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Landsvirkjun

Seismic Monitoring in Krafla, Námafjall and Þeistareykir

April to August 2017

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Abstract:

In Þeistareykir, Krafla and Námafjall geothermal areas and their surroundings, 2559 earthquakes were recorded by the local seismic network between April 1st 2017 and August 31st 2017. The vast majority of these events (2209) were located in and around the Krafla geothermal field. In Þeistareykir and Námafjall 184 and 118 earthquakes were located respectively. The spatial distribution is comparable to the localization form the last trimester report. In Krafla most earthquakes are shallow (few events deeper than 3 km) and activity extends over a larger area than Þeistareykir and Námafjall where the seismic activity is limited to narrow columns reaching down to 4.5 and 7–8 km depths respectively.

While there are high b-values (> 1) in all three areas, in Þeistareykir there is a noticeable high number of bigger events (M_L > 1.0). It remains unresolved whether this is due to a stronger crust than in Krafla and Námafjall or because of detection limits due to relatively small number of seismic stations in the area.

Keywords:

Seismicity, earthquakes, brittle-ductile boundary, magnitude, Krafla, Námafjall, Þeistareykir, Landsvirkjun, ÍSOR

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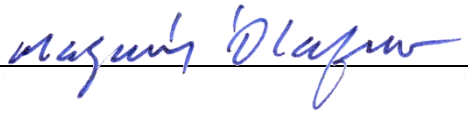	Ólafur G. Flóvenz

Ágrip

Alls 2559 jarðskjálftar voru staðsettir á neti Landsvirkjunar á svæðinu frá Námafjalli að Þeistareykjum á tímabilinu frá apríl til og með ágúst 2017. Langflestir, eða 2209, voru í Kröflu og næsta nágrenni. Á Þeistareykjum voru 184 jarðskjálftar staðsettir og 118 við Námafjall. Dreifing jarðskjálftanna var svipuð og á tímabilinu frá desember 2016 til loka mars 2017 og lýst er í skýrslu um virkni á því tímabili.

Í Kröflu er upptakadýpi langflestra jarðskjálfta minna en 2,5 km frá yfirborði. Á Þeistareykjum eru flestir jarðskjálftar ofan 4,5 km dýpis og við Námafjall ofan 7 km.

Stærðardreifingu jarðskjálfta má túlka sem svo að jarðskorpan sé almennt veik á svæðinu. Við Námafjall er dýptardreifing jarðskjálfta lagskipt og stærðardreifing breytileg.

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1 Introduction

This report covers the seismic activity in the geothermal areas of Þeistareykir, Krafla and Námafjall from April 1st 2017 until August 31st 2017. During this period a total of 2559 earthquakes where recorded by the local network consisting of 17 seismic stations operated by ÍSOR for Landsvirkjun. Additionally, data of the regional SIL network operated by the Iceland Meteorological Office was available for earthquake location. For a detailed description of the network, see Blanck et al. (2017a).

Of the 2559 events, the vast majority or 2209 events are located in Krafla geothermal area. In Þeistareykir 184 earthquakes could be located and in Námafjall 118. The remaining 48 events lie outside the three fields as they were defined for the analysis in this report (black boxes in Figure 1), most of them at greater depth between Námafjall and Krafla area and north of Krafla area (up to 7–8 km depth).

