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The 2014-15 Bárðarbunga-Holuhraun magmatic rifting event: A seismic study

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On 16 August 2014 an unusual sequence of earthquakes began near the SE rim of the ice-covered Bárðarbunga caldera in central Iceland. Over the course of 2 weeks a dyke propagated 48 km beneath the glacier northeastwards and into the Holuhraun lava field, where it erupted for 6 months. It became the largest eruption in Iceland for 230 years. During this time, a gradual, incremental caldera collapse took place at the central volcano. We use accurate relative earthquake locations of ∼48,000 earthquakes to analyse the seismic response to the event, both due to the dyke propagation, and the subsequent caldera collapse. We define the thickness of the seismogenic crust under Bárðarbunga as ∼ 7 km, based on the depth extent of observed seismicity. The bulk of the seismicity directly beneath the volcano is located at 1-4 km below the surface, whereas the dyke exited the caldera at 4-6 km depth, propagating at ∼ 6 km b.s.l..

Of the ∼48,000 earthquakes located, ∼31,000 delineate the segmented, lateral dyke intrusion as it fractured a pathway through the crust, utilizing pre-existing weaknesses. Despite the extensional rift setting, the dyke emplacement generated exclusively double-couple earthquakes. At the leading edge of the propagation, earthquake source mechanisms show exclusively strike-slip faulting, in contrast to the conventional model of normal faulting above a propagating dyke. We observe right-lateral strike-slip faulting as the dyke propagates to the NE, and an abrupt change to left-lateral strike-slip faulting as the dyke turns and propagates in a more northerly direction into the northern volcanic zone. This shows that the direction of fault motion is determined by the opening of the dyke and pre-existing fabric, rather than by the regional extension.

Approximately 5,000 of the recorded earthquakes are associated with the caldera collapse, delineating faults accommodating the subsidence and showing good correlation with geodetic data. The seismicity reveals activation of both inner and outer caldera faults with ∼60° inward dipping planes, but with an order of magnitude difference in the cumulative seismic moment on the northern and southern sides. Detailed analysis of the source mechanisms shows that ∼90% of the events can be explained by double couple failure. We find the dominant failure mechanism during the collapse to be steep normal faulting, with sub-vertical P-axes, and fault planes striking sub-parallel to the caldera rim. The southeastern part of the caldera, whilst experiencing less activity, shows a mixture of failure mechanisms, owing to the interaction of the caldera collapse and the dyke exit. We suggest a complex asymmetric caldera collapse, not controlled by a single caldera ring fault.