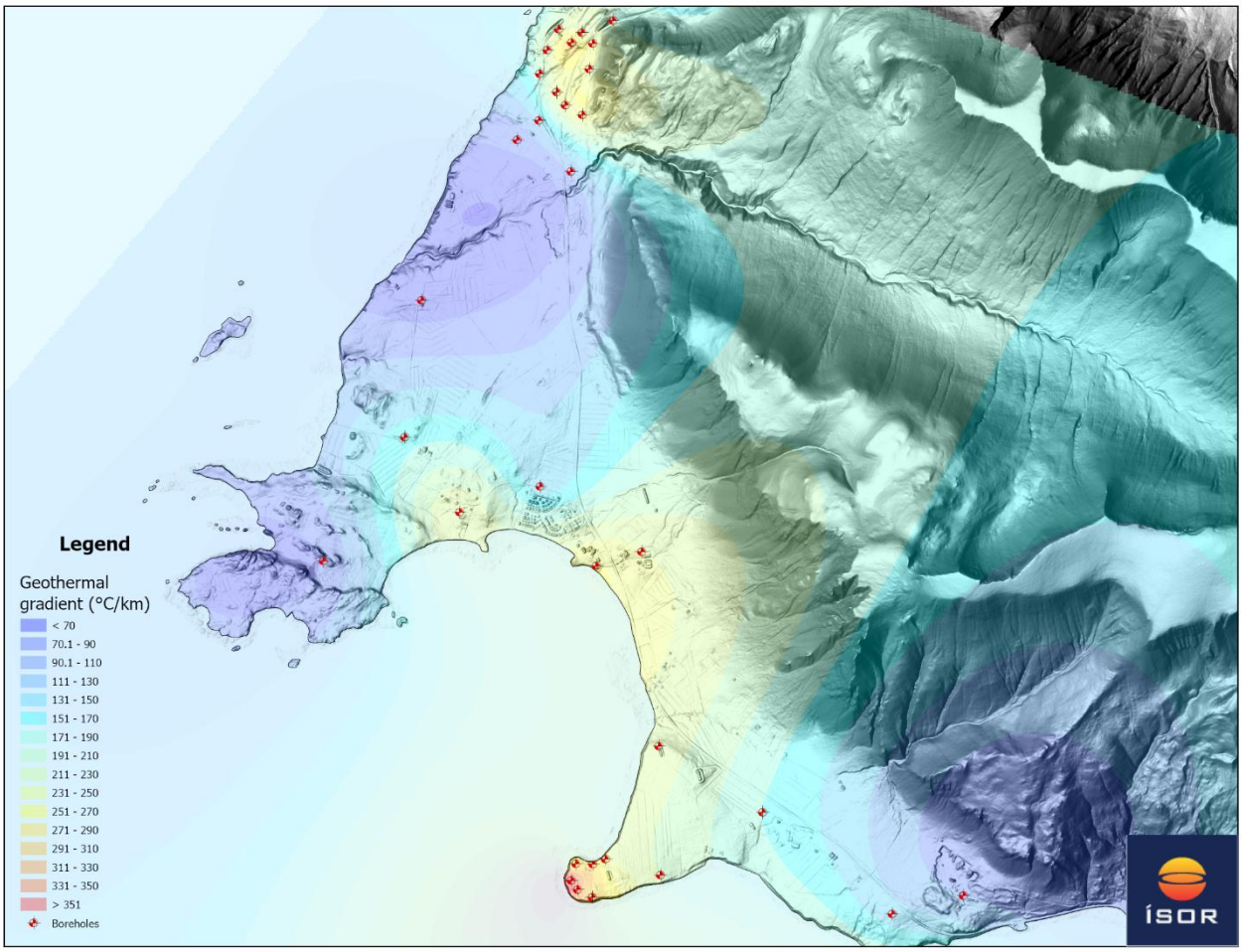



**Figure 2. Geothermal gradient map after the first part of the survey.**

For the Brimnes anomaly, it is likely that the actual maximum lies offshore, west of the headland, though its precise orientation remains unclear. Comparisons can be drawn with other anomalies in the capital area, including those mapped at Geldinganes (Ásgeirsdóttir and Ingimarsson, 2019) and at Laugarnes (Friðleifsson, 1990; Björnsson et al., 1999). The Geldinganes anomaly trends slightly more easterly than the orientation inferred here at Kjalarnes, though the two are broadly comparable. At Laugarnes, multiple interpretations have been proposed. The anomaly trend suggested by Björnsson et al. (1999) is almost identical to the one drawn here for Kjalarnes, although additional effects of drawdown at Laugarnes extend northwest (Friðleifsson 1995).

