Torfajökull 2005 – seismic project

I Scientific report

II Technical report

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Abstract

Torfajökull is a rhyolitic volcano with a prominent caldera and vigorous geothermal activity, located in south Iceland. We operated a 30-station network of broadband Güralp 6TD seismometers inside and around the Torfajökull caldera from mid-June until early October 2005. As a result an excellent dataset with 98.8% recovery was obtained. The main focus of the project was low-frequency earthquakes, which occur in the southern part of the caldera. Intriguing data on these events were recorded, for the first time also with stations very close to their origin. An ample dataset was gathered on high-frequency earthquakes, which occur principally in the western part of the caldera, in close connection to geothermal activity.

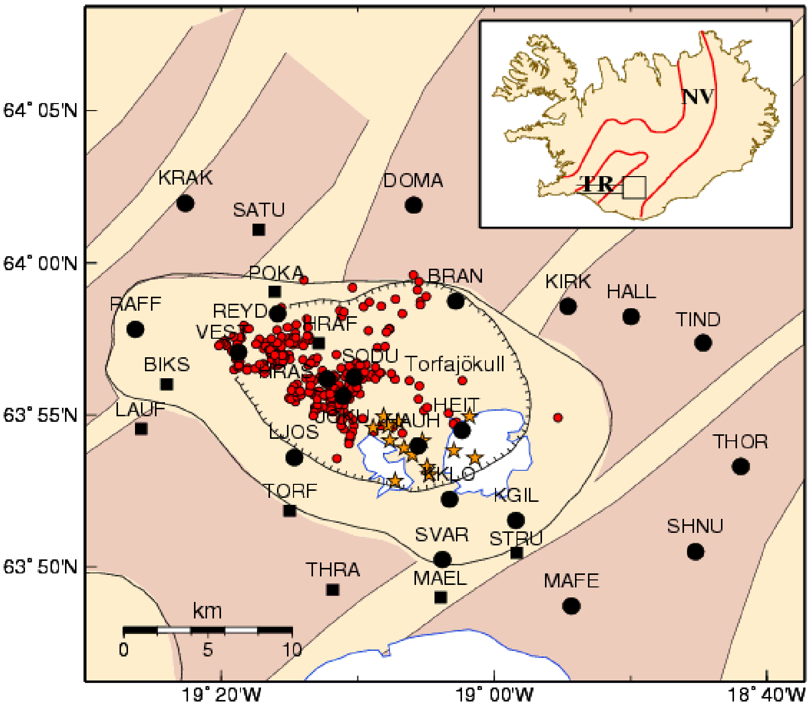

Figure 1. The location of Torfajökull within the southern end of the Icelandic Neovolcanic Zone (NV). TR stands for the transform zone. The central volcano of Torfajökull is outlined and its caldera hatched, areas of eruptive fissure swarms are shaded. White areas are glaciers. The 2005 seismic network is shown with black squares (2002 sites re-occupied) and black dots (new sites). Red dots denote the approximately 800 high-frequency earthquakes located by Fiona Campbell and Nick Borner. Orange stars show the low-frequency earthquakes located so far.

Geological and seismic background

Torfajökull in south Iceland is a large rhyolitic volcano massif, rising about 500 m above the surrounding basaltic landscape, 450 km^2 in area. It is the largest silicic centre in Iceland, with a 12-km-diameter caldera and an outstanding high-temperature geothermal field. It is located in the neovolcanic zone, at a junction where the eastern rift zone and a transform zone meet the intraplate volcanic flank zone of south Iceland (Fig. 1). During the last 1100 years there have been two eruptions in the Torfajökull area, the latest at the end of the 15th century.

Torfajökull is a source of persistent small-scale seismicity, with two types of events being observed. High-frequency earthquakes (Fig. 2) are located mainly in the western part of the caldera and low-frequency earthquakes (Fig 3.) cluster in the south. High-frequency earthquakes occur typically in swarms and are small in size (magnitude < 3). They have been interpreted to be related to hydrothermal cooling of a magma body (Soosalu and Einarsson 1997). Low-frequency earthquakes are also small in size (magnitude < 2), and have a frequency content of typically 1-3 Hz. Their phases are emergent and precise locations thus hard to obtain.

The 2005 Torfajökull seismic project is a continuation of a 20-station survey made in 2002 (Soosalu 2003). The main objective of the new project was to gain better understanding of the nature of the low-frequency seismicity with a more dense network of more sites in closer vicinity to the source of the seismicity. As a by-project a large number of high-frequency earthquakes was recorded, and a few teleseismic events were detected, useful for receiver function studies of crustal structure in the Torfajökull area.

