Architecture and facies distribution of organic-clastic lake fills in the fluvio-deltaic Rhine-Meuse system, The Netherlands

Ingwer J. Bos

Supplement 2

OSL report on the samples discussed in the text: methods, results and discussion

Netherlands Centre for Luminescence dating

optical dating report

Project Title:	**Alluvial architecture of fine-grained deposits**
Project Location:	**Vecht, Netherlands**
Project number:	**NCL- 3206**
Researcher:	**Ingwer Bos**
Authors:	**Jakob Wallinga & Candice Johns**
Date:	**11/09/2007**

CONTENTS

OWNERSHIP OF RESULTS & DISCLAIMER

SUMMARY

Ingwer Bos (TNO Bouw en Ondergrond) submitted six samples from three cores penetrating Holocene deltaic sediments filling peat lakes in the western Netherlands for optical dating. The purpose of the project is to investigate the rate of infilling of lakes by fluvial sediments of the Vecht, a part of the Rhine-Meuse system.

Sample preparation for optical dating was relatively straight-forward. Using standard methods we were able to separate the quartz fraction for analysis. The luminescence behaviour was good. Based on a number of tests we choose suitable parameters for equivalent dose determination.

Special attention was given to the dose rate estimation. The samples were taken from non-uniform sediments showing alternations of clay and sand in mm – dm scale intervals. In addition, water content of the clayey intervals was very high, thereby shielding the mineral grains from radiation. Based on the geometry of the sediments appropriate assumptions were made to calculate the dose rate experienced by the grains used for equivalent dose determination.

Optical dating results suggest that the lacustrine deposits at site 25G1057 formed between 3.5 ka and 2.8 ka. This is somewhat older than the expected age range of 2.7 – 2.45 ka. For the other two sites only samples near the top of the lacustrine sequence were dated. At site 25G1054 the age obtained is 2.9 ka, similar to the age obtained for the top of the sequence at the first site. For site 25H0740 and age of 2.5 ka is obtained, which is inline with expectations.

Additional information on the results is obtainable through the online NCL database: www.LumiD.nl using the login name and password provided.

Summary of optical dating results

Sample NCL	Client	Location X	Y	Depth (m)	Equivalent dose (Gy)	(s.e.)	Dose rate (Gy/ka)	(s.e.)	Age (ka)	(s.e.)	Validity
NCL-3206022	25G1057 M3	128526	477358	4.26	5.22	0.14	1.50	0.08	3.49	0.21	Likely OK
NCL-3206023	25G1057 M4	128526	477358	3.405	5.51	0.16	1.74	0.08	3.16	0.17	Likely OK
NCL-3206024	25G1057 M5	128526	477358	2.365	4.74	0.12	1.69	0.06	2.80	0.13	Likely OK
NCL-3206025	25G1057 M7	128526	477358	1.695	4.76	0.15	1.68	0.06	2.83	0.14	Likely OK
NCL-3206026	25G1054 M2	128144	477486	2.34	4.91	0.15	1.71	0.08	2.87	0.16	Likely OK
NCL-3206027	25H0740 M1	130220	478551	1.635	4.13	0.15	1.69	0.06	2.45	0.12	Likely OK

OPTICAL DATING

Optical dating is short for optically stimulated luminescence (OSL) dating. The method determines the last exposure to light of sand or silt-sized minerals. To obtain a burial age for sediments, the sediment grains need to be exposed to sufficient daylight prior to deposition and burial.
Optical dating makes use of a tiny light signal (luminescence) that can be emitted by minerals like quartz, feldspar and zircon. The luminescence signal is proportional to the amount of ionising radiation absorbed by the mineral since its last exposure to daylight. Optical dating assumes that the luminescence signal was completely reset at the time of burial, i.e. that light exposure during transport of a grain (e.g. by wind or water) was sufficient to 'bleach' the mineral. A few minutes of intense sunlight or equivalent exposure to less intense light is needed. After deposition the luminescence signal builds up due to exposure of the mineral grain to ionising radiation from natural radionuclides in its direct vicinity and a small contribution from cosmogenic rays. The intensity of the luminescence signal is a measure of the time elapsed since deposition and burial.
The age of a sample is given by the equation: Age = Equivalent dose / Dose rate. The equivalent dose is the amount of radiation received by the mineral since burial. The dose rate is the amount of ionising radiation received by the sample per year.
The age range for which optical dating can be successfully applied is site and sample dependent. Saturation of the luminescence signal usually limits reliable application of quartz optical dating to the last 150 ka, although it may be possible to go further back in time when dose rates are low. At its lower end, the age range is confined by the completeness of resetting of the luminescence signal. In ideal cases luminescence dating can be applied to deposits of only a few years old.
The accuracy attainable through optical dating is about 5 to 10% of the age of a sample (see Murray and Olley, 2002). For samples older than 80 ka and younger than 1000 years the accuracy is normally less.
More information about optical dating is available in the textbook 'An Introduction to Optical Dating' by Aitken (1998) or in recent review papers by Duller (2004), Stokes (1999) or Wallinga (2002).

INFRASTRUCTURE AND EQUIPMENT AT NCL LABORATORY DELFT

The NCL Delft laboratory is equipped with orange / amber safelights to prevent bleaching of the luminescence signal during sample handling. Room lighting is provided by *Illford DL10* lamps equipped with *Ilford #902* filters. The fume cupboard is illuminated by a luminescent tube filtered with an *Encapsulite A10/ND4* filter. Tests indicated that prolonged exposure of quartz minerals to these safelights had a negligible effect on the luminescence signal (<1% bleaching after 24 hours exposure).
Samples are stored in sealed light-tight PVC bags. After preparation of the quartz fraction the samples are kept in light-tight vials inside a light-tight box. Light tightness of all storage facilities was tested by prolonged exposure of packed samples in *a Hönle SOL2* solar simulator. Drying of samples takes place at 50^{o}C in a *Binder ED53* oven; we fitted a light trap to the ventilation opening to prevent light exposure during drying.
For equivalent-dose determination we make use of four *Risø TL/OSL readers*; specifications of each are presented in Table 1. The machines are calibrated monthly to check the machines and monitor decay of the beta source. For calibration we make use of annealed

quartz which was given a 5 Gy gamma dose (calibration quartz provided by Andrew Murray, Nordic Laboratory for Luminescence dating, Risø, DK).

For dose rate assessment we make use of a *Canberra* broad energy HPGe gamma spectrometer. The spectrometer was calibrated using quartz flower spiked with K_2SO_4, Uranium ore and Thorium ore (Blaauw et al., 2000).

Table 1. *Specifications of Risø TL/OSL readers used for equivalent dose determination*

	Reader B	**Reader C**	**Reader D**	**Reader E**
Type	Risø TL/OSL-DA-15	Risø TL/OSL-DA-15	Risø TL/OSL-DA-15	Risø TL/OSL-DA-20
Purchased in	2002	2003	2004	2006
Heating	Roomtemp. – 700°C	Roomtemp. – 700°C	Roomtemp. – 700°C	Roomtemp. – 700°C
Source	1.48 GBq $^{90}Sr/^{90}Y$	1.48 GBq $^{90}Sr/^{90}Y$	1.48 GBq $^{90}Sr/^{90}Y$	1.48 GBq $^{90}Sr/^{90}Y$
Dose-rate (Gy/s)	0.153 Gy/s	0.122 Gy/s	0.028 Gy/s	0.108 Gy/s
Blue stimulation	470 nm, 35 mW/cm^2	470 nm, 35 mW/cm^2	470 nm, 35 mW/cm^2	470 nm, 35 mW/cm^2
Infrared stimulation	875 nm, 130 mW/cm^2	875 nm, 130 mW/cm^2	875 nm, 116 mW/cm^2	875 nm, 116 mW/cm^2
Single grains stim.	532 nm, 50 W/cm^2	-	-	-
Extra features	1) Single grain attachment	-	1) Second hotplate 2) Radioluminescence	-

SAMPLE PREPARATION

On arrival of samples for luminescence dating the samples are split in two. One part is used for equivalent-dose determination, the other for dose rate assessment.

Equivalent dose sample preparation

The sample for equivalent dose determination is kept in the dark and handled in safelight conditions only. The sample is wet-sieved using a *Retsch AS200 Basic Analytical Sieve Shaker* to obtain a narrow grain-size range for analysis. The exact grain-size range is chosen depending on the grain-size distribution of the sample. Grains of selected size are then treated for 40 minutes with 10% HCl to remove carbonates and treated for 15 to 75 min, depending on the sample, with 10% H_2O_2 to remove organic material.
In the next step the grains are washed with 10% HF then treated with 40% HF for 30 minutes while continuously stirred by a magnetic stirrer. The HF treatment acts to dissolve all feldspars, and etch the outer 10 µm skin of the quartz grains that was exposed to alpha-radiation. After HF treatment the sample is washed with 10% HCl to remove fluorides, and rinsed several times with water to remove traces of chemicals used. Finally the sample is sieved once more to avoid any grains that were badly attacked by the HF treatment. The HF treatment is repeated if tests with infrared stimulated luminescence indicate that the sample is contaminated with feldspars.

