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The coversands and timing of Late Quaternary earthquake events along the Peel Boundary Fault in the Netherlands

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Abstract

The coversands along the Peel Boundary Fault in the Netherlands were investigated by a luminescence dating approach combining Infrared Optically Stimulated Luminescence (IRSL) and Thermoluminescence (TL) methods. At the Neer trench, ten samples were collected and investigated in order to set up an independent chronological framework for the deposition history of the fluvio-aeolian and aeolian sediments and hence the timing of Late Weichselian and Holocene earthquake events. Five sedimentary units could be distinguished by this chronological approach. The oldest fluvio-aeolian unit yielded a mean deposition age of 35.9±0.4 ka and is designated to correlate with the Middle Weichselian. An IRSL age estimate of 20.1±2.9 ka was determined for the sediment that most likely represents the Older Coversands I, and a mean luminescence age of 15.1±1.2 ka for deposits just below the Beuningen gravel bed. The aeolian sediment from above the Beuningen horizon yielded an IRSL age estimate of 9.4±1.0 ka. The youngest deposits from the colluvial wedge yielded <6.9±0.7 ka BP, and so an earthquake event was likely to occur during the Middle or Late Holocene, as evidenced by the luminescence age estimates.

Keywords: Earthquake, luminescence dating, fluvio-aeolian deposits, coversand, Roer Valley Graben, Quaternary

Introduction

The Roer Valley Graben forms the most prominent Cenozoic tectonic feature in the Netherlands and Belgium. It belongs to the NW trending branch of the N-S elongated West Central European Rift system ranging from the eastern coast of Spain near Valencia through the Rhône and Rhine valleys into Northern Germany and the North Sea. The Roer Valley Graben (Fig. 1) is considered to be an active fault system as evidenced recently by the important earthquake with a magnitude of ML=5.8 of the Richter scale near Roermond in April 1992 (Ahorner, 1994). At the southern flank, the Roer Valley Graben is bounded by the complex Feldbiss Fault System and in the north by the Peelrand Fault or 'Peel Boundary Fault' (van den Berg & Lokhorst, 2000). In Belgium, the southern displacement zone is defined by the Bree fault (Camelbeeck & Meghraoui, 1998; Vanneste et al., 1999, 2001), a left-stepping propagation of the Feldbiss Fault. The Peel Boundary Fault has been investigated in detail to reconstruct the earthquake and rupturing history of the southwest border of the Roer Valley Graben in the southern part of The Netherlands (Geluk et al., 1994; van den Berg et al., 1996; van den Berg & Lokhorst, 2000). The exposed sediments in the trench near the village of Neer indicate a transition from a fluvial aggradation terrace to an aeolian sand sheet, as evidenced by fluvio-aeolian sands. Similar sediments were investigated recently near the village of Bree in NE Belgium (Vanneste et al., 1999; Frechen et al., 2001a).

In this study, Infrared Optically Stimulated Luminescence (IRSL) and Thermoluminescence (TL) age estimates are presented in order to test the suitability of the dating techniques and to set up an independent chronological framework for the aeolian and fluvio-aeolian accumulation periods of the coversands in the study area. Ten samples were taken from a trench near the village of Neer (Fig. 2). A similar study on a sediment core from the key section at Panheel is in preparation (van den Berg & Frechen, in prep.).

Site Geology

The trench is situated about 1 km to the NW of the village of Neer along the Peel Boundary Fault (Fig. 1). The site is located at a Maas river fill terrace, which was abandoned by the river close to the end of the last Late Pleniglacial (van den Berg, 1996). The surface shows a vertical offset of about 1.10 m along the fault zone.

The exposed sediments confirm the transition from a fluvial aggradation terrace into an aeolian sand sheet defined as fluvio-aeolian sands. The overlying sand sheet has a thickness of about 1.50 m. Within the lower part of the sand sheet, a well-developed deflation horizon, which is correlated with the Beuningen gravel bed, is intercalated. This horizon has an age estimate of approximately 16 ka (cp. Bateman & van Huissteden, 1999; Frechen et al., 2001a).

A red brown Bts horizon is intercalated in the sand and associated with dung-beetle burrows. These soil features are related to the climatic conditions of the Bölling-Alleröd interstadial ranging most likely from 14.5 to 12.8 ka BP (Hoek, 1997; Stuiver et al., 1995; van den Berg & Lokhorst, 2000).

A major fault offset affected both the Beuningen gravel bed and the overlying soil horizon. The fault offset in the trench has the same magnitude as at the surface. The offset indicates evidence for at least three rupture events (F-1, F-2 and F-3). The F-1 and F-2 events occurred after the formation of the Beuningen gravel bed but before the end of the Bölling-Alleröd interstadial (van den Berg & Lokhhorst, 2000). A thin fissure filled with black topsoil material is thought to represent the presence of a Holocene rupture event (F-3).