### 3.3 Esjuberg

In March 2025, four temperature-gradient wells were drilled on the Esjuberg property. The well locations were selected based on field observations, as a considerable number of springs are present in the area. The spring temperatures are not particularly high, but during ~–4 °C frost conditions in December 2024 most measured around 5 °C, with the warmest reaching 9.7 °C. Since most springs emerge from beneath landslide deposits, their positions do not necessarily indicate true upflow zones.

Historical records describe a 26 °C warm pool in the marsh east of the farm buildings. Although the pool has not been observed for decades, available evidence suggests that well EB-10 is located close to its former site. All four wells reached 100 m depth. Immediately after measurements were taken, it became evident that two wells (EB-10 and EB-11) had much higher gradients than anticipated. In EB-10 the gradient was estimated at ~430 °C/km, and in EB-11 at ~270 °C/km. Such values are exceptionally high and indicate the presence of a nearby convective geothermal system. It should be emphasized, however, that although the gradient is expressed in °C/km, this does not mean that such temperatures can be expected at 1 km depth. Where convection occurs, temperature profiles deviate from the simple conductive gradient and become nearly vertical beneath the mixing zone.

Given these results, additional drilling was recommended and carried out in April 2025. This included two more research wells (one 100 m deep and one 200 m deep) and deepening EB-10 to 200 m. The aim was to better constrain the extent of the thermal anomaly. During the deepening of EB-10, an unexpected event occurred. The well, which had previously shown a uniform and reliable profile, began to experience downflow of colder water from above. When downflow occurs, evaluating the true gradient becomes difficult. One common solution is to insert tubing and fill the annulus with sand to block the inflow. Despite this disturbance, EB-10 still showed a strong temperature rise at depth. Interpreting the gradient from the bottom up to ~5 °C gave ~350 °C/km, still extremely high. If only the lowest 25 m were considered, the gradient exceeded 600 °C/km, an unrealistically steep value.

Well EB-14, drilled to 100 m, yielded a clearer profile. Evaluating the lowest 25–30 m gave ~530 °C/km, also exceptionally high. EB-15, drilled just above EB-14, was extended directly to 200 m. No measurements were made until total depth was reached. EB-15 also showed strong downflow and remained cold almost to the bottom, but at 185 m the temperature rose sharply to nearly 90 °C. Interpreting the gradient from the bottom upward to ~5 °C produced ~420 °C/km.