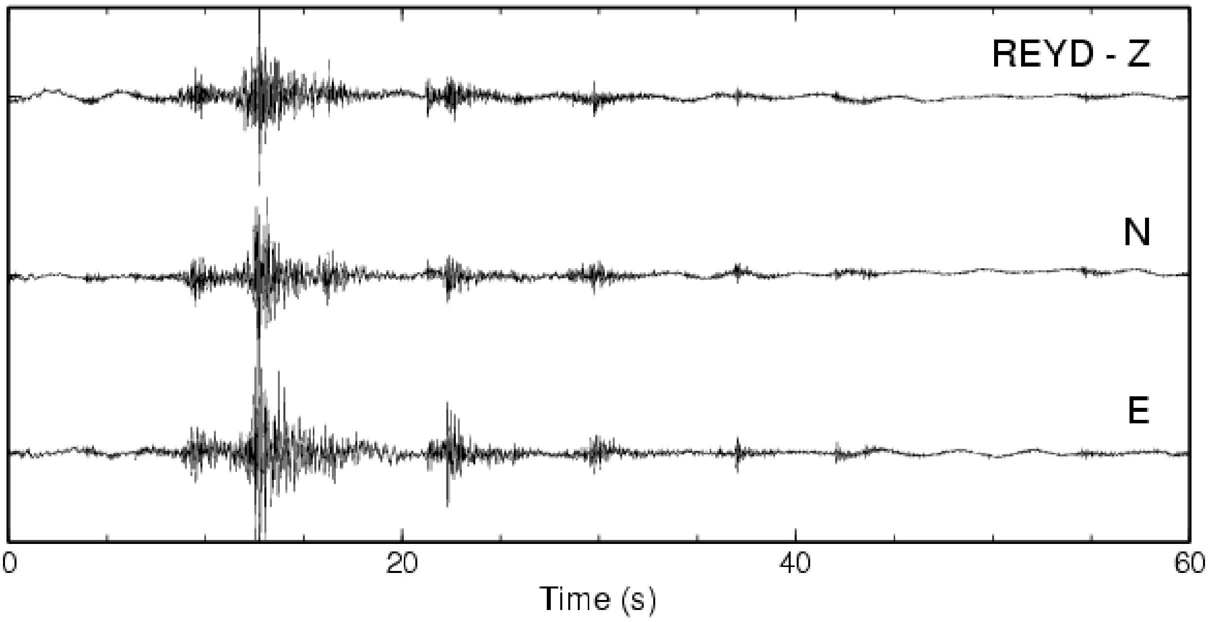

Figure 2. An example of a swarm of high-frequency earthquakes in the western part of Torfajökull, recorded by the station REYD. All the three components have the same arbitrary scale and no filtering is applied.

