TERRA MOTAE

The Roermond earthquake of 13 April 1992, the Netherlands: geological aspects

Vladimir G. Trifonov[1], Jean Klerkx[2] and Karel Theunissen[2]

[1]*Laboratorium of Neotectonics and Remote Sensing, Geological Institute of the Russian Academy of Sciences, 7 Pyzhevsky, Moscow 109017, Russia;* [2]*Department of Geology and Mineralogy, Royal Museum of Central Africa, 13 Leuvensesteenweg, 3080 Tervuren, Belgium.*

ABSTRACT

The epicentre of the Roermond earthquake is located near the western boundary fault of the Roer valley trough, one of the deepest and the most active in the Quaternary part of the Lower Rhine graben. The Late Pleistocene and Holocene activity of the trough is manifested by offsets of the main (Mindel) and the lower (Riss and Late Pleistocene) terraces along the boundary faults.

Surface fractures have been observed in an area of more than 50 km^2: 2.5–3.5 km to the north of the town of Roermond, at 0.8 km to the south of the village of Herkenbosch and in the southeastern part of the village of Montfort. Three types of ruptures were differentiated: scarps up to 50 cm high along open fractures near the Maas River; open fractures (continued by scarps in some places) and open fractures with a liquefaction of the Quaternary alluvium sands. The last type is predominant. The location of the ruptures depends on the landscape and water-table of the region. While they could be produced solely by hydraulic shock during the earthquake (increased by the wet spring season), the majority of the ruptures strike N50°W ± 10°, i.e. parallel to the main trough faults, or N55°E ± 10°, along 'neotectonic lines', parallel to the Maas valley and deduced from space imagery. Thus, the ruptures could be the secondary surficial effect of the earthquake, linked indirectly with the active tectonics of the region.

Terra Nova, **6**, 301–305, 1994.

INTRODUCTION

The Roermond earthquake occurred at 01h20m on 13 April 1992, in the southern Netherlands. According to the Royal Netherlands Meteorological Institute, the magnitude of the earthquake was 5.7 ± 0.2 and coordinates of the epicentre were 51°9.8′N and 5°57.0′E (Fig. 1). According to the data of the Observatoire Royal de Belgique, $M_L = 5.9 \pm 0.2$, $\varphi = 51°10.90'N$, $\lambda = 5°57.26'E$ and the hypocentre depth $H = 15.7 \pm 1$ km. Two possible focal planes strike to the NW and are characterized by normal faulting (Camelbeeck *et al.*, 1992).

NEOTECTONICS

The epicentre of the Roermond earthquake is situated along the NW-trending Lower Rhine rift. This area is characterized by thinned continental crust of 24–30 km within average $V_p = 6.2–6.5$ kms^{-1} and absence of the lower high-velocity layer (Prodehl, 1981; Meissner *et al.*, 1987; Belousov and Pavlenkova, 1989). The Lower Rhine rift was formed in the Oligocene, although the North Holland graben-type basin was in existence from the Jurassic and the Lower Cretaceous as a southern part of the North Sea rift system (Ziegler, 1981, 1982).

The Lower Rhine rift widens and deepens to the NW, and its structure varies along different cross-sections. In a northern cross-section, around Amsterdam, it is a wide basin with a depth of up to 3 km. To the SE the rift consists of several blocks divided by normal faults (Zijerveld *et al.*, 1992). Cross-sections around Roermond–Venlo and Aachen–Köln show the rift to divide into a western and an eastern branch with the Peel–Erkelenz horst between them. The Roer valley trough is the deepest part of the western graben in the Roermond–Venlo cross-section (Fig. 1). The Erft block, located to the SE of the Roer Valley, marks the deepest part of the western graben in the Aachen–Köln cross-section (Quitzow and Vahlensieck, 1955).

The Lower Rhine graben started to develop in the Oligocene by propagation of the fault system to the SE. During the Neogene continuous subsidence and sedimentation are typical for the entire rift area. The sedimentation was mostly alluvial with marine ingressions in the Middle and the Late Oligocene and the Middle Miocene. The fault movements are outlined by different thicknesses of sedimentation across the faults. Subsidence dramatically increased in the Roer valley trough at about 3 Ma (Zijerveld *et al.*, 1992).

