

# Palaeoseismology: in search of large earthquakes

*Palaeoseismological research along the Roer Valley Graben*

*by Bernard Dost and Láslo Evers*

**Introduction** • The Netherlands is generally regarded a low seismicity area. This means that large earthquakes are rare, but not necessarily absent. Seismic hazard analysis for the Netherlands and immediate surroundings is based on the historical occurrence of seismicity in the region. Unfortunately, the historical catalogue is limited in time and moreover the magnitude of most events before 1960 is poorly known. Instrumental observations started around 1900 and it was not before 1935 that Richter designed a magnitude scale that was accepted and generally used. However, even though we have only access to a catalogue of events over a limited time frame, a statistical analysis of the historical dataset enables a hazard estimation <sup>1)</sup>. In this analysis, based on Poisson statistics, a reference return period of earthquakes of 475 years is adopted, corresponding to an exceedence probability of 10% in 50 years. The south-eastern part of the Netherlands shows the strongest hazard, related to the Roer Valley Graben (RVG). There is interest from the (re)-insurance companies considering the economic importance of the region. Calculations of the potential losses for a hypothetical earthquake of magnitude 6.4 near Cologne at 10 km depth amounts to a loss of 55 billion US \$ <sup>2)</sup>.

Fortunately there are methods to extend the observation period. One way is to use written historical data, though the interpretation will not always be easy. In some cases, like a reported historic event in the Northern part of the Netherlands in 1262 <sup>3)</sup>, earthquake phenomena are reported in combination with strong winds and the association of three reported

phenomena with an earthquake is doubtful. The help of a historian is indispensable for the evaluation of the written sources. In this way the observational period can be extended from 100 years to approximately 700 years. Looking at an even longer timescale, palaeoseismology, the study of prehistoric earthquakes, may add additional information. Looking in detail at the near surface geology of large faults, a search is made for traces of movements at the surface (surface rupture) that may be interpreted as being caused by large earthquakes.

## *There is a strong indication of surface rupture for 3 events in the last 30.000 years*

The Roer Valley Graben is the main active tectonic feature in the Netherlands and did produce earthquakes of moderate size (Uden, 1932, local magnitude  $M_L = 5.0$ , Roermond 1992,  $M_L = 5.8$ ). Both events are located at the Peel boundary fault (PBF), the north-eastern boundary of the RVG (Figure 1). This fault was selected as a target for the first palaeoseismic investigation in the Netherlands. Since the average depth of earthquakes around the PBF is 17 km, a surface rupture requires an event of a large magnitude. The recent Roermond event (April 13, 1992) of local magnitude 5.8 (moment magnitude  $M_w = 5.3$ ) left no traces along the fault at the surface, although earthquake related phenomena like liquefaction (sand boils) and triggered landslides were observed in the region.

The south-western bordering fault of the RVG, the Feldbiss fault, has been investigated previously in a series of palaeoseismological studies <sup>4)</sup>. Five trenches have been excavated in the period 1996 - 1999, sampling a fault segment of 5 - 10 km. Although not all trenches show the same events, there is a strong indication of surface rupture for 3 events in the last 30.000 years (30 kyr). Inferred magnitudes for these events are between 6.2 and 6.8, which is a full magnitude higher than the 1992 Roermond event. These studies triggered interest in the subject of scientists in the neighbouring countries and resulted in a European project (PALEOSIS), which was carried out in the period 1998 - 2000. For the RVG area a German group focussed its attention on the Rurrand fault, the extension of the PBF, while KNMI and the Netherlands Institute of Applied Geosciences (NITG-TNO) focused on the PBF. The third partner, the Royal Observatory in Brussels (ORB), acted as co-ordinator and assisted in the research of the other partners.

**Site selection** • The Peel boundary fault has a visible surface expression in the Netherlands. On aerial photographs the fault can be identified in the south-eastern part of the country as a small scarp. This is confirmed by geodetic levelling data and mapping of tectonic lineaments <sup>5)</sup>.

