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Bien à vous,
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Chronological Separation of Interglacial Raised Beaches from Northwestern Europe Using Thermoluminescence

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Thermoluminescence (TL) age estimates have been obtained on coarse-grained detrital feldspar from Eemian beach sand (substage 5*e*), early Weichselian dune sands (substages 5*d* and 5*b*), and pre-Eemian beach sand. The past radiation dose is obtained using the additive dose method. Even for the oldest samples, which date to 300,000 yr B.P. by other methods, the TL signal is not in saturation and can be doubled by the addition of laboratory radiation doses without saturation being achieved. This is contrasted with the behavior of polymineral, silt-sized grains from loess in the adjacent area. The TL age estimates are systematically underestimated by about 40% when compared with the expected geological ages. However, they are in correct stratigraphic order and demonstrate that stage 5 beach deposits can be distinguished from those resulting from earlier high sea levels using TL signals from potassium feldspars.

INTRODUCTION

For the last two decades, uranium–thorium, electron spin resonance, and amino-acid racemization dating techniques have provided Quaternary geologists with ages from which most of the current Pleistocene shoreline geochronology has evolved. These dating techniques rely, however, upon finding appropriate material *in situ* (e.g., molluscs or corals) and are therefore confined to fossiliferous raised beaches. By contrast, the thermoluminescence (TL) dating technique for clastic sediments (Wintle and Huntley, 1982) is applied to detrital minerals (e.g., quartz and feldspars) and should therefore offer the potential to date raised beaches that lack faunal remains. The objective of the present work is to test this hypothesis by applying the TL dating method to shallow marine sediments from well studied early Weichselian, Eemian, and pre-Eemian coastal sites, in northwestern France and the Channel Islands, located along the eastern margins of the North Sea and the English Channel.

Recent advances in TL methodology have been comprehensively reviewed by Berger (1988). Thermoluminescence dating methods can be applied to either quartz or feldspar grains. The extraction and measurement of feldspars from burnt stones from archaeological sites have been described by Mejdahl (1985a). The same sample preparation methods and a similar approach (Mejdahl, 1985b, 1986) have been used for the dating of aeolian sands in Den-

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mark (Kolstrup and Mejdahl, 1986). Their study provided ages of 40,000 to 17,000 yr by combining the data for both minerals. However, they demonstrated that the upper age limit for dating using quartz from that environment was less than 70,000 yr because of the relatively low saturation level for the quartz signal. Only for dunes from southeastern Australia, where the radioactive content of the sands is very low, has separation of interglacial deposits of different ages on the basis of TL measurements been achieved using quartz grains (Huntley *et al.*, 1985; Gardner *et al.*, 1987; Readhead, 1988). For samples older than about 70,000 yr in an environment containing several ppm of U and Th and about 1% K_2O (as found in northern Europe), the TL signal from quartz is in saturation. Instead potassium feldspars have been used because of their higher saturation level; this would result in a dating limit of about one million yr in this environment.

Mejdahl (1988) has proposed that the upper limit of TL dating applied to the alkali feldspar fraction is determined by the long-term stability of the TL signal rather than by its saturation level. In his study of Tertiary sands, Mejdahl (1986) found ages in the region of 300,000–500,000 yr, rather than 700,000 to 2,000,000 yr predicted from the stratigraphy. He concluded that the ages were underestimated as a result of slow, long-term thermal decay (Mejdahl, 1989). He found an apparent mean life of about 700,000 yr for the higher temperature signal (300–350°C) and concluded that corrections of about 4, 8, and 20% would need to be applied to TL ages of 50,000, 100,000, and 200,000 yr, respectively. These deviations from the known ages cannot be checked in this time region because they are of the same magnitude as the uncertainty in the geological age.

In a study of potassium feldspars from sandy loess in Nebraska, Canfield (1985) found that the TL age estimates were considerably underestimated for samples related to a volcanic ash bed that had been correlated with the 600,000-yr-old Pearlette ash.

In contrast to the results of Kolstrup and Mejdahl (1986), recent studies of younger sands from Denmark (Grün *et al.*, 1989) and the Netherlands (Dijkmans *et al.*, 1988) gave TL age estimates for the potassium feldspar extracts that were up to 40% less than the geological ages based on radiocarbon dates.

With the above results clearly in mind, we set out to test (a) whether we could obtain absolute ages in agreement with the expected geological ages and (b) if not, whether we could use the TL results to discriminate between beach sediments from different interglacial periods.