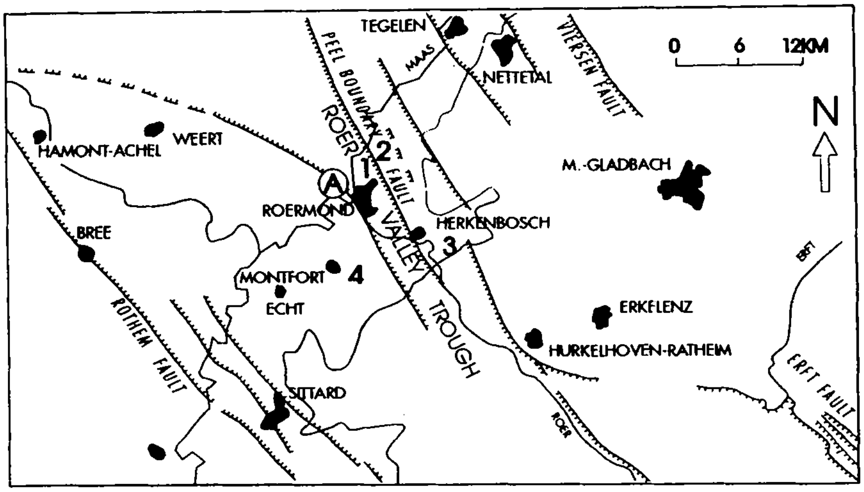


Fig. 1. *Neotectonic schema of the Roermond district (Quitzow; Vahlensieck, 1955; Pannekoek, 1955); with location of the epicentre of the earthquake of 13 April 1992, and seismic rupture areas (1–4).* ▪ *normal fault, active in Quaternary;* ɯɯɯ *active normal fault, inferred.*

During the Quaternary the northwestern part of the rift was subsiding faster than the southeastern part and up to 600 m of marine and alluvial deposits were accumulated in the northwestern Netherlands (Pannekoek, 1955). Two 'bays' of this sedimentary basin penetrated to the SE along the grabens, divided by the central Peel–Erkelenz horst. The eastern 'bay' did not penetrate far to the SE, and the faults of the eastern part of the rift zone were not actually active during the Quaternary. The tectonic activity is limited to the western graben. Normal faults significantly affect the main (Mindel) terrace, whereas the Lower terraces (Late Pleistocene) are affected by only small offsets.

In the Roermond–Venlo cross-section the Roer valley trough is bounded on both sides by several normal faults (Fig. 1). Three faults on its northeastern side offset the main terrace by up to 70 m (Pannekoek, 1955). The Riss and the Late Pleistocene alluvium up to 25 m thick were accumulated in the axial part of the trough. Even the Late Pleistocene deposits are offset along the Viersen normal fault (Quitzow and Vahlensieck, 1955). Evidence of differentiated Middle and Late Quaternary movements has been proposed also for the southwestern flank of the trough (Zijerveld *et al.*, 1992). Geodetic measurements show continuing movements within the graben (Waalewijn, 1966).

In the Aachen–Köln cross section the Erft block subsided during the Quaternary up to 100 m and the Main Terrace was offset at the eastern side of the block by up to 50–60 m (Quitzow and Vahlensieck, 1955). The levelling data of 1952 were compared with data from 1933 for the western part of the Aachen–Köln line and with data from 1921 for the eastern part. The comparison showed that the rift area was subsiding right up to its borders. However, while the eastern part of the rift (the central horst and the eastern graben) had subsided by 5–10 mm only, the Erft block had subsided by 20 mm, on average, and the Roer block had dropped down up to 40–50 mm.

Thus, the Roermond earthquake occurred near the Roer valley trough, which is the most active part of the Lower Rhine rift zone. Its activity is manifested by the Pleistocene and perhaps the Holocene offsets along the normal faults and is recorded from geodetic data and records of the historical and present-day seismicity (Illies *et al.*, 1979; Ahorner, 1983). The Roermond earthquake was probably a result of displacement along the SW-trending normal fault bounding the axial part of the Roer valley.

