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Methodological problems in thermoluminescence dating of Weichselian coversand and late Holocene drift sand from the Lutterzand area, E. Netherlands

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Abstract

A thermoluminescence dating study of eolian sands was performed for methodological purposes. The twelve samples that were dated include Upper Pleniglacial and Late Glacial coversands as well as late Holocene drift sands from stratigraphically well-known, partly ^{14}C dated exposures, along the Dinkel river in the eastern Netherlands.

A new approach was used to determine the equivalent dose (ED) after previous attempts were unsatisfactory. This approach proved promising, enabling to establish an ED value with a small uncertainty. However, the present results show that most of the TL ages of the Weichselian coversands are too low by about 20–40% compared to the radiocarbon dates, although some samples do not disagree with the geological evidence. This problem has also been encountered for coversand samples from Denmark and the reason is not yet fully understood.

In spite of the problems that still exist TL proved a powerful method to distinguish between eolian sands with a relatively large age difference. It is still questionable whether TL dating enables a distinction between lithostratigraphical units of the Weichselian coversands in NW Europe.

Introduction

Eolian sands of Pleistocene age, both dunes and sand sheets, are widely distributed in NW Europe (Koster 1988). They have usually been deposited during glacial or stadial periods (e.g. Ruegg 1983). Radiocarbon dating cannot be used to date these eolian sands, since zones with organic material within these deposits usually represent the short-lasting interstadial periods of non-deposition of eolian sediments. However, thermoluminescence (TL) dating is applied to the minerogenic sediment itself and theoretically determines the time of deposition. Hence it could contribute to a better understanding of the stratigraphical record. In recent years much progress has been made in the TL dating technique as applied to a wide range of sediments and eolian sediments are commonly regarded as the most suitable sediment type for this technique. Successful results have been obtained with loess (Wintle 1987) and these studies have led to the recognition and understanding of periods of deposition and non-deposition during the Late Pleistocene (e.g. Juvigné & Wintle 1988).

TL dates for eolian sands have already been published (e.g. Kolstrup & Mejdahl 1986, Jungner 1987, Lundqvist & Mejdahl 1987, Dijkmans et al. 1988). Nevertheless there still is uncertainty as to the most suitable laboratory method to be used and it is still necessary to carry out experiments on material from well-dated stratigraphical sections of eolian sand to understand the intricacy and limitations of the method. In this paper the results of a TL dating study of stratigraphically controlled, radiocarbon-dated Weichselian and Holocene eolian sands are presented. The study froms part of a collaborative EEC project aiming to improve the TL dating technique of eolian sands.

The Lutterzand section

Weichselian eolian sands (coversands) in the Netherlands belong to the Twente Formation. A detailed lithostratigraphic division is well established (e.g. Van der Hammen & Wijmstra 1971; Doppert et al. 1975) and the Dinkel Valley in the Twente region (E. Netherlands) comprises several type localities. In the Lutterzand area natural exposures along the Dinkel River have had their stratigraphy documented in detail by Wijmstra & Schreve-Brinkman (1971). Samples from this locality (Fig. 1) have been selected for the present study, since a sequence of Upper Pleniglacial and Late Glacial coversands is present. Moreover, these coversands are partly covered by late Holocene drift sands of the Kootwijk Formation. TL dating of the coversand sequence not only permitted a comparison between TL dates and the established chronostratigraphy, but also indicated the ability of the TL dating method to discriminate within a limited chronostratigraphic sequence of eolian sands. In other words, are the TL ages of eolian sands in the right order when the expected ages are relatively close together? Moreover, TL ages should unequivocally distinguish the late Holocene drift sands from the Late Glacial coversands.

Twelve samples were collected from three exposures along the Dinkel River (Fig. 1). The base of section A is formed by Younger Coversand I or Older Coversand II. The local absence of the Lower Loamy Bed prevents further discrimination. This sediment is covered by a peat layer: the Usselo Layer from the Allerød Interstadial. Van der Hammen & Wijmstra (1971) have dated this bed at two localities in the Dinkel Valley: GrN-4899: 11,630 ± 65 B.P. and GrN-4900: 11,630 ± 90 B.P. The Younger Coversand II deposits overlying the peat layer are clearly distinguished from drift sands of the Kootwijk Formation by a well-developed Holocene podsolic soil. According to Castel et al. (1989) the majority of these drift sands in Northwest Europe have been developed from the Middle Ages onwards.

In section B (Fig. 1) a light-grey horizon presumably represents the Lower Loamy Bed of the Bølling interstadial. This marker horizon enables a distinction between Older and Younger Coversand.

The Beuningen Complex in section C (Fig. 1) forms another stratigraphic marker. It consists of a gravel string (Beuningen Gravel Bed) and the Beuningen Soil in which periglacial phenomena can be recognized. The coversand type overlying the pebble bed cannot be established. The distinction between the underlying Older Coversand I deposits and the upper (fluvial) sands of the Mekkelhorst Member is not very clear and Van Huissteden & Vandenberghe (1988) proposed a refinement of the lithostratigraphy, whereby these two are combined into the Beverborg Member. However, for the purpose of this study it is important that the samples from section C are assumed to be coversands.

Thermoluminescence dating

Aitken (1985) elaborately discussed the physical background of the thermoluminescence (TL) dating method; here only is presented a brief and simplified account of the principles.

