

Comparison of the macroseismic field of the 1992 Roermond earthquake, the Netherlands, with those of large historical earthquakes in the Lower Rhine Embayment and its vicinity

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Abstract

The macroseismic field of the Roermond earthquake of April 13, 1992, has been compared with those of large historical earthquakes ($M_L \geq 5.5$) in the Lower Rhine Embayment and its vicinity: those of Düren (1755, 1756), Tollhausen (1878), North-Brabant (1932) and Euskirchen (1951). The historical earthquakes were reconstructed and analysed mainly on the basis of contemporary historical documents.

All investigated earthquakes caused at least moderate damage in their epicentral regions. While the earthquakes of Düren (1756) and Tollhausen (1878) reached the epicentral intensity VIII, the others produced only epicentral intensities between VII and VII–VIII. The mean value of the absorption coefficient $\alpha = 0.002 \pm 0.001 \text{ km}^{-1}$ was calculated from the intensity attenuation curves. The macroseismic focal depths of the Tollhausen (1878), North-Brabant (1932) and Euskirchen (1951) earthquakes range from 9 to 8 km, whereas the Düren (1755, 1756) and Roermond (1992) earthquakes occurred at a depth range from 14 to 18 km.

The strongest event in historical time was the Düren (1756) earthquake. Its macroseismically determined local magnitude $M_L = 6.1$ was slightly larger than the local magnitude of the Roermond earthquake $M_L = 5.9$.

Introduction

The Roermond earthquake of April 13, 1992, provides an excellent macroseismic database allowing the drawing of detailed isoseismal maps. The macroseismic field of this earthquake was compared with those of large earthquakes ($M_L \geq 5.5$) in the Lower Rhine Embayment and its vicinity since the 18th century (Fig. 1): the Düren (1755, 1756), Tollhausen (1878), North-Brabant or Uden (1932) and Euskirchen (1951) earthquakes, which produced epicentral intensities I_0 from VII to VIII (MSK-scale) and were felt in wide parts of central and western Europe (Fig. 2).

The earthquakes of the 18th and 19th century were reconstructed and analysed mainly on the basis of contemporary historical documents such as chronicles, newspapers, diaries or letters. A critical review of the sources known so far, together with a thorough

search through archives was carried out. The search for documents was concentrated on the epicentral regions of the earthquakes. Public and ecclesiastical archives and libraries have been visited and numerous, mostly hand-written documents have been examined. The sources were analysed with regard to their credibility and completeness, taking into account predominantly the contemporary purpose of the document, the time interval between the described earthquake and the origin of the document, and the social and educational background of its writer. Complementary information was taken from secondary historical literature of which the original source cannot be traced, but which seem to be trustworthy, and from the available earthquake catalogues.

The North-Brabant (1932) and Euskirchen (1951) earthquakes were analysed on the basis of documents, questionnaires and letters kept in the macroseismic