Dose rate sample preparation

The sample for dose rate estimation is handled in normal light. The sample is dried at 105°C for 12 hours and ashed at 500°C for 24 hrs. From the weight loss during drying and ashing the water and organic contents are calculated. Both are expressed as weight percentages, relative to the ashed sediment weight. Samples containing grains greater than 200 µm are ground in an Agate ball mill. Then the sample is mixed with molten wax, poured into a mould to create a disc of 9-cm diameter and 2 cm thickness. From the weights of sample and wax used, and the weight of the disc, the amount of sample in the disc is calculated. The sample is measured after a minimum of two weeks storage to allow radon build-up.

MEASUREMENTS

Equivalent dose determination

Using quartz minerals for optical dating has shown to give the most reliable dating results (e.g. Murray and Olley, 2002). We therefore prefer using this mineral for routine analyses at the NCL Delft laboratory. We apply the Single-Aliquot Regenerative-dose (SAR) procedure as proposed by Murray and Wintle (2000, 2003) to obtain the dose received by the sample since burial (=equivalent dose).

***Table 2**, The SAR procedure (modified from Murray and Wintle, 2003)*

Step	Action	Measured
1	Regenerative beta dose[1]	
2	10s Preheat at 220 °C[2]	
3	40s IR stimulation @175 °C	
4	40s Blue stimulation @ 110 °C	L_n, L_i[3]
5	Fixed test beta dose[4]	
6	Cutheat to 200 °C	
7	40s IR stimulation @175 °C	
8	40s Blue stimulation @ 110 °C	T_n, T_i[5]
9	40s Blue bleaching at 240 °C[6]	
10	Repeat step 1-7 for number of regenerative doses	
Extra 1	Fixed test beta dose	
Extra 2	Cutheat to 200 °C	
Extra 3	40s IR stimulation @ 50 °C[7]	IR_e
Extra 4	40s Blue stimulation @ 125 °C	T_e

1. *No beta dose is administered for measurement of the natural OSL signal in the first cycle of the procedure L_n*
2. *The preheat temperature is selected based on the preheat-plateau test and dose-recovery test (see Fig. A1 & Fig. A2).*
3. *The signal used for analysis is the signal measured during the first 0.32 s of stimulation minus the average background signal determined over the last 4 s of stimulation.*
4. *The test dose is normally chosen to be approximately 25% of the equivalent dose.*
5. *Response to the fixed test dose is used to monitor sensitivity changes of the material during the measurement routine.*
6. *The preheat temperature plus 20°C is used as an added bleaching step before the sample is dosed (step 1).*
7. *After completion of the standard SAR routine, we use IR stimulation to check whether the sample is contaminated by feldspar.*

For measurement we mount the centre 2 mm of stainless steel discs with a few milligrams of sample material (a few hundred grains of quartz). Using the SAR procedure we estimate the equivalent dose on each aliquot. The SAR procedure normally comprises five cycles. In each cycle a different regenerative dose is given and the ratio of regeneration (L_i) to test dose (T_i) OSL response is plotted on a dose response curve. The equivalent dose is then obtained by interpolation through projecting the L_n/T_n ratio on the dose response curve (Fig. 1).
Internal tests in the SAR procedure indicate whether the equivalent dose obtained can be accepted for analysis. Tests incorporated are:

1) *Recycling test.* This test aims to establish whether the sensitivity correction works satisfactory. The first regenerative dose given to the sample is repeated in the fifth cycle; the L_i/T_i ratio obtained in both cycles should be identical.
2) *Recuperation test.* In the fourth cycle no regenerative dose is given. The L_4/T_4 ratio obtained should be close to zero.
3) *Feldspar test.* After completion of the standard SAR procedure (step 1-8, Table 2) an additional test dose is administered and the sample is stimulated with IR light prior to the normal blue stimulation. This test is twofold: the IR response should be small compared to the blue response, and the T_e (measured after IR exposure) should be similar to the previous testdose response (T_5).

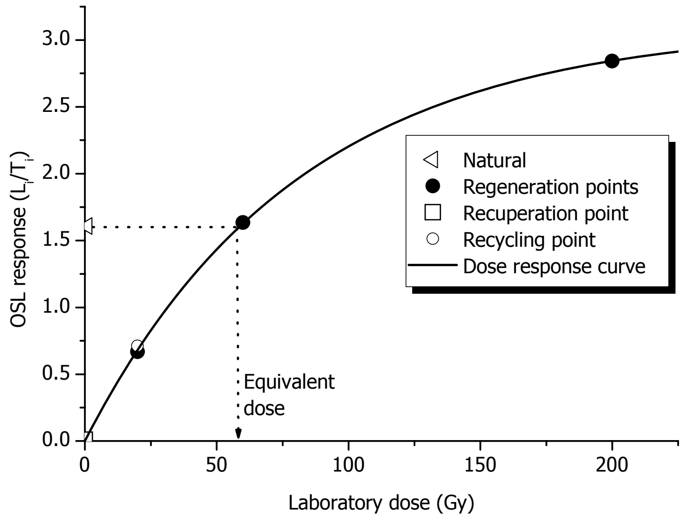


Figure 1. *Graphical presentation of the equivalent dose determination using the SAR procedure (outlined in Table 2). The test-dose corrected OSL responses to the natural (triangle) and regeneration doses (dots) are plotted against the beta dose given in the laboratory. The equivalent dose is then obtained through interpolation by projecting the natural response on the reconstructed dose response curve (solid line). The regeneration doses are chosen such that they encompass the natural. To test whether the OSL signal is completely reset during each measurement cycle a zero dose is included (recuperation point – square). To test whether the sensitivity correction works satisfactorily, the first regeneration dose is repeated at the end of the measurement procedure (repeat point – open circle).*

Table 3. *Applied thresholds for accepting data for analysis.*

Test	Ideal case	Accepted if *
1 – Recycling test	$(L_5/T_5) / (L_1/T_1) = 1$	$0.8 < (L_5/T_5) / (L_1/T_1) < 1.2$
2 – Recuperation test	$(L_4/T_4) / (L_1/T_1) = 0$	$(L_4/T_4) / (L_1/T_1) < 0.1$
3 – Feldspar test	$IR_e/T_e = 0$, $T_e/T_5 = 1$	$IR_e/T_e < 0.2$ or $T_e/T_5 > 0.9$

Measurements are repeated until at least 19 aliquots have given results passing the rejection criteria. The equivalent dose used for age estimation is then obtained through an iterative procedure: single aliquot equivalent doses removed more than 2 standard deviations from the sample mean were removed in an iterative procedure to avoid overestimation of the equivalent dose due to incorporation of aliquots containing grains for which the OSL signal was not reset prior to deposition. This procedure is standard used at the NCL and gives reliable results if only a small fraction of aliquots contains grains for which the OSL signal was not reset.

Tests for sample characterisation

Prior to equivalent dose (D_e) determination, a number of tests are performed to characterise the luminescence behaviour of the samples and determine suitable parameters for the SAR procedure. The tests are listed in Table 4.

Table 4. *Tests for sample characterisation.*

Test	Goal	Performed on
1 – Scan	Rough estimate of D_e, test for feldspar contamination	Each sample
2 – Preheat plateau	Select suitable preheat temperature for analysis	Selected samples*
3 – Dose recovery	Retrieve given laboratory dose using the SAR procedure	Each sample
4 – Dose response	Characterise luminescence behaviour at high doses	Selected samples*
5 – OSL components	Check whether fast OSL component is dominant	Each sample

* See Table A1 for list of selected samples

Dose rate determination

The natural dose rate is calculated from the radionuclide concentration of sediments surrounding the sample, the depth of the sample below the surface and the water content of the sample. We determine the radionuclide concentration by high-resolution gamma-ray spectroscopy (Murray et al., 1987); spectral data are converted to activity concentrations and infinite matrix dose rates using the most recent conversion data available (private communication Murray & Nathan, 2004). The natural dose rate was calculated from the infinite matrix dose rate using attenuation factors given by Mejdahl (1979). A contribution from cosmic rays was included based on the depth and burial history of the sample, following equations presented by Prescott and Hutton (1994). A correction was made for attenuation of the dose rate by water using the attenuation factors given by Zimmerman (1971).

RESULTS OF NCL PROJECT 3206

Sample characterisation

Figures and tables with regards to sample characterisation are presented in Appendix A. Table A1 provides a summary of characterization tests performed on selected samples.

1) Scan

The samples have moderately bright luminescence signals and all satisfy the requirements of the recycling and recuperation tests. All samples have some feldspar contamination, the signal of which was removed using post-IR blue (PIRB) stimulation. All samples are appropriate for OSL analysis based on the results of this test.

2) Preheat plateau

In the preheat plateau test, the equivalent dose is measured for a range of preheat temperatures. Based on our experience with other samples and the results shown in Figure A1 we chose a 10-s preheat at 220^{o}C for equivalent dose determination. The scatter between single-aliquot equivalent dose results shown in Figure A1 is not related to the preheat temperature used. The samples have recycling ratio's near unity from 200°C to 240°C (3206024),from 200°C to 280°C (3206026), and from 200°C to 220°C (3206027),

3) Dose recovery

During this test a sample is first bleached at room temperature to zero the dose and then given a dose similar in magnitude to the natural dose. Next, the sample is tested using the SAR procedure to determine if it can recover the given dose. The objective is to reproduce the natural circumstances. Ideally, the ratio of the given dose to recovered dose is unity. This is the most stringent method available to determine if the dose received in nature can be measured accurately in the laboratory. The 3206 samples return an average given dose to recovered dose ratio of 1.05 ± 0.02 (individual results listed in Table A2).