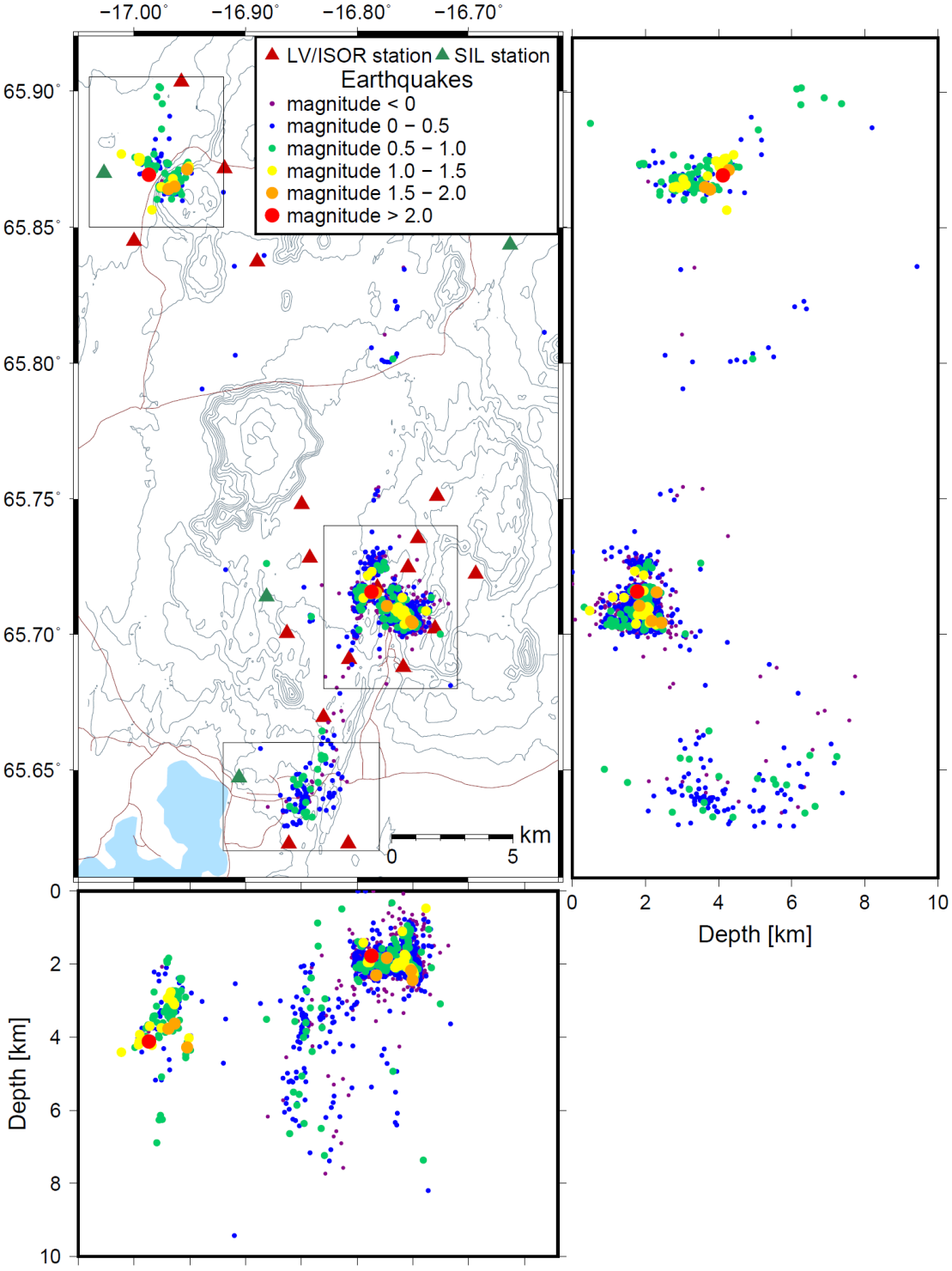

Figure 1. *Spatial distribution of earthquakes in Þeistareykir (box in the northwest), Krafla (central) and Námafjall (south) geothermal area in surface projection and E-W and N-S sections.*

2 Recorded earthquakes

2.1 Krafla

Krafla geothermal field shows a similar earthquake distribution as seen in the last annual and trimester reports (Blanck et al., 2017a, b). Earthquakes inside the geothermally active area (ca. 15 km²) are very shallow with the majority of events between 1.5 to 2.5 km depth (Figure 2). The ratio of small events is relatively high with the few bigger events (M_L 1.5 and higher) being located in the lower half of the active depth range (Figure 1).

The brittle-ductile boundary, which is per definition the depth above which 95% of earthquakes have occurred, is at about 2.3 km depth (Figure 2) exactly as in the last trimester report (Blanck et al., 2017b).

