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Nesjavellir Geothermal Area – High Temperature Well Targeting and Results

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ABSTRACT

The Nesjavellir geothermal field is a part of the Hengill geothermal system, SW Iceland. The area has been under exploration and development since the 1980´s. A geothermal power plant with 120 MWe capacity was onset in 1990. In 2018 three sectors within the Nesjavellir field were reviewed with the objective to locate new production wells to sustain the power production. Available datasets such as geology, faults, geophysical surveys and well data were used to compile a 3D geological model of the field. Within each sector of the field, the most feasible targets were chosen. From available well pads well paths were designed and analyzed in the 3D geological model. From the results of the well path analysis each well path was ranked. This paper describes the targeting process, 3D modelling and the results of drilling.

1. INTRODUCTION

The Nesjavellir geothermal system is one of the high-temperature geothermal systems within the Hengill area, producing around 120 MWe. This geothermal system has been in use since 1990 when hot water production started (Axelsson 2010) but research on the area began much earlier. Five shallow wells were drilled in 1965 for exploration. Drilling did not continue until 1985 when 13 more wells were drilled. Nesjavellir is located around 25 km east of Reykjavík, in the northern part of mt. Hengill. This paper summarizes the work around locating and designing production wells in the area for Reykjavík Energy. Most of high-temperature geothermal wells for power production are drilled directionally in order to decrease environmental impact and penetrate more faults. All wells designed within this project were designed to be directionally drilled. Three sections of Nesjavellir were researched further and two wells located within each sector. In 2018, two of these six wells were drilled with good results.

2. GEOLOGICAL SETTING

The Nesjavellir geothermal area has been researched intensely in the past few decades. Nesjavellir is a rift valley extending from Hengill mountain, to lake Þingvallavatn in the north-east. The fissure swarm is around 5 km wide and extends up to 40 km towards the south-west and is a seismically active area.

The largest part of the Hengill volcano is build up of hyaloclastite formations that erupted during glacial periods but intermediate and felsic rocks have been found in many drill holes in Nesjavellir as well as crystalline lava formations (Franzson 1988 and Franzson et. Al. 2010). Analysis of drill cuttings show that hyaloclastite formations are dominant down to around 500 m where crystalline basaltic formations take over. Intrusions are observed from around 1000 m and below 2000 m, intrusions become very common (up to 100 %). Dioritic intrusions are considered to contribute substantially to the permeability in the geothermal system (Franzson 1988 and Franzson et. Al. 2010).

The faults in Nesjavellir are essentially of two types. There are those that are younger than 115.000 years old and the ones that are older. The younger ones form a NA-SV graben as well as N-S trending faults that cut through the valley (Figure 1) (Franzson 1988). This affects the permeability within the geothermal system.

Feed zones in the wells in Nesjavellir are controlled mostly by three principal components; from surface and down to around 800 m, the feed zones are mostly located at lithological boundaries. Below 800 m the feed zones are often connected to intrusions which tend to tilt slightly to the south, under the Hengill volcano. However, the biggest impact is from vertical faults and eruptive fissures extending from Hengill, leading hot water and steam to the north to Nesjavellir. This can for example be seen in the alteration, which tends to be higher closer to these large faults (Franzson, 1988).