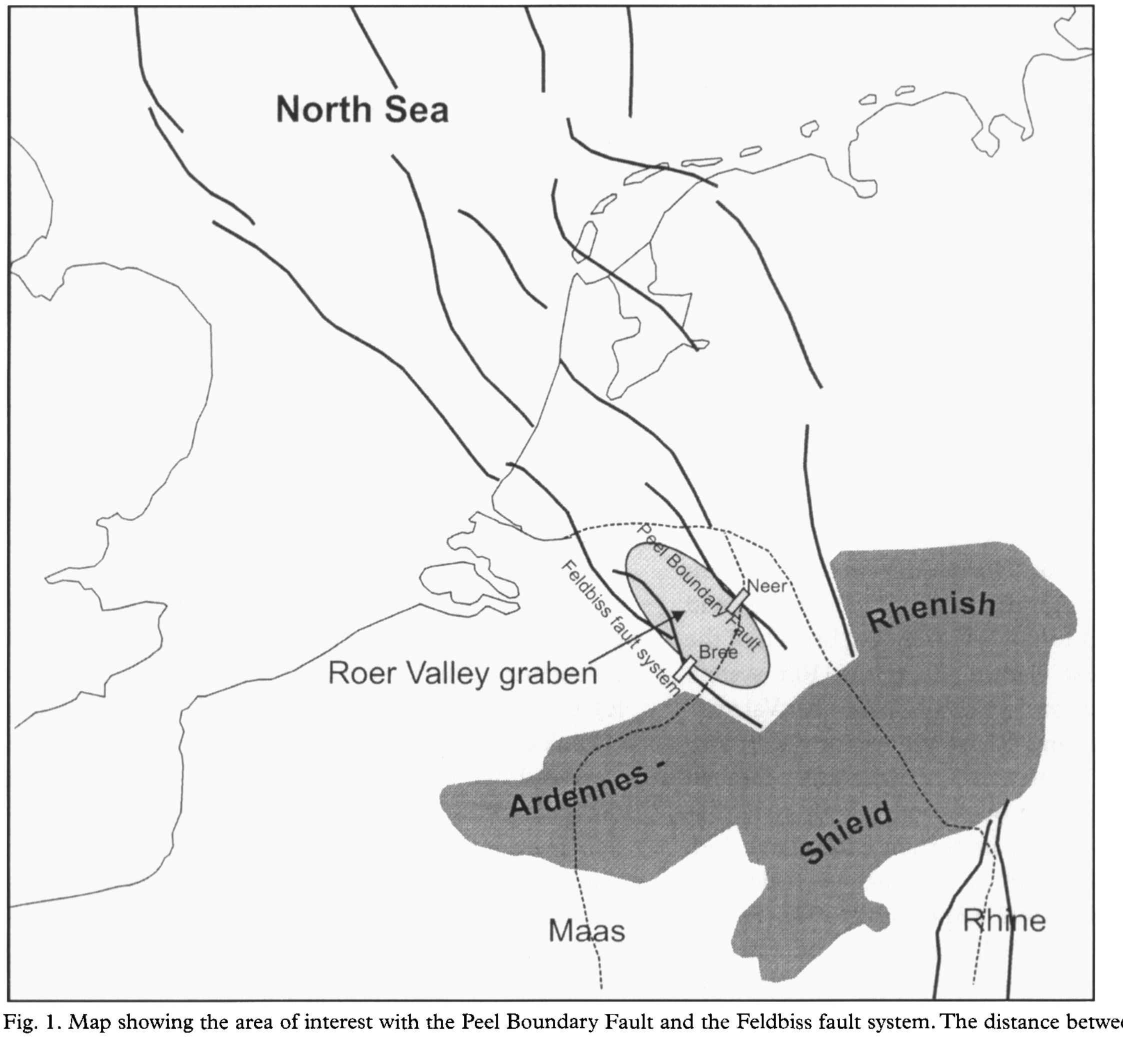

Fig. 1. Map showing the area of interest with the Peel Boundary Fault and the Feldbiss fault system. The distance between the Neer section in the Netherlands and the Bree section in Belgium is about 40 km.