4) Dose response

Figure A2 shows the saturation of the OSL signal at high doses. The results show that the luminescence signal is far from saturation for the natural samples and thus suitable for dating by the SAR method.

Equivalent dose

In Appendix B we present results of the equivalent dose determinations. Single aliquot equivalent dose distributions are shown graphically as histograms in Appendix B. Results on individual aliquots are reported in Table B2.

The results show a Gaussian shaped dose distribution for all samples, with a few aliquots showing greater doses. This is likely due to the incorporation of grains for which the OSL signal was not completely reset prior to deposition. In the iterative procedure these results are rejected for further analysis. We expect the equivalent doses obtained using this iterative procedure to be appropriate estimates of the true burial dose.

Dose rate

The samples are taken from deposits with alternating layers of sand and clay with thicknesses ranging from a few millimetres to about 12 cm. Because in situ measurement of the dose rate was not possible, dose rates needed to be calculated based on the geometry of the deposits and the radionuclide contents of the different lithologies. Since the sediments in the layers were well sorted, we assumed that the sand fraction used for equivalent dose estimation was from the sandy layers recognized during sampling.

Water and organic contents are important for dose rate calculation, as both substances absorb radiation and thereby shield the mineral grains. Based on a porosity of 34% for sandy sediments (Weerts, 1996), we assumed a water content of 20 ± 3% by weight for sandy layers. For other sediments the water content and organic contents as measured in the laboratory was used to estimate water and organic content attenuation. Due to the high water and organic contents (combined up to 75% by weight) the attenuation is very important for these samples. An uncertainty of 20 % on the measured values was included to allow for possible changes during geological burial and due to sampling.

As beta particles travel no more than a few millimetres, we assumed that the beta dose rate for sand laminae with thicknesses greater than one cm arose solely from the sandy layers themselves. Beta dose rates for these samples are therefore based on the radionuclide contents of sample 25G1057 M7; this was the only sandy sample for which we had enough material for the analysis. For thin sand laminae we calculated the fraction of the beta dose arising from within the layer, and the fraction from the surrounding, based on equations given by Aitken (1985, p. 295).

The gamma rays reaching the grains used for equivalent dose determination derive from a sphere of about 30 cm, but the majority of the deposited dose is from the direct vicinity (within a few cm's, see Aitken, 1985). Gamma dose rates were calculated from the radionuclide contents of the sediments surrounding the sample used for equivalent dose determination, and the radionuclide contents of the sandy deposits (based on sample 25G1057 M7). Based on the thickness of the sand layers different weighing of the two components was applied. Details about the assumptions and results are given in the tables in Appendix C.

It is worthwhile noting that the radionuclide content of the sandy deposits is much lower than that of the clayey sediments. However, due to the greater water content of the latter, dose rates in both types of deposits are similar. Hence the effects of using different weighing factors are minor.

An internal dose rate of 0.06 ± .03 Gy/ka was assumed based on earlier work (Murray, personal communication 2004). Results of the gamma spectrometry measurements showed no indications of disequilibrium. Instant burial to present depth was assumed for estimation of the cosmic ray contribution to the dose rate.

The dose rates results and assumptions are presented in Appendix C (Table C1 and C2); the obtained values are similar for all samples and range between 1.50 and 1.76 Gy/ka.

Optical ages

Optical ages were calculated by dividing the measured equivalent doses by the calculated dose rates. All sources of uncertainty were taken into account. Results are presented with a one sigma uncertainty (standard error).

Optical dating results suggest that the lacustrine deposits at site 25G1057 formed between 3.5 ka and 2.8 ka. This is somewhat older than the expected age range of 2.7 – 2.45 ka. For the other two sites only samples near the top of the lacustrine sequence were dated. At site 25G1054 the age obtained is 2.9 ka, similar to the age obtained for the top of the sequence at the first site. For site 25H0740 and age of 2.5 ka is obtained, which is in line with expectations.

There is no evidence that the equivalent dose is overestimated due to incomplete resetting of the OSL signal in some grains at the time of deposition. Nevertheless, we cannot completely rule out this possibility. The results are very dependent on assumptions with regard to the water content of the clayey sediments. If the water contents as measured in the laboratory are not representative for the water contents of the sediments in their natural environment this will affect the ages (a 1% overestimation of the water content will lead to ~1% underestimation of the age).

REFERENCES

Aitken, M.J. 1985. Thermoluminescene dating. Academic Press, London.
Aitken, M.J. 1998. An Introduction to Optical Dating. Oxford University Press, Oxford, 267 pp.
Blaauw, M., Bode, P., Glass, H.J. 2000. Het bepalen van de prestatiekenmerken van NEN 5697. Eindrapportage aan het Nederlands Normalisatie instituut. IRI rapport 133-00-01. TUDelft, 66p.
Bøtter-Jensen, L., Bulur, E., Duller, G.A.T., Murray, A.S. 2000. Advances in luminescence instrument systems. *Radiation Measurements* **32**, 57-73.
Duller, G.A.T. 2004. Luminescence dating of Quaternary sediments: recent advances. *Journal of Quaternary Science* **19**, 183-192.
Duller, G.A.T., Bøtter-Jensen, L, Murray, A.S., 2000. Optical dating of sand-sized grains of quart: sources of variability. Radiation Measurements 32, 453-457.
Galbraith, R.F., Roberts, R.G., Laslett, G.M., Yoshida, H., Olley, J.M. 1999. Optical dating of single and multiple grains of quartz from Jinmium rock shelter, northern Australia: Part I, experimental design and statistical models. Archaeometry 41, 339-364.
Jain, M, Murray, A.S., Bøtter-Jensen, L. 2003. Characterisation of blue-light stimulated luminescence components in different quartz samples: implications for dose measurement. *Radiation Measurements* **37**, 441-449.
Mejdahl, V., 1979. Thermoluminescence dating: beta dose attenuation in quartz grains. *Archaeometry* **21**, 61-72.
Murray, A.S., Olley, J.M. 2002. Precision and accuracy in the optically stimulated luminescence dating of sedimentary quartz: a status review. *Geochronometria* **21**, 1-16.
Murray, A.S., Wintle, A.G., 2000. Luminescence dating of quartz using an improved single-aliquot regenerative-dose protocol. *Radiation Measurements* **32**, 57-73.
Murray, A.S., Wintle, A.G., 2003. The single aliquot regenerative dose protocol: potential for improvements in reliability. *Radiation Measurements* **37**, 377-381.
Murray, A.S., Marten, R., Johnston, A., Marten, P., 1987. Analysis for naturally occurring radionuclides at environmental concentrations by gamma spectrometry. *Journal of Radioanalytical and Nuclear Chemistry* **115**, 263-288.
Prescott, J.R. and Hutton, J.T. 1994. Cosmic ray contributions to dose rates for luminescence and ESR dating: large depths and log-term time variations. *Radiation Measurements* **23**, 497-500.
Roberts, R.G., Galbraith, R.F., Yoshida, H., Laslett, G.M., Olley, J.M. 2000. Distinguishing dose populations in sediment mixtures: a test of single-grain optical dating procedures using mixtures of laboratory-dosed quartz. Radiation Measurements 32, 459-465.
Stokes, S. 1999. Luminescence dating applications in geomorphological research. *Geomorphology* **29**, 153-171.
Vandenberghe, D., Kasse, C., Hossain, S.M., De Corte, F., Van den Haute, P., Fuchs, M., Murray, A.S., 2004. Exploring the method of optical dating and comparison of optical and C-14 ages of Late Weichselian coversands in the southern Netherlands. *Journal of Quaternary Science* **19**, 73-86.
Wallinga, J., 2002a. Optically stimulated luminescence dating of fluvial deposits: a review. *Boreas* **31**, 303-322.
Wallinga, J., 2002b. Detection of OSL age overestimation using single-aliquot techniques. *Geochronometria* **21**, 17-26.
Weerts, H.J.T., 1996. Complex confining layers. Architecture and hydraulic properties of Holocene and Late Weichselian deposits in the fluvial Rhine Meuse delta, The Netherlands. Nederlandse Geografische Studies 213, 1-189.
Zimmerman, D.W., 1971. Thermoluminescent dating using fine grains from pottery. *Archaeometry* **13**, 29-52.