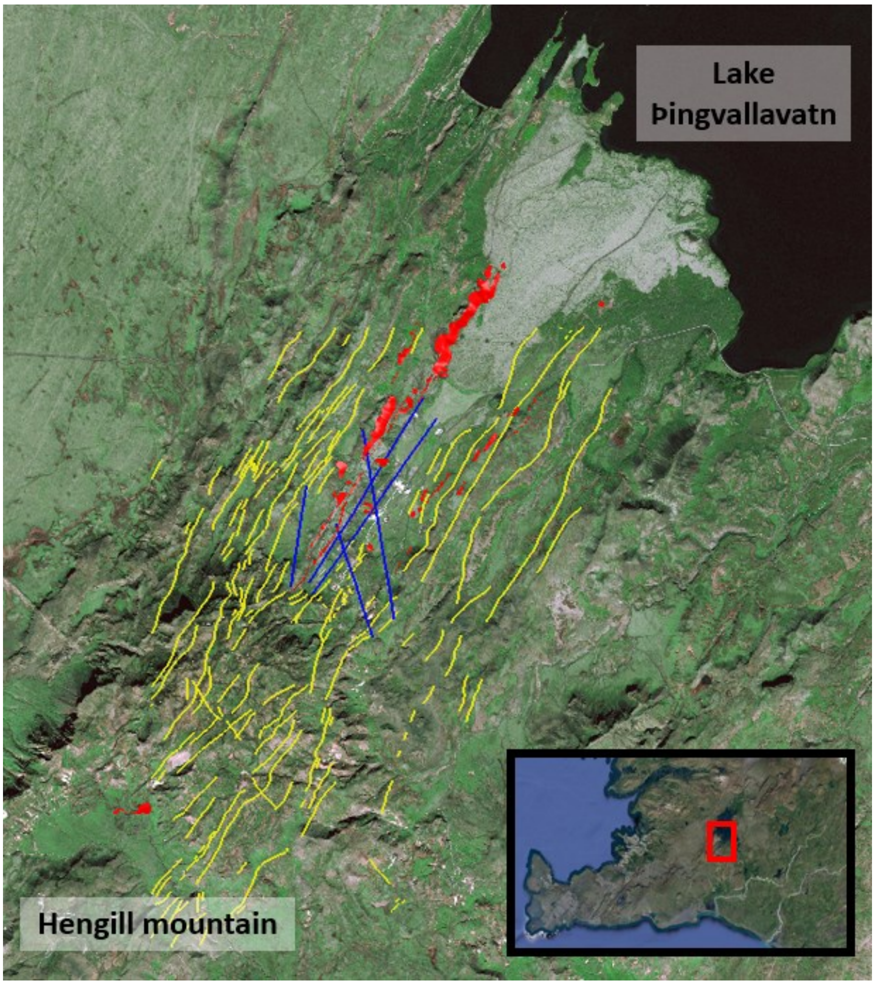

Figure 1: An aereal photograph of Nesjavellir. Nesjavellir extend from Hengill mountain to lake Þingvallavatn. The power plant is located at the center of the map. The blue lines represent faults younger than 115.000 years old and the yellow represent the older ones. The red polygons represent volcanic activity at surface.

3. DATA SETS AND CONCEPTUAL MODEL

When this project started, 29 production wells had been drilled in Nesjavellir. The newest one, NJ-29, was drilled in the spring of 2018. Three areas within the Nesjavellir geothermal area were considered; Fálkaklettar (A), closest to Hengill (B), and Hraunprýði (C). An interdisciplinary group within the Iceland GeoSurvey was formed in order to work with different data sets. The main types of data that were used were information on faults and fractures in the area, resistivity model of the area (Árnason et al. 1987) and information from wells in the area such as lithology, feed zones, temperature and power production. The well data was mostly found in phase reports for each well. The surface mapping, such as faults, was mostly done by Kristján Sæmundsson (1995). The main objective was to drill through known faults and feed zones according to surface mapping and structural geology as well as drill into high temperature. Feed zones in Nesjavellir are often connected to faults seen from surface, but also to intrusions deep in the system, both fresh basaltic intrusions and diorite intrusions. The frequency of intrusions increases with depth and it is thought that they tilt slightly under the Hengill mountain (Hjalti Franzson, 1988). To understand better the temperature of the system, both formation temperature models and alteration models were used and compared with faults, feed zones and more.

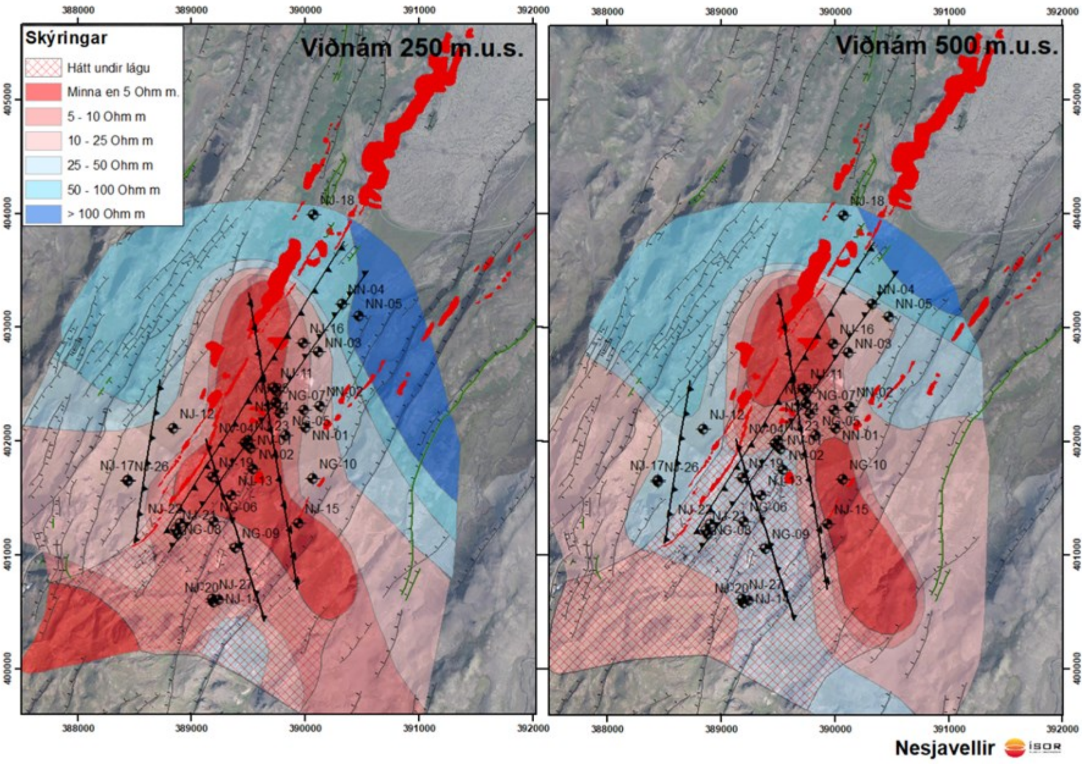

Figure 2: The maps show the resistivity at 250 m b.s.l. (left) and 500 m b.s.l. (right) (Knútur Árnason et. Al., 1987) as well as existing wells in the area, eruptive fissures (bright red), mapped faults from surface mapping (gray and green) and from well data (black) from Hjalti Franzson 1988. Where the resistivity is shown in red grids, there is high resistivity under low resistivity.

