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Source mechanism of the 1992 Roermond, the Netherlands, earthquake from inversion of regional surface waves (extended abstract)

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The Dutch-German border region experienced a strong crustal earthquake in the early morning, 3:20 local time, of April 13, 1992. The epicenter (latitude: 51.17°, longitude: 5.93°, hypocenter depth: 14 ± 3 km, origin time: 1:20:02.7UT; Ahorner 1992) is located near Roermond within the NW-SE trending Roer Valley Graben in the southeastern part of the Lower Rhine Embayment.

Broad-band, long-period surface waves recorded at regional distances (100–1500 km) were used to retrieve the centroidal source mechanism by moment tensor inversion. For a complete description of the procedure see the paper by Braunmiller et al. (1994).

We obtained three-component waveform data from Stuttgart (STU), Zürich (ETH), the German Regional Seismic Network, Kongsberg (KONO) and Toledo (TOL) of the Global Digital Seismic Network, and vertical waveform data from the British stations Charnwood Forest (CWF) and Eskdalemuir (EKA). Figure 1 shows the good azimuthal distribution of these stations. The instrument response was removed from the seismograms to obtain displacement records.

Excitation functions were calculated using the reflectivity method (e.g. Müller 1985) for a simple 30 km-thick crust ($v_p = 6.0$ km/s, $v_p = \sqrt{3} \times v_s$) overlying a mantle half-space ($v_p = 8.0$ km/s). Trial source depths of 13 and 18 km based on hypocenter depth estimates of Ahorner (1992) and Paulssen et al. (1992) were used.

We utilized Sipkin's (1982) moment tensor inversion method, extended by Koch (1991), to obtain the centroidal (average) source mechanism assuming a step-like source time function. The time domain inversion for the six independent moment tensor components is linear and minimizes the least squares norm between observed and synthetic seismograms. Synthetic and observed data were band-pass filtered (12.5–100 s).

Our simple velocity-depth structure does not account for correct travel times. An iterative procedure was applied to correct for the biases introduced to the moment tensor solution. We used the initial result of the moment tensor inversion to display the resulting synthetics together with the observed seismograms. Then we interactively aligned corresponding phases and repeated the inversion step to obtain a less biased solution.

The results of the moment tensor inversion are summarized in Table 1. Figure 2 shows the fit of the synthetic seismograms for a source depth of 18 km. The complete moment tensor for this trial depth is: $M_{xx} = 0.42 \pm 0.09$, $M_{xy} = 0.45 \pm 0.04$, $M_{xz} = - 0.33 \pm 0.02$, $M_{yy} = 0.77 \pm 0.08$, $M_{yz} = - 0.27 \pm 0.02$, $M_{zz} = - 0.73 \pm 0.03$, and seismic moment $M_0 = (9.2 \pm 0.4) \times 10^{16}$ Nm corresponding to a moment magnitude of $M_w = 5.3$. The moment tensor, which describes a general seismic (point) source, can be decomposed into a double-couple contribution, with the double couple being equivalent to a shear dislocation (Jost & Herrmann 1989). Inversions performed for centroidal depths of 13 and 18 km yield basically the same double-couple orientation. One nodal plane corresponds in both inversions to a steeply southwestward dipping (58 ± 1°) and NW-SE striking (138 ± 2°) normal fault (rake: 262 ± 2°). The aftershock distribution (T. Camelbeeck pers. comm. 1992) constrains this plane as the fault plane.

In agreement with other studies (Ahorner 1992; Paulssen et al. 1992; Dziewonski et al. 1993; see Table 1), we derived from surface wave inversion that the

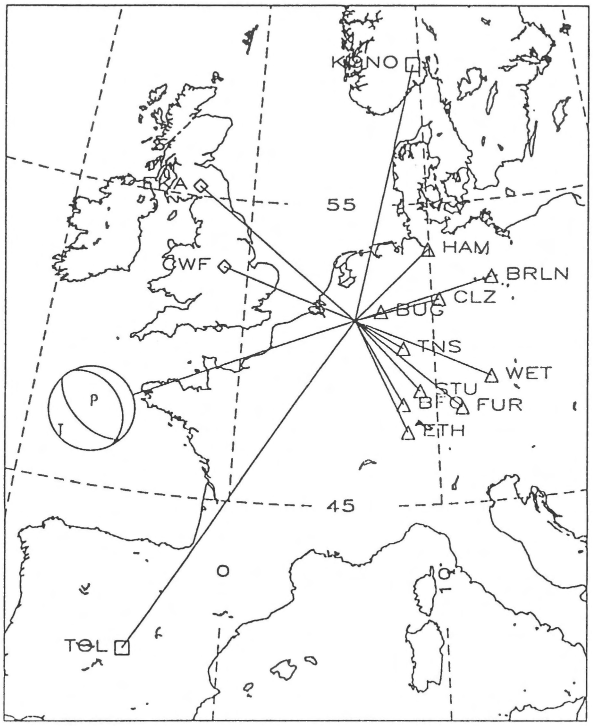

Fig. 1. Map of western Europe showing great-circle paths from the epicenter of the Roermond earthquake to stations used for surface wave inversion as straight lines. △: German Regional Seismic Network stations plus ETH and STU. □: Global Digital Seismic Network stations. ◇: British Geological Survey stations. The fault-plane solution shown corresponds to the double-couple part of our inversion result.

average source mechanism of the Roermond earthquake represents almost pure normal faulting on a steeply southwestward dipping fault. The strike of our preferred fault plane is compatible with the NW-SE trend of the Roer Valley Graben.

