

Seismic Monitoring of Volcanoes

Monitoring Strike-slip faulting during Volcanic Activity, central Iceland



Figure 1 Vatnajökull National Park

Summary

Iceland is a highly volcanic island lying upon the Mid-Atlantic ridge, the major boundary between the North American plate and the Eurasian plate. Iceland frequently experiences seismic activity and volcanic eruptions.

Iceland sometimes experiences lateral migration of magma filled dykes which can propagate for many kilometres underground. Over a 13-day period in 2014, magma propagated laterally from the Bárðarbunga volcano beneath the Vatnajökull ice cap, in the northern rift zone of Iceland, causing more than 30,000 earthquakes. These earthquakes stretched along a 48 km path, at 5-7 km depth, before finally erupting on the 29th August 2014. The University of Cambridge used a selection of Güralp 6TD, 3ESPCD and 3TD seismometers to record and track the dyke propagation beneath the ice cap before it erupted in the largest eruption for 250 years.

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Güralp Solution

The University of Cambridge deployed 45 Güralp 6TDs, 10 Güralp 3ESPCDs and 10 Güralp 3TDs in a dense network across Iceland, focussing especially on the Northern Volcanic Zone (NVZ).



Figure 3 A Güralp 3ESPCD Strong Motion Seismometer.

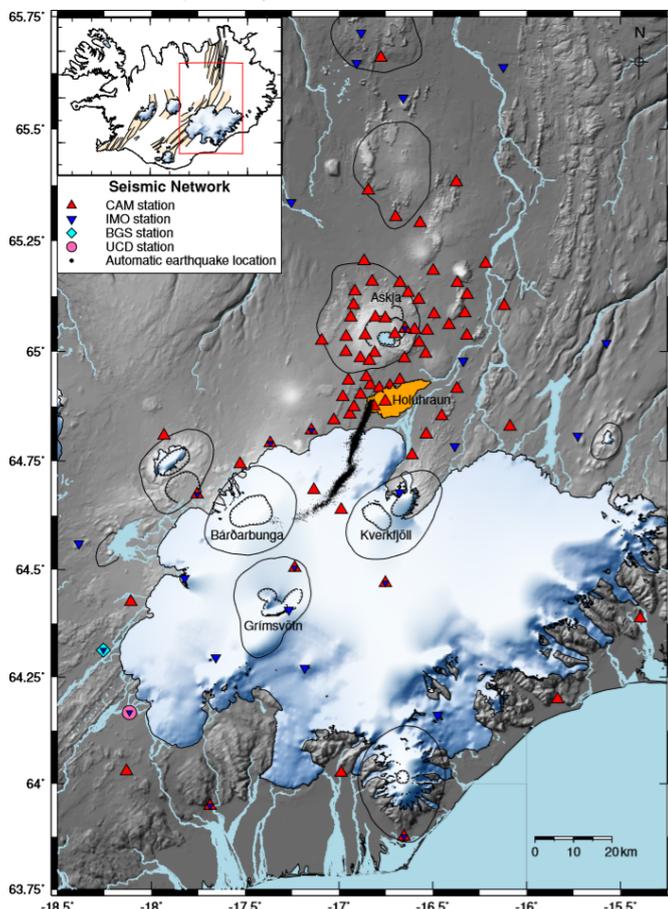
The 6TD (Figure 2) is an ideal instrument for deployment in difficult terrains: its robust and portable design makes it perfect for quick field installation. The masses do not require locking or unlocking during transportation and as it is a digital seismometer, it reduces the quantity of equipment that must be carried into the field.



Figure 2 A Güralp 6TD Medium Motion Seismometer.

The 3ESPCD (Figure 3) is a small, lightweight, broadband, triaxial digital seismometer, providing weak motion monitoring in a medium-motion sized instrument. 3ESPCDs are used for permanent volcano monitoring networks and long-term microseismic monitoring. They cover the complete seismic spectrum with a single transfer function.

The 3T (Figure 4) is our most sensitive instrument, it covers the entire



seismic spectrum under one transfer function and can record frequencies up to 120s. The 3T is traditionally installed in a vault and this weak motion sensor can record clearly earthquakes from across the globe. The 3T is widely used in many National seismic networks, with over 3000 deployed worldwide.



Figure 4 A Güralp 3T Weak Motion Seismometer.

In August 2014 at the time of the eruption, the University of Cambridge had 72 three-component broadband seismometers deployed across Iceland. The layout of the Broadband network can be seen in Figure 5.

Figure 5 The Icelandic rift system and the location of short period and broadband seismometers across Iceland. The red diamonds are broadband seismometers from the ongoing Cambridge experiment.

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Outcomes

Combining Cambridge's seismic network with 14 stations from the national seismic network of the Icelandic Meteorological Office, 1 station from the British Geological Survey and 1 station from University College Dublin, Cambridge University was able to track a dyke as it propagated in the NVZ.

The 6TDs, 3ESPCDs and 3TDs recorded data continuously at 100 samples per second. More than 30,000 earthquakes were detected during the 2014 Bárðarbunga-Holuhraun dyke intrusion, Figure 6. The seismic network successfully tracked the earthquakes along the dyke as it propagated 48km into the NVZ before its eventual eruption at Holuhraun. Using the seismic data to produce moment tensors, the earthquakes were found to be exclusively strike slip faulting, **breaking along** the local fabric as the melt forced its way forward. Low frequency tremor and long period events generated as the magma flowed were also mapped successfully using the broadband response of the sensors.