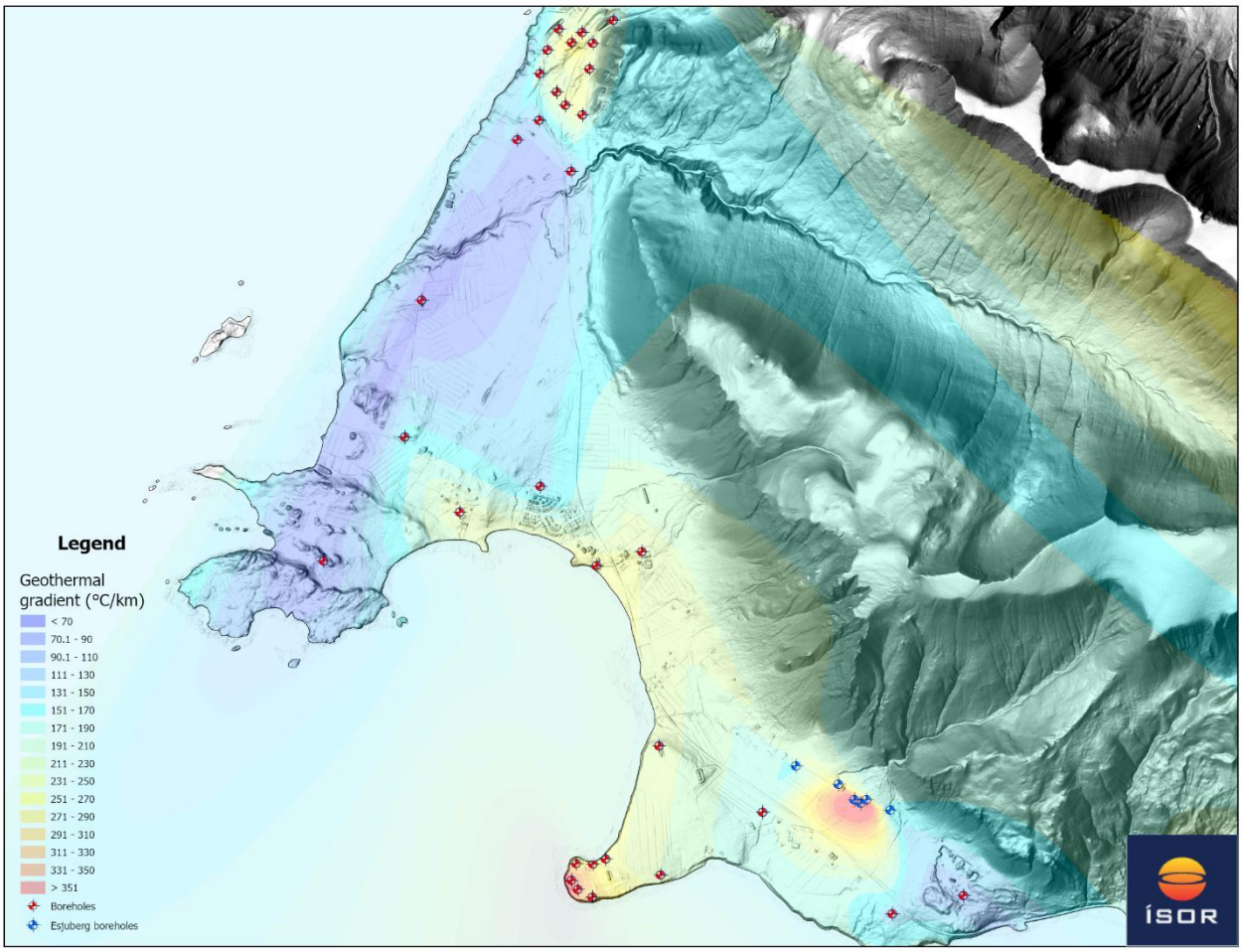



**Figure 3. Geothermal gradient map of Kjalarnes after Esjuberg wells where added.**

These very high gradients suggest that the anomalous values in EB-10 and EB-14 are essentially real, and that the local geothermal gradient peaks within a zone roughly 100 m wide. Gradients measured in the western and easternmost wells fit well with the previously known pattern, while EB-10, EB-14, and EB-15 are much higher than expected, see figure 3 (Óladóttir and Kristinsson 2025).

Now one 500 m resurge well (EB-16) has been added to see if the high gradient represents 100°C thermal waters. Figure 4 shows measurements from several of the Esjuberg wells and two measurements from the 500 m well EB-16. As in previous wells there is a downflow of cold water that goes into fractures deeper in the well, the bottom temperature represents likely actual formation temperature. The cold downflow goes into fracture at several depths like 240 m, 400 m, 440 m and 480 m. These fractures should give over 90°C – 100°C temperature. The read dotted line in figure 4 represents likely formation temperature. In a short airlift test the well gave 10 L/s

og 45°C water that represents the cold water downflow and thermal water from fractures below. It's likely that half of the water is from the cold downflow and the rest from the fractures that gives 90-100°C.

