Revisited Local Earthquake Tomography in the Tjörnes Fracture Zone

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The Tjörnes Fracture Zone (TFZ) is a ridge-transform zone on the Mid-Atlantic Ridge in northern Iceland with two main lineaments: the Husavik-Flatey Lineament (HFL) and the Grimsey Lineament (GL) (Gudmundsson, 2007). The TFZ is mostly located offshore which has made it difficult to obtain seismic or geological information from the region. The seismicity of the TFZ has mainly been monitored by the SIL network. Since 1990 the network has recorded more than 75,000 earthquakes in the TFZ with at least 9 on-land stations in the region. The average minimum-station distance is about 32 km and event-station distance goes up to 150 km. This results in relatively high uncertainties of earthquake locations (estimated errors reach 5 km in the horizontal and the vertical directions).

Figure 1. Seismicity in the Tjörnes Fracture Zone. Black dots correspond to the original SIL catalogue (before tomography) from 1990 to 2012. The two main lineaments, Grimsey and Husavik-Flatey are highlighted by the locations of the earthquakes. SIL network station are represented by green triangles, and NICE stations are the blue triangles for OBS' and red triangles for on-land stations. Stars are the shots locations.
In order to resolve the subsurface structure and the geodynamic transition from Icelandic crust to typical oceanic crust, a denser temporary network was installed in the area during the North Iceland Experiment (NICE). The network consisted of 14 OBS and 11 on-land stations and was operated from June to September 2004 (Riedel et al., 2006). This network recorded more than 1000 events together with the permanent SIL network including 16 explosions fired during the experiment. The minimum average station distance was reduced to 24 km.

A very preliminary tomography was published shortly after the data acquisition (Riedel et al., 2006). A more in-depth analysis of the data was intended but was for various reasons repeatedly delayed. Here we present new tomographic images after the dataset was carefully re-picked in search for more events.

We have applied local-earthquake tomography (LET) inverting simultaneously for earthquake locations and a velocity model (Tryggvason, 1998). We used two sets of independent data: 1) a subset of data from the SIL catalogue from 1990 to 2012, and 2) combined data from the SIL and NICE networks for earthquakes recorded during the summer of 2004 (see Figure 1 for earthquake locations and stations distribution). For the former tomography, the SIL catalogue provided around 35000 P-wave and 45000 S-wave picks with moderate precision, allowing for study of the crust to about 15 km depth, but predominantly with long paths yielding little resolution in the uppermost crust. Instead, the small NICE/SIL data provided fewer, but more precise data (2500 P-wave picks and 3500 S-wave picks) from a denser network, illuminating the upper crust better.

The relocated seismicity is mainly clustered along the HFL and the GL (Figures 2). Most of the seismicity at the HFL is relocated at depths up to 13 km. Beneath the Flatey Island, seismicity groups in several separated clusters. The GL seismicity goes from depths of 15 km for earthquakes located in the SE part of the lineament, to depths of less than 10 km beneath the Grimsey Island. However, some few earthquakes are clustered around other lineaments. The Dalvik lineament is enhanced after relocation. Also some transversal lineaments which connect the HFL with the GL (oriented in the SW-NE direction) are enhanced.

The principal characteristic of the resulting velocity models is the clear seaward increase of velocity. This may relate to progressive reduction of crustal thickness, which evidences the transition from a thicker Icelandic crust to a thinner oceanic crust (see Figure 2 (a)). Additional to this feature, some velocity anomalies appears when NICE/SIL data are used (Figure 2(b) - 2(c)). A low velocity anomaly beneath the Flatey Island appears at shallow depths (less than 5 km). Other low velocity anomalies appear at shallow depths in Eyjafjardararl Basin.

Relocating events in the preliminary models shows that the events are considerably shallower than in the SIL catalogue. A common reason for catalogue depths being overestimated is that the 1D velocity models used for routine location of events is often slightly slower than the real velocities. Moreover, a 1D velocity model is not able to describe the Icelandic-oceanic crust transition. While in contrast a 3-D tomographic velocity model results in more reliable earthquake locations, a better estimate of the seismogenic depth and therefore the largest potential event magnitude in the area.
Figure 2. Velocity model and earthquake locations resulting of tomography. Map view slices present P- and S-wave velocity models: (a) at depths from 9.25 to 10 km using the SIL data, showing the seaward increase of velocity. (b) at depth from 4.75 to 5.5 km and (c) at depth from 5.5 km to 6.25 km, using the NICE data. Velocity colour scales are presented to the right. Black dots correspond to relocated earthquakes.

References