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Precise hypocentre relocation of microearthquakes in a high-temperature geothermal field: the Torfajökull central volcano, Iceland

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SUMMARY

The Torfajökull volcanic system is one of approximately 30 active volcanoes comprising the neovolcanic zones of Iceland. The central volcano of the system is the largest silicic centre in Iceland with a caldera of approximately 12 km diameter. Its high-temperature geothermal system is one of the most powerful in Iceland. Torfajökull is a source of persistent seismicity, where both high- and low-frequency earthquakes occur. To study this microseismicity in detail, a temporary array of 20 broad-band seismic stations was deployed between 2002 June and November. These temporary stations were embedded in the permanent South Iceland Lowland (SIL) network and data from nine adjacent SIL stations were included in this study. A minimum one-dimensional (1-D) velocity model with station corrections was computed for earthquake relocation by inverting manually picked *P*- and *S*-wave arrival times from events occurring in the Torfajökull volcanic centre and its surroundings. High-frequency earthquakes from the Torfajökull volcanic centre were then relocated calculating a non-linear, probabilistic solution to the earthquake location problem. Subsequently, we correlated the waveforms of these 121 events (∼2000 observations) to define linked events, calculated the relative traveltime difference between event pairs and solved for the hypocentral separation between these events. The resulting high-resolution pattern shows a tighter clustering in epicentre and focal depth when compared with original locations. Earthquakes are mainly located beneath the caldera with hypocentres between 1 and 6 km depth and lie almost exclusively within the geothermal system. A sharp cut-off in seismicity at 3 km suggests either that there is a marked temperature increase or that this is a structural boundary. No seismic activity was observed in the fissure swarms to the northeast (NE) and southwest (SW) of the volcanic centre.

Key words: earthquake location, Iceland, microearthquakes, seismicity.

1 INTRODUCTION

Precise earthquake hypocentre locations are required to study structure and processes that trigger seismic activity. The spatial and temporal distribution of earthquakes provide information on tectonic regime and material properties of an area, and on the depth of the brittle–ductile transition.

The accuracy of hypocentre locations and their uncertainties depend on several factors, including the number and type of available seismic phases recorded at the seismometers, the accuracy with which arrival times can be measured, the network geometry, knowledge of the crustal velocity structure and the linear approximation to a set of non-linear equations, which is assumed in the inversion. Standard earthquake location routines mostly use one-dimensional (1-D) velocity models. In general, such reference models are constructed using *a priori* information such as the surface geology, and seismic refraction and reflection data. The accuracy of the 1-D model can be improved by including information from recorded earthquakes, usually by a joint hypocentre–velocity inversion (Kissling 1988; Kissling *et al.* 1994). By calculating 1-D station terms, this approach also partially accounts for the three-dimensional (3-D) velocity variations in the upper crust, which can introduce systematic biases into the estimated traveltimes and, hence, into the hypocentre locations.

Further improvements in the precision and reliability of earthquake locations can be achieved by using a probabilistic, non-linear earthquake location method instead of a linearized algorithm. The probabilistic, non-linear earthquake location problem was formulated by Tarantola & Valette (1982). Increasing computer power, and the combination of probabilistic earthquake location and non-linear, global search algorithms (Lomax *et al.* 2000), such as the Metropolis–Gibbs or the Oct–Tree Importance sampling algorithm