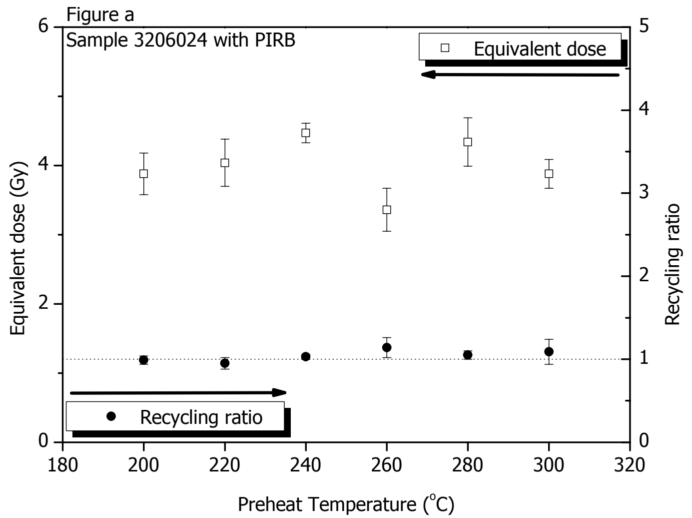
Appendix A. *Results of sample characterisation.*

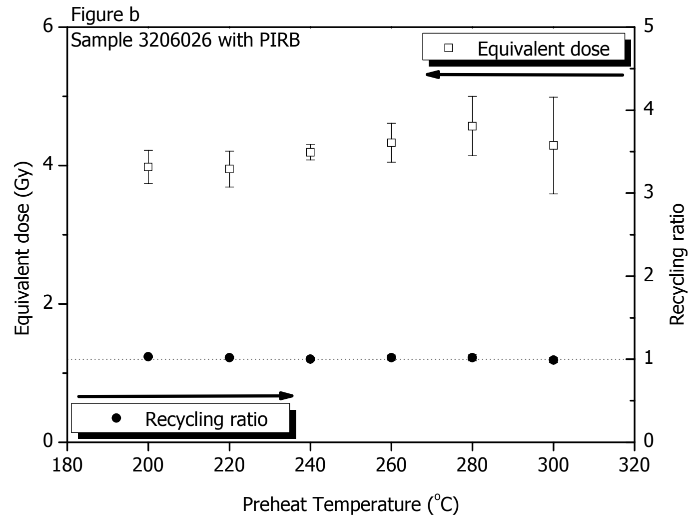
Table A1, Summary of sample characterisation

Sample code	Preheat (^{o}C, 10s)	Cutheat (^{o}C, 0s)	Grainsize (µm)	Checks			
				Scan	PH plateau	Dose recovery	Dose response
NCL-3206022	220	200	90-180	√		√	
NCL-3206023	220	200	90-180	√		√	
NCL-3206024	220	200	90-180	√	√	√	√
NCL-3206025	220	200	90-180	√		√	
NCL-3206026	220	200	90-180	√	√	√	√
NCL-3206027	220	200	180-212	√	√	√	√

Table A2, summary of dose recovery results

		Given dose	Recovered dose		Dose Ratio	
Sample code	Sample name	(Gy)	(Gy)	Standard error	given/recovered	standard error
NCL-3206022	25G1057 M3	5	5.02	0.51	1.01	0.10
NCL-3206023	25G1057 M4	5	4.83	0.32	1.05	0.07
NCL-3206024	25G1057 M5	5	5.07	-	0.99	-
NCL-3206025	25G1057 M7	5	4.76	0.09	1.05	0.02
NCL-3206026	25G1054 M2	5	4.72	0.17	1.06	0.04
NCL-3206027	25H0740 M1	5	4.68	0.10	1.07	0.02
				Averages	1.05	0.02





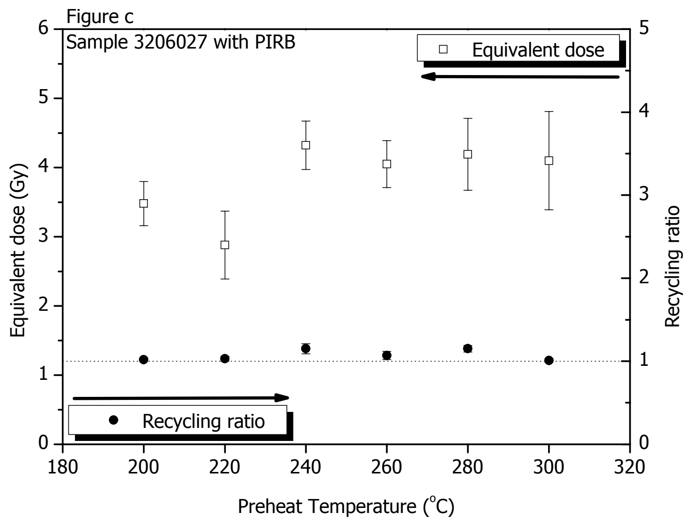
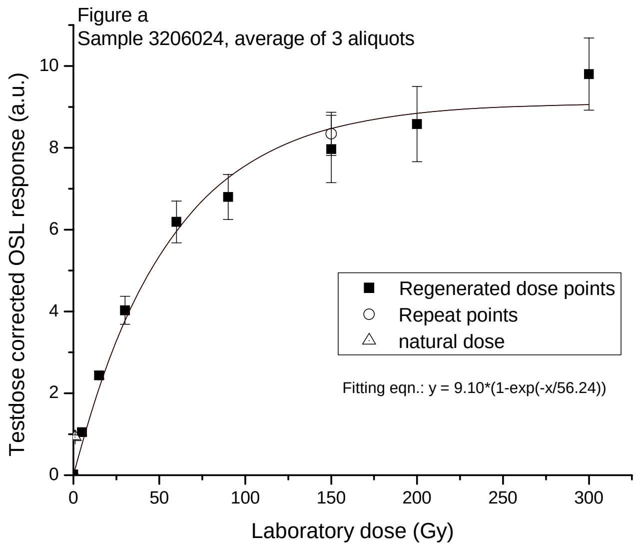
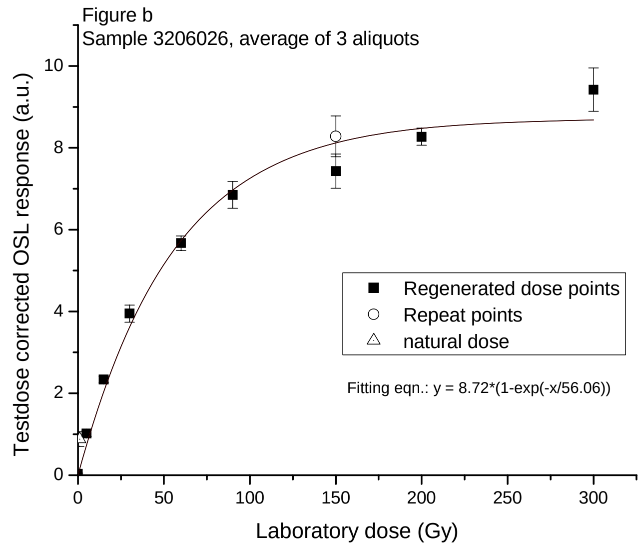


Fig. A1
The SAR procedure was used to investigate the dependency of the equivalent dose and recycling ratio on the heating temperature used prior to the OSL signal measurement of the natural and regenerated doses. Four aliquots of samples 3206024, 3206026, and 3206027 were measured at each temperature. Heating of the testdose was 200°C for all measurements. Results indicate that for the preheat temperature 220°C the equivalent dose is not dependent on the preheat used. Moreover, these temperatures the sensitivity correction works effectively, as is indicated by the recycling ratio, which is near unity.





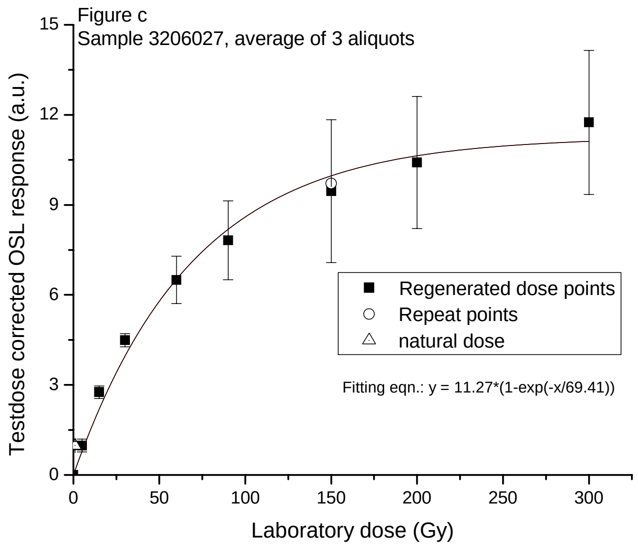
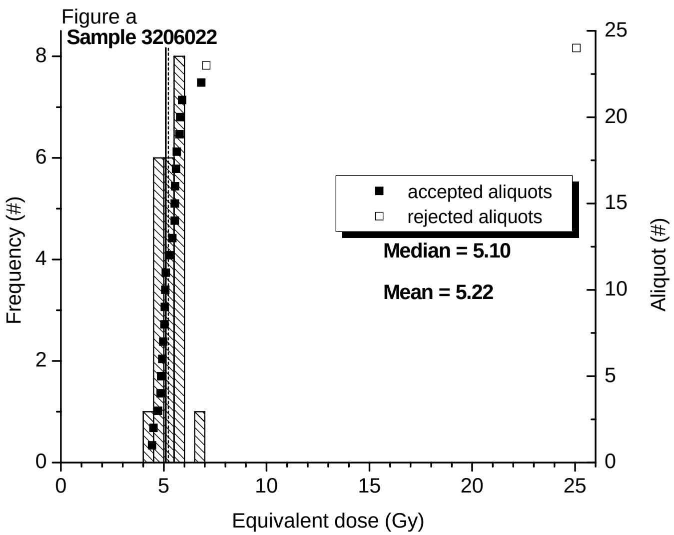