NATURE AND STRATIGRAPHIC POSITION OF THE SAMPLES

Early Weichselian, Eemian, and pre-Eemian samples were collected from six key marine sections within four distinct geographic areas: Sangatte and Herzeele in northern France, Port Racine in Normandy, Nantois in Brittany, and Belcroute and Portelet on the island of Jersey (Fig. 1). The sites were chosen because of their geographic proximity and similarity to sites previously studied by Balescu (1988). Apart from Herzeele, the sites are beyond the geographic area covered by the amino acid study carried out by Miller and Mangerud (1985). The marine deposits are, in all cases, interdigitated with continental sediments (e.g., littoral dune sand, loess, heads, peat) and palaeosols (Fig. 2). Post-depositional decalcification of these marine deposits, induced by the development of interglacial soils, or the noncalcareous nature of the bedrock geology means that few of these Pleistocene raised beaches are fossiliferous. Their chronology relies mostly on stratigraphic and geomorphic evidence with, however, some references to absolute dates provided by independent dating methods (i.e., U/Th, ESR, and amino acid dates of *in situ* marine shells) and to feld-

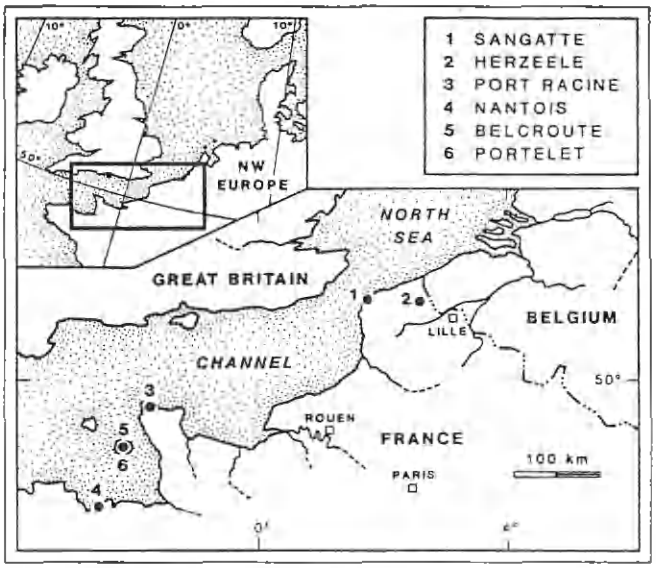

FIG. 1. Map of English Channel region showing location of sampling sites.

spar TL relative dates obtained for the interdigitated Saalian and Weichselian loess deposits using the TL relative dating technique developed by Balescu (1988) and Balescu *et al.* (1988). This relative dating technique could not be used for this project for reasons discussed later.

The stratigraphic position of the samples is shown in Figure 2. We sampled Eemian and pre-Eemian marine deposits at Sangatte, Herzeele, Port Racine, and Belcroute; most of which were deposited in a shallow marine environment. In addition, we also sampled the early Weichselian littoral dune sands of Nantois, Portelet, and Belcroute since aeolian sediments are considered the most reliable material for TL dating (Wintle and Huntley, 1982; Mejdahl and Wintle, 1984; Singhvi and Mejdahl, 1985). Surface samples were also collected from the modern shallow marine sedimentary environment, at Portelet, Belcroute, and Sangatte, in order to check the near-zero TL age of beach sand at deposition.

The samples can be classified according to their presumed age:

Modern beach sediments

POR, BER, SAR: Coarse sand collected on the modern beaches of Portelet, Belcroute, and Sangatte from the foreshore zone.

Eemian and early Weichselian sediments (130,000–74,000 yr)

Belcroute

B2 Nonfossiliferous and noncalcareous coarse sand; collected from the Belcroute raised beach culminating 8-m altitude (based on mean sea level). The latter is correlated to the Eemian (i.e., substage 5*e;* Mangerud *et al.,* 1979 and Mangerud, 1989) on stratigraphic, pedologic and geomorphic evidence (Lautridou *et al.*, 1986a). Indirect geochronologic control is provided by the U/Th dates of travertine and the amino acid dates of shells from the adjacent "8 m" raised beach of the Belle Hougue Cave (Keen *et al.*, 1981).