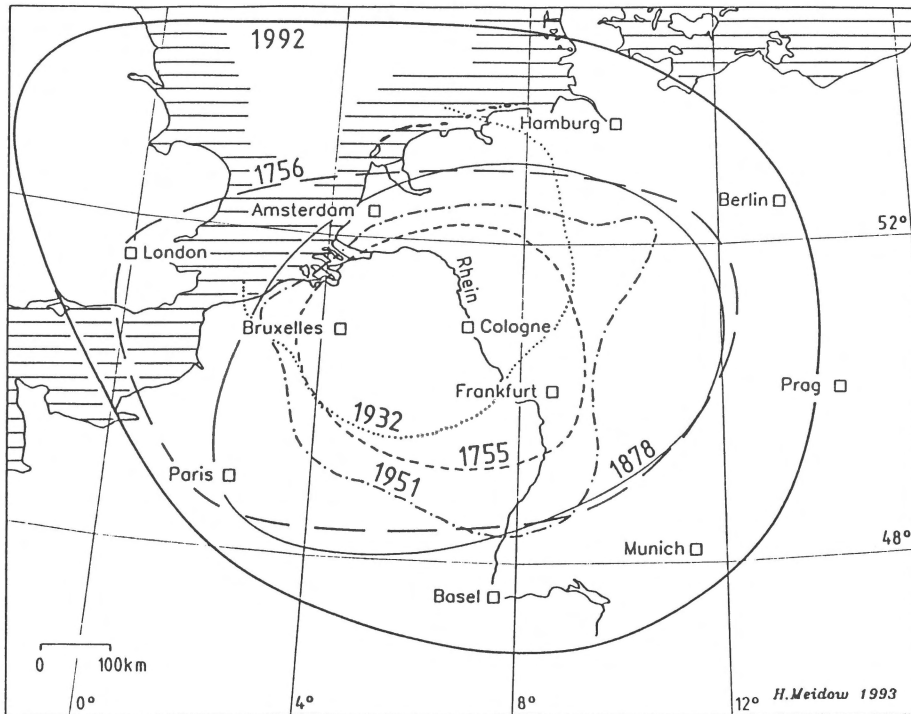


Fig. 2. Areas of perceptibility for six large earthquakes ($M_L \geq 5.5$) listed in Table 1.

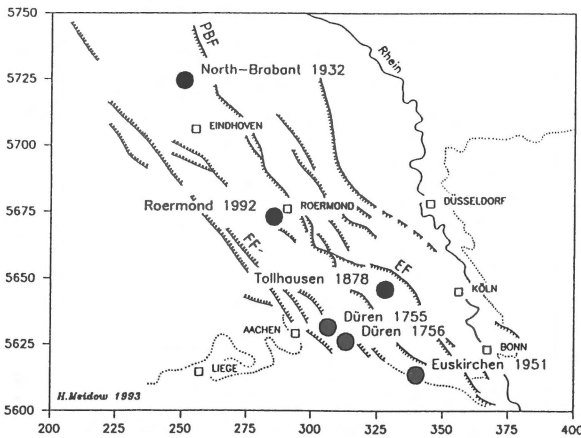


Fig. 1. Epicentres (●) of six large earthquakes ($M_L \geq 5.5$, Table 1) in the Lower Rhine Embayment and its vicinity. Dotted line indicates extent of Rhenish Massif. Lines with barbs on the downthrown side denote active fault zones. PBF – Peel Boundary Fault; EF – Erft Fault; FF – Feldbiss Fault. UTM-coordinates (km) zone 32 U.

Reconstruction of historical earthquakes

According to their credibility, completeness, and content regarding the determination of macroseismic intensity, the historical sources were weighted. Credible and complete documents containing sufficient information regarding the macroseismic intensity were weighted ‘high’, whereas those containing only little information were weighted ‘mean’. Documents which seems to be of low credibility and completeness were weighted ‘low’, even if they contain some or sufficient information concerning the macroseismic intensity. Taking into account these weights the intensity distribution of the investigated earthquakes was analysed. For the evaluation of the macroseismic intensity the MSK-64 scale was used. Isoseismal maps were drawn and the mean radii of isoseismals evaluated.

With the determined radii of isoseismal the epicentral intensity I_0 , focal depth h (km) and absorption coefficient α (km^{-1}) were calculated using an iterative computer program developed at the Department of Earthquake Geology of the University of Cologne with the following formula (Sponheuer 1960):

archive of the Department of Earthquake Geology of the University of Cologne in Bensberg. Additional information has been obtained from several scientific publications.