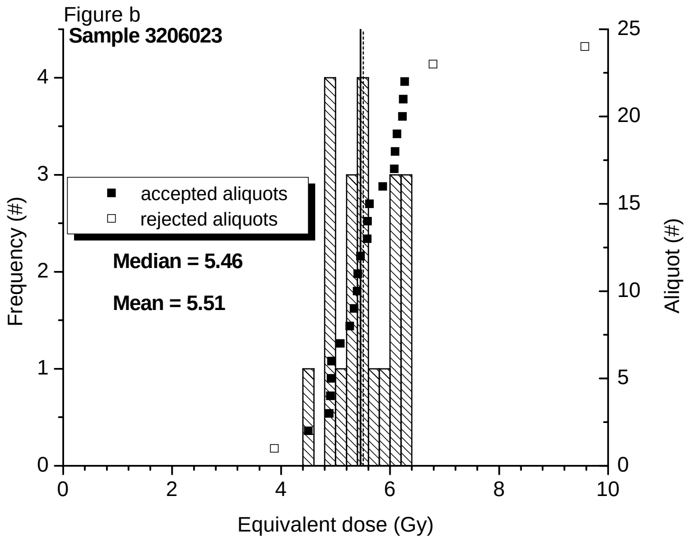
Fig. A2
The SAR procedure was used to investigate the OSL response of the sample at high doses. Three aliquots of samples 3206024, 3206026, and 3206027 were measured; a preheat temperature of 220°C was used. The mean test-dose corrected OSL response of an average of each three aliquots is shown. The dose-response curve can be satisfactorily fitted with a single saturating exponential. Equivalent doses determined on the samples (all less than 6 Gy) are far from the saturation region.

Appendix B. *Results of equivalent dose determination.*

Table B1, *summary of equivalent dose results used for dating*

Sample	Preheat	Equivalent dose				Aliquots		Recycling			Recuperation			Dose recovery		IR reduction
NCL	(°C)	(Gy)	(s.e.)	(syst.)	(rand.)	all	iterated	(ratio)	(s.e.)	point	(%)	(s.e.)	point	(ratio)	(s.e.)	(%)
NCL-3206022	220	5.2	0.1	0.1	0.1	24	21	1.01	0.02	R1	0%	0%	N	1.01	0.10	6%
NCL-3206023	220	5.5	0.2	0.1	0.1	24	21	1.04	0.02	R1	0%	0%	N	1.05	0.07	2%
NCL-3206024	220	4.7	0.1	0.1	0.1	22	19	1.02	0.01	R1	0%	0%	N	0.99		-3%
NCL-3206025	220	4.8	0.1	0.1	0.1	23	19	0.98	0.02	R1	0%	0%	N	1.05	0.02	-3%
NCL-3206026	220	4.9	0.1	0.1	0.1	29	24	0.96	0.01	R1	0%	0%	N	1.06	0.04	-17%
NCL-3206027	220	4.1	0.1	0.1	0.1	24	20	0.99	0.01	R1	0%	1%	N	1.07	0.02	-31%





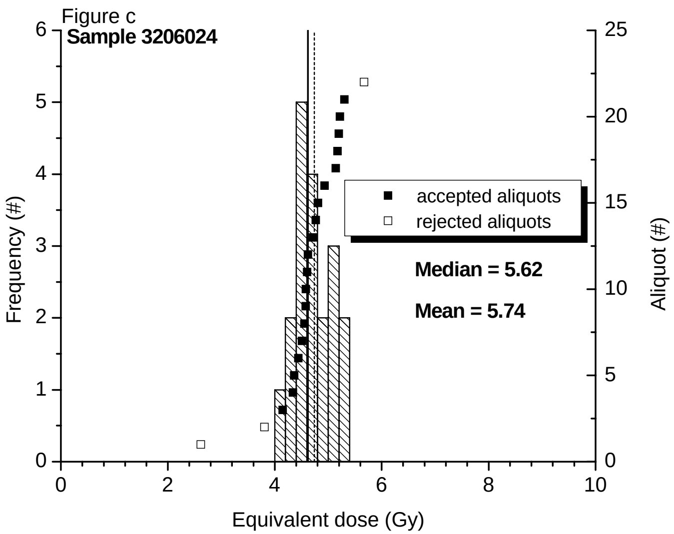
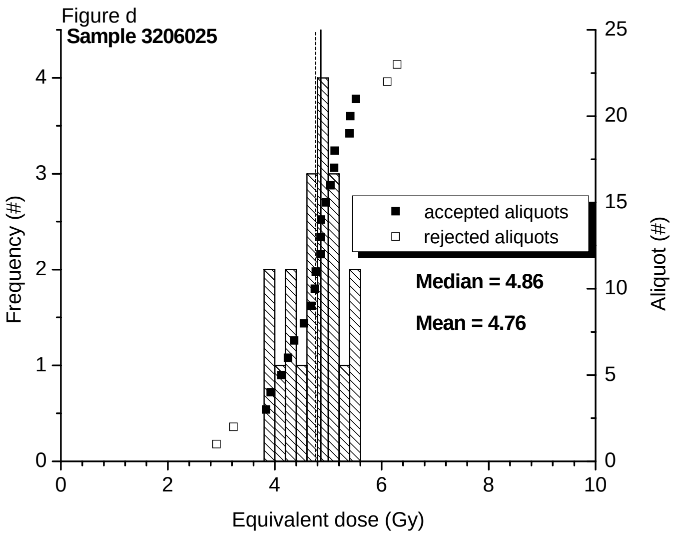
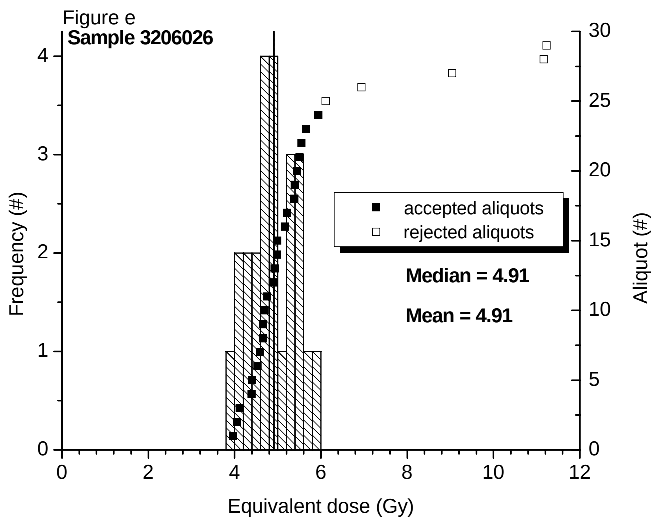


Fig. B1 a,b,c
Histogram showing the distribution of equivalent doses obtained on the aliquots. Single aliquot equivalent doses used for the sample equivalent dose estimation are shown with filled squares. Aliquots for which the single-aliquot equivalent dose was more than 2.0 standard deviations were removed from the sample mean (indicated with open squares, they were rejected in an iterative procedure). Aliquots for which results were rejected using criteria outlined in Table 3 are not presented.





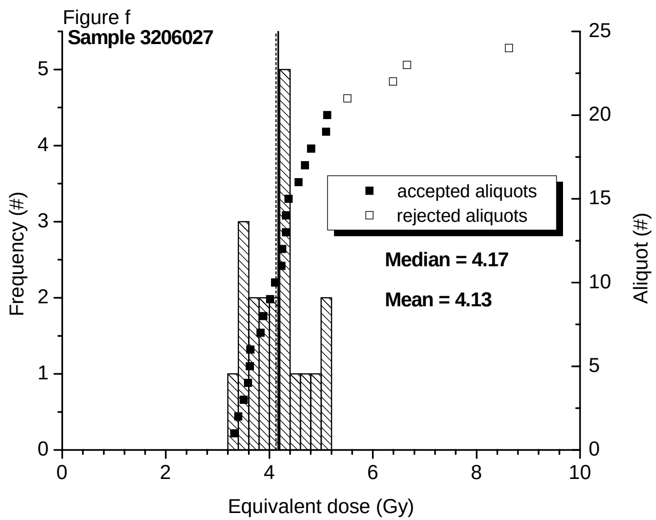


Fig. B1 d,e,f
Histogram showing the distribution of equivalent doses obtained on the aliquots. Single aliquot equivalent doses used for the sample equivalent dose estimation are shown with filled squares. Aliquots for which the single-aliquot equivalent dose was more than 2.0 standard deviations were removed from the sample mean (indicated with open squares, they were rejected in an iterative procedure). Aliquots for which results were rejected using criteria outlined in Table 3 are not presented.