# Discovering the solid Earth

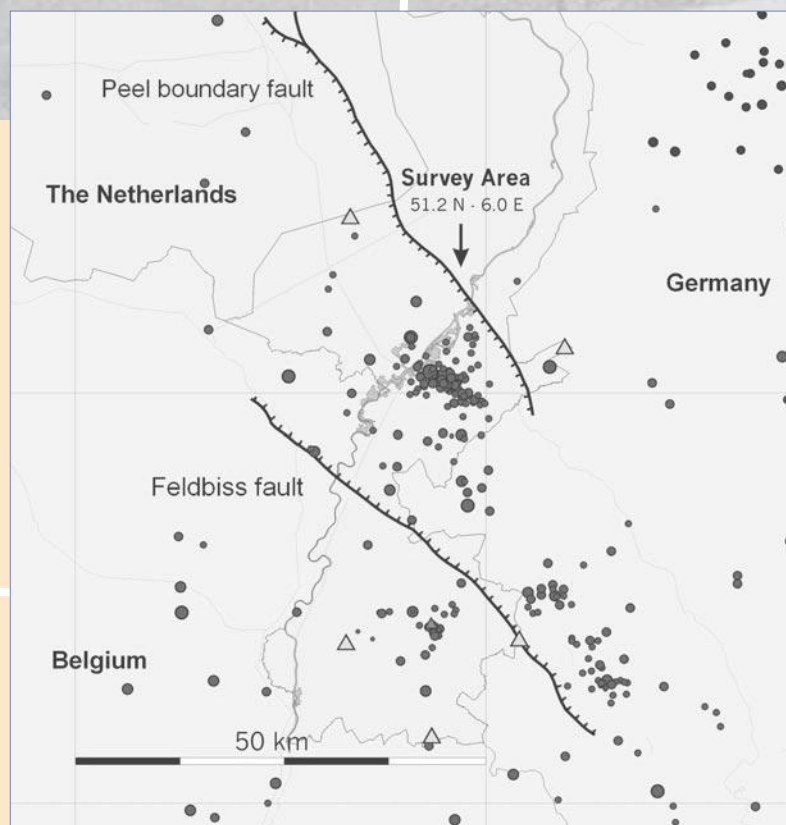


Figure 1. Overview of seismicity in the southern part of the Netherlands and surrounding region (1900-2001). The Peel boundary fault is the north-eastern boundary of the Roer Valley Graben while the Feldbiss fault bounds it to the south-west. The dots represent earthquakes and the triangles denote seismological stations.

Zooming in on the fault, the following criteria were used to define a target area for palaeoseismological research:

1. The fault zone should be simple in its configuration, preferably consisting of a single fault plane.
2. A visible step in the terrain should allow geomorphological modelling, providing additional constraints for the interpretation.
3. Dating of Holocene (< 12 kyrs Before Present) events is of crucial importance and can best be done if the trench could be related to well dated terraces of the Maas river.
4. Ground water level should be lower than the projected depth of the trench (3 m) to avoid expensive pumping during the excavation.
5. The survey area should not fall under laws preventing trenching (nature reserve).

On this basis, two potential sites were selected near the village of Neer, close to Roermond. A detailed survey using Ground Penetration Radar (GPR) was carried out at the two sites to find the exact position of the Peel boundary fault (Figure 2) and to image the fault zone close to the surface. This method shows high resolution pictures of the first few meters, but is limited by the depth of the groundwater level. The first site, where a clear step in the terrain was observed, gave no results, since the groundwater level was close to the surface. The second site, close to the village, showed at the GPR sections clear evidence of the fault scarp at depth and this site was selected to carry out additional geophysical surveys. The selected area is a square of 100m by 100m and shows a small step in the terrain (2 - 3 m) trending NW-SE.

*A detailed survey using GPR was carried out at the two sites to find the exact position of the Peel boundary fault*

After the initial GPR profiles electrical tomography (ET) was applied, an independent measure to add information on possible compositional changes in the subsurface. Lateral variations in resistivity were found to coincide with variations in the depth of the reflectors in the GPR sections, indicating a fault. Since these results were very promising, a full 3D survey was carried out to follow the fault in detail with both GPR and ET measurements <sup>6</sup>).

Although the terrain was quite smooth, less than 3 m variation in altitude over a horizontal section of 150 m, a detailed levelling profile was measured by the ORB. If the present shape of the fault scarp is due to erosion from an initial situation where a fault step was created, the original vertical offset can be inferred from geomorphological modelling. This was investigated