4. WELL TARGETING

The well targeting was done in the spring of 2018 (Ásgeirsdóttir et al. 2018). The first criteria in designing the wells was to drill from pre-made drill pads in Nesjavellir. Two wells were planned within each area and then they were ranked on how likely they were to become good producers. The wells were designed by using both Leapfrog Geothermal and an inhouse program designed by Iceland GeoSurvey. The inhouse program called Vinnsla was used to design the confidence limits, to calculate the distances to the closest wells in the area and other technical aspects, while Leapfrog was used for drilling prognosis. This prognosis was for example to predict the lithology and alteration of the wells, the faults intersected, the alteration stages, formation temperature and more.

4.1 The three main areas and the wells designed

4.1.1 Area A- Fálkaklettar

The designed trajectories for wells A1 and A2 are based on information from wells NJ-11 and NJ-24 and were drilled to the south (figure 3). Both wells were designed to go through the old eruptive fissure as well as known faults in the area. These wells would also be drilled into less known parts of the system but the closest deep well to the north is well NJ-18 which is about 1500 m away from this drill pad. If these wells turned out to be successful, the production part of the area could extend further to the north.

4.1.2 Area B- Hengill

The wells in area B are based on wells NJ-12, NJ-19, NJ-24 and NJ-25B but those wells are all good producers. Both wells are located from the same drill pad as well NJ-19. These wells are both within the resistivity anomaly and would traverse the eruptive fissures west of the drill pad. The positives are that this area is pretty well known but the negative is that the drill pad is very close to the conduit and therefore it is difficault to cut it deep in the system.

4.1.3 Area C-Hraunprýði

The wells for this area are both designed from well pad L where NJ-29 is located. The area these would be drilled into is very well known and is the major production part of Nesjavellir. The wells that are there prior to this project are good producers and all show high temperatures. Closeness to nearby wells could however be a problem. These designed wells are within the resistivity anomaly and the formation temperature model shows temperatures over 300°C.

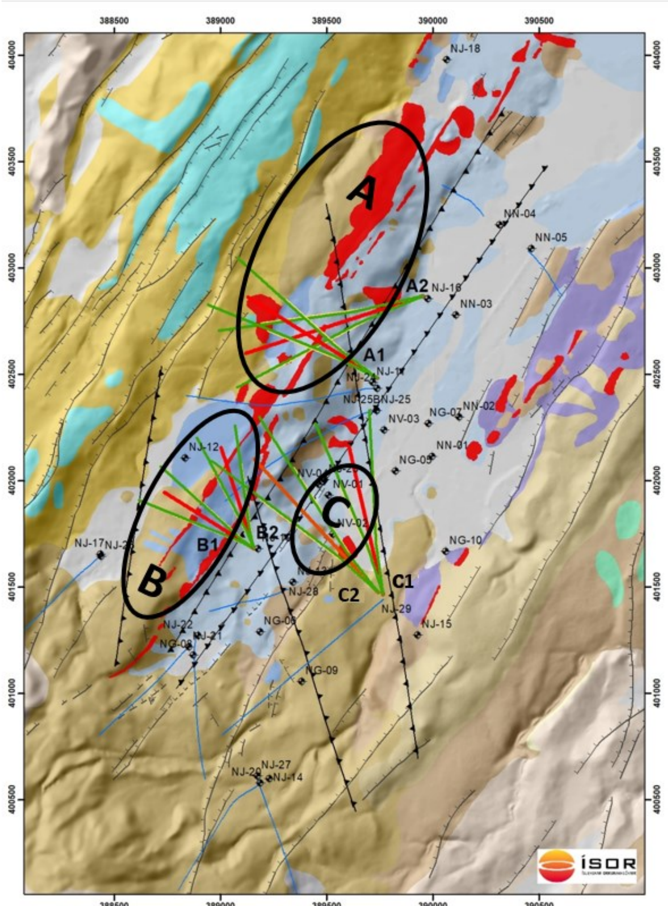

Figure 3: A simplified geological map of Nesjavellir geothermal area. The wellheads are labelled in black and the existing well trajectories are in orange lines. The grey lines stretching from SW to NE represent mapped faults seen at surface in the area. The red polygons are volcanic activities at surface. The Hengill mountain is in the SW and north of the map is lake Þingvallavatn. The areas that were researched are marked in black circles and the planned wells are in red lines with green confidence limits.

