INTERPRETING SEISMIC SIGNALS FROM ICELANDIC VOLCANOES

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Abstract

The use of relatively located micro-earthquakes to map sub-surface faults in Iceland's transform- and volcanic zones has led to substantial advances in mapping details of fault structures. The similarity of waveforms from neighbouring earthquakes with similar mechanisms enables highly accurate relative time measurements through cross-correlation of the waveforms. In volcanic regions, the events do not necessarily occur on common faults, their source time functions can be long and complicated, and the local structure can be highly heterogeneous. However, relative locations of volcano-tectonic events allow magma movements to de delineated. Over the 19-year operation of the SIL seismic network, a wealth of signals emanating from Icelandic volcanoes have been captured by and analysed. These include Hekla, Eyjafjallajökull and Katla, as well as Bárðarbunga, Gjálp and Grímsvötn beneath the Vatnajökull ice cap.

Relative locations of the roughly one thousand earthquakes recorded in Eyjafjallajökull volcano reveal a pipe-like feeder channel just northeast of the crater rim, extending from the base of the crust, at around 22 km depth, up to the 6 km depth of sill intrusion emplacement. Two main intrusion episodes have been captured: 1994 and 1999. They started with rather intense activity in the feeder pipe, at 8-12 km depth, followed a few months later during the sill emplacement with southward migration of seismicity at around 6 km depth. Focal mechanisms of the upper crustal events vary, but mechanisms of events occurring in a swarm at the base of the crust in 1996, show predominantly E-W oriented, horizontal tension in agreement with the direction of spreading. A third intrusion episode appears to be in the making in 2009, with significant activity occurring in the feeder pipe at 8-12 km depth during the summer months.

At the neighbouring Katla volcano, the seismicity is about 15 times higher, with over 11 thousand events recorded on the volcano's western flank and over three thousand in the caldera. The flank activity exhibits seasonal variations; events are emergent and dominated by long periods, even though their magnitudes are in general no greater than M_L~2.5. The flank seismicity is extremely shallow (≤1 km), and much of the activity can be grouped into similar families of events, with some of the waveform complexities explainable by multiply reflected waves trapped in the near surface layers. Inside the caldera, on the other hand, the seismicity is generally of higher frequency, often with short impulsive waveforms and sometimes exhibits wave characteristics of regular tectonic events. This activity has been relatively located revealing nearly 80% of the caldera seismicity is also very shallow, or within 4 km of the surface. The distribution of this seismicity correlates well with locations of the main cauldrons on the ice surface, confirming its association with geothermal activity in the caldera. Additionally, significant activity is located in a small area near the caldera centre, where no cauldrons form. Temporal variations in the caldera seismicity correlate with changes in cauldron size over time, leading them by 1-2 years. In 2001, the activity in most cauldrons suddenly increased, peaked in 2002 and remained high until 2004. Two years prior to this activity, in July 1999, a small peak in seismicity occurred in the centre of the caldera, followed a week later by a sudden jökulhlaup from Sólheimajökull, which drained newly formed cauldron 7. The flood was accompanied by continuous frequency-banded tremor observable on stations around Katla. The peak activity at the centre location also occurred in 2002. The most seismically productive cauldron is at the northern caldera rim; similar to Eyjafjallajökull, this region was reactivated during summer 2009 and was accompanied by small floods in glacial rivers north of Katla.

Some scattered seismicity is located below 4 km depth in the Katla caldera, but with significant absolute and relative location errors. However a few events in a small cluster near the base of the crust, below the eastern caldera rim were well located in 2007 and 2008. Their locations suggest association with magma injection from the mantle into the crust, similar to the deep events at Eyjafjallajökull in 1996 and at Hjörleifshöfdi in 2007. The apparent regional increase in seismicity at the base of the crust could be real, but may also be affected by the improved detection threshold with time.

Seismicity associated with magma movements within Vatnajökull's main volcanoes: Grímsvötn, Gjálp and Bárðarbunga has also been recorded and relatively located. Additionally, continuous banded tremor is often observed from Vatnajökull, during eruptions and drainage of the two Skaftárkatlar cauldrons, as well as the Grímsvötn subglacial lake. The transient and continuous signals generated by these events will be discussed and compared to the events generated by Katla.