After deposition a sediment is buried and exposed to a small amount of ionizing radiation, which is produced by the decay of naturally occurring isotopes (mainly of the U and Th decay chain and ^{40}K). This produces free charges which are trapped at defects of the crystal lattice. The amount of radiation to which the minerals are exposed is

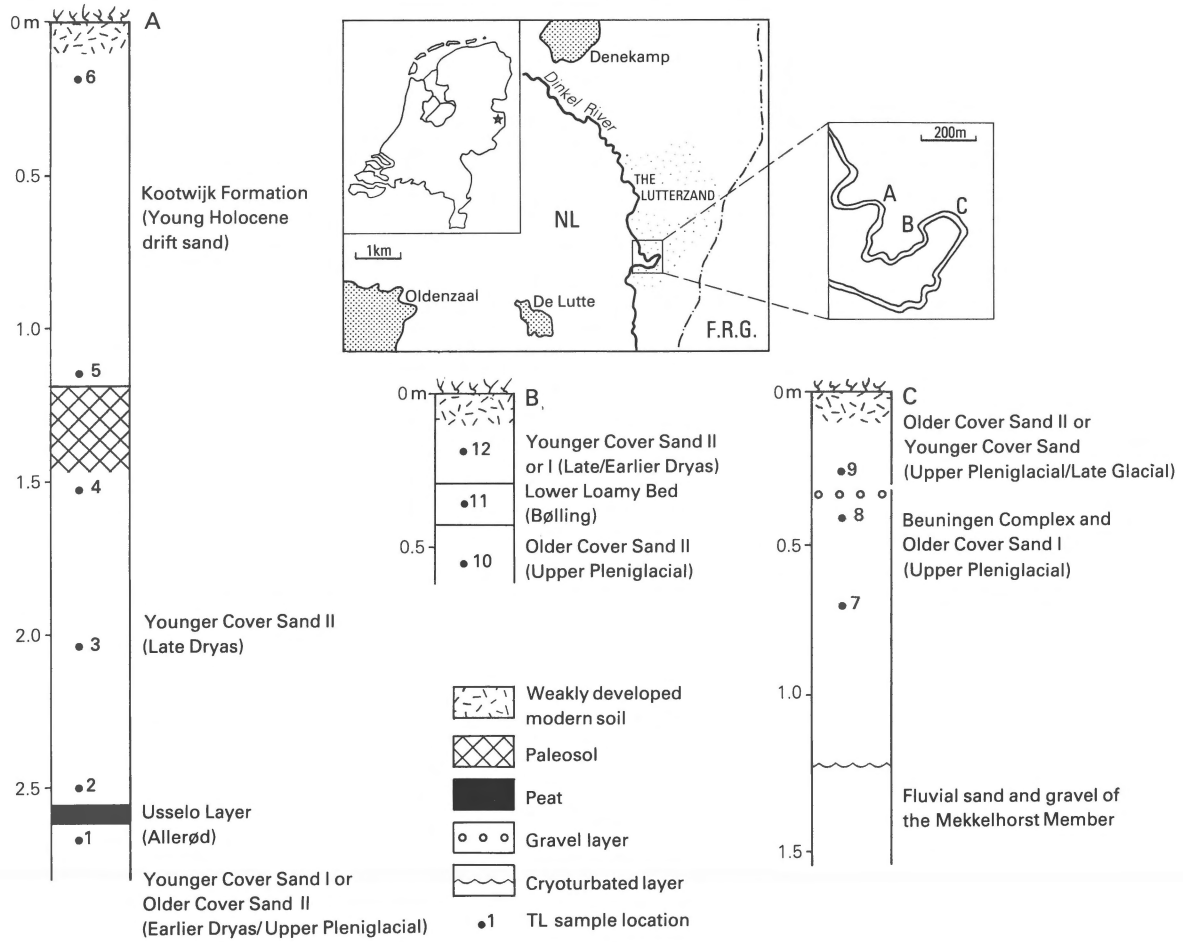

Fig. 1. Location of the natural sections along the Dinkel River in the Lutterzand area and corresponding litho- and chronostratigraphy (according to Van der Hammen & Wijmstra 1971) (chronostratigraphical classification between brackets). The position of the TL samples is indicated.

thus recorded. Thermoluminescence is the emission of light when these charges are released from the defects during heating and recombine elsewhere within the crystal. These charges may also be released by exposure to light (e.g. sunlight or a laboratory lamp). Eolian sediments, for instance, experience ample exposure to light during transportation and are usually deposited with a very low residual TL level. If a constant radiation intensity is assumed the increase of the TL intensity is proportional to the time elapsed after deposition. The amount of radiation to which a sample is exposed per unit of time is called the dose-rate and is obtained by measuring the radioactive content of the sediment (see below). Only charges which remain trapped for a long period (on the order of 10^6 yr) can be used for dating and these charges are released at high temperatures during measurement.

In the laboratory the TL signal is measured in a TL reader. A small sample is heated to about 500° C at a fixed rate and a photomultiplier tube measures the emitted light. An example of a glow curve, where the TL-signal is plotted against the temperature, is presented in Fig. 2. The unstable part of the signal in the low temperature range is usually eliminated by a preheating procedure. Moreover, possible long-term fading of the signal has to be checked and corrected for. The natural

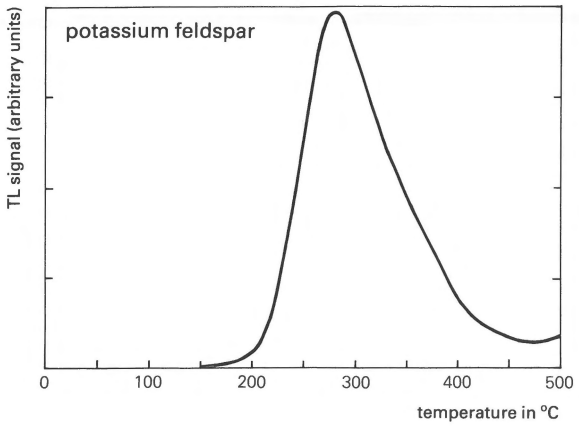

Fig. 2. Typical glowcurve of the natural TL-signal (no preheat) of a potassium feldspar separate of Younger Coversand I (sample 1). Heating rate 10° C/s, Schott UG-11 filter.