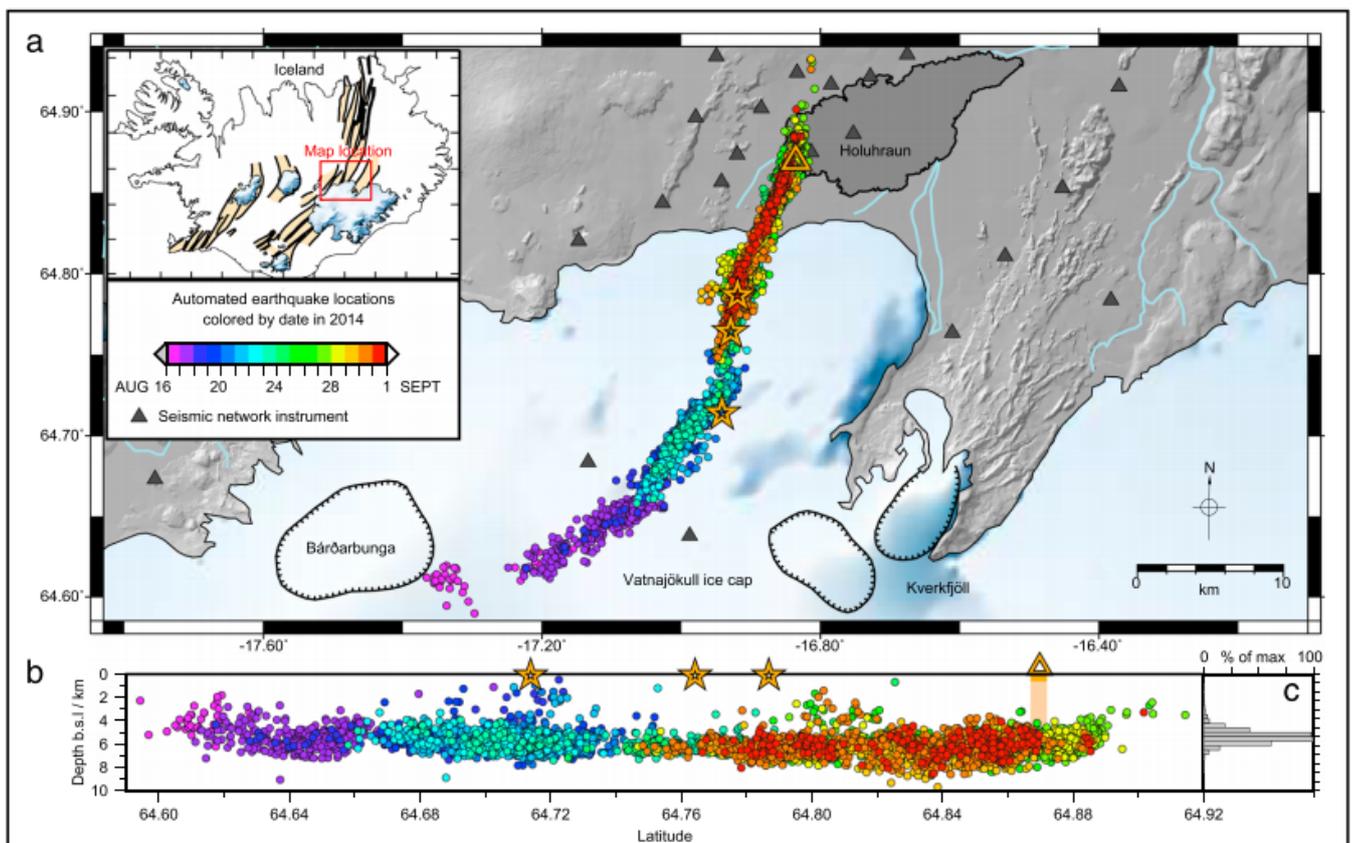


Figure 6 Seismicity produced as the dyke propagated beneath the ice sheet before the eventual eruption denoted by the orange triangle. (a) Shows the earthquake locations in a map view, (b) cross section along the dyke. The seismic stations are noted as black triangles.

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References

Ágústsdóttir, T., Woods, J., Greenfield, T., Green, R.G., White, R.S., Winder, T., Brandsdóttir, B., Steinthórsson, S. and Soosalu, H., 2016. Strike slip faulting during the 2014 Bárðarbunga Holuhraun dyke intrusion, central Iceland. *Geophysical Research Letters*, *43*(4), pp.1495-1503.

Caudron, C., White, R. S., Green, R. G., Woods, J., Ágústsdóttir, T., Donaldson, C., Greenfield, T., Rivalta, E. & Brandsdóttir, B. (2018). Seismic amplitude ratio analysis of the Bárðarbunga-Holuhraun dike propagation and eruption, *Journal of Geophysical Research, Solid Earth*, **123**, doi: 10.1002/2017JB014660

Green, R.G., Priestley, K.F. and White, R.S., 2017. Ambient noise tomography reveals upper crustal structure of Icelandic rifts. *Earth and Planetary Science Letters*, *466*, pp.20-31.

Underwood, E. (2018), A novel way to track magma flow, *Eos*, *99*, <https://doi.org/10.1029/2018EO093255>

Woods, J., Donaldson, C., White, R. S., Brandsdóttir, B., Caudron, C., Hudson, T. S. & Ágústsdóttir, T. (2018) Long-period seismicity reveals magma pathways above a propagating dyke during the 2014-15 Bárðarbunga rifting episode, Iceland, *Earth and Planetary Science Letters*