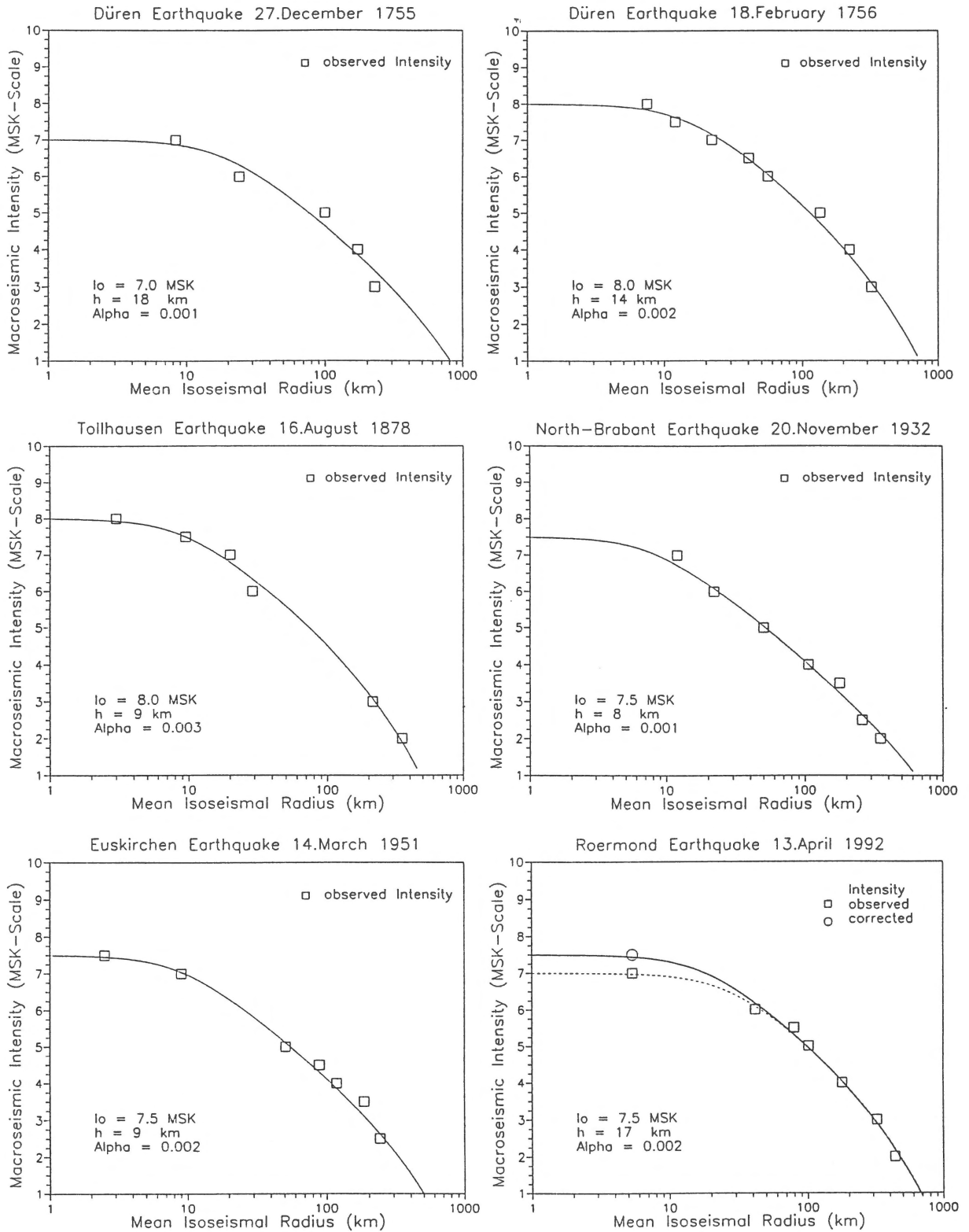


Fig. 3. Calculated intensity attenuation curves for the six large earthquakes listed in Table 1. The attenuation is calculated according to the method of Sponheuer (1960). The squares denote the observed mean isoseismal radii. The corrected intensity of the epicentral region of the Roermond earthquake is indicated by the circle.