TL-signal of a sample is compared with the signal from subsamples that have been given a known amount of (e.g. β) radiation in the laboratory. The amount of radiation equivalent to that which produced the natural TL-signal has to be calculated. For that purpose it is also required to expose subsamples to a light source (the sun or a lamp) that bleaches (part of) the TL-signal. Several methods to obtain the Equivalent Dose (ED) are discussed below. The ED is calculated for a range of temperatures and must be constant. If this is the case a plateau exists when the ED is plotted against the temperature and the ED value can be used for the age determination. The age equation is expressed as

$$\text{TL age} = \frac{\text{equivalent dose}}{\text{dose-rate}}$$

Radiation doses are given in the Gray (Gy) units.

Review of methods of equivalent dose (ED) determination

Several techniques have been developed to obtain the ED for sediments which may not have been well-bleached when they were deposited. Those include the partial-bleach (R-gamma) method, described by Wintle & Huntley (1980) and Wintle & Prószyńska (1983) for fine-grained material. For this method two TL versus dose growth curves are constructed by adding laboratory doses both to subsamples with natural TL and to subsamples that are bleached for a short time. The intercept of the two lines on the dose-axis gives the ED (Fig. 3A). This assumes that the signal $I(T) = I_0(T) + I_d(T)$. $I_0(T)$ is the signal that was in the sample at the time of deposition, which contains both an unbleachable component and the fraction of the previous bleachable TL signal which was not totally removed by sunlight exposure. $I_d(T)$ is the TL due to the radiation dose received by the sample after burial (Huntley 1985). It assumes that the fractional bleaching of $I_d(T)$ is independent of that radiation dose. This method has been applied successfully to fine grain silts (Berger 1984, 1985, Berger et al. 1987), even when TL growth has been shown to be non-linear.

This technique has not been adopted for sediments with a larger grain-size. Instead techniques have been developed which involve the measurement of the TL response of two, separated mineral components, quartz and potassium feldspars (Fig. 3B) (Mejdahl 1985). This method relies on the different bleaching behaviour of the two minerals and the fact that potassium feldspars have a substantial internal dose-rate. The total dose-rates differ by about a factor of two. Kolstrup & Mejdahl (1986) used this approach for eolian sand which had filled frost wedges in Denmark. In this case the ED is chosen by constructing TL versus dose growth curves for the two minerals. Sets of residual TL signals were constructed using different bleaching times and corresponding doses were obtained when the growth curves were extrapolated to intercept the residual levels (Fig. 3B). The pair of residual signals which was assumed to be the residual level at deposition was that for which the accumulated doses gave equal ages when the appropriate dose-rates were applied.

More recently other methods have been developed because problems were encountered in the extrapolation of the growth curve for quartz; the response became non-linear by 50 Gy. Lundqvist & Mejdahl (1987) measured the TL from potassium feldspar only. Bleaching experiments were carried out using natural sunlight and a total bleach meth-

od (Fig. 3C) was applied to obtain the ED. The use of the residual obtained after a 12 hour bleach by a lamp was justified by a plateau being obtained for the equivalent dose as a function of temperature.

Further use of the dose plateau as the basic criterion for accepting the ED has been discussed by Mejdahl (1988). In that paper he described the 'plateau method', whereby a range of residual TL values is obtained by exposing subsamples for different periods of time. The residual value which resulted in the best plateau for the ED as a function of temperature should then be used. This could be applied either to the additive dose method (as in the methods described above) or to the regeneration method of ED determination. In the latter case subsamples are first bleached to a residual TL level and subsequently the TL signal is regenerated by adding several doses. The laboratory dose needed to attain the natural TL level is the ED (Fig. 3D).

The additive dose-plateau method was used for ED determination in a preliminary study on one of the Younger Coversand I samples from the Lutterzand area (Dijkmans et al. 1988). Both daylight and sunlamp (SOL-2) exposures were used. It was found that for short bleaching times (10–20 minutes of lamp exposure) the ED values decreased with increasing glow curve temperatures, whereas for longer bleaching times the values tended to increase. A reasonable ED plateau was obtained for a residual signal obtained after 40 minutes exposure to SOL-2 and this ED was used to obtain a preliminary TL age estimate.

Procedure and results

Sample preparation and TL measurements

The bulk samples were treated with H_2O_2 to remove possible organic matter and then sieved. Heavy liquid separation of potassium feldspar was achieved using non-toxic sodium polytungstate with a specific gravity of 2.58 and the light grains were then etched in 10% HF for 40 minutes. Instead of using the 100–300 μm grains (Lundqvist & Mejdahl 1987), a more restricted grain-size fraction