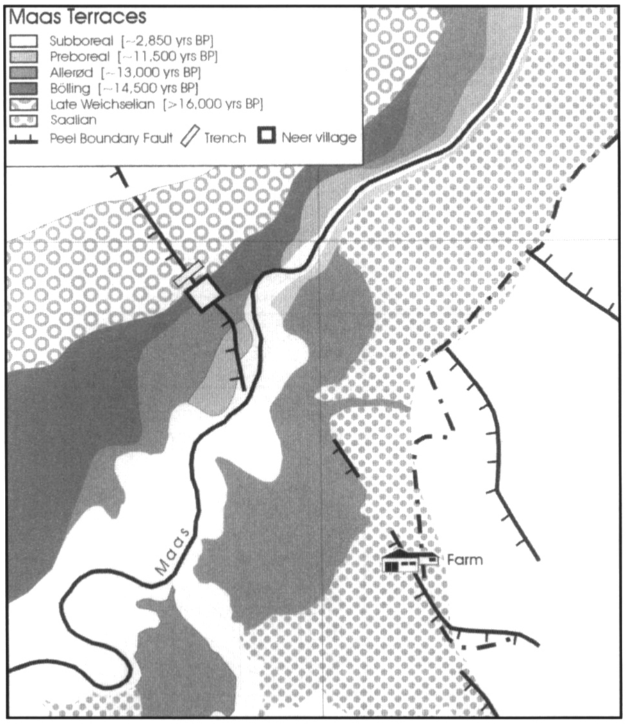

Fig. 2. Map showing the location of the trench near the village of Neer and its surrounding with abandoned Maas terraces. The trench is about 200 m in the NW of the village of Neer.

The surface expression of the fault is a scarp on the Maas terrace 1 (T-1). There is no scarp visible anymore on terraces T-3 and T-4. The expression on T-2 is unknown because the fault passes through the urban area of the village of Neer (Fig. 2).

However, the F-2 event occurred most likely before the onset of the Alleröd. The fault trace crosses three of the four exposed terraces of the river Maas (T-2 through T-4, Fig. 2). The oldest event (F-1) most likely took place before the formation of the Bts horizon.

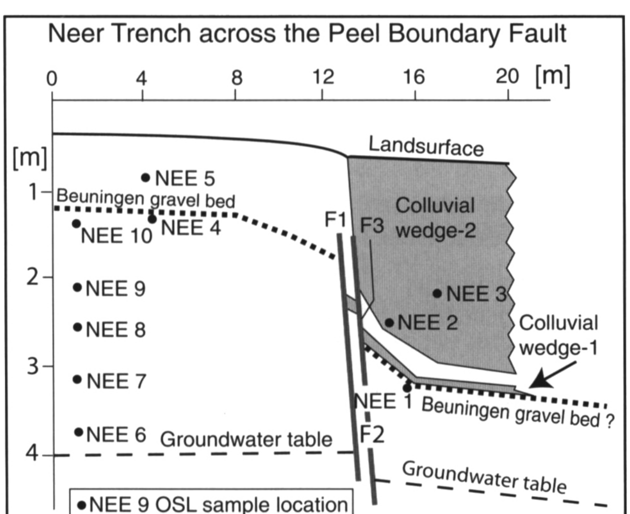

Fig. 3. Idealized sketch of the sample positions at the Neer Trench. The stratigraphic position of the Beuningen gravel bed is based on litho-stratigraphic evidence.

Van den Berg & Lokhorst (2000) propose that the F-2 faulting event took place before the formation of the T-3 terrace and so most likely occurred between the Bölling and Alleröd interstadials.

The sample positions are distributed over the footwall (7 samples) and the hanging-wall (3 samples) (Figs. 3 and 4). The stratigraphically uppermost sample NEE3 and 2 (hanging-wall) were taken from the clay-rich sandy colluvial wedge (colluvial wedge-2, Fig. 3), designated to represent Middle Holocene deposits.

Sample NEE 1 derived from the same material below colluvial wedge-1, whereas samples NEE4-10 were taken from the undisturbed part of the foot-wall in the trench; NEE5 derives from aeolian sand just above the deflation horizon designated to represent the Beuningen gravel bed. Samples NEE4, 10 and 9 were taken from more or less aeolian silt-rich sand below the Beuningen gravel bed and samples NEE8-6 derived from well-layered fluvio-aeolian deposits, which consist of silt-rich sand accumulated by episodic flooding events (Fig. 3).

Luminescence Methodology and Experimental Details

A detailed discussion of the methodology and the state of the art of luminescence dating of Weichselian and Holocene aeolian and fluvio-aeolian deposits is presented elsewhere (Wintle, 1997). The experimental details from the present study are identical like those described in Frechen et al. (2001a) and hence only summarized here.