Table B2, equivalent dose results for individual aliquots

Accepted data:

Sample No	Run No	Disk No	Counts	IR Counts	Fs Test 1 IRTD / R5TD	Fs Test 2 IR / IR TD	recycling	% recuperation (zero/natural)	De Gy	error	Iteration De fit?
3206022	n7ca045d.BIN	1	2603	-4	0.92	0.00	0.97	-0.01	4.73	0.47	ok
3206022	n7ca045d.BIN	2	955	-10	0.97	-0.03	0.98	0.01	5.77	0.80	ok
3206022	n7ca045d.BIN	3	2839	3	0.98	0.00	1.15	0.00	5.06	0.49	ok
3206022	n7ca045d.BIN	4	1000	5	0.90	0.01	1.08	-0.01	4.98	0.61	ok
3206022	n7ca045d.BIN	5	1399	6	0.93	0.01	0.91	0.01	4.43	0.61	ok
3206022	n7ca045d.BIN	6	2341	1	0.97	0.00	0.98	0.00	5.80	0.63	ok
3206022	n7ca045d.BIN	7	6888	-9	0.96	0.00	0.91	0.00	7.06	0.60	reject
3206022	n7ca045d.BIN	8	3311	-3	1.02	0.00	1.07	0.00	5.60	0.50	ok
3206022	n7ca045d.BIN	10	6123	-10	1.01	0.00	1.05	0.00	5.63	0.41	ok
3206022	n7ca048d.BIN	1	2040	7	0.97	0.01	1.03	0.02	5.54	0.55	ok
3206022	n7ca048d.BIN	2	2977	78	0.92	0.07	0.85	0.00	5.42	0.47	ok
3206022	n7ca048d.BIN	3	1763	17	0.95	0.02	1.06	0.00	5.33	0.67	ok
3206022	n7ca048d.BIN	4	650	18	0.87	0.08	1.08	0.02	5.54	0.80	ok
3206022	n7ca048d.BIN	5	4159	17	0.93	0.01	0.97	0.01	4.50	0.42	ok
3206022	n7ca048d.BIN	6	3788	67	0.98	0.04	1.03	-0.01	4.87	0.48	ok
3206022	n7ca048d.BIN	7	1597	79	0.87	0.10	0.96	0.01	5.10	0.48	ok
3206022	n7ca048d.BIN	8	1785	46	0.91	0.06	1.00	0.00	4.85	0.58	ok
3206022	n7ca048d.BIN	9	1047	16	0.83	0.05	0.98	-0.01	6.83	0.85	reject
3206022	n7ca048d.BIN	10	4027	39	0.93	0.02	1.04	0.00	5.90	0.65	ok
3206022	n7ca048d.BIN	11	1862	807	1.03	1.22	1.16	0.00	4.94	0.51	ok
3206022	n7ca048d.BIN	12	28468	8	0.89	0.00	1.01	0.00	25.07	1.63	reject
3206022	n7ca048d.BIN	13	1215	33	0.87	0.06	0.86	0.01	5.55	0.65	ok
3206022	n7ca048d.BIN	14	2905	17	0.96	0.02	1.03	0.00	5.04	0.42	ok
3206022	n7ca048d.BIN	15	9534	14	0.91	0.00	0.99	0.00	5.08	0.38	ok

Results

Iterated		
avg De	5.22	0.09
median De	5.10	
Stdev	0.43	
# aliquots	21	
Not iterated		
avg De	6.19	
median De	5.37	0.83
Stdev	4.07	
# aliquots	24	
recycling	1.01	0.02
recuperation	0.2%	0.1%
IR reduction	6.4%	11.3%

Accepted data: Sample No	Run No	Disk No	Counts	IR Counts	Fs Test 1 IRTD / R5TD	Fs Test 2 IR / IR TD	recycling	% recuperation (zero/natural)	De Gy	error	Iteration De fit?
3206023	n7ca045d.BIN	11	442	22	0.96	0.12	1.09	0.01	6.13	1.07	ok
3206023	n7ca045d.BIN	12	2522	-1	1.08	0.00	1.19	0.00	6.23	0.66	ok
3206023	n7ca045d.BIN	13	7124	-5	0.96	0.00	0.99	0.00	5.59	0.38	ok
3206023	n7ca045d.BIN	14	4914	4	1.02	0.00	0.99	0.00	4.92	0.41	ok
3206023	n7ca045d.BIN	15	2098	0	1.05	0.00	0.90	0.01	4.93	0.58	ok
3206023	n7ca045d.BIN	16	2993	-11	1.13	-0.01	1.10	0.00	5.39	0.67	ok
3206023	n7ca045d.BIN	17	3490	9	1.04	0.01	0.97	0.00	5.63	0.57	ok
3206023	n7ca045d.BIN	18	14141	-1	1.03	0.00	1.05	0.00	5.41	0.41	ok
3206023	n7ca045d.BIN	19	1901	-7	0.94	-0.01	0.86	0.00	4.50	0.45	ok
3206023	n7ca045d.BIN	20	764	3	1.07	0.01	1.18	0.00	5.34	0.75	ok
3206023	n7ca048d.BIN	16	2524	4	1.02	0.00	1.09	0.00	6.09	0.56	ok
3206023	n7ca048d.BIN	17	984	3	0.88	0.01	1.05	-0.01	6.24	0.91	ok
3206023	n7ca048d.BIN	18	3214	-1	0.91	0.00	0.99	0.00	5.26	0.49	ok
3206023	n7ca048d.BIN	19	1587	-5	1.04	-0.01	1.11	0.01	6.27	0.74	ok
3206023	n7ca048d.BIN	20	2753	22	0.98	0.02	1.03	0.00	5.46	0.52	ok
3206023	n7ca048d.BIN	22	3682	0	0.94	0.00	1.06	0.00	5.58	0.55	ok
3206023	n7ca048d.BIN	23	1499	16	0.96	0.02	0.98	-0.01	5.87	0.65	ok
3206023	n7ca048d.BIN	24	1097	-2	0.90	-0.01	0.96	0.00	4.89	0.57	ok
3206023	n7ca048d.BIN	25	5469	33	0.94	0.02	1.06	0.01	9.58	0.81	reject
3206023	n7ca048d.BIN	26	3816	34	0.95	0.03	1.06	0.00	6.79	0.59	reject
3206023	n7ca048d.BIN	27	2012	5	0.84	0.01	1.14	0.01	4.91	0.47	ok
3206023	n7ca048d.BIN	28	4631	-6	0.92	0.00	1.02	0.00	5.09	0.47	ok
3206023	n7ca048d.BIN	29	2875	3	0.92	0.00	1.07	0.00	6.08	0.62	ok
3206023	n7ca048d.BIN	30	5307	19	0.91	0.01	1.06	0.01	3.88	0.27	reject

Results

Iterated		
avg De	5.51	0.12
median De	5.46	
Stdev	0.53	
# aliquots	21	
Not iterated		
avg De	5.67	
median De	5.52	0.22
Stdev	1.06	
# aliquots	24	
recycling	1.04	0.02
recuperation	0.1%	0.1%
IR reduction	2.4%	11.5%

Accepted data:

Sample No	Run No	Disk No	Counts	IR Counts	Fs Test 1 IRTD / R5TD	Fs Test 2 IR / IR TD	recycling	% recuperation (zero/natural)	De Gy	error	Iteration De fit?
3206024	n7ca045d.BIN	21	1416	-5	1.10	-0.01	1.09	0.01	4.76	0.52	ok
3206024	n7ca045d.BIN	22	273	7	0.89	0.04	0.98	-0.03	2.62	0.50	reject
3206024	n7ca045d.BIN	23	12149	5	1.05	0.00	1.04	0.00	4.34	0.28	ok
3206024	n7ca045d.BIN	24	498	2	1.00	0.01	1.03	0.01	4.72	0.72	ok
3206024	n7ca045d.BIN	25	432	-14	1.22	-0.05	0.90	-0.02	3.81	0.63	reject
3206024	n7ca045d.BIN	26	1580	-4	1.07	-0.01	1.00	0.01	5.67	0.58	reject
3206024	n7ca045d.BIN	27	1000	-1	1.20	0.00	1.05	0.00	4.56	0.68	ok
3206024	n7ca045d.BIN	28	2941	7	1.16	0.00	0.98	0.00	4.81	0.44	ok
3206024	n7ca045d.BIN	30	692	9	1.10	0.03	1.03	-0.02	4.61	0.68	ok
3206024	n7ca048d.BIN	31	1845	34	0.94	0.05	1.05	0.00	4.93	0.47	ok
3206024	n7ca048d.BIN	32	2332	2	1.02	0.00	1.15	0.00	5.30	0.49	ok
3206024	n7ca048d.BIN	33	1523	18	1.00	0.03	0.90	0.00	5.20	0.62	ok
3206024	n7ca048d.BIN	34	3320	3	0.94	0.00	0.91	0.00	5.18	0.48	ok
3206024	n7ca048d.BIN	35	4895	37	0.94	0.02	0.97	0.00	4.62	0.34	ok
3206024	n7ca048d.BIN	36	2166	26	0.92	0.03	1.04	0.01	4.58	0.41	ok
3206024	n7ca048d.BIN	37	8153	23	0.99	0.01	1.09	0.00	5.22	0.40	ok
3206024	n7ca048d.BIN	38	943	-3	0.99	-0.01	1.00	0.02	4.36	0.58	ok
3206024	n7ca048d.BIN	39	642	4	0.91	0.01	0.98	0.00	4.15	0.72	ok
3206024	n7ca048d.BIN	40	1645	37	1.00	0.04	1.10	0.00	5.14	0.51	ok
3206024	n7ca048d.BIN	41	2630	7	1.02	0.01	1.04	0.01	4.44	0.37	ok
3206024	n7ca048d.BIN	43	1400	3	1.05	0.00	1.11	0.01	4.51	0.43	ok
3206024	n7ca048d.BIN	45	492	7	1.17	0.02	1.09	-0.03	4.58	0.79	ok