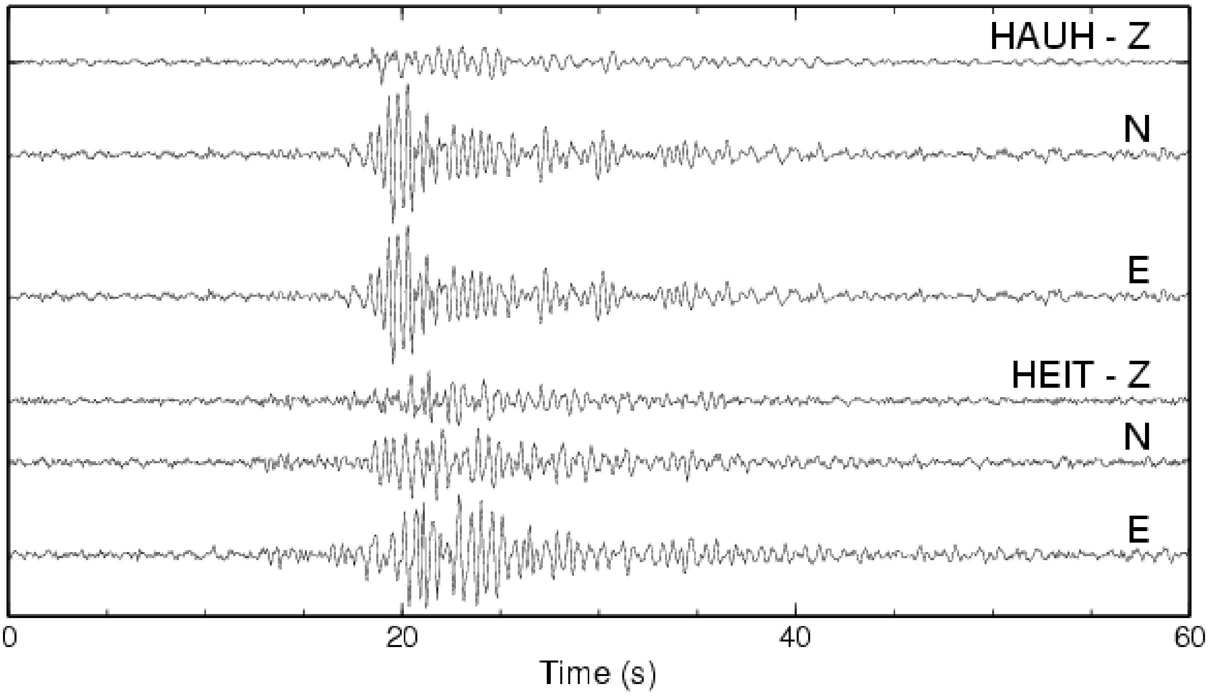

Figure 3. A low-frequency earthquake recorded by the stations HAUH and HEIT. All the traces have the same arbitrary scale and are bandpass filtered 0.8-8 Hz. The length of the records is the same 60 seconds as in Fig. 2.

Field installations of the Torfajökull 2005 seismic project

The instrumentation of the network consisted of thirty broadband Güralp 6TD seismometers borrowed from SEIS-UK. They were used with individual GPS clocks and the power source was an 80 Ah battery together with a solar panel. The terrain in the Torfajökull area is rough and challenging. Getting to the sites involves driving on steep slopes and crossing rivers by fords. The sites were chosen by optimizing between accessibility and vicinity to the active areas. It was possible to drive with 4WD cars to most of the sites, and the two sites closest to the area of low-frequency earthquakes were reached by helicopter transport. The deployment was done during the latter half of June and pick-up during end-September to mid-October.

The network was serviced and data downloaded once, at the beginning of August. As the time between visits was rather long and the seismometers had 3 or 4 Gbyte memory, the sampling rate was set to 50 samples per second to avoid data being written over. To save batteries, the GPSs were not set to continuous mode, but to one-hour-cycles.

Table 1. The volume of data gathered

Site	°N	°W	Alt (m)	Installed	Pick-up	Operation (days)	Days of data	Recovery (%)
LAUF	63.90916	19.43146	658	9-Jun	5-Oct	117.95	117.95	100
BIKS	63.94943	19.41237	779	9-Jun	5-Oct	117.90	117.90	100
RAFF	63.96364	19.43877	911	9-Jun	5-Oct	117.86	117.86	100
KRAK	64.03248	19.37757	682	10-Jun	5-Oct	117.06	117.06	100
SATU	63.01809	19.28747	671	10-Jun	4-Oct	116.18	116.18	100
DOMA	64.03158	19.09841	652	10-Jun	4-Oct	116.18	116.18	100
BRAN	63.97903	19.04707	620	10-Jun	4-Oct	116.07	116.07	100
POKA	63.98442	19.26821	917	11-Jun	5-Oct	116.09	116.09	~100
HRAF	63.95618	19.21494	897	11-Jun	5-Oct	116.08	109.08	94
REYD	63.97201	19.26449	917	11-Jun	5-Oct	116.03	116.03	100
VEST	63.95115	19.31254	872	11-Jun	5-Oct	115.74	115.74	100
SODU	63.93718	19.17151	1078	14-Jun	19-Oct	127.09	127.09	100
HRAS	63.93641	19.20482	1018	14-Jun	5-Oct	113.03	113.03	~100
JOKU	63.92701	19.18447	1109	14-Jun	19-Oct	126.95	126.95	100
TORF	63.86405	19.24982	547	15-Jun	7-Oct	113.96	113.96	100
LJOS	63.89330	19.24454	697	15-Jun	7-Oct	113.86	113.86	100
MAEL	63.81640	19.01667	619	15-Jun	6-Oct	113.09	88.44	~78
KGIL	63.85869	18.97325	603	15-Jun	6-Oct	112.98	112.98	100
STRU	63.84095	18.97253	576	15-Jun	6-Oct	112.91	107.31	95
THRA	63.82057	19.19711	580	16-Jun	6-Oct	112.32	112.32	100
SVAR	63.83705	19.06336	605	16-Jun	7-Oct	112.98	112.98	~100
KKLO	63.87033	19.05419	655	16-Jun	7-Oct	112.93	112.93	~100
MAFE	63.81170	18.90571	552	16-Jun	6-Oct	111.97	111.97	100
HALL	63.97064	18.83239	601	20-Jun	6-Oct	107.78	107.78	~100
KIRK	63.97617	18.90944	605	20-Jun	6-Oct	107.70	105.20	~98
TIND	63.95618	18.74455	682	21-Jun	6-Oct	107.06	107.06	100
THOR	63.88849	18.69845	490	21-Jun	6-Oct	107.03	107.03	100
SHNU	63.84140	18.75374	591	21-Jun	6-Oct	107.00	107.00	100
HAUH	63.89973	19.09278	963	22-Jun	20-Oct	120.10	120.10	100
HEIT	63.90829	19.03936	971	22-Jun	20-Oct	120.05	120.05	100