The samples were taken in light-tight cylinders in the field. The sediments were prepared for the luminescence analysis by removing the carbonate in 0.1 N hydrochloric acid, by sieving to separate the 100-200 µm grain-size fraction, followed by treatment with 0.01 N sodium oxalate and 30% hydrogen peroxide to remove clay coatings and organic matter, respectively. Potassium feldspar and quartz minerals were extracted from all samples by heavy liquid separation with sodium polytungstate (2.58, 2.62 and 2.70 g/cm^3). The potassium-rich feldspar grains were fixed on aluminium discs and successively irradiated in at least six different dose steps by a Sr-90 beta source. The samples were stored at room temperature for more than six weeks and then measured using a TL/OSL Risø reader (TL/OSL-DA-15). A filter combination of Schott BG-39 and Corning 7-59 was placed between photomultiplier and aliquots, for both IRSL and TL measurements. After 25 s of IR exposure (880±80 nm), the same discs were heated immediately to obtain their TL at a heating rate of 5° C/s

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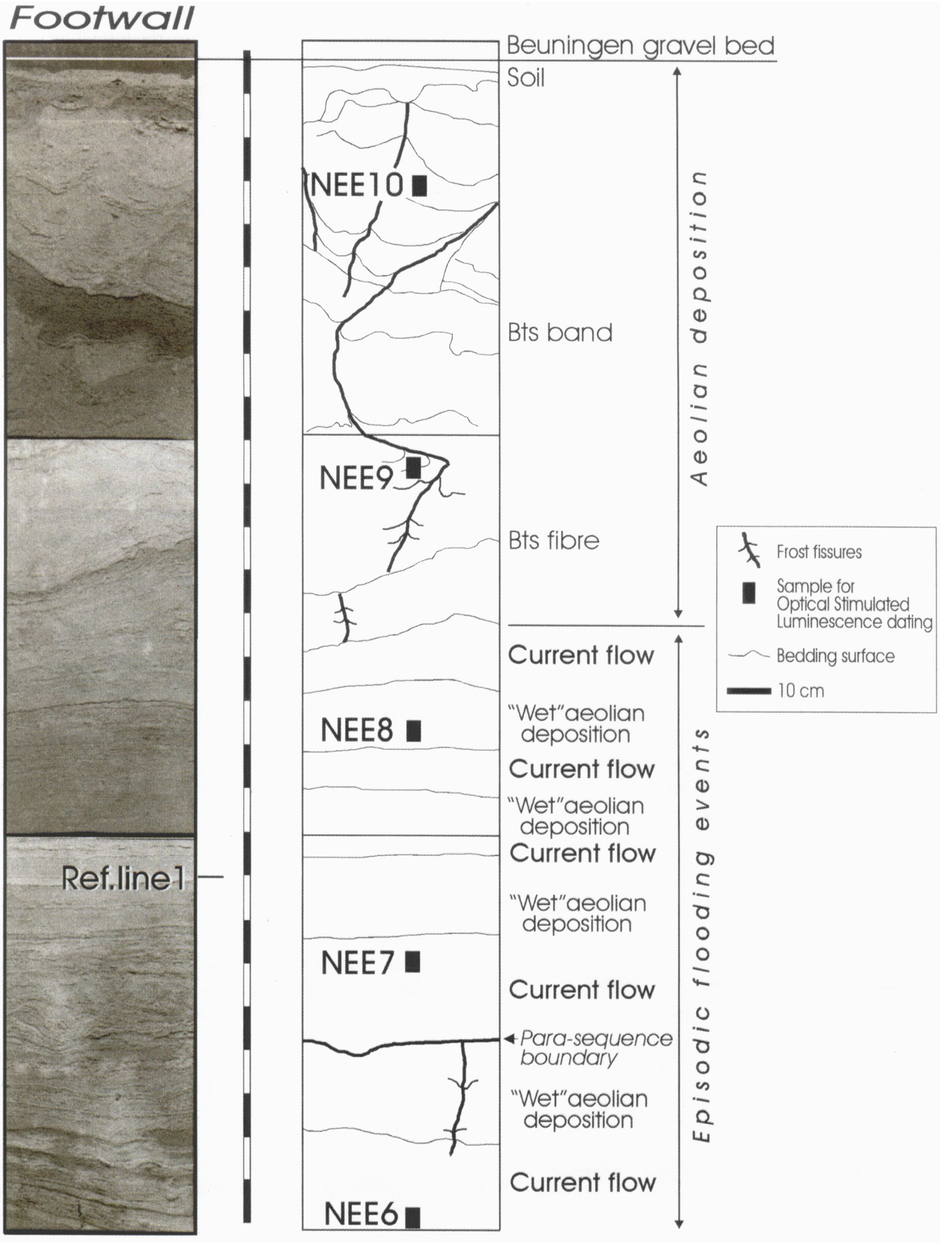

Fig. 4. Sample positions and lithological interpretation from the foot-wall at the Neer trench.

up to 450° C. Second glow normalization was applied in order to reduce the disc-to-disc scatter for both IRSL and TL. Dose-dependent sensitivity changes were not found.