B3 Noncalcareous coarse sand collected from the littoral dune sand lying on top of the Eemian beach deposit; this dune contains interstratified pedogenetic horizons that are correlated with Saint Germain I and Saint Germain II (i.e., substages 5*c* and 5*a;* Woillard, 1978) according to Van Vliet-Lanoë (Van

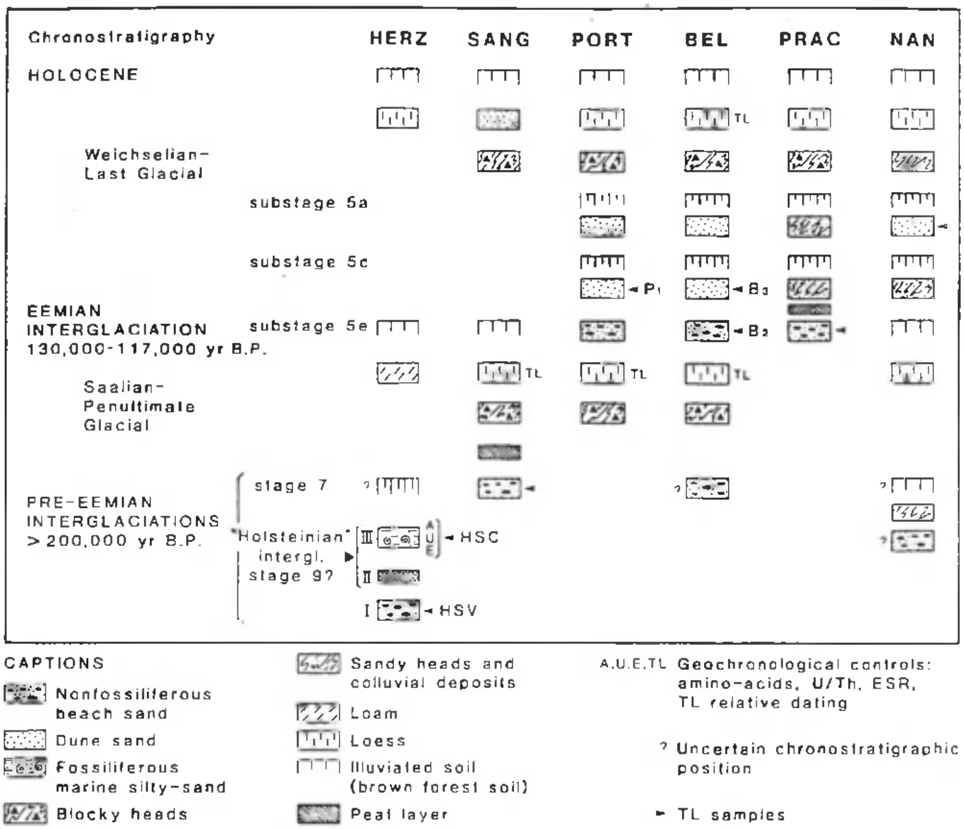

FIG. 2. Schematic representation of the investigated sequences. Chronostratigraphical schemes according to Lautridou (1985) and Lautridou *et al.* (1986a, 1986b). Pedostratigraphical data by Van Vliet-Lanoë (1986).

Vliet-Lanoë, 1986; Lautridou *et al.*, 1986a). The TL sample came from a layer of dune sand deposited during the retreat from the maximum sea level; it is assigned by Van Vliet-Lanoë to Melisey I (i.e., substage 5*d*).

Portelet

P1 Noncalcareous coarse sand collected from the early Weichselian dune sand overlying the Eemian pebble beach deposits of Portelet (8-m altitude) which is correlated with the early Weichselian (substage 5*d*) dune of Belcroute (Lautridou *et al.*, 1986a).

Port Racine

PRAC Nonfossiliferous and noncalcareous coarse sand from the Port Racine raised beach culminating at 5-m altitude (relative to "Niveau Général Français" (NGF) or French mean sea level). This beach is assigned to the Eemian (i.e., substage 5*e*) on stratigraphic, pedologic, and geomorphic evidence (Lautridou, 1985; Lautridou *et al.*, 1986a).

Nantois

NAN Noncalcareous coarse sand collected from the early Weichselian dune sand (Lautridou *et al.*, 1986a); the layer investigated is assigned to Melisey II (substage 5*b*) (Van Vliet-Lanoë in Lautridou *et al.*, 1986a).

Pre-Eemian sediments (>200,000 yr)

The pre-Eemian samples were collected from the middle Pleistocene marine stratigraphic units of Sangatte and Herzeele (northern France). Both definitely predate the Eemian interglaciation but their correlation with either stage 7 or 9 of the deep sea oxygen isotope record remains problematic.