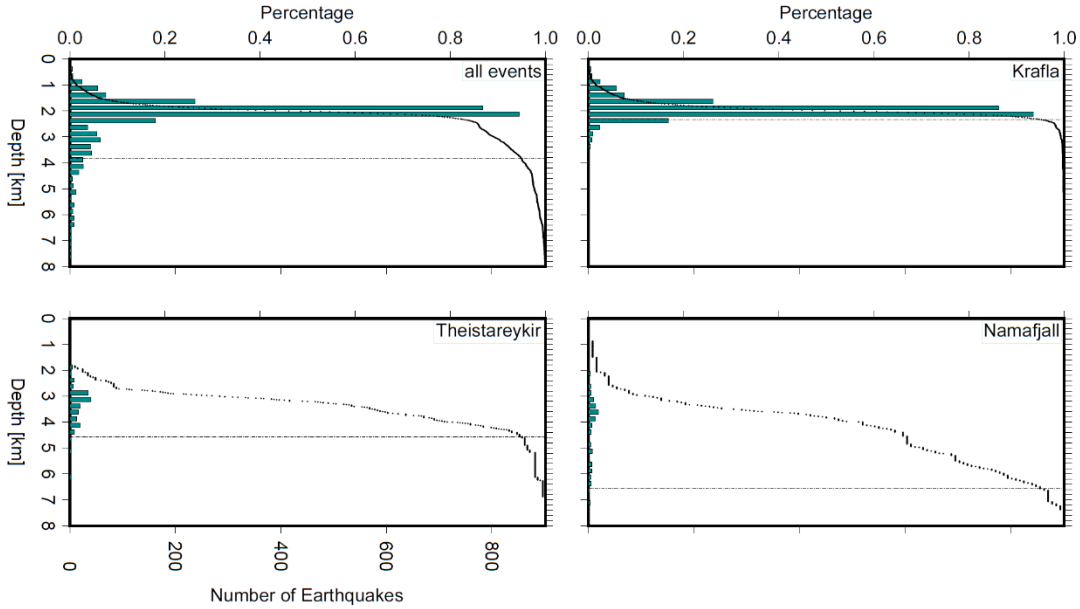

Figure 2. *Depth distribution of the events located in Krafla, Þeistareykir and Námafjall geothermal areas. The green bars indicated the absolute number of earthquakes recorded in each depth range, the dotted line the normalised cumulative number. The dashed line shows the depth above which 95% of all events have been located, the so-called brittle-ductile boundary.*

2.2 Þeistareykir

In Þeistareykir seismic activity is mostly limited to a vertical column (ca. 2 x 2 km) from about 2 to 5 km depth directly underneath the geothermally active area. Additionally, there are a few events located slightly north of the main field at even greater depth (5 to 7 km). 95% of the earthquakes have been located at shallower depth than 4.6 km (see Figure 3). This is similar to the distribution that can be seen in earlier reports (e.g. Kristján Ágústsson, 2016).

As in the last trimester report there is a relatively large amount of larger earthquakes with a local magnitude of 0.5 and more that have been recorded. It was suggested that this could be a consequence of the limited sensitivity of the local seismic network that consists of only 4 seismic stations in the near surroundings. Recently, a new station was installed at Þeistareykir east of the seismic active area that will increase the sensitivity of the network considerably. It will be interesting to see if it will change the magnitude distribution of events in the area.

2.3 Námafjall

Seismic activity in Námafjall geothermal area is, similar to Þeistareykir, distributed over a larger depth range (surface area ca. 3 x 3 km) compared to Krafla. The shallowest events were located at about 2 km depth and the deepest ones in 7 km. The brittle-ductile boundary, defined as the depth where 95% of earthquakes occur above, is at 6.6 km depth. Similar to last trimester's report there appears to be a seismic gap at about 5 km depth with almost no activity, reflecting the layering of the activity as described by Ágústsson and Guðnason, 2016. Most events here have a local magnitude (M_L) between 0 and 1.0, no higher magnitude event has been recorded.