Seismic ruptures

The earthquake of 13 April produced widespread minor damage in the Roermond district

From the geological and seismotectonic points of view the most interesting features concern ruptures in the land surface, distributed over an area of more than 50 km^2 both in and outside the Roer valley trough. They have been identified in three areas:

- along the eastern side of the Maas River 2.5–3.5 km to the north of the town of Roermond (Figs 2 and 3; sites 1 and 2 on Fig. 1);
- 0.8 km to the south of the village of Herkenbosch (Fig. 4; site 4 on Fig. 1);
- in the southeastern part of the village of Montfort (site 4 on Fig. 1).

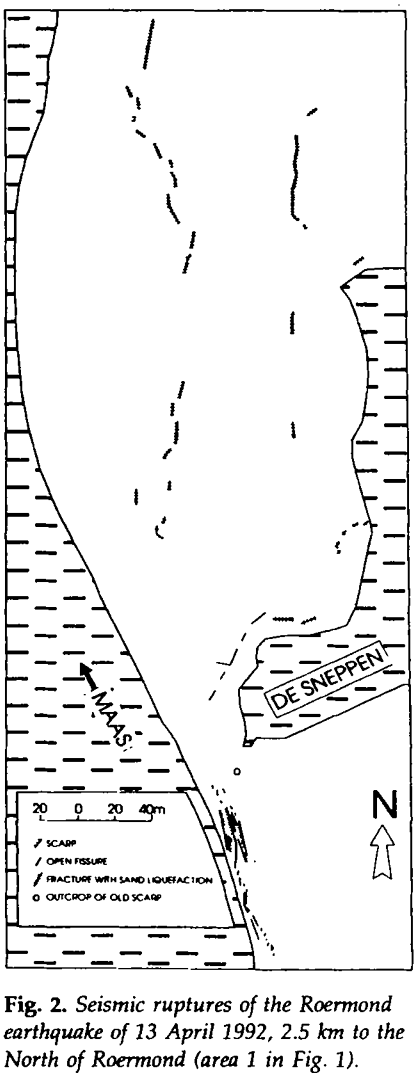
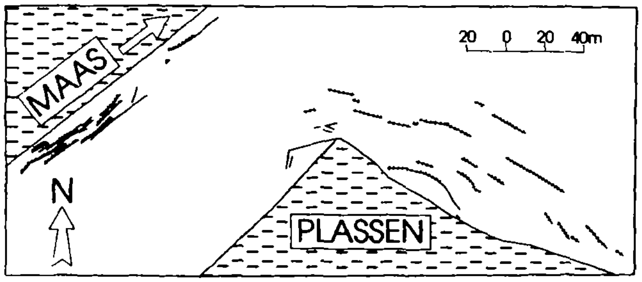


Fig. 2. *Seismic ruptures of the Roermond earthquake of 13 April 1992, 2.5 km to the North of Roermond (area 1 in Fig. 1).*



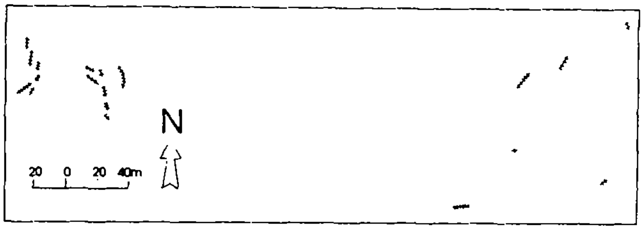


Fig. 3. *Seismic ruptures of the Roermond earthquake of 13 April 1992, 3.5 km to the North of Roermond (area 2 in Fig. 1; the symbols are shown in Fig. 2).*

Fig. 4. *Seismic ruptures of the Roermond earthquake of 13 April 1992, 0.8 km to the South of Herkenbosch (area 3 in Fig. 1; the symbols are shown in Fig. 2)*