Sangatte

SANG Glauconiferous coarse sand with sparse shell fragments. The sample was collected in the access pit for the Channel Tunnel (for exact location see Antoine (1989); Figure 3, layer 12). The raised beach at Sangatte (culminating at nearly 10 m above NGF) lies on chalky bedrock and is overlain by a nonpolleniferous peat layer (Sommé, 1977; Balescu and Haesaerts, 1984). It is assigned to a pre-Eemian interglaciation on stratigraphic, pedologic, and geomorphic evidence (Balescu and Haesaerts, 1984). However, its correlation with stage 7 or 9 of the deep-sea isotope record is not unambiguously established. It has been tentatively correlated with stage 7 by Haesaerts and Dupuis (1986).

Herzeele

The Herzeele marine formation (culminating at 12 m above NGF) rests on Tertiary clayey sediment. The marine sediments are subdivided into 3 layers (I, II, and III) which are separated by a polleniferous peat layer. The pollen records correlate the middle and the upper marine layers (II and III, respectively) with the Holsteinian interglaciation (Sommé *et al.*, 1978; Lautridou *et al.*, 1986b; Vanhoorne and Denys, 1987).

HSC Calcareous and fossiliferous silty-sand collected from unit 4 in the upper marine layer III. This sediment is characterized by the abundance of mollusc shells (*Cardium edule*) and is considered to have been deposited in a nearshore marine environment (tidal flat). Unit 4 is shown by pollen analysis to be of Holsteinian age. The absolute dates obtained for shells collected from unit 4 are still controversial. Sarnthein *et al.* (1986) and Barabas *et al.* (1988) obtained U/Th and ESR dates of 300,000 to 350,000 yr B.P. which suggest a correlation with stage 9. Further ESR dates were obtained for the same shells by Schwarcz and Grün (1988) who concluded the deposit was from stage 7 with an age of ca. 260,000 yr B.P. On the other hand, molluscs from unit 4 of Herzeele yield a mean *D/L* ratio of 0.31 (Miller and Mangerud, 1985) which implies that they are correlative with the Holsteinian marine deposits ("Cardium sands") of northwestern Germany which have been dated to ca. 200,000 yr by ESR (Linke *et al.*, 1985). On the basis of these conflicting absolute ages, the upper marine layer III (HSC) of Herzeele has been correlated with either stage 7 or 9.

HSV Glauconiferous coarse sand, noncalcareous and nonfossiliferous, collected from the lowest marine layer I. This shallow marine sand has not provided a reliable pollen record but has been tentatively classified as Cromerian (?) by Sommé *et al.* (1978).

PRINCIPLES OF THERMOLUMINESCENCE DATING OF SEDIMENTS

The basis of the TL dating method is that detrital minerals such as quartz and feldspars are deposited with a reduced TL level (i.e., residual TL level) as a result of exposure to sunlight during transport (Wintle and Huntley, 1982). After deposition, the TL level in the mineral grows again as a result of exposure to the natural background radiation resulting mainly from the radioactive decay of U, Th, and K present within the mineral and its surroundings. The resulting TL level consists of a component that is easily bleached or easily removed by light exposure and a small residual TL level that cannot be reduced to zero. Assuming a constant natural background radiation intensity, the increase of TL above the residual level will be a measure of the radiation dose received by the minerals since deposition and thereby of the age. The TL age in 10^3 yr is given by the ratio

$$\text{TL age} = \frac{\text{dose received since deposition or equivalent dose (ED)}}{\text{effective dose rate}},$$

where ED is expressed in grays and the dose rate in grays per 10^3 yr.

The equivalent dose (ED) is defined as the artificial laboratory radiation dose that yields the same TL level as the natural radiation dose received since deposition.

METHODS

Sample Preparation

In our dating technique, the TL is measured using feldspars, extracted from the 150–250 and 250–300 μm grain-size fractions. They were obtained by dry sieving and were subsequently treated with HCl (10%) to remove calcium carbonate and H_2O_2 to remove organic matter. The heavy liquid separation of K-feldspar was achieved using sodium polytungstate with a specific gravity of 2.58 (Mejdahl, 1985a). The separated K-feldspars were etched with 10% HF for 40 min to remove the outer layer which has received alpha radiation from external sources.

TL Measurement

All TL measurements were performed on an automated TL reader (Botter-Jensen, 1988). The TL signals were detected using a photomultiplier tube (EMI 9635B) and a Schott UG11 filter (transmission window 280–380 nm). Because of the large amount of light generated by the samples, a neutral density filter (ND1) was also used. A constant heating rate of 10°C/sec was employed. Sample cups containing 20 mg of K-feldspar grains were heated in N_2 after initial evacuation of the glow oven. TL intensities were normalized by the second glow TL response to correct for small variations in weight between sample cups.