3 Magnitude distribution

The frequency-magnitude or Gutenberg-Richter relation (Gutenberg and Richter, 1956) describes the observation that small earthquakes are more common than bigger ones. On global scale, an earthquake of a certain magnitude is 10 times more likely to occur than an earthquake which larger in magnitude by 1. Local deviations from this relationship can indicate variations from the average strength of the crust. For more detail on the Gutenberg-Richter relation and its implications see Blanck et al. (2017a).

In this trimester report, earthquakes with magnitudes from -1.29 to 2.16 have been measured in the Krafla geothermal area (Figure 3), in Námafjall magnitudes lie between -0.32 and 0.87 and in Þeistareykir between -0.22 and 2.14. In all three areas we see smaller earthquakes than during the last trimester. This could be due to calmer weather conditions and the resulting decrease in noise that we have in the spring and summer in comparison to the winter months. Especially the smallest events that have been recorded in the Krafla geothermal area show us how sensitive the seismic network is already today as it allows us to record very small movements of the curst.

The magnitude-frequency relation displayed for all events recorded in the area (see Figure 3) shows an even distribution of earthquakes in respect to magnitudes that can be approximated by a single straight line in Krafla and Þeistareykir. In Námafjall the magnitude distribution is more divers and 2 lines are needed to approximate the magnitude-frequency relationship.