4.2 Main results from the well targeting

From known faults (from surface and well data), the formation temperature model, a resistivity model and drilling history in the area, the well designs were categorized and ranked based on their probability of being good producers. Area A is very interesting when it comes to expanding the area, but it is very unknown and very few wells are in the area, especially west of the eruptive fissure. Due to this, the formation temperature model is very inaccurate and unknown if there is a temperature inversion in the area. When designing the wells in area B, it was considered that NJ-12 would not be connected to the power plant but currently it is not in use. However, NJ-12 is a very powerful and hot well, so the area around NJ-12 is known to be good. These B-wells were designed with the aim to get the power from that part of the system. The wells within the C area were to be drilled on either side of NJ-23 which is a good production well. The wells within this area are all good production wells and therefore this area was considered the most promising area to get more power. Closeness to other wells in the area could however be a problem. The formation temperature model shows very high temperatures and one of the designs (C2) intersects some known major faults in the area.

To meet the increasing power demand the well designs were ranked based on power probability and was C-2 considered the best option. In order to expand the area, either A-1 or A-2 were considered the best options in order to estimate the size of the geothermal system to the north and west of the eruptive conduit. In the spring of 2018, well NJ-30 was drilled according to design C-2 and subsequently, well NJ-31 was drilled according to design A-1 (Figures 4 and 5).

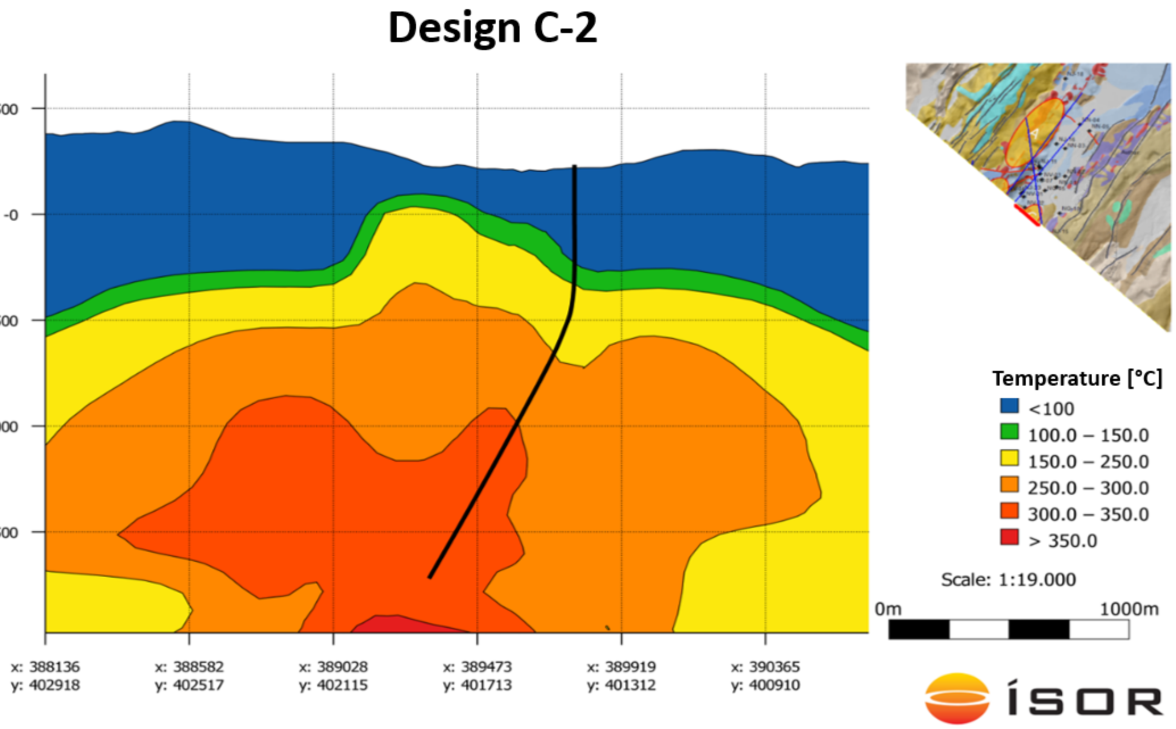

Figure 4: The C-2 design (black well trajectory) with the temperature model of Nesjavellir.