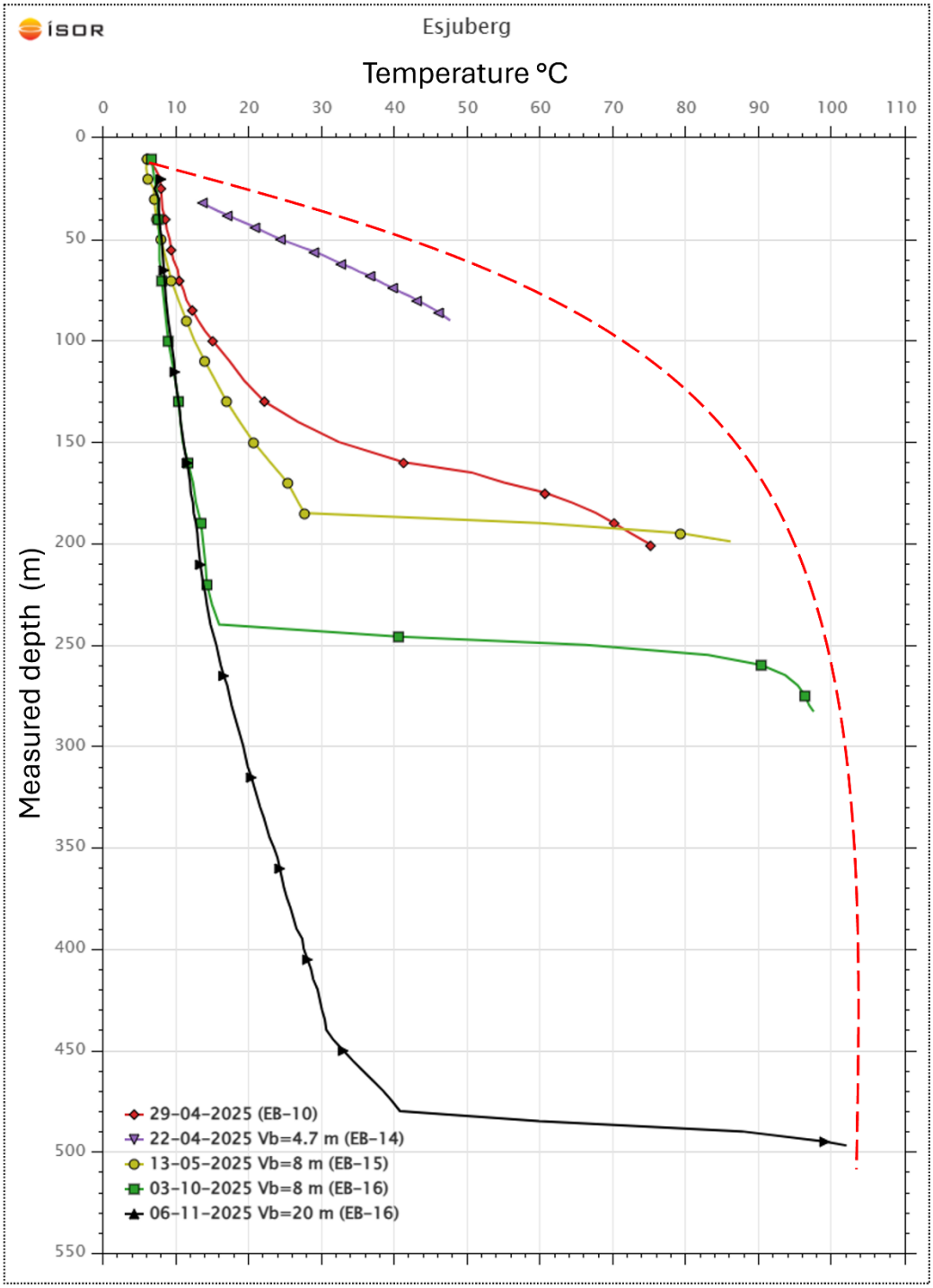



**Figure 4. Heat measurements form several wells in Esjuberg with likely formation temperature (read dotted line).**

The most reasonable conclusion is that these areas that is Brimnes and Esjuberg represent separate upflow zones. The Esjuberg anomaly appears well constrained to the east and west, but the area to the south and southwest remains untested. To the north and northeast, Esja mountain forms a natural boundary, limiting exploration in those directions.

Figure 5 shows a thermal gradient map of the Reykjavik and Kjalarnes area, there we can see several geothermal systems. The dominant fracture trend in Southwest Iceland is roughly N–S to NE–SW, though its nature is uncertain. Given the age and infill of local bedrock, effective permeability likely requires relatively young, active fracture or dike systems. Stress-field interpretations for southwest Iceland vary, but the prevailing maximum

horizontal stress is likely NW–SE, periodically rotating during rifting episodes on the Reykjanes Peninsula. Such stress patterns would facilitate northeast-directed dike intrusions into the crust of southern West Iceland. The effects of the South Icelandic seismic zone on the Reykjavík area is not well known but could also affect activating fractures. A probable explanation for the water-bearing fractures in these low-temperature systems is the presence of geologically young dikes extending far from magma sources associated with the Reykjanes, Eldvörp, Svartsengi, and Krýsuvík volcanic systems. (Sæmundsson 2029).