ED Determination

The ED was determined by the additive gamma dose technique. The procedure used is illustrated in Figures 3a and 3b: aliquots of the same natural (unirradiated) K-feldspar sample are given artificial gamma radiation doses. A saturating exponential is then fitted to the experimental data points (Mejdahl, 1985c). The extrapolation toward

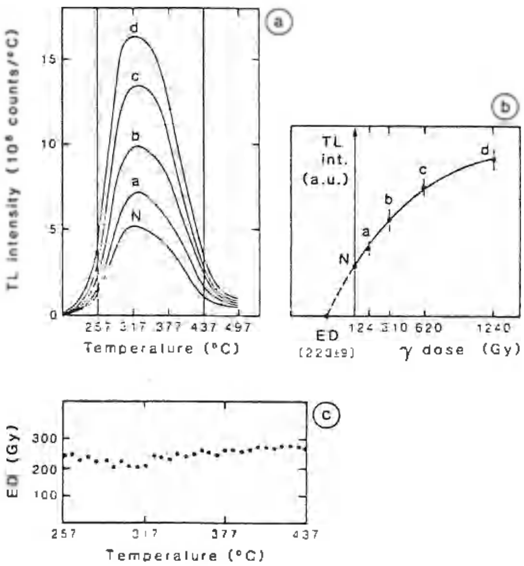

FIG. 3. (a) Representative glow curves for K-feldspars (150–250 μm) from an early Weichselian dune sand (sample P1). N: natural TL signal (unirradiated sample); a, b, c, and d: TL signals of similar samples that have been given additional laboratory γ doses. The samples have been preheated for 62 hr at 140°C prior to glowing. (b) TL growth curve for K-feldspars from the same sample P1, using the additive γ dose technique. γ doses are added to the natural level. The TL signal is integrated over the temperature range 257–437°C. An exponential function is fitted to the points. The intersection of the curve with the dose axis yields the equivalent dose (ED). (c) Plateau test: Equivalent dose (accumulated dose) versus temperature for K-feldspars from the same sample P1.

the dose axis provides the ED intercept. No correction for the residual level has been made (i.e., no residual subtraction has been performed) in view of the very low TL signal yielded by equivalent modern beach sands, as shown in the following section.

The ED was obtained for the glow curve area centered around the high-temperature peaks (i.e., in the temperature range 257–437°C). For each sample, up to 10 replicate ED determinations have been performed, in order to test the reproducibility of the results. In general, the precision of the mean ED value is about ±10–15% at the 1σ level.

Dose Rate Evaluation

The gamma dose rate was either measured *in situ* with a portable gamma spectrometer or estimated from the concentrations of U, Th, and K measured by gamma spectrometry. The external beta dose rate was measured for the bulk sample by thick source beta counting (Sanderson, 1988); it has been corrected for beta attenuation (Mejdahl, 1979) and water attenuation (Aitken, 1985). The K content of the potassium feldspar grains was determined using the Riso GM multicounter system (Botter-Jensen and Mejdahl, 1988). Water contents were calculated using the present-day range of water uptake, since, although they were water-laid, the fossil beach sands would have been well above sea level during Weichselian time. A cosmic dose rate of 0.03 grays/10^3 yr was used for all ancient samples which had present day depths of about 8 m. For Sangatte 0.01 grays/10^3 yr was calculated (Prescott and Stephan, 1982).

RESULTS

TL Characteristics of the Samples

Thermoluminescent minerals are characterized by their glow curves, i.e., plots of TL signal intensity versus temperature. A representative glow curve of K-feldspar from one of the samples dated is shown in Figure 3a. It generally exhibits two natural overlapping peaks occurring around 320° and 350°C, when a 140°C preheating for 62 hr is used prior to glowing.

Saturating Behavior

Representative growth curves (i.e., plots of TL signal versus added gamma dose) for K-feldspar from all the nonmodern samples are plotted in Figure 4. It should be stressed that their natural TL levels have not yet reached saturation.

Bleaching Behavior

The bleaching characteristics have been studied using a sunlight simulator (SOL 2 from Dr. Hönle, Martinsried, FRG). According to the manufacturer, this lamp has a similar spectral distribution to sunlight and produces a constant intensity up to 6.5 times that of natural sunlight.