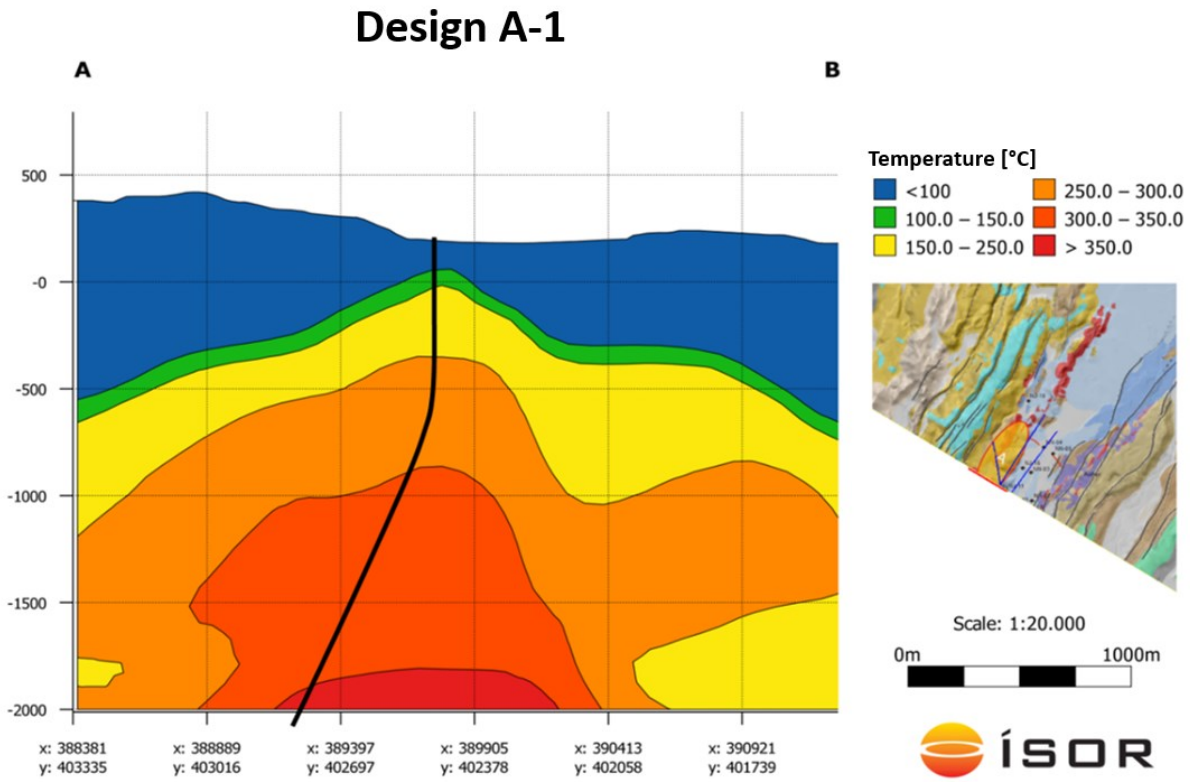

Figure 5: The A-1 design (black well trajectory) with the temperature model of Nesjavellir.

5. MAIN RESULTS FROM DRILLING

5.1 Drilling and results from NJ-30

In the spring of 2018, well NJ-30 was drilled according to design C-2. The well was drilled with 12 ¼” production part with a 9 $^5/_8$” liner, aiming in between two wells, NJ-19 and NJ-23 (vertical wells), under the center of the rift valley. The formation temperature in both wells is high and they are both good producers. The design of the well was a conventional design for Icelandic high-temperature wells with a kick-off point at 400 m, building at 2,5°/30 m up to 25° inclination.

According to the Leapfrog model, several faults would be intersected (Figure 6 and Table 1). During drilling, the largest feed zones the well intersected were seen at 920 m, 1055-1065 m, 1090 m and 1790-1865 m, but some smaller ones were also seen, both during drilling and logging (figure 7). These depths correlate nicely with the predictions. The two hottest temperature logs were logged once the well had been heating up and shows that the well is very hot (up to 290°C) and the well head pressure is quite high (48 bars). This complies very well with the predicted feed zones from the model as can be seen in table 1 below. The temperature model indicated very high temperatures as can be seen in figure 4. This was then confirmed during drilling with high temperature alteration minerals but epidote (~240°C) appeared above 900 m and prehnite shortly after that. Total loss of circulation occurred at around 980 m depth MD when drilling through an intrusion. The total depth of the well is 2049 m MD. At the end of drilling, injection tests with spinner logs indicated an injectivity index of 10-13 l/s/bar.