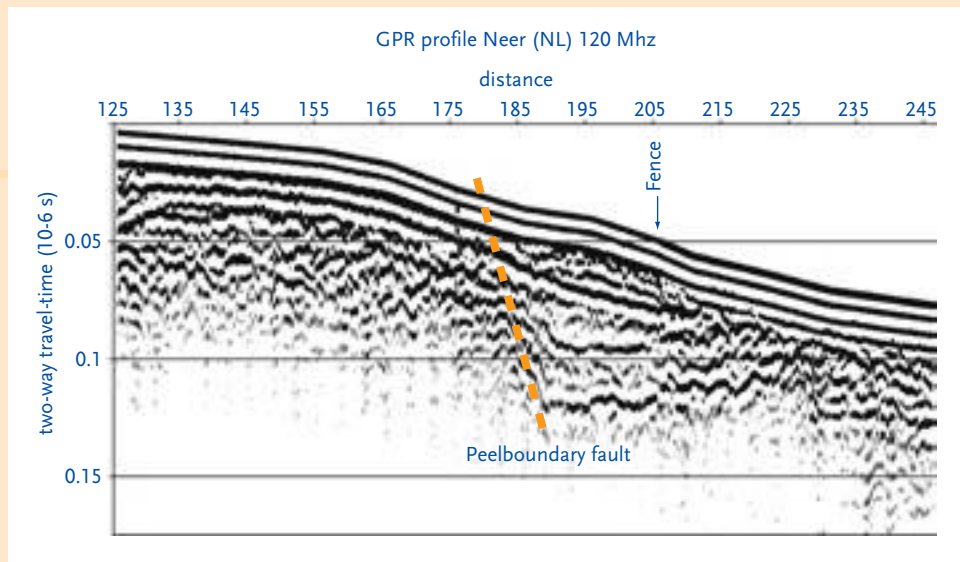


Figure 2. Ground Penetrating Radar (GPR) section in the survey area, running from NE to SW over a total length of 120 m.

*Discovering  
the solid Earth*

at both the trenches along the Feldebiss fault and the PBF, resulting in comparable figures for both faults. Since the last glacial maximum (14 - 19 kyrs BP) a total vertical offset of more than 1 m is inferred.

**Trench analysis** • After site selection a trench of 60 m in length, 3 m deep and 3 - 4 m wide was made (Figure 3). As expected on the basis of GPR and ET measurements, the fault was captured within the trench and a detailed geological survey was carried out by geologists of the NITG-TNO in cooperation with colleagues from the ORB. The survey focused on recent geological history (< 25 kyrs BP) exposed in the trench. A typical horizon clearly present in the trench is the Beuningen gravel bed, which is dated at 16 kyrs BP. This horizon showed displacements of 55, 30 and 5 - 10 cm, corresponding to three postulated events. Other geological horizons deeper in the trench show the same displacements as the Beuningen horizon, suggesting no additional movements between 25 and 16 kyrs BP. The most recent history is disrupted by human activity, like ploughing, and detailed soil analysis was needed to study the faulting process in detail. The two main events are postulated to have taken place in a period of less than 2 kyrs between 16 kyrs BP and 14 kyrs BP. The third, most recent and smallest event cannot be dated, but occurred presumably in the late Holocene (< 12 kyrs).

It should be noted that the results described are based on a number of assumptions. First of all the nature of the displacements found in the trench is assumed to be co-seismic. This is based on circumstantial evidence, like the identification of liquefied sands close to the fault zone. It

*The two main events  
are postulated to have taken place  
in a period of less than 2 kyrs*

may be that part of the displacement found was generated by a-seismic movement. A further assumption is that all events did generate surface displacement in one large earthquake. However, the displacement may be caused by more than one earthquake within a period of e.g. 100 years, which could diminish the size of the postulated events. These assumptions introduce an uncertainty in the results and one should keep these in mind.

**Inferences** • Based on the measured displacements at the surface, an estimate can be made of the magnitude of the events. Empirical relations have been developed between surface displacement, rupture length, rupture area and magnitude <sup>7)</sup>. Because data from only one trench are available, two methods can be used. The first method is based on an estimate of the fault rupture length. This estimate is made on the basis of regional

# Discovering the solid Earth



Figure 3. View on the trench looking to the south-west.

Magnitudes. The original definition of magnitude by Richter in 1935 was intended for epicentral distances up to 600 km. The scale was based on the measurement of amplitudes from recordings of a standard short period seismometer and as a result saturates for large earthquakes that generate longer periods outside the pass band of the instrument. In order to extend this definition to larger distances and to overcome saturation, new definitions were added: body wave magnitude ( $m_b$ ) and surface wave magnitude ( $M_s$ ). All these measures, however, are based on amplitudes of seismic waves and suffer saturation for the larger events. The moment magnitude ( $M_w$ ), however, is based on the measurement of the seismic moment, which more directly represents the amount of energy released at the source. The moment magnitude does not saturate and is the reference magnitude in palaeoseismic research.

geology- the lateral extent of the single fault plane as can be followed in seismic reflection lines- and on the basis of regional subsidence data. The estimated rupture length at Neer is 10 - 20 km which implies a magnitude of  $M_w = 6.2$  (10 km) to 6.6 (20 km). The second method is based on an estimate of the maximum surface displacement. At Neer the maximum displacement measured in the trench is 10 - 50 cm. These values relate to a magnitude of  $M_w = 6.0$  (10 cm) and 6.5 (50 cm). Both methods give comparable results. However, accuracy is limited and can only be improved when more trenches are opened along the fault zone. Then average displacement can be used and the continuation of the events can be traced. The magnitude estimates for the largest events are more than one magnitude unit higher than the values for the Roermond event ( $M_w = 5.3$ ).