The natural TL (N) and the residual glow curves of K-feldspar from two modern beach samples (Figs. 5a and 5b) show that both samples (BER and POR) appear to be well bleached. The natural TL of the modern samples is not more than 6% of the signal from the natural TL of the older sands

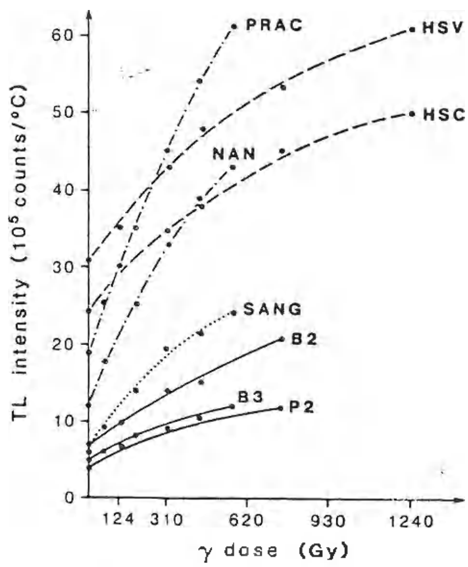

FIG. 4. Comparative TL growth curves for K-feldspars from early Weichselian, Eemian, and pre-Eemian sand samples. TL integral 257°–437°C; UG11 + neutral density (ND1) filters.

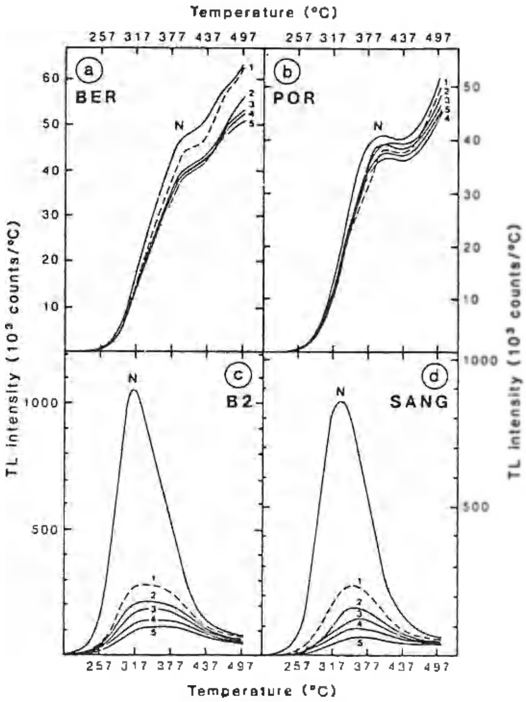

FIG. 5. Residual TL signal in K-feldspars after different exposure times to a SOL 2 lamp. (N) natural TL signal; (1) 5 min of lamp exposure; (2) 10 min; (3) 20 min; (4) 40 min; (5) 80 min. (a and b) modern beach sands; (c and d) Eemian and pre-Eemian beach sands, respectively. UG11 filter, 62 hr preheating at 140°C prior to glowing.

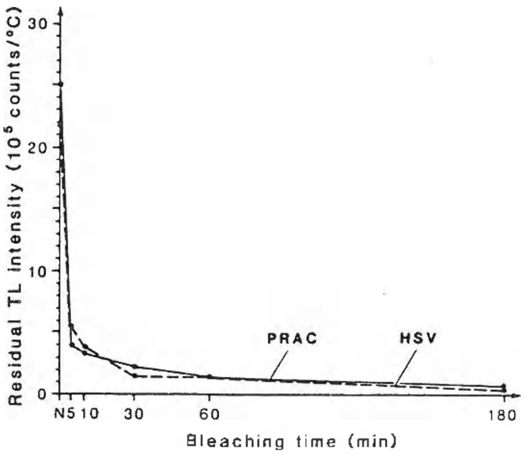

FIG. 6. Bleaching of the TL level in K-feldspars, using a SOL 2 lamp. Samples PRAC (Eemian) and HSV (pre-Eemian). The residual TL signal, averaged over the temperature range 323°–347°C, is plotted as a function of bleaching time (in minutes); (N) Natural TL signal. UG11 filter; 62 hr preheating at 140°C prior to glowing.

from the same sites (i.e., in Belcroute, Portelet, and Sangatte).

Figure 6 compares the K-feldspar bleaching curves (i.e., plots of residual TL level versus bleaching time) of Eemian and pre-Eemian sand samples. The TL signal is removed very rapidly at first, such that about 70 to 80% is lost in the first 5 min of lamp exposure, corresponding to about 30 min of direct sunlight. The residual TL level, which makes up only 6% of the natural TL signal, is reached after about 80 min in both cases. These experiments demonstrate that the coarse feldspar grains from the fossil beach sands are easily bleachable and are likely to have been well bleached at deposition. This study confirms the measurements made on fine grains (4–11 μm) from modern littoral sediments in Spitsbergen (Forman, 1988).