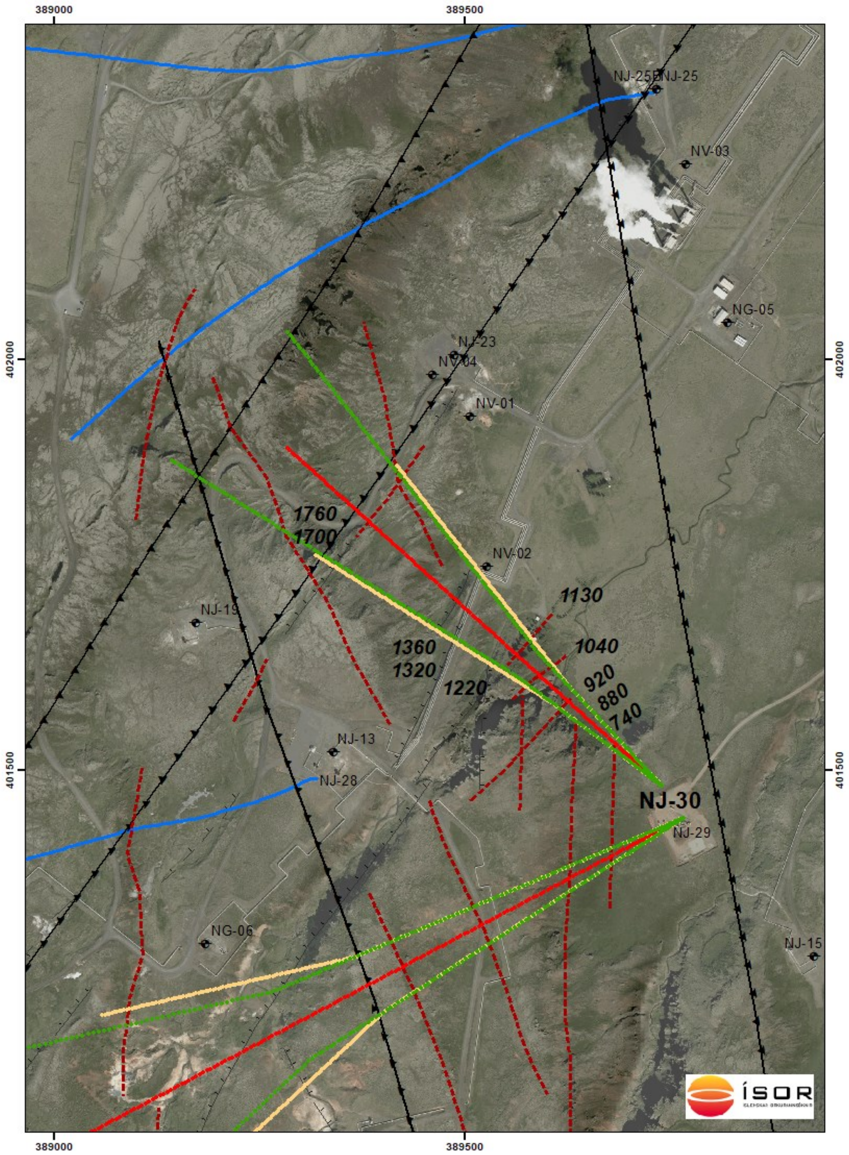

Figure 6: The designed well trajectory for well NJ-30 and the predicted depth to feed zones.

Table 1: Feed zones in well NJ-30 according to the geological model.

Depth MD	Tectonics	Probability (1 - small, 2 - medium - 3 - high)
740	N-S depression at surface	1
880	N-S depression at surface	1
920	NA-fracture at surface	1
1040	NA-fracture at surface	2
1130	NA-faults at surface	3
1220	N-S faults at surface	2
1320	NA-faults at surface	3
1360	NA-faults at surface	3
1700	NA-faults at surface	3
1760	NA-faults at surface	3

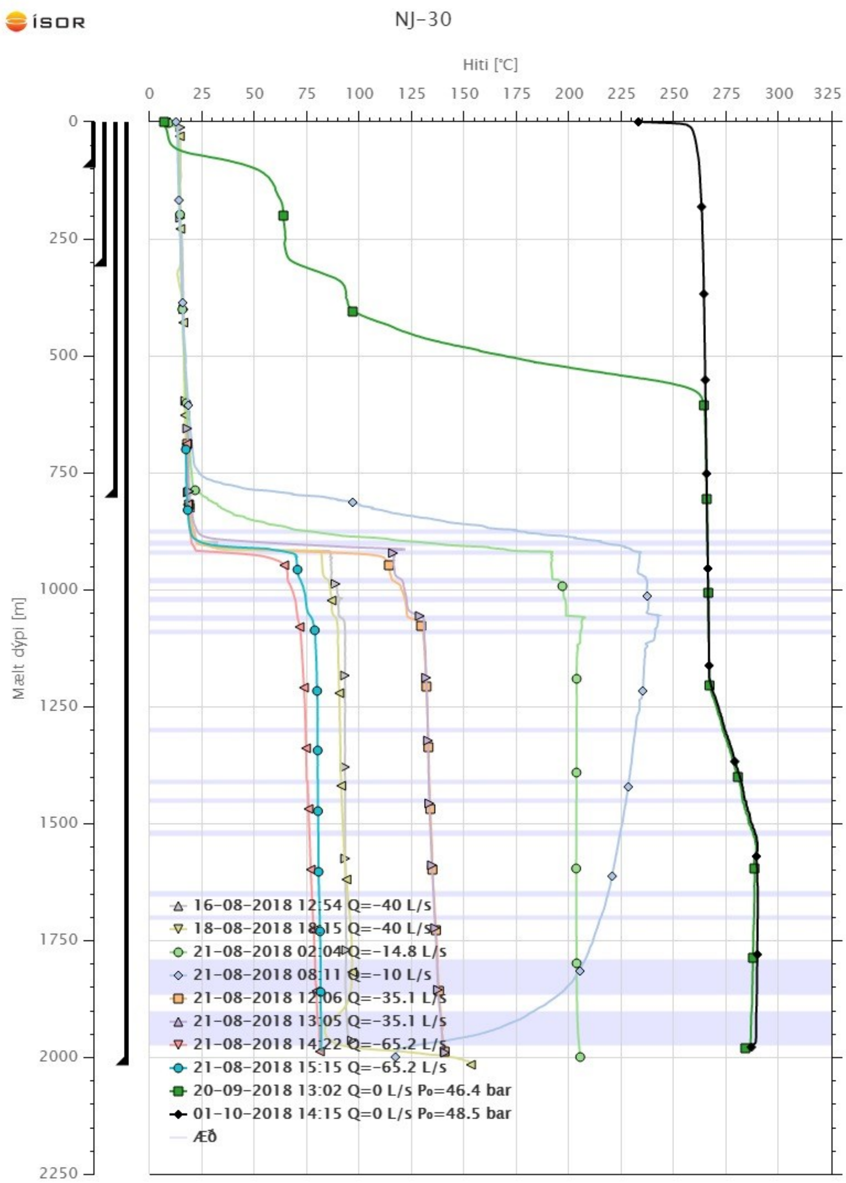

Figure 7: Temperature logs that were logged close to the end of drilling as well as two logs after drilling and heating up. The casing depths can be seen on the left and the blue shaded areas are feed zones according to spinner and injection tests.