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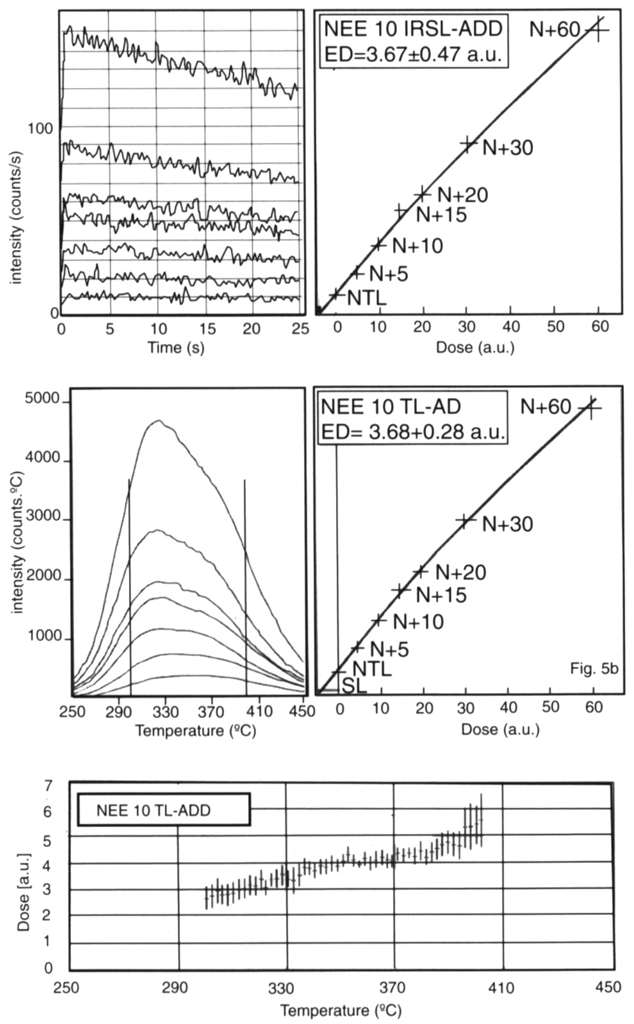


Fig. 5a-b. IR decay curves, TL glow curves, TL plateau and regression analysis of sample NEE10 using the additive dose method (total bleach method). The equivalent dose (ED) yielded 26.1±3.3 and 26.1±2.0 a.u. (1 a.u.=7.1 Gy) for IRSL and TL, respectively.

A multiple aliquot protocol was applied using the additive dose method. Equivalent doses were obtained by integrating the 10-25 s region of the IR decay curve and the 300-400°C region of the TL glow curve. An exponential growth curve was fitted for the different dose steps and compared for the natural luminescence signal to estimate the equivalent dose using the software developed by Rainer Grün, Canberra. Examples of IR decay curves, TL glow curves and the resulting regression analysis are presented in Figs. 5a and 5b. Fading experiments have not indicated significant fading under the present applied technique over a delay between irradiation and measuring of more than 3 months.

Dose rates for all samples were obtained from potassium, uranium and thorium content, as measured by gamma spectrometry in the laboratory. A potassium content of 9±1% was assumed for the potassium-rich feldspars (Wallinga & Duller, 2000) and a water content ranging from 10 to 17% depending on the sample depth and the present groundwater level.

Results

The potassium content ranges from 0.55 to 1.0% (mean value 0.78%), uranium from 0.7 to 2.1 ppm (mean value 1.4 ppm) and thorium from 1.9 to 6.5 ppm (mean value 3.7 ppm). The total dose rate is between 1.3 and 2.4 μGy/a (mean value: 1.8 μGy/a).

The equivalent dose (ED) values range from 14.8±1.3 Gy to 80.4±5.8 Gy and from 18.0±1.1 to 56.9±4.0 Gy for IRSL and TL, respectively. The mean TL ED underestimation compared to IRSL is 18%. However, this mean TL equivalent dose underestimation is mainly based on the lowermost three samples (NEE8, 7 and 6), which yielded an underestimation of 13%, 57% and 29%, respectively. These values are in the range of those TL age underestimation previously reported for Dutch coversand (Dijkmans et al., 1988, 1992).