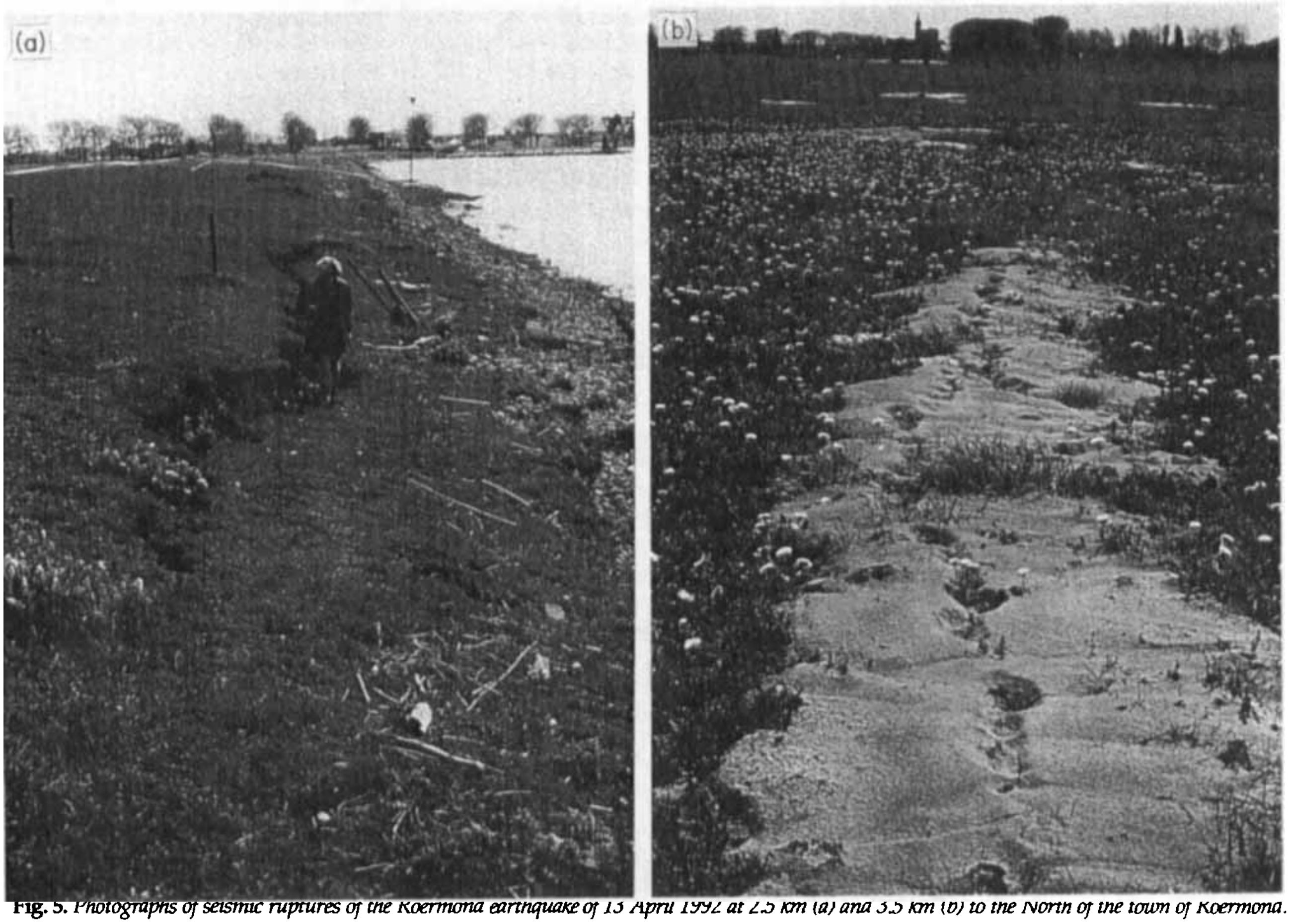


Fig. 5. *Photographs of seismic ruptures of the Roermond earthquake of 13 April 1992 at 2.5 km (a) and 3.5 km (b) to the North of the town of Roermond.*

Three types of seismic ruptures have been differentiated: simple open fractures, scarps along open fractures and open fractures with liquefaction.

Scarps

Scarps are only found along open fractures. Their offset is usually no more than 10–15 cm, although in some places it increases up to 50 cm (Fig. 5).

Narrow troughs as wide as 40–60 cm occur at the subsided side of the some major scarps. Small (up to 5 cm) strike-slip components of offset are found in segments of scarps, where the strike diverges from the general trend.

The occurrence of scarps is limited to the banks of the Maas River in the marginal part of the Lower terrace (Figs 2 and 3).

Open fractures

Open fractures occur as continuations of the scarps or develop independently from them in sites 1 and 2 near the Maas River (Figs 2 and 3).