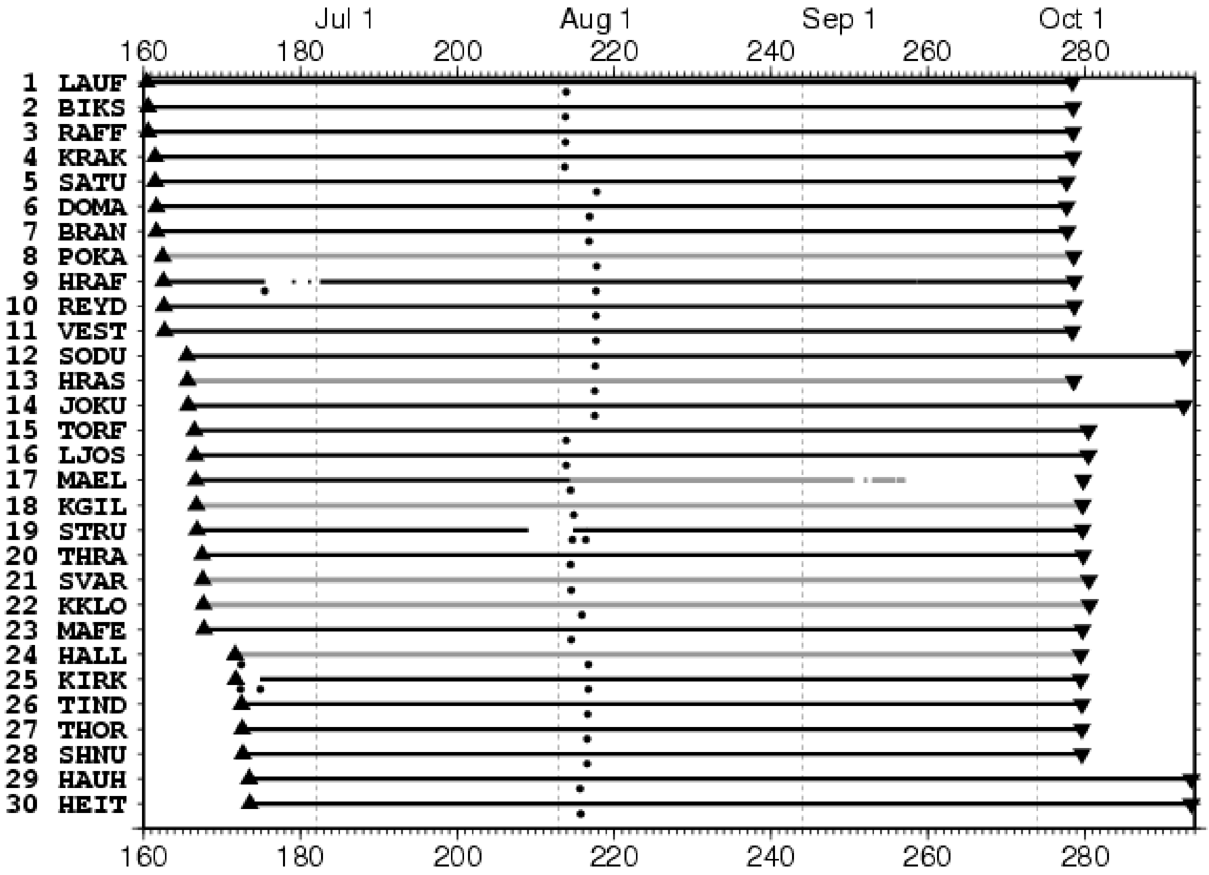

Figure 4. The station operation chart. A triangle shows the installation time of a station and an inverted triangle the pick-up. Solid thick line shows the times when data were gathered at the station, black when GPS was working normally, grey when a faulty GPS produced patchy data. Dashed line represents sporadic data. Dots under each line are site checks.