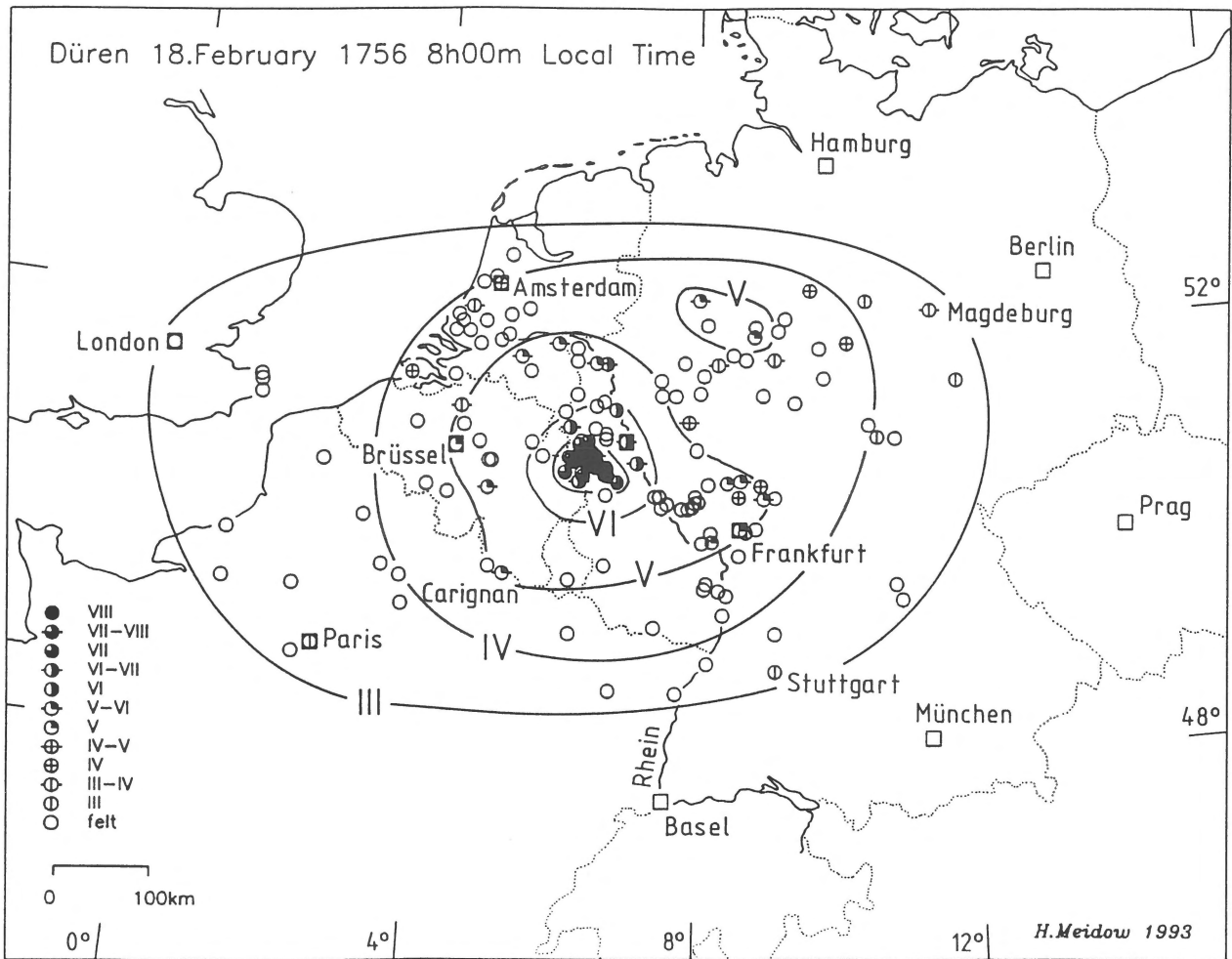


Fig. 4. Isoseismal map of the Düren (1756) earthquake (intensities in units of the MSK-scale).

$$I_n = I_0 - 3\log(\sqrt{\Delta_n^2 + h^2}/h) - 3\log(e)\alpha(\sqrt{\Delta_n^2 + h^2} - h) \quad (1)$$

where Δ_n (km) is the mean radius of isoseismal I_n . The calculation is based on the well-known intensity attenuation law of Sponheuer (1960), which has been described in detail by Schneider (1975) and others. The absorption coefficient α was assumed to be nearly constant with regard to the macroseismic depth determination, because the correlation between ray path and attenuation parameter is not sufficiently known for the central European crust.