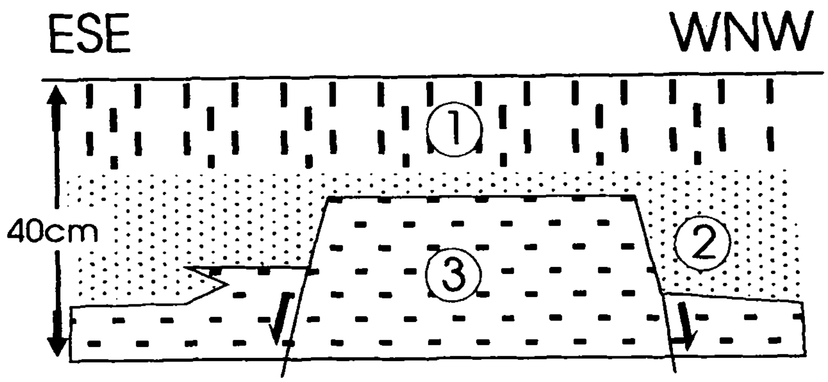


Fig. 6. *Outcrop in the lower terrace between the southern coast of the De Sneppen Lake and the northern end of the scarp system of 1992 (Fig. 2). The signs of the older Holocene faulting are seen. Perhaps, they manifest the previous strong earthquake (1) recent soil; (2) clay and silt with lenses, enriched by organic material (^{14}C-site of collecting the sample for the ^{14}C dating); (3) brown clay and silt.*

Open fractures with liquefaction

The open fractures with liquefaction of Quaternary alluvium sands (Fig. 5b) are present in all of the investigated areas. In area 1 the fractures are located between the Maas river and a small lake (De Sneppen). Individual fractures are usually not longer than 30 m, but appear in sets 70–140 m long. The main trend of the fractures is N–S, although some of them trend NW. The N–S direction corresponds to the axis of a morphological ridge between the Maas River and the Sneppen lake. In area 2, the individual fractures are no longer than 30 m in length, but appear in belts typically 180 m long and 50 m wide. One fracture zone appears to the north of the Plassen lake and strikes NW, which approximately corresponds to the trend of the adjacent Peel Boundary fault.

South of Herkenbosch, fractures occur in fields near the Beatrix farm and in the vicinity of the Roer river. Fractures with liquefaction are relatively short (no longer than 8 m) and strike in different directions, mainly NW and NE. Landsliding occurred on the right side of the Roer river (Fig. 4).

At Montfort, liquefaction fractures, not longer than 6 m, appear along a NE-trending zone as long as 150 m. Inside this zone the fractures strike along different directions: the most common direction is N50–55°W, other directions are N20–30°E and even E–W.

The seismic ruptures often present an en-échelon disposal. To the north of Roermond right lateral en-échelon rows are more common than left lateral ones.

DISCUSSION

Seismic ruptures occur in the vicinity of rivers (Maas and Roer), but also in flat areas. Scarps and open fractures are restricted to the close vicinity of the Maas river. Their trend parallels the Maas river, more or less N–S or NE, and their origin is most probably related to slumping along the river banks.

The open fractures with liquefaction have a general N–S trend in area 1, but N50°W in area 2. In both localities there appears to be a relationship between the ruptures and the landscape features and the hydrogeology of the area. Particularly with regard to area 1, the influence of the Maas river at one side and of the Sneppen lake at the other side suggest that the fractures have accompanied sand liquefaction associated with hydraulic shock during the earthquake. This may have been particularly effective because of the high water content of the alluvium sands during the wet spring season. A similar explanation may be proposed for the liquefaction ruptures in area 2, due to their vicinity and their parallel trend with the Plassen lake, although the NW trend corresponds to the strike of the normal faults along the general trend of the Roer Valley trough, whereas the N50°E trend coincides with some weakly developed lineaments appearing to the south of the area on satellite images.

At Montfort, where the liquefaction ruptures are located in a flat area without any apparent influence of topographic features and local hydrogeology, the fracture belt trends NW, corresponding to the normal faults of the Roer Valley trough. However, individual fractures only partly follow this trend, they are complemented by N30°E and E–W trending fractures.