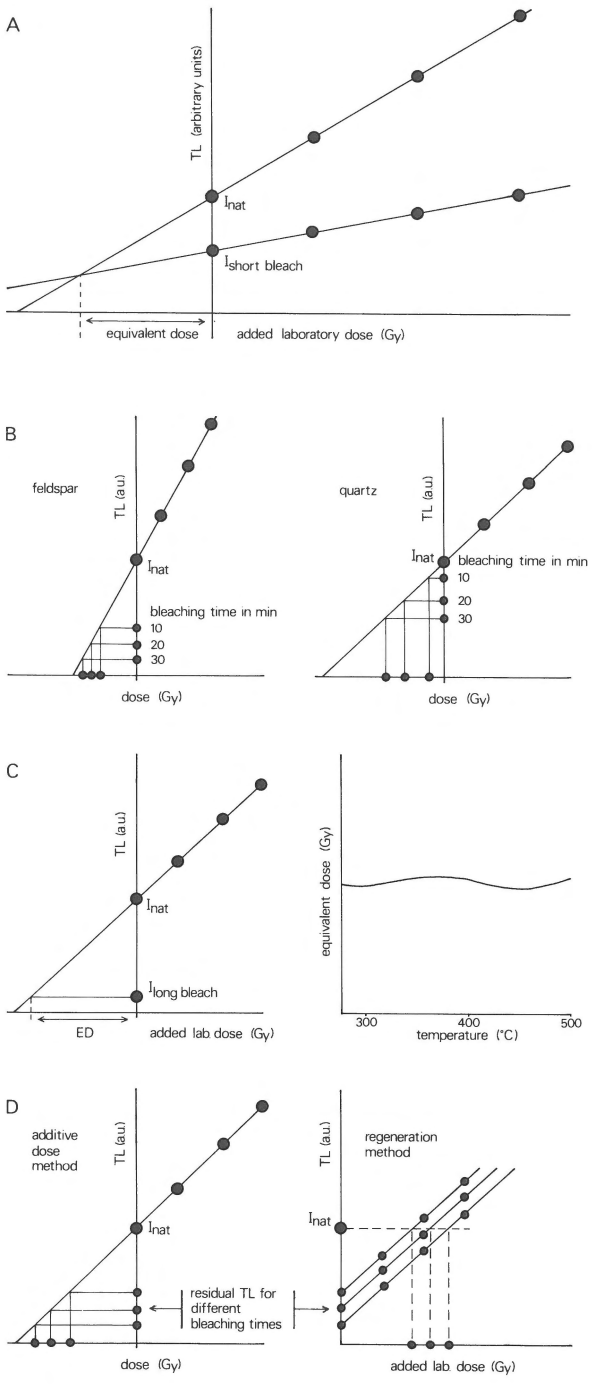

Fig. 3. Explanation of several methods to determine the Equivalent Dose (ED). A. The partial bleach method. B. The quartz-feldspar method. C. The total bleach method (left) and an example of a plateau of the ED as a function of temperature (right). D. The additive dose method and the regeneration method. The latter can both be used in combination with the plateau method for partially bleached sediments.

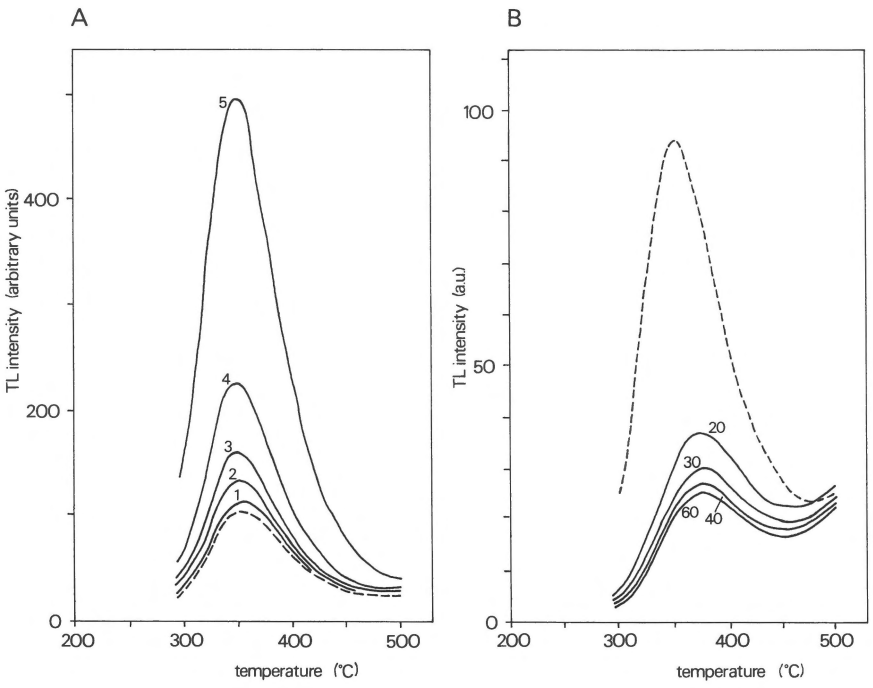

Fig. 4. Representative glow curves of potassium feldspar separates from a Weichselian coversand sample (sample 11) following the procedure of the present study (preheat at 290° C for 10 s; heating rate 10° C/s; UG-11 filter; black body had not been subtracted; each line represents an average of four measurements). Only the relevant part of the temperature range is shown. A. Natural TL (broken line) and additive doses: (1) 2.6 Gy, (2) 6.5 Gy, (3) 13 Gy, (4) 26 Gy and (5) 65 Gy. B. natural TL (broken line) (note scale differences between Fig. A and B) and residual TL after bleaching samples with natural TL. Bleaching time, using the SOL-2 lamp, is indicated in minutes.