Anomalous Fading

All K-feldspar samples have been preheated at 140°C for 62 hr, just after gamma irradiation (in order to remove the unstable component of the TL signal) below 320°C (Grün *et al.*, 1989). Preheated feldspar samples have been stored at room temperature for 3 to 6 weeks; no significant increase of the ED with the storage time has been observed.

TL Age Estimates Obtained for Feldspars

The estimated mean ED values, the radioactivity data, and the resulting dose rates are listed in Table 1 together with the calculated TL ages for each sand sample investigated. The total dose rates are in the range 0.81–4.11 grays/10^3 yr. The mean ED values obtained for the Pleistocene sediments are in the range 105–453 grays; the calculated TL ages range between 53,000 and 201,000 yr.

Most measured samples yield relatively good plateaux; that is, the ED plotted as a function of temperature remains constant over the 257–437°C temperature range, as shown in Figure 3c.

Figure 7 compares these TL ages with

TABLE 1. TL Results and Radioactivity Data for the Sand Samples Investigated

Sites	Sample	Geological estimates*	ED ± σ (Gy)	Grain size (μm)	Water content (wt.%)	External beta dose rate (Gy/10³yr)	External gamma dose rate (Gy/10³yr)	Internal K content[a] (%)	Internal beta dose rate[b] (Gy/10³yr)	Total dose rate[c] (Gy/10³yr)	TL age ± σ (10³yr)	Expected age (10³yr)
Belcroute	BER	M.Bs	7 ± 0.7	150–250	18	1.50 ± 0.08	0.60 ± 0.01	10.9 ± 0.3	0.61 ± 0.09	2.86	2.4 ± 0.4	~0
	B2	E.Bs	223 ± 31	250–300	10 ± 5	1.68 ± 0.08	1.20 ± 0.02	11.3 ± 0.2	0.79 ± 0.10	3.69	60 ± 9	~120 (substage 5*e*)
	B3	W.Ds	236 ± 18	150–250	10 ± 5	2.43 ± 0.12	1.04 ± 0.02	11.1 ± 0.2	0.62 ± 0.09	4.11	57 ± 5	~110 (substage 5*d*)
Portelet	POR	M.Bs	4 ± 0.4	150–250	4	1.82 ± 0.09	0.74 ± 0.01	10.6 ± 0.5	0.59 ± 0.09	3.30	1.2 ± 0.1	~0
	P1	W.Ds	242 ± 24	150–250	10 ± 5	2.04 ± 0.10	1.09 ± 0.02	11.5 ± 0.2	0.64 ± 0.10	3.80	64 ± 7	~110 (substage 5*d*)
Nantois	NAN	W.Ds	124 ± 12	150–250	10 ± 5	1.11 ± 0.05	0.55 ± 0.01	11.4 ± 0.2	0.63 ± 0.09	2.33	53 ± 6	~90 (substage 5*b*)
Port Racine	PRAC	E.Bs	149 ± 18	150–300	10 ± 5	1.00 ± 0.05	0.45 ± 0.01	12.8 ± 0.1	0.71 ± 0.11	2.19	68 ± 9	~120 (substage 5*e*)
Sangatte	SANG	PE.Bs	105 ± 12	250–300	10 ± 5	0.23 ± 0.01	0.11 ± 0.002	6.5 ± 0.1	0.45 ± 0.05	0.81	130 ± 17	186–245
Herzeele	HSC	PE.Ms	453 ± 55	150–250	33 ± 10	0.97 ± 0.05	0.70 ± 0.01	9.9 ± 0.1	0.55 ± 0.08	2.25	201 ± 26	250 or 300?
	HSV	PE.Bs	409 ± 49	150–250	10 ± 5	1.00 ± 0.05	0.51 ± 0.01	9.7 ± 0.2	0.54 ± 0.08	2.08	196 ± 25	>260 or >300?

Note. *M.Bs: modern beach sand; W.Ds: early Weichselian dune sand; E.Bs: Eemian beach sand; PE.Bs: pre-Eemian beach sand; PE.Ms: pre-Eemian marine (nearshore) sand.

[a] Potassium content of the feldspar grains.

[b] Beta dose rate from inherent potassium in feldspars.

[c] Includes cosmic ray contribution.

the ages expected from independent geological and geochronological evidence.