The data gathered

The data recovery was excellent, altogether 98.8% (Table 1 and Fig. 4). Only one instrument (MAEL) got out of order towards the end of the measuring period. One station (STRU) had a faulty solar panel regulator, but only some five days of data before the service trip were lost because of this problem. The station HRAF was working during the days 182-258 as an experimental station of the national seismic network run by the Icelandic Meteorological Office. There are some small data gaps around this period because of installation work.

Unfortunately, seven of the GPSs were discovered to be faulty after returning from the field. Because their internal battery was not working properly, they did not remember leap seconds. Every time such a GPS started its hourly search of satellites, it initially recorded data 13 seconds too late before catching up with the satellites. This lead to production of numerous short files with a too late timing. However, these data are useful, if the timing is corrected with -13 seconds. In the future, we strongly recommend always to use continuous GPS to avoid any problems like this. The power consumption of a continuous GPS does not appear to be markedly higher than of a one-hour-cycle GPS.

The data were processed following the SEIS-UK instructions described in fieldwork and data treatment reports provided by them. The original Güralp raw format was converted to mseed. Back-up copies were made on DVD discs of both the formats. Mseed format data are also stored by SEIS-UK and in the IRIS database with the network code YA of the year 2005.

Preliminary results

The level of the low-frequency earthquake seismicity was rather modest throughout the measuring period. Prior experience from stations at distances of 7-8 km and more was that the signals are emergent and precise phase picking is laborious and time-consuming. P-wave arrivals are particularly small and obscure, S-wave arrivals are more distinct (Soosalu et al. 2006). This appears to be the case also when these signals are recorded by seismic stations at close vicinity (the stations HAUH, HEIT, KKLO, see Fig. 1). The frequency content from close-by observations is the same 1-3 Hz, as previously observed. Only occasionally impulsive P-wave onsets and higher frequencies are observed at the closest sites. A crude event location list is under construction. More sophisticated locating analysis using the waveforms will be done based on this event list. In general, these earthquakes cluster in the area where the geothermal fields have hottest temperatures within Torfajökull (> 340° C), according to chemical analysis of steam and water samples (Bjarnason and Ólafsson 2000).

The high-frequency seismicity was exceptionally abundant during the summer of 2005, and several hundreds of earthquakes, up to magnitude 3.1 were detected and located very precisely. The majority of this activity occurred in the western part of the Torfajökull caldera at depths of 1-5 km, correlating well with the locations of geothermal fields that have recently been mapped in great detail (Sæmundsson and Friðleifsson 2001). This dataset supports the interpretation of a geothermally cooling magma chamber suggested by Soosalu and Einarsson (1997). A small cluster of high-frequency earthquakes were also detected in an unexpected location in the vicinity of the station HEIT in the eastern part of the caldera.

Formerly unknown persistent activity of minor low-frequency earthquakes in the vicinity of the station HEIT was discovered. Typically these signals are short in duration and large at HEIT records, are visible at HAUH but are beyond detectability at other sites. Presumably they are shallow events related to geothermal activity there.

Presentations, publications and research in progress

The first results of the Torfajökull 2005 campaign have been presented at the meeting of the Volcanic and Magmatic Studies Group in the U.K.:

Campbell, Fiona, M., Robert S. White & Heidi Soosalu (2006). High-frequency microseismicity at the Torfajökull volcano, South Iceland. Volcanic & Magmatic Studies Group, 40th Anniversary Meeting, Leeds, U.K., 4-6 January, 2006, p. 42-43.

Soosalu, Heidi, Robert S. White, Fiona Campbell & Páll Einarsson (2006). Low-frequency earthquakes at the Tofajökull volcano, Iceland – evidence for a cryptodome? Volcanic & Magmatic Studies Group, 40th Anniversary Meeting, Leeds, U.K., 4-6 January, 2006, p. 31-32.

More presentations based on the Torfajökull data will be given in forthcoming relevant meetings. The high-frequency earthquake dataset has formed the material of two final year undergraduate student projects at the University of Cambridge, the first half by Fiona Campbell in 2005 and the latter half by Nick Borner in 2006. A summarizing article will be written based on the whole high-frequency earthquake dataset. Heidi Soosalu is at the moment analysing the low-frequency earthquakes, which will provide material for another article. Julian Drew, a Cambridge PhD student, is using the high-frequency earthquakes for developing and testing an automatic event detection tool. Kristín Jónsdóttir, a PhD student at the Uppsala University, is using our recordings as additional data for her tomographic study on the neighbouring Katla volcano.

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