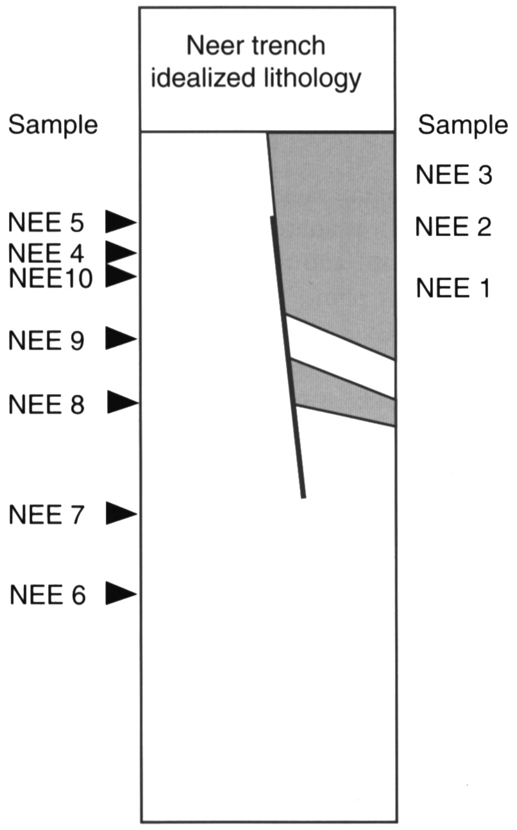
The two lowermost samples, NEE6 and 7, yielded IRSL age estimates ranging from 35.6±5.7 ka to 36.1±3.9 ka (Fig. 6).

Sample NEE8 is significantly younger, as evidenced by an IRSL age estimate of 20.1±2.9 ka. The three uppermost samples of the foot-wall, NEE4, 9 and 10, yielded IRSL age estimates ranging from 14.2±2.3 to 16.4±2.5 ka, which is in agreement with their stratigraphical position below the deflation horizon correlated with the Beuningen gravel horizon. The uppermost sample in the undisturbed footwall, NEE5, yielded an IRSL age estimate of 9.4±1.0 ka.

The chronostratigraphic position of sample NEE1, taken from the hanging-wall just below the Beuningen gravel bed, is not clear. An IRSL age estimate of 10.8±1.7 ka was determined, which is not in agreement with the geological expected age and the stratigraphic position below the Beuningen gravel bed. The IRSL age estimate is too young for aeolian coversands deposited in sheet facies in this region. Alternatively, the Beuningen gravel bed is not present in the sequence near the fault system. Furthermore, several gravel bed events could have occurred during the late Weichselian along the Maas valley. The stratigraphically uppermost samples, NEE2 and 3, yielded IRSL age estimates ranging from 6.9±0.7 to 12.0±1.2 ka.

Discussion

Systematic TL age underestimation compared to IRSL was determined for most of the samples, confirming the results of Dijkmans et al. (1988, 1992). The methodological reasons for the TL age underesti-



Age estimates in 1000 years			Stratigraphy
TL	IRSL	Average IRSL	
NEE3: 8.4±0.8 NEE2: 9.7±1.4	NEE3: 6.9±0.7 NEE2:12.0±1.2		Middle Holocene (Colluvial wedge -2)
NEE5: 9.3±0.8 NEE1:13.7±1.6	NEE3: 9.4±1.0 NEE2:10.8±1.7		Younger Coversand II+I
NEE4: 11.8±2.1 NEE10:16.4±1.9 NEE9: 14.5±1.8	NEE4: 14.2±2.3 NEE10:16.4±2.5 NEE9: 14.6±1.9	15.1±1.2	Older Coversand II
NEE8: 17.4±2.0	NEE8:20.1±2.9		Older Coversand I
NEE7: 15.4±2.3 NEE6: 25.6±2.8	NEE7:35.6±5.7 NEE6:36.1±3.9	35.9±0.4	Middle Weichselian Coversand

Fig. 6. Idealized sketch with the IRSL age estimates and the chronostratigraphic interpretation of the data. The sediments from below the deflation horizon, as indicated by the line between samples NEE4 and NEE5, are correlated with the Older Coversand II by luminescence dating results. This is not in agreement with the geological estimates. The deflation horizon is correlated with the Beuningen gravel bed and so the coversand material immediately below this horizon is designated to represent the Older Coversand I.

mation are not yet clear (cp. Wallinga & Duller, 2000). The IRSL results are within the standard deviation in agreement with geological age estimates for most of the samples (Bateman & van Huissteden, 1999; Frechen et al., 2001a). However, additional combined dating approaches are required on different dating material from the same section, for example radiocarbon dating on organic matter and luminescence on quartz and potassium-rich feldspar.

The palaeo-moisture content and its fluctuation during the geological past are difficult to determine resulting in some uncertainty about the dose rate calculation. In the present study, a moisture content (water weight %) of 10±5 and 17±5% was estimated based on sedimentological and hydrological properties. The potential error and the influence of the moisture on luminescence age calculation is presented in Tables 3 and 5.

Table 1. Dosimetric results of the samples from Trench 1 (BR) and Trench 4 (OPI). Alpha efficiency was estimated to 0.08±0.01 and the internal potassium content to 9±1% for all samples. [Gy/ka] means Gray per thousand years. The cosmic dose attenuation is negligible for the present data set and hence was not determined, a value of 150 μGy/a was applied for all samples.