DISCUSSION

The TL age estimates obtained for the samples correlated with stage 5 underestimate the expected age by about 40%. The TL ages for the early Weichselian dune sands are comparable with those obtained for the Eemian beach sands but cannot be separated from the latter. The analytical precision of our TL technique is thus inadequate to allow any distinction of substages within stage 5. On the other hand, there is a clear chronological distinction between the beach sands from substage 5*e* and those which are thought to be pre-Eemian.

The TL age estimate for Sangatte is also underestimated by 40% if it is correlated with stage 7 (Haesaerts and Dupuis, 1986). The same claim can be made for the upper marine layer III (sample HSC) from Herzeele if it is correlated with stage 9, rather than stage 7. The results from Herzeele show also that there is little difference in age between the nearshore sand from the upper (III) marine layer and the beach sand from the lower (I) marine layer; this conclusion contradicts the tentative hypothesis of Sommé *et al.* (1978).

In spite of the lack of definitive independent dates for Sangatte and Herzeele, the results displayed in Figure 7 imply that the potassium feldspar TL dates are all underestimated by about 40%. This underestimation is similar in magnitude to the systematic underestimation that was obtained in the same laboratory using the same mineral fraction from Danish cover sands (Grün *et al.*, 1989). Such a systematic deviation cannot be explained by any thermal instability which would result in a time-dependent underestimation of the age. The latter behavior has been found for fine polymineralic silt grains from loess (Debenham, 1985; Wintle, 1985a, 1985b; Wintle *et al.*, 1984) and prevents chronological separation of pre-Weichselian loess when this grain size is used for the TL measurements.

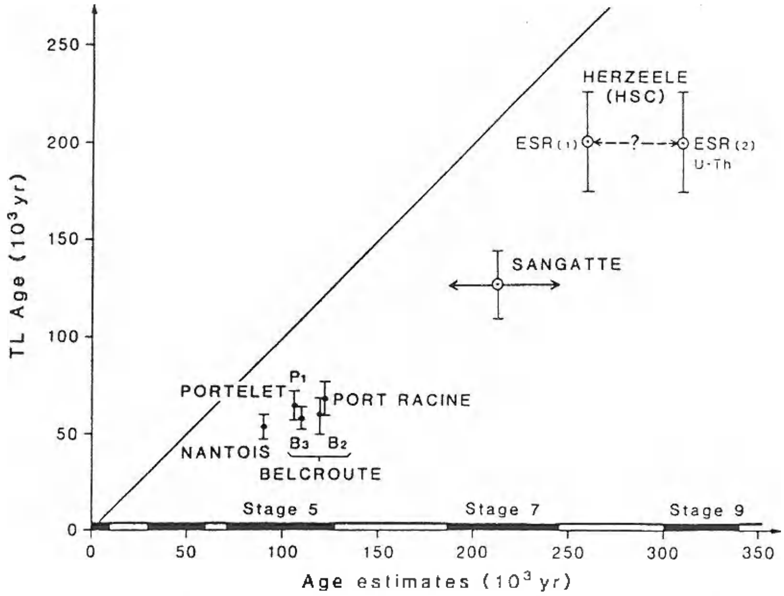

FIG. 7. Feldspar absolute TL ages versus age estimates. ESR (1): dates from Schwarcz and Grün (1988); ESR-U/Th (2): dates from Sarnthein *et al.* (1986) and Barabas *et al.* (1988).

The chronological separation obtained for the sands used in this study is analogous to that obtained for potassium feldspars from the coarse silt fraction of loess in the neighboring parts of northwestern Europe (Balescu *et al.*, 1988). This approach could not be adapted for the larger grained sediments in the current study because of variations in the relative contributions of the internal potassium content to the total dose rate experienced by the grains.

CONCLUSIONS

This preliminary TL study indicates that Pleistocene raised beaches are potentially datable by the TL method when using coarse feldspar grains together with the additive gamma dose technique. We have demonstrated that the modern beach sands are well bleached. Moreover, we have shown that the Pleistocene interglacial beach sands yield underestimated TL ages. However, these are in correct stratigraphical order and lead to a clear chronological discrimination between Eemian and pre-Eemian raised beaches.

The feldspar TL method we suggest offers great potential in providing a consistent relative chronology for otherwise undated Pleistocene raised beaches. This method, therefore provides new perspectives for (1) a better understanding of the Quaternary stratigraphy of the coastal marine sequences and (2) the reconstruction of Pleistocene shoreline history.

TL appears to be a viable alternative to uranium–thorium, electron spin resonance, and amino acid racemization dating techniques when fossils are not present, but more work is needed before the cause of our systematic age underestimation is understood.

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