In the northern continuation of the scarps of area 1 to the south of the De Sneppen lake an outcrop was studied showing signs of an older seismic offset of the lower terrace deposits (Fig. 6). This outcrop shows that another earthquake with similar pattern of rupture has occurred in the Roermond district in the Holocene. ^{14}C dating should allow the age of this event to be determined, and to estimate the recurrence interval between it and the earthquake of 1992.

CONCLUSIONS

The Roermond earthquake of 13 April 1992 manifested the ongoing activity of the Lower Rhine rift zone. In spite of its moderate magnitude and the great depth of the hypocentre (15 km) the earthquake produced significant ruptures on the land surface.

The location of these ruptures depends on the topography and the hydrological and hydrogeological peculiarities of the region. Most of the surface effects, particularly the ruptures with liquefaction, appear to be produced by a hydraulic shock related to local hydrogeological conditions. On the other hand, in some places the majority of the ruptures as well as the zones of concentration of fractures strike either to N50°W $\pm$ 10°, i.e. parallel to the main trough faults, or to N55°E $\pm$ 10°, i.e. along minor neotectonic lines, identified in the region and observed on satellite imagery to the south of Roermond. Thus, although the secondary result of the earthquake, the ruptures seem to be linked indirectly with the active tectonics of the region. Their study is important not only to understand the recent geodynamics of the Lower Rhine graben zone, but also to estimate the interaction of recent geological processes and different geological hazards of the region, as well as to identify areas of possible concentration of seismic damage during future earthquakes.

REFERENCES

Ahorner L. (1983) *Historical seismicity and present-day micro-earthquake activity of the Rhenish Massif Central Europe.* In: *Plateau Uplift.* (ed. by K. Fuchs, K. van Gehlen, H. Malzen, H. Murawski and A. Semmel), pp. 198–221. Springer, Berlin.

Belousov V.V. and Pavlenkova N.I. (1989) Earth's crust types in Europe and North Atlantic, *Geotectonics*, **3**, 3–14 (in Russian).

Camelbeeck Th., Verbeiren R., Martin H., Duthye P., Dehaen P., Snissaert M., Fobelts P., De Becker M. and Bukasa B. (1992) Le tremblement de terre de Roermond du 13 avril 1992: analyse préliminaire, *Ciel et Terre*, **108**, 81–84.

Illies H., Pzodehl C., Schmincke H-U., and Semmel A. (1979) The quaternary uplift of the Rhenish shield in Germany, *Tectonophys.* **61**(1/3), 197–225.

Meisnner R., Wever Th. and Flüh E.R. (1987) The Moho in Europe. Implications for crustal development, *Annal. Geophys.*, **5B**(4), 357–364.

Milanovsky E.E. (1987) *Riftogenesis in the Earth's history: Riftogenesis in the mobile belts.* Nedra, Moscow, 298 pp. (in Russian).

Pannekoek A.J. (1955) Einige Beispiele Quartärer Tektonik in den Niederlanden (Vozläufige Mitteilung), *Geol. Rndsch.*, **43**, 5256.

Prodehl C. (1981) Structure of the crust and upper mantle beneath the Central European rift system, *Tectonophys.* **80**, 255–269.

Quitzow H.W. and Vahlensieck O. (1955) Über pleistozäne Gebirgsbildung und rezente Krustenbewegungen in der Niederrheinischen Bucht, *Geol. Rndsch.* **43**, 56–67.

Waalewijn A. (1966) Investigations into recent crustal movements in the Netherlands, *Ann. Acad. Sci. Fenn. A*, **90**, 401–412.

Ziegler P.A. (1981) Evolution of sedimentary basins in North-West Europe. In: *Petroleum Geology of the Continental Shelf of North-West Europe*, pp. 3–39. Inst. of Petroleum, London.

Ziegler P.A. (1982) Faulting and graben formation in Western and Central Europe, *Phil. Trans. R. Soc. A*, **305**, 113–143.

Zijerveld L., Stephenson R., Cloething S., Duin E. and Van der Berg M.W. (1992) Subsidence analysis and modelling of the Roer Valley Graben (SE Netherlands), *Tectonophys.* **208**, 159–171.

Manuscript received 10 November 1992; revision accepted 26 June 1993