Sample	Uranium [ppm]	Thorium [ppm]	Potassium [ppm]	Moisture [%]	Dose rate [Gy/ka]
NEE1	1.01±0.07	2.50±0.17	0.73±0.04	17±5	1.51±0.13
NEE2	1.89±0.13	5.33±0.37	1.00±0.05	17±5	2.12±0.15
NEE3	2.02±0.14	5.96±0.42	0.91±0.05	17±5	2.12±0.15
NEE4	0.95±0.07	2.26±0.16	0.71±0.04	12±5	1.54±0.13
NEE5	1.88±0.13	5.32±0.37	0.98±0.05	5±2	2.38±0.17
NEE6	2.14±0.15	6.50±0.46	0.98±0.05	17±5	2.19±0.18
NEE7	0.71±0.05	1.89±0.13	0.55±0.03	17±5	1.27±0.13
NEE8	0.85±0.06	1.91±0.13	0.57±0.03	17±5	1.32±0.13
NEE9	1.03±0.07	2.56±0.18	0.68±0.03	17±5	1.48±0.13
NEE10	1.06±0.07	2.42±0.17	0.73±0.04	12±5	1.59±0.14

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Table 2. Results of equivalent dose determination, TL and IRSL age estimates.

Sample	TL ADD	IRSL ADD	TL ADD	IRSL ADD
	Palaeodose in Gray [Gy]		Age in 1000 years [ka]	
NEE1	20.7±1.6	16.4±2.1	13.7±1.6	10.8±1.7
NEE2	20.7±1.6	25.5±1.8	9.7±1.1	12.0±1.2
NEE3	18.0±1.1	14.8±1.3	8.4±0.8	6.9±0.7
NEE4	18.2±2.9	21.9±3.0	11.8±2.1	14.2±2.3
NEE5	22.2±0.9	22.5±2.3	9.3±0.8	9.4±1.0
NEE6	56.9±4.0	80.4±5.8	25.6±2.8	36.1±3.9
NEE7	19.7±2.1	45.7±5.3	15.4±2.3	35.6±5.7
NEE8	22.9±1.4	26.4±2.8	17.4±2.0	20.1±2.9
NEE9	21.4±2.0	21.7±2.2	14.5±1.8	14.6±1.9
NEE10	26.1±2.0	26.1±3.3	16.4±1.9	16.4±2.5

Table 3: Influence of moisture (H_2O weight %) on dose rate calculation determined for sample NEE5 with an internal potassium content of 9±1%, as applied for the age determination in this study. The consequence for the luminescence age estimates will be of the same magnitude as the values for the dose rate but with opposite sign.

Moisture [weight %]	Dose rate [Gy/ka]	Dose rate alteration [%]
5	2.38	+5
10	2.27	0
15	2.17	–5
20	2.04	–10
25	1.93	–15
30	1.82	–20
35	1.70	–25

An additional source of error concerning the dose rate determination is the internal potassium content of the potassium-rich feldspar. Bulk samples prepared by heavy liquid separation were not suitable for measuring this, and provided only an evaluation of the quality of the heavy liquid separation (Frechen et al., 2001b). However, the enriched potassium-rich feldspar subsamples are contaminated by quartz in most cases and so responsible for an underestimation of the true potassium content. Single grain measurements are required in order to get a more reliable result of the internal potassium content of potassium-rich feldspars. The potential error and the influence on age calculation is presented in Table 4 and 5 (cp. Frechen et al., 2001a). In the present study a potassium content of 9±1% was applied following the value of Wallinga & Duller (2000). Huntley & Barril (1997) proposed a value of 12.5±1%, and so the data of Wallinga & Duller (2000) and this study are probably slightly underestimated.

Table 4. Influence of internal potassium content on the dose rate determination calculated for sample NEE5. A moisture content of 10±5% was applied, as done for the age calculations of sample NEE5 in this study. The consequence for the luminescence age calculation will be of the same magnitude as the values for the dose rate but with opposite sign.

Potassium Content [%]	Dose rate [Gy/ka]	Dose rate alteration [%]
8	2.20	–3
9	2.27	0
10	2.34	+3
11	2.41	+6
12	2.47	+9
13	2.54	+12

A radioactive disequilibrium owing to radon loss would influence the dose rate calculation and so the age estimates (cp. Prescott & Robertson, 1997) but was not determined for this study.

The oldest samples from Neer yielded a Middle Weichselian deposition age, for which an IRSL mean age of 35.9±0.4 ka (2 data points) was determined (Fig. 7).

The deposition age of these coversands is in agreement with those calculated for stratigraphically similar sediments in Trench 4 at the Bree section in Belgium (Frechen et al., 2001a).