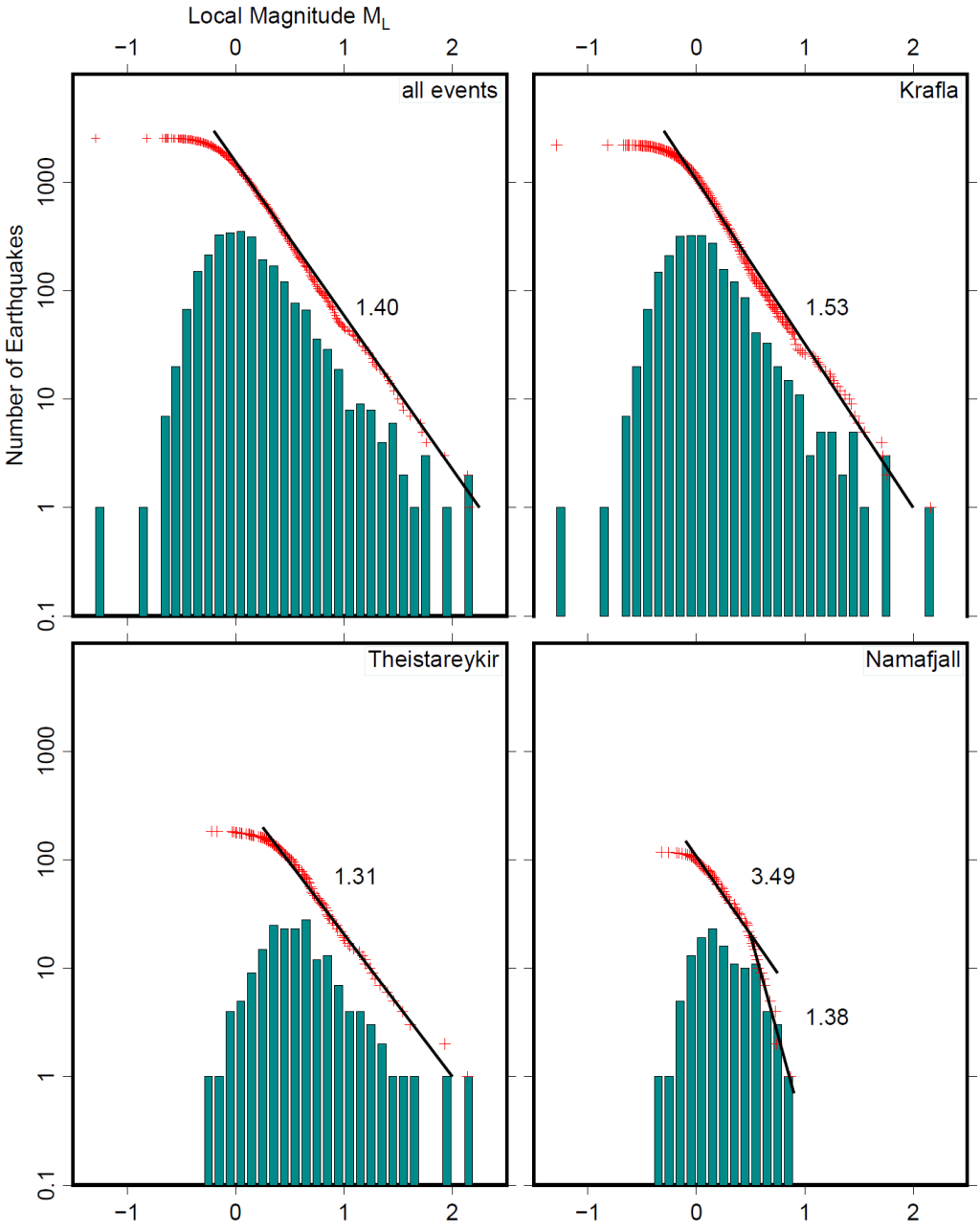

Figure 3. *Magnitude-frequency relation. In Krafla and Þeistareykir the magnitude frequency relation can be approximated with a single straight line. In Námafjall the distribution is more complex.*

The average slope of the line for all events together or so-called b-value is about 1.40. A b-value higher than 1 shows that there is a relatively high number of small earthquakes compared to bigger ones and this is an indication of rather weak crust. Stress cannot be built up over longer periods to be released in few bigger events but is instead released early in many small earthquakes.

In Krafla and Þeistareykir, the distribution can be approximated rather well by a single straight line with b-values equal to 1.53 and 1.31, respectively. In Þeistareykir there is a

relatively high number of bigger earthquakes in comparison to the other two areas even though the b-value is still well above 1. Nineteen events of magnitude 1.0 and more have been recorded in Þeistareykir. This is in agreement with the results from last trimesters report and supports the assumption that the structure of the crust in Þeistareykir is sturdier in comparison to the other two areas, allowing stress to be build up to higher levels before being released.

In Námafjall two lines would be needed to approximate the magnitude distribution. As previous analysis of this area has shown, the seismic activity shows different behaviour above and below 3.9 km depth (Ágústsson and Guðnason, 2016), indicating different physical properties in the two depth ranges.

4 Summary

- During the reporting period between April 1st 2017 and August 31st 2017 a total of 2559 earthquakes were located by the local seismic network in the geothermal areas of Þeistareykir, Krafla and Námafjall and their surroundings.
- The vast majority of the events (2209) were located in and around the Krafla geothermal field.
- In Þeistareykir 184 earthquakes were located.
- In Námafjall 118 earthquakes were located.
- In Krafla most of the earthquakes were shallow (few events deeper than 3 km) and distributed over a wider area than in the other places. It results in minimum depth of 2.3 km to the brittle ductile boundary beneath the production field.
- The seismic activity in Þeistareykir was limited to a narrow column (~4 km^2) reaching about 4.5 km into the crust indicating the minimum upper limit of the brittle ductile boundary at that depth.
- The seismic activity Námafjall was limited to a narrow column (~9 km^2) reaching 6 to 7 km into the crust indicating the minimum upper limit of the brittle ductile boundary.
- In Þeistareykir, a relatively large number of bigger earthquakes (magnitude > 1.0) have been recorded compared to the other two areas leading to higher b-value (1.53) that indicates a stronger crust in Þeistareykir. Alternatively, it could be an artefact caused by the small number of seismic stations in the area making detection and location of small earthquakes relatively difficult.
- In Námafjall, the already been observed seismic gap at about 5 km depth persists. In line with previous analysis the seismic activity shows different behaviour above and below 3.9 km depth indicating different physical properties in the two depth ranges.
- The observed earthquakes between Krafla and Námafjall reach up to 7–8 km depth indicating a greater depth to the brittle ductile boundary in-between these geothermal systems.

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