Seismic moment estimates based on waveform inversion (13.3×10^{16} Nm, Dziewonski et al. 1993) and body wave spectra (6.5×10^{16} Nm, Ahorner 1992; 8.3×10^{16} Nm, M.-C. Oncescu pers. comm. 1992), corresponding to $M_w = 5.2$–5.4, agree well with our estimate of $(9.2 \pm 0.4) \times 10^{16}$ Nm. Local magnitude (M_L) estimates of 5.8 (T. Camelbeeck pers. comm. 1992) and 5.9 (Ahorner 1992), however, are considerably higher. The relatively (with respect to $M_L = 5.8$–5.9) minor damage in the epicentral region and the relatively small accelerations measured (Ahorner 1992) may indicate low seismic moment release consistent with our estimate.

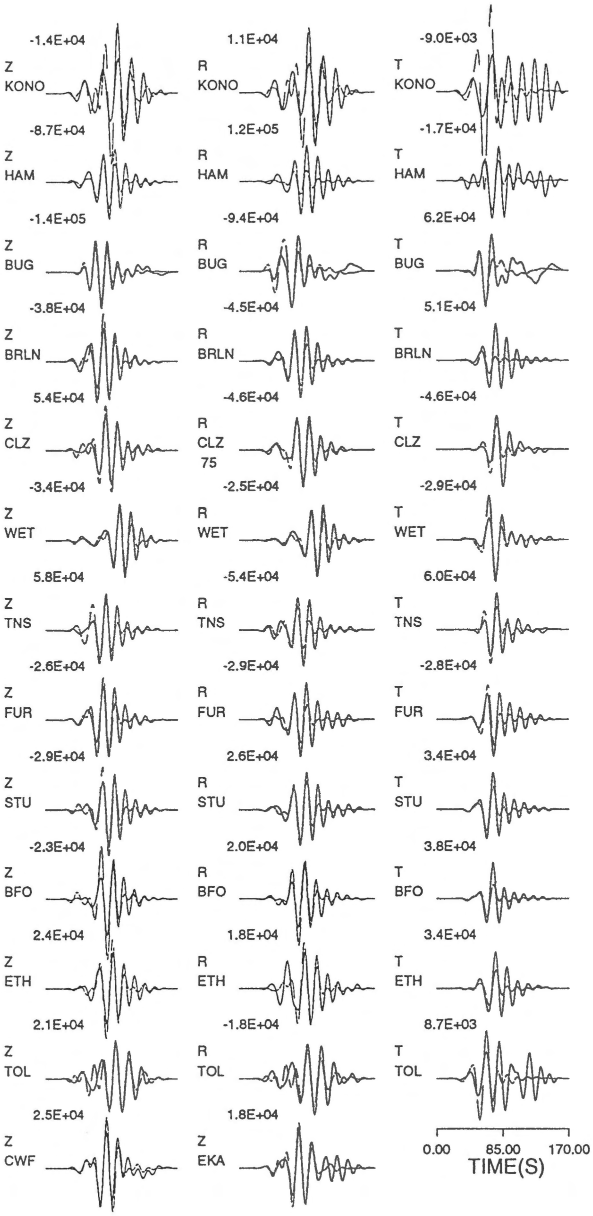

Fig. 2. Fit of the synthetic seismograms (dashed) to the observed displacement seismograms (solid) for a source depth of 18 km. The inversion window is 170 s long. The seismograms are normalized with respect to the maximum observed amplitude, which is shown above each trace (in nm). The first column shows the vertical (Z), the second the radial (R), and the third the transverse component (T). The bottom row shows the vertical (Z) component of the two British stations. The stations are ordered according to azimuth.

The source depth is not very well resolved by the long-period surface waves. A centroid depth of 18 km fits slightly better than 13 km (Table 1). Waveform modelling by Paulssen et al. (1992) indicates a source depth of 20 ± 4 km, whereas Ahorner (1992), using arrival time data, obtains 14 ± 3 km. Our inversion results are not able to resolve this discrepancy. More

Table 1. Source parameters of the Roermond earthquake

Depth (km)	Strike (°)	Dip (°)	Rake (°)	M_0 (10^{16} Nm)	I/D (%)	DC (%)	NMSE	Ref.
13*	139 ± 2	58 ± 1	263 ± 2	9.4 ± 0.5	23	89	0.44	TS
18*	138 ± 2	58 ± 1	262 ± 2	9.2 ± 0.4	15	95	0.43	TS
14	124	68	270	6.5				A
20	124	70	270					P
15*	143	68	273	13.3	0	86		CMT

Depth: centroid depth. Strike, dip, rake: following convention of Aki & Richards (1980). M_0: seismic moment. I/D: ratio of isotropic to largest deviatoric eigenvalue of moment tensor. DC: double couple component of deviatoric part (following Dziewonski et al. 1981). NMSE: normalized mean square error (following Sipkin 1982). Ref.: reference; TS: this study; A: Ahorner (1992); P: Paulssen et al. (1992); CMT: Dziewonski et al. (1993). Uncertainties following strike, dip, rake, and M_0 are two standard deviations computed using a jack-knife and bootstrap procedure. *: fixed during inversion.

detailed studies are warranted to resolve the nucleation depth, which could lend additional insight into maximum hypocenter depths of crustal earthquakes in the Lower Rhine Embayment.

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