The remaining stratigraphical units are significantly younger. Sample NEE8 yielded an IRSL age estimate

Table 5. Maximum influence of internal potassium content and moisture on dose rate calculations for sample NEE5. The consequence for the luminescence age calculation will be of the same magnitude as the values for the dose rate but with opposite sign.

Potassium Content [%]	Moisture [%]	Dose rate [Gy/ka]	Dose rate alteration [%]
8	35	1.63	–28
9	10	2.27	0
13	5	2.66	+17

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Stratigraphy	Age estimates in 1000 yrs Bateman & van Huissteden (1999)				Age estimates in 1000 yrs Frechen et al. (2001a)				Age estimates in 1000 yrs This study		
	14C uncal	14C cal	OSL	Av. OSL	14C uncal	14C cal	IRSL	Av. IRSL	TL	IRSL	interpretation
Younger drifts and Holocene soil	7.54±0.05	<1.0	0.6±0.1						8.4±0.8 9.7±1.1	6.9±0.7 (12.0±1.2)	<6.9±0.7
Younger Coversand II Younger Coversand I	10.55±0.40 12.90±0.21	15.3-11.8	13.1±0.9 11.7±1.5	12.5±1.1		10.5-10.2 13.2-12.7	9.6±1.9 (6.8±1.2) 11.4±1.8 9.9±1.1	10.3±1.0	9.3±0.8 13.7±1.6	9.4±1.0 10.8±1.7	10.1±1.0
Older Coversand II	14.0±0.15	16.8-15.3	17.6±2.6 16.1±1.9 13.9±1.3	15.8±1.8			14.2±2.0 15.4±2.8 18.0±2.7 14.8±4.9 16.3±2.2 14.7±3.1 12.9±2.4 14.8±2.4	15.1±1.5	11.8±2.1 16.4±1.9 14.5±1.8	14.2±2.3 16.4±2.5 14.6±1.9	15.1±1.2
Beuningen gravel bed											
Older Coversand I	19.1±0.18 27.5±0.25	30.5-22.5	21.9±1.9				(12.0±2.5) 22.2±2.5		17.4±2.0	20.1±2.9	20.1±2.9
Early to Middle Weichselian coversand					26.1±0.3 30.5±0.5 39.1±1.4		44.6±6.2 69.9±9		(15.4±2.3) 25.6±2.8	35.6±5.7 36.1±3.9	35.9±0.4
Early Weichselian / Saalian coversand							101±10				

Fig. 7. Idealized sketch of the Dutch coversand stratigraphy including the previous chronological results of Bateman & van Huissteden (1999) and Frechen et al. (2001a). The Beuningen gravel bed is defined as a deflation horizon between Older Coversand I and II.

of 20.1±2.9 ka for the fluvio-aeolian sediments, and so a correlation with the Older Coversand I is likely. The aeolian deposits from the foot-wall (samples NEE4, 9 and 10) yielded a mean IRSL age of 15.1±1.2 ka (3 data points) below a deflation horizon, which is correlated with the Beuningen gravel bed, and so provide an upper age limit for this marker horizon. Similar IRSL age estimates were determined for a discontinuity in loess/palaeosol sequences at Harmignies in Belgium (Frechen et al, 2001c). The mean luminescence age of 15.1±1.2 ka at the Neer section is in agreement with the chronologic results determined for sediments from a similar stratigraphical position at the Bree trenches (Fig. 7). These sediments are designated to correlate with the Older Coversand I from lithological evidence only, alternatively with the Older Coversand II based on the dating results only. An IRSL age estimate of 9.4±1.0 ka was determined for the aeolian sediments from the foot-wall above the Beuningen gravel bed, suggesting a deposition during the Boreal. At that time, the landscape is supposed to be well-covered by forest, and so widespread deposition of sand sheet is not likely. A correlation with the Younger Coversand II, in the second part of the Younger Dryas, is more likely for the sands. If true, this would imply an age underestimation of about 20%. It is interesting to note that a moisture content of 30% would be in agreement with the geologically expected deposition ages (Table 3). In turn, this would suggest that the sands have been fully saturated with pore water since their deposition. Furthermore, such an interpretation would also have significant consequences for the obtained values of deeper positioned samples from the Neer trench.

Luminescence age estimates from three samples of the hanging-wall are not as clear as the previously described results. Deposition ages of 12.0±1.2 and 6.9±0.7 ka were determined. However, it is very likely that the sediment of the colluvial wedge-2 accumulated rapidly and so was not sufficiently exposed to sunlight prior to deposition. It is very likely that these determined IRSL and TL age estimates are overestimates. A deposition of the colluvial wedge-2 and so an earthquake event was likely to occur during the Middle or Late Holocene.

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