Apart from the magnitude, also recurrence times of large earthquakes are important for hazard estimation. Although results from the trench at Neer provide a first view on the activity of the PBF at longer time scale, the fact that only two events were observed at a relatively short time scale (2 kyrs) is a complicating factor. There is a need for more trenches to correlate events and to obtain a better understanding on the recurrence times.

*There is a need for more trenches to correlate events and to obtain a better understanding on the recurrence times*

**General picture** • The findings along the Peel boundary fault are comparable to the findings of palaeoseismic research along the Feldbiss fault. The recent geological history shows traces of possible large events. Recurrence times are not yet accurately known, but the findings at Neer suggest that the occurrence of large events is irregular in time. The Feldbiss fault is investigated in more detail<sup>8</sup>). Five trenches have been opened in the period 1996 - 1999 enabling a correlation of events sampling 5 km fault length. Three events in the last 30 kyrs are identified. The most recent event is dated 600 - 900 AD and is visible in three trenches.

Trenching along the continuation of the Peel boundary fault, the Rurrand fault in Germany, close to the city of Jülich unfortunately showed little results. This is due to the fact that the trench did not show recent deposits, due to the presence of a plough layer disrupting the geology record. However, the trench showed on a longer time scale (250 kyrs) episodic faulting<sup>9</sup>).

Palaeoseismic research applied to active faults in a low seismicity area sheds some light on the existence of large earthquakes that occur on a longer timescale. In order to get a more complete picture, more trenches are needed enabling a correlation of events over the rupture front of a postulated

palaeo-earthquake. Since the region is either densely populated or part of a nature reserve where trenching is not permitted, the possibilities of further research is limited. However, in view of the increased vulnerability of modern society to hazards it is worthwhile to continue the search for large earthquakes in a low seismicity area like the Roer Valley Graben.

- 1) Crook, T. de, 1996. *A seismic zoning map conforming to Eurocode 8, and practical earthquake parameter relations for the Netherlands*. Geol. Mijnbouw, **75**, 11-18.
- 2) Allman, A. and A. Smolka, 2001. *Increasing Loss Potential in Earthquake Risk-A Reinsurance Perspective*. In: Proceedings of the Workshop: Evaluation of the Potential for Large Earthquakes in Regions of Present Day Low Seismic Activity in Europe, Han-sur-Lesse, Belgium, March 2000, Edited by T. Camelbeeck, 1-4.
- 3) Houtgast, G., 1991. *Catalogus Aardbevingen in Nederland*. KNMI Publication, **179** (in Dutch).
- 4) Camelbeeck, T and M. Meghraoui, 1998. *Geological and geophysical evidence for large palaeo-earthquakes with surface faulting in the Roer Graben (north-west Europe)*. Geophys. J. Intl., **132**, 347-362.
- 5) Van den Berg, M.W., W. Groenewoud, G.K. Lorenz, P.J. Lubbers, D.J. Brus and S.B. Kroonenberg, 1994. *Patterns and velocities of recent crustal movements in the Dutch part of the Roer Valley rift system*. Geol. Mijnbouw, **73**, 157-168.
- 6) Demanet, D., L.G. Evers, H. Teerlynck, B. Dost and D. Jongmans, 2001. *Geophysical investigation across the Peelboundary fault (the Netherlands) for a palaeoseismological study*. Geol. Mijnbouw, special issue, to be published.
- 7) Wells, D.L. and K.J. Coppersmith, 1994. *Empirical relationships among magnitude, rupture length, rupture area and surface displacement*. Bull. Seism. Soc. Am., **84**, 974-1002.
- 8) Camelbeeck, T., K. Vanneste, K. Verbeek, M. Meghraoui, R. Pelzing, K. Hinzen, B. Dost and M. van den Berg, 2000. *Long term seismic activity in the Lower Rhine Embayment*. In: Proceedings of the HAN 2000 Palaeosis workshop, Han-sur-Lesse, Belgium, March 2000, 35-38.
- 9) Lehmann, K., J. Klostermann, R. Pelzing and K.G. Hinzen, 2001. *Palaeoseismological investigations at the Rurrand Fault, FRG*. In: Proceedings of the Workshop: Evaluation of the Potential for Large Earthquakes in Regions of Present Day Low Seismic Activity in Europe, Han-sur-Lesse, Belgium, March 2000, Edited by T. Camelbeeck, 93-96.