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A Seismological Portrait of the Anomalous 1996 Bardarbunga Volcano, Iceland, Earthquake

H. Tkalcic, D. S. Dreger, G. R. Foulger, B. R. Julian and A. Fichtner

Research School of Earth Sciences, The Australian National University, Canberra ACT 0200, Australia

Berkeley Seismological Laboratory, University of California at Berkeley, Berkeley, CA 94720, USA

Department of Earth Sciences, Durham University, Durham DH13LE, UK

United States Geological Survey, Menlo Park, CA 94025, USA

Department of Earth and Environmental Sciences, Ludwig Maximilian University, Munich, Germany

The Bardarbunga volcano lies beneath the 500-m-thick Vatnajokull icecap, the largest glacier in Europe. M5+ earthquakes with atypical seismic radiation have occurred beneath the Bardarbunga caldera and have been routinely reported in the Global Centroid Moment Tensor catalog. An earthquake with Mw 5.6 and a strong non-double-couple radiation pattern occurred beneath the caldera 29 September, 1996. A peculiarity of that earthquake was that it was the first in a sequence of seismic and magmatic events and that it was followed, not preceded or accompanied, by a major eruption which ultimately led to a breakout flood from the subglacial caldera lake. The earthquake was recorded well by the regional-scale Iceland Hotspot Project seismic experiment. Several hypotheses were proposed to explain the seismically observed displacement field and the sequence of observed events. The most popular is the inflation of a shallow magma chamber that might have caused rupture on ring faults below the chamber.

In general, resolution of non-double-couple sources is complicated by our imperfect knowledge of Earth structure. Iceland has a heterogeneous crust, with variable thickness, and thus a one-dimensional structural model is not appropriate for waveform modeling. We investigated the earthquake with a point source complete moment tensor inversion method using regional long-period seismic waveforms and a composite structural model of Iceland based on joint modeling of teleseismic receiver functions and surface-wave dispersion curves. When the composite structural model is used, the waveform modeling yields a non-double-couple solution with a strong, vertically oriented compensated linear vector dipole component and a statistically insignificant volumetric contraction. The absence of a volumetric component is surprising in the case of a large volcanic earthquake that cannot be explained by shear slip on a planar fault. A possible mechanism that can produce an earthquake without a volumetric component involves two offset sources with similar but opposite volume changes. We show that although such a model cannot be ruled out, it is unlikely.

In order to investigate the hypothesis of a rupture occurring on a ring fault, we simulated different caldera geometries and various rupture scenarios on the walls of a conical surface. We obtained excellent fits for ruptures extending along one-half perimeter of the caldera at a super-shear velocity, but could not determine the location of the initiation point nor the

rupture propagation direction.

If studied in different frequency bands, the point source moment tensor inversion fails, however, to simultaneously explain the observed data, and this indicates the presence of finite-source effects. Using a three-dimensional model of the Icelandic crust and upper mantle, we perform a probabilistic finite source inversion. One of the most robust outcomes of this is a well constrained source duration and approximately equal amount of energy radiated by individual segments. This indicates that the caldera dropped coherently as a single block. We speculate that a small-scale eruption that could have gone unnoticed prior to the caldera drop caused the earthquake. The caldera drop could have increased the pressure in the magma chamber thus inducing the principal eruption.