(as indicated in Table 2) was used to reduce systematic errors in the β dose calculation as proposed by Dijkmans et al. (1988). The choice of grain-size was determined by the natural grain-size distribution for each sample and the amount of sample material available. The automated Risø reader (Bøtter-Jensen et al. 1983, Bøtter-Jensen 1988) at the Godwin Laboratory in Cambridge (U.K.) was used for the TL measurements. A Schott UG 11 (ultraviolet) filter was placed between the sample and the photomultiplier tube to enhance the TL-signal from feldspar, and a heating rate of 10° C/s incorporating a preheat for 10 s at 290° C (Mejdahl & Winther-Nielsen 1982) was employed. Subsamples of 20 mg were weighed and used for each glow curve and second glow normalization was performed only if the reproducibility was poor. Most of the irradiations were carried out using the $^{90}Sr/^{90}Y$ source in the Risø reader. The software developed by Dr. R. Grün was used for calculations and graphics.

Bleaching was carried out using a sunlight simulator (SOL-2 from Dr. Hönle, Martinsried, F.R.G.) which has a spectral distribution similar to natural sunlight and produces a constant intensity up to 6.5 times that of natural sunlight. Typical bleaching responses for potassium feldspar of a coversand sample (equivalent to the present sample 1) and of a late Holocene drift sand sample (equivalent to the present sample 6) have already been published (Dijkmans et al. 1988).

As an example, glowcurves for potassium feldspar of one of the coversand samples are presented as Fig. 4. The TL signal increases with additive dose, whereas it decreases rapidly by sunlamp exposure. The glowcurves of a late Holocene drift sand sample (Fig. 5), on the contrary, clearly show that the natural TL-signal contains only a small bleachable component. In other words, only a very small TL signal has accumulated in the short period after deposition of the drift sand sample.

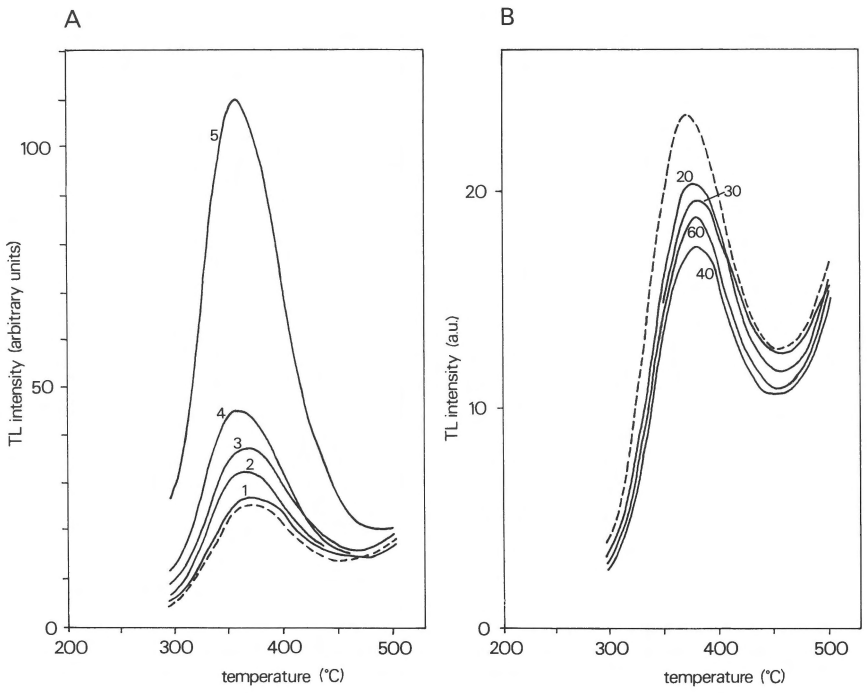

Fig. 5. As Fig. 4, for a late Holocene drift sand sample (sample 5). Additive doses are (1) 0.4 Gy, (2) 1.1 Gy, (3) 2.2 Gy, (4) 4.3 Gy and (5) 10.8 Gy. Note the difference in bleachable TL-signal between the drift sand and the coversand.

A small fading correction of 4% for potassium feldspars separated from eolian sand in Denmark had to be applied to the feldspar EDs by Kolstrup & Mejdahl (1986). Therefore, short term fading tests were carried out on six of the Lutterzand samples. The grains were irradiated and stored at 125° C for two days before being measured and compared with freshly irradiated grains. Both sets of samples were measured using the 10 s preheat at 290° C, as used for all TL measurements, and signal loss of less than 4% was observed. A significant difference in the data sets would have been expected if there was an anomalous fading component of the type described by Clark & Templer (1988). A long term fading test was also carried out. For this purpose samples were again irradiated, but this time stored at room temperature for two months before being measured and likewise compared with freshly irradiated samples. Again a signal loss of about 4% was observed and consequently neglected.

Equivalent dose (ED) determination

The additive dose-plateau method was also applied to the series of 12 samples in the present study. However, poor plateaux were often found as exemplified in Fig. 6, and the method was considered unsatisfactory for routine application. The main causes probably were the lack of TL response above 400° C, as shown in Fig. 4 & 5, and also the very slight shift of the TL signal to lower temperatures with increasing radiation dose. Such a shift, if caused by the presence of a second order kinetic TL component as reported for feldspars by Levy (1982), will result in non-linear growth curves for temperatures affected by this behaviour. On the other hand the total glow curve area increases linearly with dose. In this case shifting the peaks so that their maxima coincide, as proposed by Berger & Huntley (1982) and later justified by Chen et al. (1983), can be used. In practice this is difficult to apply for such a sharply rising and falling glow curve if there is any random thermal delay between the thermocouple temperature and that of the feld-

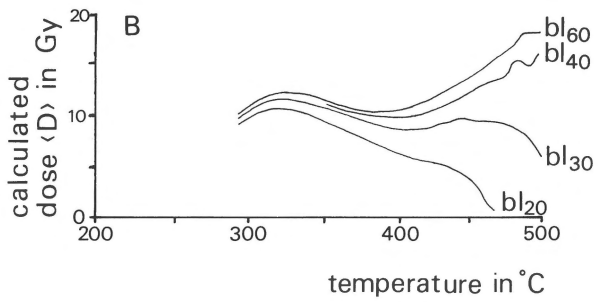

Fig. 6. Dose versus temperature plots for four different bleaching times (20, 30, 40 and 60 mins, SOL-2 lamp) indicating poor plateau and increasing dose with bleaching time (sample 11).

spar grains. Possible causes for poor plateau are further indicated by Dijkmans & Wintle (1989). For these reasons the integral about the peak was used for the growth curve.