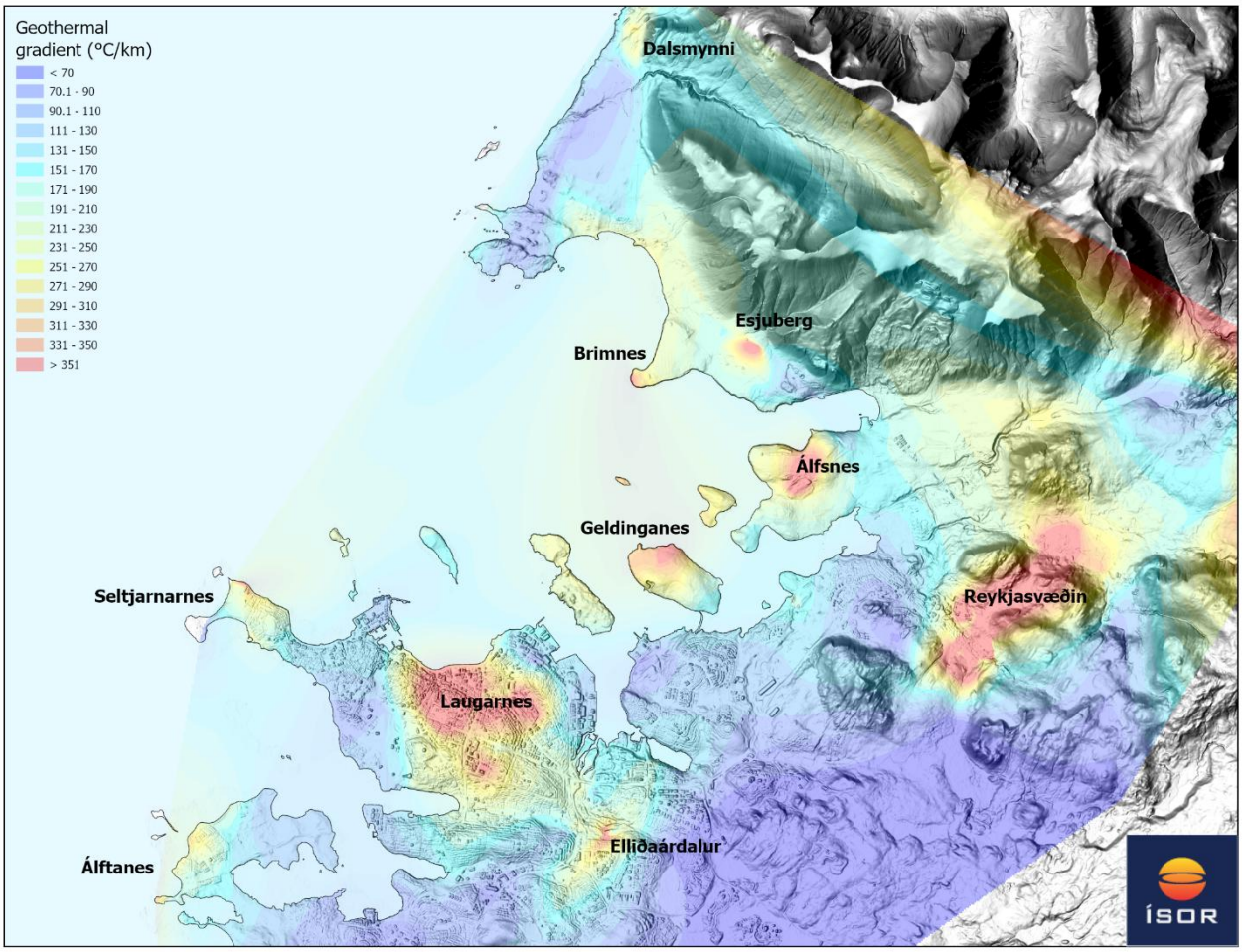



**Figure 5. Thermal gradient map of the larger Reykjavík area, the high gradient represents individual geothermal systems.**

## 4 CONCLUSIONS

Temperature-gradient drilling across Kjalarnes, combined with historical data and new investigations at Esjuberg, demonstrates that the region hosts multiple previously unconfirmed low-temperature geothermal systems. Earlier studies had already hinted at elevated gradients at Álfsnes, Arnarholt, Vallá, and Kollafjörður, but the extensive 2022–2025 drilling program has clarified the structure, extent, and significance of these anomalies. Main conclusions emerge, that, Brimnes and Esjuberg represent distinct upflow zones.The Brimnes anomaly appears to extend offshore, while the Esjuberg anomaly forms a compact, exceptionally high-gradient zone (~350–530 °C/km), with measured temperatures approaching 90 °C at only 185–200 m depth. And well EB-16 confirms that fractures at depth contain water of at least 90–100 °C. These characteristics are consistent with an active convective geothermal system.

Overall, the results indicate that Kjalarnes contains multiple viable geothermal reservoirs with temperatures exceeding 100 °C at accessible depths. The Esjuberg system is particularly promising and warrants further drilling, including deeper production-scale wells, to determine its reservoir size, permeability, recharge characteristics, and long-term utilization potential. Continued structural analysis and 3-D geophysical surveys are recommended to refine the conceptual model of the area and guide sustainable development.

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