Two different magnitudes were calculated. Firstly, the Karnik-magnitude M_K based on a relationship

between epicentral intensity I_0 , focal depth h and magnitude:

$$M_K = 0.5 I_0 + \log(h) + 0.35 \quad (2)$$

found by Karnik (1969) for European earthquakes. The macroseismic magnitudes based on this formula are comparable to the instrumental surface wave magnitudes M_S . Secondly, the local magnitude M_L estimated with an empirical relationship found by Ahorner (1983) especially for the Lower Rhine Embayment:

$$M_L = 0.67I_n - 1.33 + 2\log(R_n) + 0.87\alpha(R_n - 10) \quad (3)$$

where R_n is the hypocentral distance (km) for the isoseismal I_n . The calculation of the local magnitude is averaged over all intensities.

Table 1. Macro seismic data for six large earthquakes ($M_L \geq 5.5$) in the Lower Rhine Embayment and its vicinity since the 18th century. Macro.: magnitude determined from macro seismic data; instr.: magnitude determined from seismogram data

	Düren 1755	Düren 1756	Tollhausen 1878	N-Brabant 1932	Euskirchen 1951	Roermond 1992
Epicentral intensity						
I_0 (MSK-64)	VII	VIII	VIII	VII	VII–VIII	VII
Focal depth h (km)	18	14	9	8	9	17
Absorption coefficient α (km^{-1})	0.001	0.002	0.003	0.001	0.002	0.002
Mean isoseismal radius intensity V (km)	100	135	60	50	51	102
Maximum radius of perceptibility (km)	230	460	370	380	320	660
Felt area A (km^2)	(160 000)	(360 000)	(180 000)	210 000	220 000	600 000
Karnik-magnitude M_K	5.1	5.5	5.3	5.0	5.1	5.3
Local magnitude M_L	5.8 (macr.)	6.1 (macr.)	5.9 (macr.)	5.5 (instr.)	5.7 (instr.)	5.9 (instr.)

For every earthquake the calculated intensity attenuation curve according to the formula of Sponheuer (1960) is plotted along with the observed mean isoseismal radii (Fig. 3). The results of the reconstruction and the determined macro seismic source parameters are listed in Table 1.

The Düren earthquakes of December 27, 1755, ($I_0 = \text{VII}$, $M_L = 5.8$) and of February 18, 1756, ($I_0 = \text{VIII}$, $M_L = 6.1$) occurred approximately 10 km south-west of the town of Düren in the border region between the Lower Rhine Embayment and the Hohes Venn (Sieberg 1940, Schwarzbach 1951, Ahorner 1984, Meidow 1990). The first epicentre is located between the towns of Eschweiler and Stolberg ($50^\circ 48' \text{N}$, $6^\circ 15' \text{E}$). The second epicentre is located near the small village of Hürtgen at the north-eastern edge of the Hohes Venn ($50^\circ 45' \text{N}$, $6^\circ 21' \text{E}$). Both epicentres are lying close together and are most probably correlated with the active Feldbiss fault system, which is one of the south-western border faults, of the Roer Valley Graben.

The epicentre of the Tollhausen earthquake of August 26, 1878, ($I_0 = \text{VIII}$, $M_L = 5.9$) is located about 8 km west of the town of Bergheim near the village of Tollhausen ($50^\circ 56' \text{N}$, $6^\circ 33' \text{E}$; Sponheuer 1952, Nennstiel 1930). The earthquake occurred within the central part of the Lower Rhine Embayment and can be correlated with the active Erft fault system, which separates the Erft block from the Ville block.

The North-Brabant earthquake of November 20, 1932 ($I_0 = \text{VII}$, $M_L = 5.5$) occurred near the town of Uden ($51^\circ 42' \text{N}$, $5^\circ 36' \text{E}$) in the northern part of the Lower Rhine Embayment. The epicentre is located within the Roer Valley Graben at the Peel Boundary Fault (Van Rummelen 1945, Houtgast 1992).

The Euskirchen earthquake of March 14, 1951, ($I_0 = \text{VII–VIII}$ (resp. 7.5), $M_L = 5.7$) occurred at the western border of the Lower Rhine Embayment near the town of Euskirchen ($50^\circ 38' \text{N}$, $6^\circ 44' \text{E}$; Schwarzbach 1951, Ahorner 1984).