Four bleaching times (20, 30, 40 and 60 minutes) were then used to obtain four bleached TL levels,

$$I_b = I_0 + f\, I_d, \qquad (1)$$

where I_0 is the TL signal at deposition, I_d is the TL due to radiation dose since deposition, which can be bleached by the lamp, and f is the fraction of I_d which survives the light exposure. The eolian sands used in the present study are considered to have been well-bleached (Dijkmans et al., 1988: Fig. 5). Extrapolation of the growth curve until it intersects with the projected I_b level will produce a dose value D (Fig. 7B). Values of D increase with increasing bleaching time as also shown in Table 1. The relationship between D and the true ED will be given as

$$ED = D/(1 - f), \qquad (2)$$

where f is taken from equation (1). This is almost the same as method (a) of Wintle & Huntley (1980). In their method the value of D is obtained by regenerating the TL signal by irradiation after bleaching. In the present study values for f were obtained in a similar way for individual samples and the procedure is indicated in Fig. 7C. The sample was exposed to light for 5 hours using the SOL-2 lamp; a small part was measured (I_B) and the rest was given a gamma dose of about 34 Gy. Part of this was also measured ($I_{B\,+\,gamma}$) and subsamples of the remaining irradiated material were exposed to the lamp for a short bleach (20, 30, 40 and 60 min) and subsequently measured (I_{SB}). The fraction f of the gamma-induced TL that is left after various light exposures can thus be obtained.

For each bleaching time the value is similar for each sample. Individual values and the detailed methodology have been published elsewhere (Dijkmans & Wintle 1989). The values of f that have been used to obtain the values of ED from the

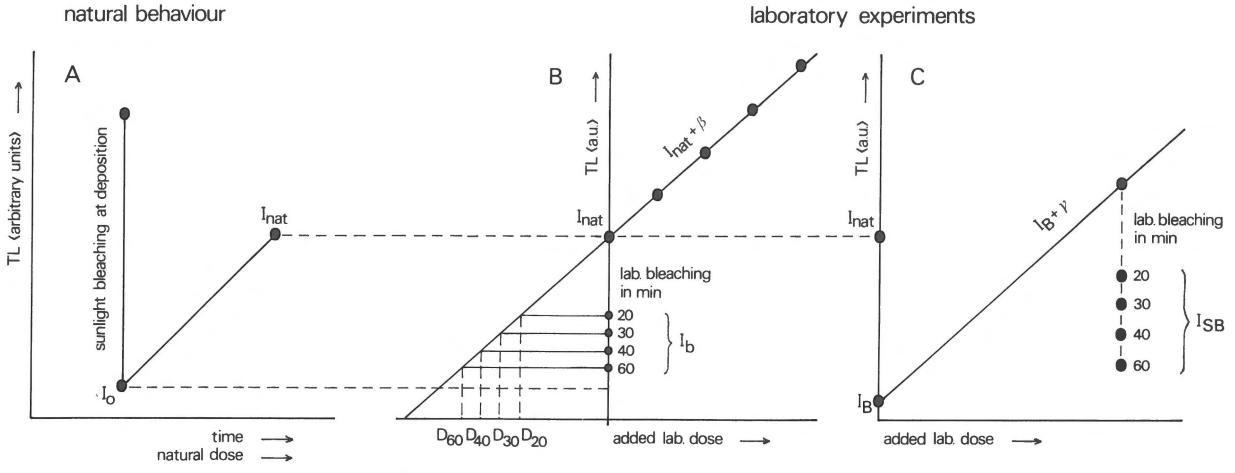

Fig. 7. Explanation of the procedure of ED determination used in the present study. A. Natural behaviour of a sample during geological time. B. determination of dose values (D), which are dependent on the used bleaching time. C. Method to determine the factor f (explained in detail bij Dijkmans & Wintle 1989).

values of D using equation 2 are 0.249 for t = 20 mins, 0.219 for 30 mins, 0.189 for 40 mins and 0.162 for 60 mins. These values for f are the effective mean f values for the 12 samples as argued by Dijkmans & Wintle (1989). The results are presented in Table 1. Using this method, it appears that the ED values calculated from different bleaching times only show very little variation which is not systematic.

Dose-rate determination

The radiation absorbed by the potassium feldspar fraction has the following components: (a) α radiation from inherent U and Th in the grains, (b) β radiation from the bulk sample, (c) β radiation from K and Rb in the grains, (d) gamma radiation from the immediate environment of the sample and (e) a component resulting from cosmic radiation. The calculated and measured values of these components are given in Table 2 for the twelve samples.

(a) α countings of three of the present samples were reported by Dijkmans et al. (1988). The values of about 0.3 Gy/ka for potassium feldspar grains are assumed to be equal for all samples. An efficiency factor of 0.2 was assumed from measurements reported by Kolstrup & Mejdahl (1986) giving an α dose-rate of only 0.06 Gy/ka for all of the present samples.