5.2 Drilling and results from NJ-31

Once NJ-30 had been drilled, the rig was moved to drill well NJ-31. The well was drilled with 12 ¼" production part with a 9 $^{5}/_{8}$" liner, according to design A-1. The well was to penetrate Kýrdalshryggur (eruptive fissure) and known faults in the area. The design of the well was a conventional design with a kick-off point at 400 m, building at 2,5°/30 m up to 30° inclination. The well was planned 2500 m MD with 300° azimuth.

According to the Leapfrog model, the formation temperature in the area is very high (figure 5). This was also seen in the cuttings from the drilling but amphibole, epidote, prehnite and wollastonite, which are all high-temperature secondary minerals, were very common and had been analyzed throughout the production part down to the TLC zone. The total depth of the well is 2355 m MD.

Feed zones in the well were seen at 810 m, 890 m, 990 m, 1250 m, 1550 m and 1940 m and can be linked to the faults that were predicted beforehand (Figure 8 and Table 2). The temperature logs can be seen in figure 9. The preliminary results indicate that the injectivity index is around 5,5 l/s/bar which is quite high for Nesjavellir.

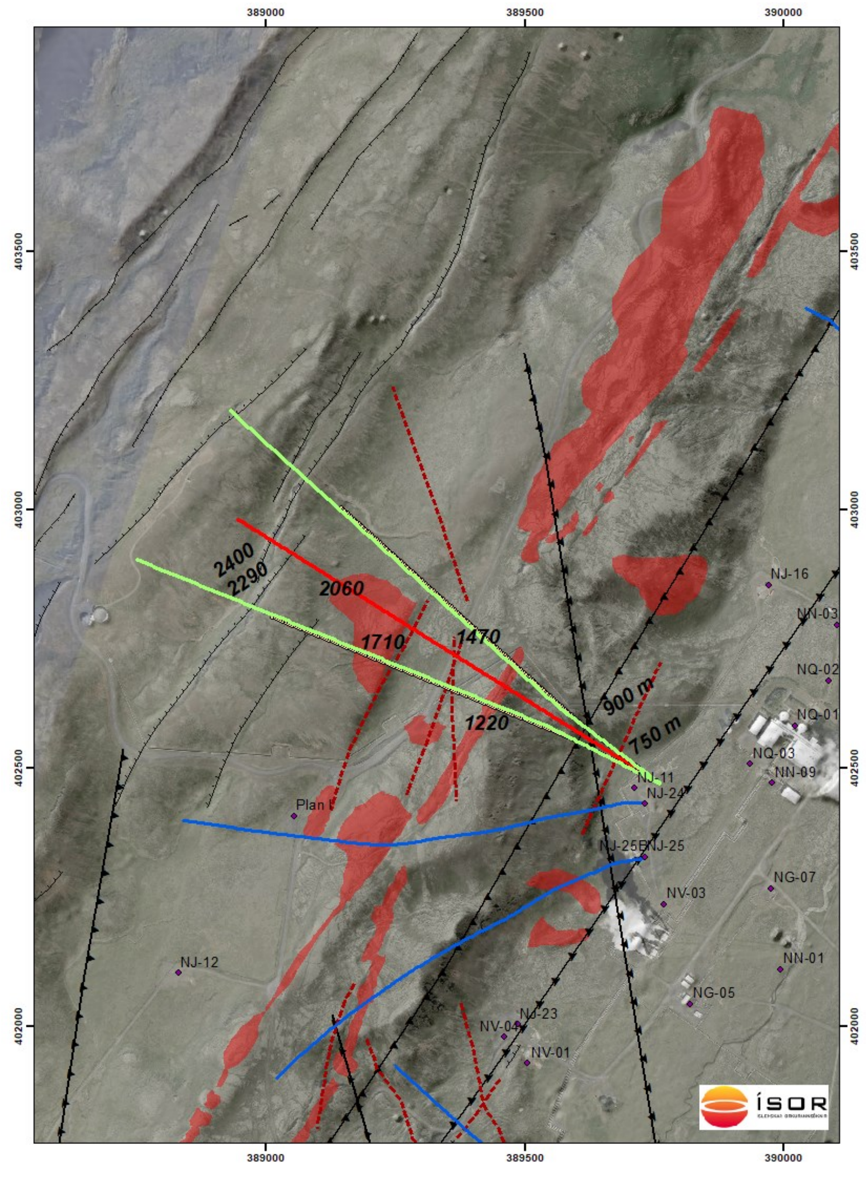

Figure 8: The designed well trajectory for well NJ-31 and the predicted depth to feed zones.