Results

Iterated		
avg De	4.74	0.08
median De	4.62	
Stdev	0.34	
# aliquots	19	
Not iterated		
avg De	4.64	
median De	4.61	0.13
Stdev	0.62	
# aliquots	22	
recycling	1.02	0.01
recuperation	-0.1%	0.3%
IR reduction	-3.2%	18.1%

Accepted data: Sample No	Run No	Disk No	Counts	IR Counts	Fs Test 1 IRTD / R5TD	Fs Test 2 IR / IR TD	recycling	% recuperation (zero/natural)	De Gy	error	Iteration De fit?
3206025	n7ca053d.BIN	1	1100	158	1.01	0.25	1.00	0.00	2.91	0.29	reject
3206025	n7ca053d.BIN	2	4824	2316	0.96	1.93	0.91	0.01	5.11	0.47	ok
3206025	n7ca053d.BIN	3	1986	26	0.90	0.04	0.89	0.01	5.52	0.62	ok
3206025	n7ca053d.BIN	4	1441	-1	0.97	0.00	1.04	-0.01	4.55	0.48	ok
3206025	n7ca053d.BIN	5	1025	13	0.92	0.03	0.90	0.00	5.04	0.65	ok
3206025	n7ca053d.BIN	6	3021	73	0.93	0.07	1.08	0.00	4.86	0.46	ok
3206025	n7ca053d.BIN	7	2188	64	0.93	0.06	0.96	0.00	4.75	0.44	ok
3206025	n7ca053d.BIN	8	1907	718	0.98	0.85	0.99	-0.01	4.13	0.42	ok
3205025	n7ca055d.BIN	1	2431	19	1.02	0.02	0.92	0.00	4.87	0.49	ok
3205025	n7ca055d.BIN	2	2673	7	1.01	0.01	0.89	0.00	4.25	0.37	ok
3205025	n7ca055d.BIN	3	978	9	1.05	0.02	0.85	-0.02	4.86	0.58	ok
3205025	n7ca055d.BIN	4	501	31	0.98	0.08	1.06	0.06	3.23	0.48	reject
3205025	n7ca055d.BIN	5	3731	53	1.09	0.04	1.01	0.01	5.40	0.47	ok
3205025	n7ca055d.BIN	6	1100	77	1.25	0.10	1.10	0.01	5.12	0.58	ok
3205025	n7ca055d.BIN	7	424	15	1.06	0.05	1.09	-0.01	4.76	0.88	ok
3205025	n7ca055d.BIN	8	2342	40	1.02	0.04	1.03	0.00	5.41	0.53	ok
3205025	n7ca055d.BIN	9	1055	611	1.14	0.81	1.03	-0.01	3.92	0.46	ok
3205025	n7ca055d.BIN	10	1893	71	1.03	0.07	0.93	-0.02	4.95	0.54	ok
3205025	n7ca055d.BIN	11	2406	72	1.11	0.05	0.94	0.00	4.68	0.46	ok
3205025	n7ca055d.BIN	12	1449	15	0.98	0.02	0.91	0.00	3.84	0.39	ok
3205025	n7ca055d.BIN	13	1613	30	1.22	0.05	1.14	-0.02	6.11	0.65	reject
3205025	n7ca055d.BIN	14	1919	13	1.08	0.01	0.93	0.01	4.36	0.41	ok
3205025	n7ca055d.BIN	15	3278	30	1.05	0.03	0.94	0.01	6.29	0.55	reject

Results		
Iterated		
avg De	4.76	0.11
median De	4.86	
Stdev	0.49	
# aliquots	19	
Not iterated		
avg De	4.74	
median De	4.86	0.17
Stdev	0.80	
# aliquots	23	
recycling	0.98	0.02
recuperation	0.1%	0.3%
IR reduction	-2.9%	18.7%

Accepted data: Sample No	Run No	Disk No	Counts	IR Counts	Fs Test 1 IRTD / R5TD	Fs Test 2 IR / IR TD	recycling	% recuperation (zero/natural)	De Gy	error	Iteration De fit?
3206026	n7ca060d.BIN	7	243	8	1.25	0.04	0.94	-0.01	5.45	1.81	ok
3206026	n7ca060d.BIN	9	606	-4	1.17	-0.01	1.03	0.00	4.53	0.71	ok
3206026	n7ca060d.BIN	10	454	25	0.93	0.14	1.01	0.00	5.22	1.07	ok
3206026	n7ca060d.BIN	13	258	11	0.95	0.07	0.99	-0.01	6.11	2.11	reject
3206026	n7ca060d.BIN	14	512	32	1.53	0.13	0.87	0.00	4.98	1.03	ok
3206026	n7ca060d.BIN	16	1645	12	1.08	0.01	1.01	0.03	4.70	0.55	ok
3206026	n7ca060d.BIN	19	1403	21	1.27	0.04	0.96	-0.01	4.99	0.69	ok
3206026	n7ca060d.BIN	20	547	-8	1.08	-0.03	1.05	-0.03	11.17	3.47	reject
3206026	n7ca060d.BIN	21	4458	2	1.24	0.00	1.00	0.01	4.40	0.36	ok
3206026	n7ca060d.BIN	22	4457	3	1.10	0.00	0.97	0.00	4.12	0.35	ok
3206026	n7ca060d.BIN	23	4513	-2	1.13	0.00	0.92	0.00	5.16	0.47	ok
3206026	n7ca060d.BIN	24	2259	16	1.18	0.01	0.96	0.00	5.94	0.68	ok
3206026	n7ca060d.BIN	25	2669	-5	1.19	-0.01	0.97	0.02	5.55	0.61	ok
3206026	n7ca060d.BIN	26	3834	-3	1.06	0.00	0.98	0.00	4.58	0.41	ok
3206026	n7ca060d.BIN	27	8141	8	1.07	0.00	0.97	0.00	4.66	0.34	ok
3206026	n7ca060d.BIN	28	720	8	1.15	0.03	0.97	0.00	4.39	0.66	ok
3206026	n7ca060d.BIN	29	703	10	1.50	0.04	0.96	0.02	6.94	1.33	reject
3206026	n7ca060d.BIN	30	6705	1	1.11	0.00	0.98	0.00	4.89	0.34	ok
3206026	n7ca060d.BIN	31	645	-3	1.13	-0.01	0.82	-0.02	4.93	0.87	ok
3206026	n7ca062d.BIN	1	1221	-11	1.09	-0.03	0.90	-0.02	9.04	1.38	reject
3206026	n7ca062d.BIN	3	1267	11	1.50	0.01	1.00	0.00	5.66	0.73	ok
3206026	n7ca062d.BIN	4	1104	-3	1.46	-0.01	1.12	0.00	5.38	0.77	ok
3206026	n7ca062d.BIN	5	1254	20	1.05	0.05	0.87	-0.01	11.23	2.01	reject
3206026	n7ca062d.BIN	6	6906	22	1.17	0.00	1.08	0.00	4.75	0.33	ok
3206026	n7ca062d.BIN	7	4900	13	1.08	0.00	1.04	0.00	4.06	0.31	ok
3206026	n7ca062d.BIN	9	1328	-2	1.09	0.00	0.81	-0.05	5.51	0.71	ok
3206026	n7ca062d.BIN	10	1913	6	1.17	0.00	0.94	0.00	4.66	0.45	ok
3206026	n7ca062d.BIN	11	717	-4	1.12	-0.01	0.96	-0.03	3.96	0.54	ok
3206026	n7ca062d.BIN	12	684	8	1.15	0.02	0.86	0.00	5.40	0.94	ok

Results

Iterated		
avg De	4.91	0.11
median De	4.91	
Stdev	0.53	
# aliquots	24	
Not iterated		
avg De	5.60	
median De	4.99	0.34
Stdev	1.84	
# aliquots	29	
recycling	0.96	0.01
recuperation	-0.4%	0.3%
IR reduction	-17.2%	20.8%