(b) External β radiation from the bulk sample was measured by a thick source β counter (Sanderson 1988). A relative attenuation factor was applied to the calculated dose-rate depending on the grain-size fraction that was used. Moreover a correction corresponding to a water content of 10% (0.889) was applied. Although the present water content at the natural sections is 6% or less, an average of 10% is considered as more realistic in these sediments (Dijkmans et al. 1988). The resulting values are given in Table 2.

(c) The K content of the feldspar grains was measured using a GM multicounter system (Bøtter-Jensen & Mejdahl 1985) (Table 2), in order to determine the internal β radiation from K and Rb in the grains. It is not necessary to measure the Rb content, since there is a strong correlation of Rb with K with a K : Rb ratio of about 270 : 1 (Mejdahl 1987). The corresponding dose-rate was calculated by applying conversion factors taken from Nambi & Aitken (1986) and considering the absorbed β dose fraction applicable to the corresponding grain-size fraction.

(d) Usually the gamma radiation and the cosmic ray contribution are measured directly in the

Table 1. Measured values of Dose (D) for the temperature range between the half peak height and calculated values of the equivalent dose (ED) using the factor f, for the twelve samples from the Lutterzand. The standard deviation of the mean ED only is the variation of the four ED values. All units in Gy

Sample No.	D_{20}	D_{30}	D_{40}	D_{60}	ED_{20}	ED_{30}	ED_{40}	ED_{60}	mean ED ± 1σ
Lutte 6	1.5	1.4	1.6	1.9	2.0	1.8	2.0	2.3	2.0 ± 0.2
Lutte 5	−0.1	0.2	0.5	0.3	−0.1	0.3	0.6	0.4	0.3 ± 0.3
Lutte 4	8.9	8.0	9.8	11.1	11.9	10.2	12.1	13.2	11.9 ± 1.2
Lutte 3	9.0	9.9	10.1	10.3	12.0	12.7	12.5	12.3	12.4 ± 0.3
Lutte 2	9.8	10.2	10.9	11.4	13.0	13.1	13.4	13.6	13.3 ± 0.3
Lutte 1	10.8	11.7	12.1	11.9	14.4	15.0	14.9	14.2	14.6 ± 0.4
Lutte 12	8.5	9.6	9.3	10.4	11.3	12.3	11.5	12.4	11.9 ± 0.6
Lutte 11	9.0	10.3	10.9	11.1	12.0	13.2	13.4	13.3	13.0 ± 0.7
Lutte 10	10.0	10.6	11.0	11.5	13.3	13.6	13.6	13.7	13.6 ± 0.2
Lutte 9	9.6	10.7	10.7	11.1	12.8	13.7	13.2	13.3	13.3 ± 0.4
Lutte 8	14.6	15.5	16.1	16.6	19.4	19.8	19.9	19.8	19.7 ± 0.2
Lutte 7	14.4	14.8	15.2	16.1	19.2	19.0	18.7	19.2	19.0 ± 0.2

field by a portable scintillation counter. However, this was not available in the present study. A second approach for determining the environmental radiation (without the cosmic contribution) is gamma spectrometry in the laboratory of a relative large sample. This has been done for several eolian sand samples from the Lutterzand area and documented by Wintle & Dijkmans (1988). A consistent ratio was found between the gamma dose-rate and the mean β dose-rate obtained by different methods. It was argued that, within a limited geographical area, such as the Lutterzand, the gamma dose-rate of homogeneous material can be obtained by using the β dose-rate and a conversion factor. This factor was established to be 0.42 with an error of only 4%. This number was applied to the (dry, infinite, external) β dose-rate of the samples in the present study. A water correction of 0.90, corresponding to a 10% water content and a value of 1.1 for h_{gamma} (Readhead 1987) was applied in the calculation.

(e) The cosmic ray contribution was considered to be 0.14 Gy/ka for all samples. At the surface the dose rate is 0.28 Gy/ka and rapidly decreases to 0.14 Gy/ka with depth as the soft component of the cosmic radiation is absorbed (Aitken, 1985).

Thermoluminescence dates

The mean ED values shown in Table 1 and the total dose-rate from Table 2 have been used to calculate the TL age of the twelve sand samples (Table 3). The TL age of the two late Holocene drift sand samples agree well with the expected ages. Nevertheless the youngest sample (No. 6) shows a higher TL age than the underlying sample (No. 5), illustrating the large error for these young samples. Most likely the age of these two samples should be almost identical.

The TL ages of some of the coversand samples approach the expected ages considering the upper uncertainty (samples 4, 2, 9), although they are somewhat too young. Nevertheless the remaining seven coversand samples show TL ages that are 20–50% too low. This problem of low TL ages has also been encountered during the present research programme by Grün et al. (1989) and Balescu et al. (in press). They worked with potassium feldspar from eolian sands and beach sands and used the same laboratory equipment that was used for the Dutch samples. One possibility for such an underestimation of the ED is that the measured TL is coming from a small number of grains which contain relatively little potassium; on the other hand the internal β dose-rate is calculated using the average measurement for all the grains used for the TL

Table 2. Grain-size fraction (in μm) used for dating, K concentration (in %) measured and dose-rates (in Gy/ka) calculated for potassium feldspar grains from 12 sand samples. The samples are in stratigraphical order. For explanation see text