Table 2: Feed zones in well NJ-31 according to the geological model.

Depth MD	Tectonics	Probability (1 - small, 2 - medium - 3 - high)	Comments
750	NNA depression in landscape	2	Possible dip to the east
900	N-S and NNA faults from Hjalti Franzson	3	Cross, possibly at 860-980
1220	Eruptive fissure	3	Could appear earlier
1470	NA and N-S fault in landscape	1	
1710	NA-fault	2	Fault/ledge in landscape
2060	NA- fault	2	Dip to the west
2290	NA- fault	3	Dip to the west
2400	NA- fault i	3	Dip to the west

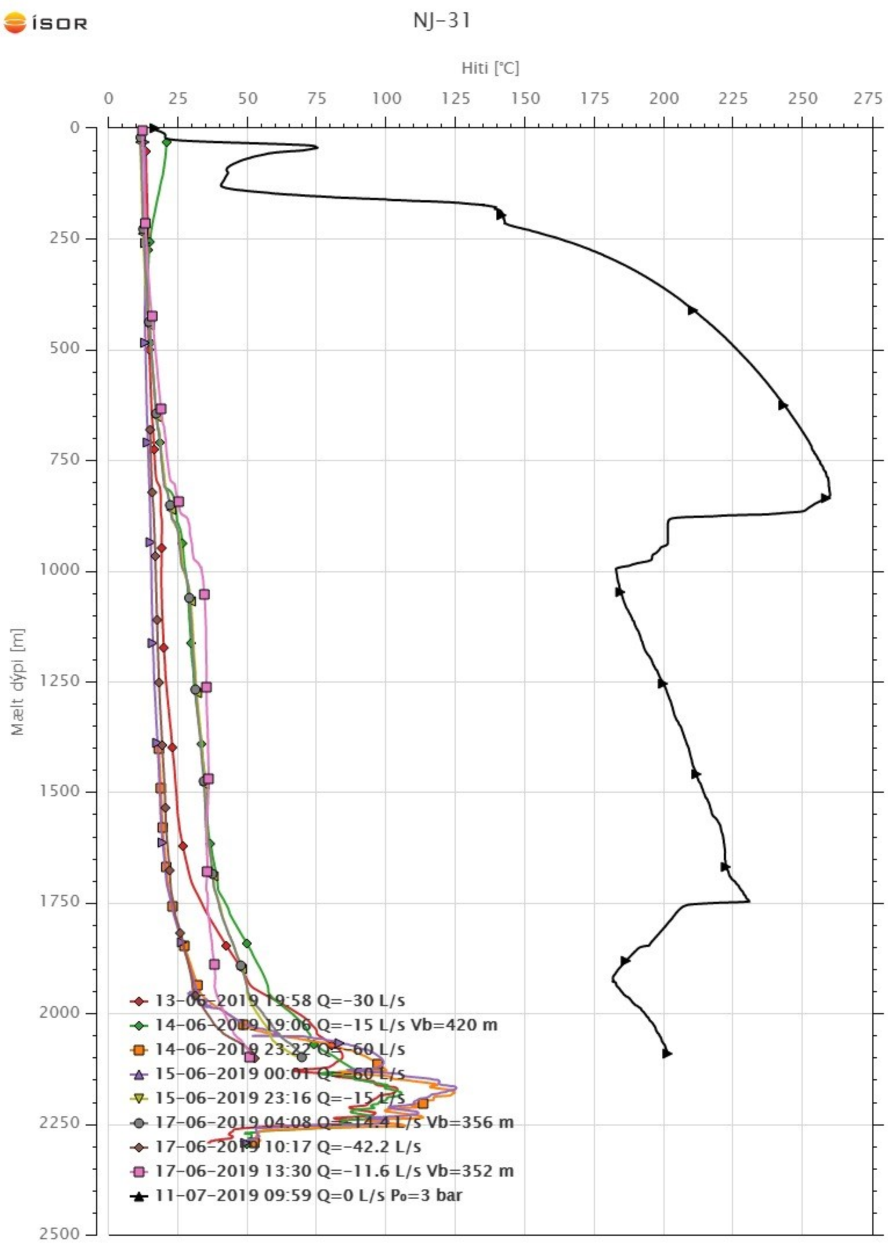

Figure 9: Temperature logs that were logged close to the end of drilling as well as one log after drilling and heating up.

6. CONCLUSIONS

In order to estimate the power production of the two wells, further research and logging needs to be done. Drilling of NJ-31 finished quite recently and it takes some time to let the wells heat up and carry out further testing. However, the first tests indicate that well NJ-30 is the most powerful well in Nesjavellir. It is apparent that the well was very successful and many of the predictions made beforehand, both in wells NJ-31 and NJ-31, on feed zones and temperature for example were correct. Well NJ-31 is heating up and building pressure. Therefore, the end results will become clear in the coming months. The first tests show that the wells are quite successful.

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