Accepted data: Sample No	Run No	Disk No	Counts	IR Counts	Fs Test 1 IRTD / R5TD	Fs Test 2 IR / IR TD	recycling	% recuperation (zero/natural)	De Gy	error	Iteration De fit?
3206027	n7ca053d.BIN	17	11441	145	0.96	0.04	1.03	0.00	4.81	0.31	ok
3206027	n7ca053d.BIN	18	1958	232	0.96	0.29	1.01	0.00	3.89	0.41	ok
3206027	n7ca053d.BIN	21	2438	72	1.00	0.08	0.98	0.00	4.25	0.40	ok
3206027	n7ca053d.BIN	22	4183	1	0.96	0.00	1.01	0.00	4.69	0.40	ok
3206027	n7ca053d.BIN	23	2399	129	0.98	0.18	0.93	0.00	4.23	0.39	ok
3206027	n7ca053d.BIN	24	5226	232	1.01	0.09	0.99	0.01	4.57	0.36	ok
3206027	n7ca055d.BIN	16	5783	250	1.14	0.09	0.92	0.00	4.32	0.32	ok
3206027	n7ca055d.BIN	17	8592	185	1.18	0.09	1.01	0.02	8.63	0.79	reject
3206027	n7ca055d.BIN	18	2262	255	1.24	0.18	0.90	0.00	3.32	0.32	ok
3206027	n7ca055d.BIN	19	1897	66	1.15	0.06	1.01	0.00	3.83	0.40	ok
3206027	n7ca055d.BIN	22	4602	132	1.16	0.08	0.92	0.03	5.09	0.50	ok
3206027	n7ca055d.BIN	23	2177	26	1.18	0.01	1.00	0.03	3.62	0.34	ok
3206027	n7ca055d.BIN	24	1726	51	1.12	0.05	0.94	0.00	3.59	0.34	ok
3206027	n7ca055d.BIN	25	1398	61	1.32	0.06	0.92	0.01	3.64	0.39	ok
3206027	n7ca055d.BIN	26	2917	15	1.06	0.01	1.07	0.00	6.39	0.65	reject
3206027	n7ca055d.BIN	27	2453	7	1.01	0.01	0.96	0.00	4.01	0.36	ok
3206027	n7ca055d.BIN	28	1375	384	1.43	0.42	1.06	0.01	4.32	0.49	ok
3206027	n7ca055d.BIN	29	249	74	2.26	0.31	1.15	-0.06	5.12	1.37	ok
3206027	n7ca055d.BIN	30	282	4	0.99	0.02	0.82	-0.09	4.37	1.15	ok
3206027	n7ca060d.BIN	1	665	-5	1.41	-0.01	0.90	0.00	4.11	0.65	ok
3206027	n7ca060d.BIN	2	396	46	4.21	0.11	1.02	-0.05	6.66	2.14	reject
3206027	n7ca060d.BIN	4	542	11	1.21	0.02	1.09	-0.01	3.40	0.48	ok
3206027	n7ca060d.BIN	5	876	6	1.25	0.01	1.05	0.01	3.50	0.39	ok
3206027	n7ca060d.BIN	6	30900	109	1.22	0.01	0.97	0.01	5.51	0.32	reject

Results

Iterated		
avg De	4.13	0.12
median De	4.17	
Stdev	0.54	
# aliquots	20	
Not iterated		
avg De	4.58	
median De	4.28	0.25
Stdev	1.22	
# aliquots	24	
recycling	0.99	0.01
recuperation	-0.4%	0.5%
IR reduction	-30.8%	31.0%

***Appendix C.** Results of dose rate determination*

Table C1: Information on samples used for dose rate estimation

	Location			Depth (m)		Lithology	Thickness	Attenuation information:					
Sample	x	y	face (m N	lower	upper		of sand	water content		organic content		total	
							laminae	%	s.e.	%	s.e.	%	s.e.
Core 25G1057													
M3	128526	477358	-1.3	4.46	4.06	silty clay, sand ad	1 mm	73.4	14.7	1.7	0.3	75	15
M4	128526	477358	-1.3	3.57	3.24	clay with sand lar	2-4 mm	64.4	12.9	5.6	1.1	70	13
M5	128526	477358	-1.3	2.39	2.34	fine sand	6 cm						
M6a	128526	477358	-1.3	2.34	2.27	sandy clay		26.5	5.3	1.8	0.4	28	5
M6b	128526	477358	-1.3	2.49	2.39								
M7	128526	477358	-1.3	1.76	1.63	fine sand	12 cm	20.0	3.0	0.4	0.1	20	3
M8a	128526	477358	-1.3	1.63	1.55	sandy clay		33.9	6.8	1.6	0.3	36	7
M8b	128526	477358	-1.3	1.83	1.76	sandy clay							
Core 25G1054													
M1	128144	477486	-1.1	2.28	2.2	sandy clay		68.0	13.6	3.7	0.7	72	14
M2	128144	477486	-1.1	2.4	2.28	sandy clay/ sand	2 mm						
M3	128144	477486	-1.1	2.5	2.4	sandy clay							
Core 25H0740													
M1	130220	478551	-1.35	1.7	1.57	sand with clay lar	2-5 cm						
M2a	130220	478551	-1.35	1.57	1.52	sandy clay		23.5	4.7	1.3	0.3	25	5
M2b	130220	478551	-1.35	1.75	1.7	sandy clay							

Table C2: Radionuclide concentrations

Sample NCL	Radionuclide concentrations Uranium (Bq/kg)	(s.e.)	Thorium (Bq/kg)	(s.e.)	K-40 (Bq/kg)	(s.e.)
25G1057 M3	30.41	0.20	29.35	0.68	374	4
25G1057 M4	36.43	0.24	35.90	0.63	477	4
25G1057 M6	20.34	0.25	19.59	0.68	406	6
25G1057 M7	14.20	0.13	14.24	0.30	422	3
25G1057 M8	19.44	0.19	18.80	0.48	418	4
25G1054 M1	35.31	0.23	34.24	0.57	463	3
25H0740 M2	21.52	0.26	21.11	0.60	358	6

Table C3: Dose rate assumptions

NCL sample	Thickness of sand laminae	De on sample	Depth (m)	Beta dose rate on samples: (1) surround	weighting	(2) sand layer	weighting	Gamma dose rate on samples: (1) surround	weighting	(2) sand layer	weighting
Core 25G1057											
NCL-3206022	1 mm	M3	4.26	25G1057 M3	60%	25G1057 M7	40%	25G1057 M3	100%		
NCL-3206023	3 mm	M4	3.405	25G1057 M4	28%	25G1057 M7	62%	25G1057 M4	100%		
NCL-3206024	6 cm	M5	2.365		-	25G1057 M7	100%	25G1057 M6	62%	25G1057 M7	38%
NCL-3206025	12 cm	M7	1.695		-	25G1057 M7	100%	25G1057 M8	43%	25G1057 M7	57%
Core 25G1054											
NCL-3206026	2 mm	M2	2.34	25G1054 M1	39%	25G1057 M7	61%	25G1054 M1	100%		
Core 25H0740											
NCL-3206027	3.5 cm	M1	1.635		-	25G1057 M7	100%	25H0740 M2	73%	25G1057 M7	27%

Table C4: Dose rate results

Sample NCL	Depth (m)	Dose rates Internal alpha (Gy/ka)	(s.e.)	External beta (Gy/ka)	(s.e.)	External gamma (Gy/ka)	(s.e.)	Cosmic (Gy/ka)	(s.e.)	Total (Gy/ka)	(s.e.)	(syst.)	(rand.)
NCL-3206022	4.26	0.06	0.03	0.81	0.07	0.50	0.03	0.13	0.01	1.50	0.08	0.08	0.01
NCL-3206023	3.405	0.06	0.03	0.94	0.06	0.61	0.04	0.14	0.01	1.74	0.08	0.08	0.01
NCL-3206024	2.365	0.06	0.03	0.96	0.05	0.52	0.02	0.16	0.01	1.69	0.06	0.06	0.01
NCL-3206025	1.695	0.06	0.03	0.96	0.05	0.49	0.02	0.17	0.01	1.68	0.06	0.06	0.01
NCL-3206026	2.34	0.06	0.03	0.92	0.07	0.58	0.04	0.16	0.01	1.71	0.08	0.08	0.01
NCL-3206027	1.635	0.06	0.03	0.93	0.05	0.53	0.03	0.17	0.01	1.69	0.06	0.06	0.01

Appendix D. *Quartz optical dating results*

Table D1: optical dating results

Sample NCL	Client	Location X	Y	Depth (m)	Equivalent dose (Gy)	(s.e.)	Dose rate (Gy/ka)	(s.e.)	Age (ka)	(s.e.)	(syst.)	(rand.)	Validity
NCL-3206022	25G1057 M3	128526	477358	4.26	5.22	0.14	1.50	0.08	3.49	0.21	0.20	0.07	Likely OK
NCL-3206023	25G1057 M4	128526	477358	3.405	5.51	0.16	1.74	0.08	3.16	0.17	0.15	0.07	Likely OK
NCL-3206024	25G1057 M5	128526	477358	2.365	4.74	0.12	1.69	0.06	2.80	0.13	0.12	0.05	Likely OK
NCL-3206025	25G1057 M7	128526	477358	1.695	4.76	0.15	1.68	0.06	2.83	0.14	0.12	0.07	Likely OK
NCL-3206026	25G1054 M2	128144	477486	2.34	4.91	0.15	1.71	0.08	2.87	0.16	0.15	0.07	Likely OK
NCL-3206027	25H0740 M1	130220	478551	1.635	4.13	0.15	1.69	0.06	2.45	0.12	0.10	0.07	Likely OK

Appendix E. *Location of sampling sites (Google Earth through www.lumid.nl)*