Sample No.	Grain-size	K	Alpha	Internal beta	External beta	Gamma	Cosmic	Total dose-rate
Lutte 6	90–300	8.6	0.06	0.506	0.671	0.317	0.140	1.694
Lutte 5	90–210	6.0	0.06	0.303	0.717	0.334	0.140	1.554
Lutte 4	90–150	5.3	0.06	0.250	0.612	0.281	0.140	1.283
Lutte 3	150–210	6.9	0.06	0.358	0.659	0.311	0.140	1.528
Lutte 2	90–210	5.3	0.06	0.269	0.706	0.329	0.140	1.504
Lutte 1	150–210	7.2	0.06	0.375	0.870	0.411	0.140	1.856
Lutte 12	90–210	9.6	0.06	0.482	0.855	0.398	0.140	1.935
Lutte 11	90–210	5.1	0.06	0.260	0.980	0.457	0.140	1.897
Lutte 10	90–210	6.7	0.06	0.339	0.703	0.327	0.140	1.569
Lutte 9	90–210	7.6	0.06	0.384	0.593	0.276	0.140	1.453
Lutte 8	90–210	13.0	0.06	0.655	0.718	0.335	0.140	1.908
Lutte 7	90–210	12.4	0.06	0.624	0.532	0.248	0.140	1.604

analysis. Another cause for error could be the choice of the UG-11 filter. Recent measurements by Grün et al. (1989) demonstrated that larger EDs could be obtained using a filter which passes in the blue rather than in the ultra-violet part of the spectrum. This aspect needs further investigation.

Discussion and conclusions

1. A new approach was applied to determine the ED. Although the dose values obtained increased with bleaching time, the ED for all twelve samples converged when a factor f was applied. It appeared possible to obtain a value for the ED with only a very small uncertainty. This is in accordance with the theoretical basis of the method as presented by Dijkmans & Wintle (1989). Although the TL age of most of the samples is still too low, the use of the factor f to determine the ED further brings the TL ages nearer to the expected ages.
2. For most of the coversand samples the 'apparent' TL age does increase with depth within the sections. Moreover the highest TL ages have been obtained for the Older Coversands. There seems to be a systematic underestimation of the age. This is likely to have a methodological background as it was also observed by other members of the research group for samples from other localities. The reason for this has not yet been established and needs further research. On the basis of the present results, however, it is not likely that lithostratigraphical units of the Weichselian coversands in NW Europe can be distinguished by the TL dating method. Probably the age difference of these deposits is too small to be registered by TL dating.
3. The underestimation of the TL age is larger for the Older Coversand I samples (below the Beuningen gravel layer) than for any other of the samples. This might be explained by the fact that these samples possibly contain a fluvial component as indicated by Van Huissteden & Vandenberghe (1988), although this did not show at the sample location. However, it must be mentioned that the upper age of the Older Coversand I deposits is not well established. Kolstrup (1980) gives an age of 19,100 ± 180 B.P. (GrN-8594: Staphorst extract) for the beginning of the formation of the Beuningen Gravel Bed and therefore of the upper limit of the Older Coversand I deposition. The present samples from the Lutterzand area suggest that the upper limit is even lower than that, assuming that the underestimation of the TL age is a constant fraction of the true age. It is uncertain whether the formation of the Beuningen Gravel

Table 3. Thermoluminescence ages for twelve eolian sand samples from the Lutterzand area. Y.C.S. = Younger Coversand; O.C.S. = Older Coversand; expected ages after Koster (1988)

Sample No.	Lithostratigraphy	Dose rate in Gy/ka	Equivalent dose in Gy	TL Age in ka	Expected age in ka
Lutte 6	Kootwijk F.	1.694	2.0	1.2 ± 0.2	< 1
Lutte 5	Kootwijk F.	1.554	0.3	0.2 ± 0.2	< 1
Lutte 4	Y.C.S. II	1.283	11.9	9.3 ± 1.0	10–11
Lutte 3	Y.C.S. II	1.528	12.4	8.1 ± 0.5	10–11
Lutte 2	Y.C.S. II	1.504	13.3	8.8 ± 0.5	10–11
Lutte 1	Y.C.S. I/O.C.S. II	1.856	14.6	7.9 ± 0.4	11.8–14
Lutte 12	Y.C.S. II/I	1.935	11.9	6.2 ± 0.5	10–12
Lutte 11	Lower Loamy Bed	1.897	13.0	6.9 ± 0.5	12–13
Lutte 10	O.C.S. II	1.569	13.6	8.7 ± 0.5	13–14
Lutte 9	O.C.S. II/Y.C.S.	1.453	13.3	9.2 ± 0.6	10–14
Lutte 8	O.C.S. I	1.908	19.7	10.3 ± 0.8	± 22.5–29
Lutte 7	O.C.S. I	1.604	19.0	11.8 ± 1.0	± 22.5–29

Layer began synchronously for an extensive area and C-14 ages from that period are extremely rare. Additional TL analyses of Older Coversand I samples from various locations are required to solve this problem.

4. For young eolian sands the residual TL at deposition is relatively large compared to the accumulated TL after that event. The uncertainty of a TL age determination will thus be large and a wide variation will undoubtedly occur if duplicates are analysed. This effect resulted in a higher TL age for the uppermost drift sand sample. Nevertheless the TL ages of the late Holocene drift sands agree reasonably well with the expected ages. Moreover TL appeared very suitable to differentiate between eolian sands with a large relative age difference such as the late Holocene drift sands and the Late Glacial coversands. Coversands and drift sands are similar in composition and the Holocene podsolic soil that has developed in coversand is often truncated. The Holocene drift sands often contain a visible amount of dark particles (organic matter) derived from these eroded soils, that enables discrimination of the two eolian sand types in the field. However, a distinction may be troublesome. TL might serve as a tool to discriminate between these two sedimentary units. The dose-rate of these similar materials would be in the same order of magnitude. Therefore only a rough TL measurement (e.g. only an ED determination) would be sufficient for that purpose. Further research is carried out to determine whether different phases of Holocene drift sand formation can be distinguished by TL measurements.

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