The epicentre of the Roermond earthquake of April 13, 1992, ($I_0 = \text{VII}$, $M_L = 5.9$) is located a few kilometres south-west of Roermond in the Netherlands ($51^\circ 10.1' \text{N}$, $5^\circ 55.9' \text{E}$; Ahorner 1992, 1994). The earthquake occurred at the Peel Boundary Fault, the north-eastern border of the Roer Valley Graben. This graben is filled with more than 1500 m of unconsolidated Cenozoic sediments. The seismic energy absorption due to the very thick sedimentary graben fill resulted in a decreased epicentral intensity of about 0.5 degrees at the surface (Meidow & Ahorner 1994). Therefore, the intensity attenuation was calculated using a corrected epicentral intensity $I_0 = \text{VII–VIII}$ (resp. 7.5).

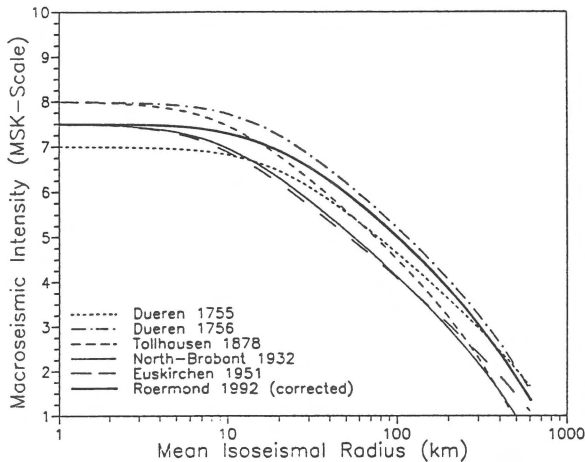


Fig. 5. Summary plot of intensity attenuation curves for the six large earthquakes listed in Table 1. The attenuation is calculated according to the method of Sponheuer (1960). The mean absorption coefficient, α , is $0.002 \pm 0.001 \text{ km}^{-1}$.

Conclusions

The investigated historical and recent earthquakes (Table 1) are the largest events which occurred in the Lower Rhine Embayment and its vicinity since the 18th century. They all reached a Karnik-magnitude $M_K \geq 5.0$ and a local magnitude of $M_L \geq 5.5$ and caused significant damage to buildings in the epicentral regions. The epicentral intensities range from $I_0 = \text{VII}$ to VIII.

The Roermond earthquake of April 13, 1992, is one of these largest events. Although its epicentral intensity $I_0 = \text{VII}$ does not reach the strength of the earthquakes of Düren (1756), Tollhausen (1878) and Euskirchen (1951), the Karnik-magnitude and the local magnitude are only slightly smaller than those of the Düren (1756) earthquake. The Düren (1756) earthquake with its local magnitude of approximately $M_L = 6.1$ is the strongest event in the region known from historical records.

As events occurred farther back in time, the available information about macroseismic observations gets less. This is particularly obvious on the periphery of the felt areas, i.e. intensities II and III, where the information density is already low. For example, for the Düren (1756) earthquake the intensity II is not documented in the existing historical sources (Fig. 4). For historical earthquakes it is therefore probably better to talk about areas of knowledge than about felt areas.

When comparing these areas this must be taken into account. However, in practice it is useful to assume that the maximum radii of perceptibility of the investigated historical earthquakes are more or less comparable to the mean radii of the isoseismal II for recent earthquakes.

Macroseismic focal depth estimates, obtained from the best fit of empirical intensity attenuation relations (Fig. 5) with absorption coefficients of $\alpha = 0.002 \pm 0.001 \text{ km}^{-1}$, range from 8 to 18 km. The predominant depth range for tectonic events in the Rhenish Massif and its vicinity is 6 to 14 km (Ahorner 1983). Although the macroseismic depth determination contains a large uncertainty (up to $\pm 5 \text{ km}$), the largest earthquakes occurred predominantly in the lower part of the seismogenic active zone.

The Roermond earthquake was not an unusual or surprising event for the Lower Rhine Embayment. Earthquakes of comparable size occurred in this area since the 18th century and can be expected again in the future. Under unfavourable circumstances, i.e. shallow focal depth combined with soft sedimentary subsoil of minor thickness, it seems possible that an earthquake with local magnitude about 6.0 produces an epicentral intensity larger than VIII (Ahorner 1992).

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