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SHORT PAPER

Thermoluminescence Dating of the Middle Pleistocene Raised Beach of Sangatte (Northern France)

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TL dating of both quartz and potassium feldspar grains from the Pleistocene beach of Sangatte, at the southern limit of the North Sea Basin, give self-consistent ages of 200,000 ± 45,000, 205,000 ± 14,000, and 229,000 ± 18,000 years, respectively. These results allow the beach deposits to be correlated with oxygen isotope stage 7 (244,000–190,000 yr) (Martinson *et al.*, 1987). The existence of a fossil beach cliff line at 10 m above French O.D. demonstrates that the Strait of Dover was open during the penultimate interglaciation. © 1992 University of Washington.

The Sangatte raised beach, located at the edge of the Strait of Dover (Fig. 1a), is the only known site (apart from Herzeele; Sommé *et al.*, 1978) where middle pleistocene marine and periglacial deposits interdigitate at the southeastern North Sea coastline. Such sites are important since they provide an opportunity to link the marine and terrestrial stratigraphy. In particular, dating the beach sand at Sangatte enables us to put a time constraint on the opening of the Strait of Dover.

Previous estimates of the age of the Sangatte raised beach were based on stratigraphic, geomorphologic, and pedostratigraphic evidence. Initially it was thought to be Eemian (last interglaciation) because of its height above sea level (de Heinzelin, 1966); more-recent studies suggested a pre-Eemian age: Stage 7 (Sommé, 1977; Balescu and Haesaerts, 1984; Haesaerts and Dupuis, 1986) or stage 9 (Antoine, 1989). Previous TL results from the loess deposits (unit F, Fig. 1b) overlying the raised beach (unit B, Fig. 1b) were consistent with their accumulation during stage 6 (Balescu, 1988; Balescu *et al.*, 1988). A recent TL study of potassium (K)-feldspar from the interglacial marine deposit also supported a pre-Eemian age; however, it yielded only relative TL ages because of apparent long-term instability of the ultraviolet component of the feldspar TL signal (Balescu *et al.*, 1991). In this study, we present self-consistent TL age estimates obtained for quartz and for the blue component of the K-feldspar TL signal for the Pleistocene marine deposit of Sangatte.

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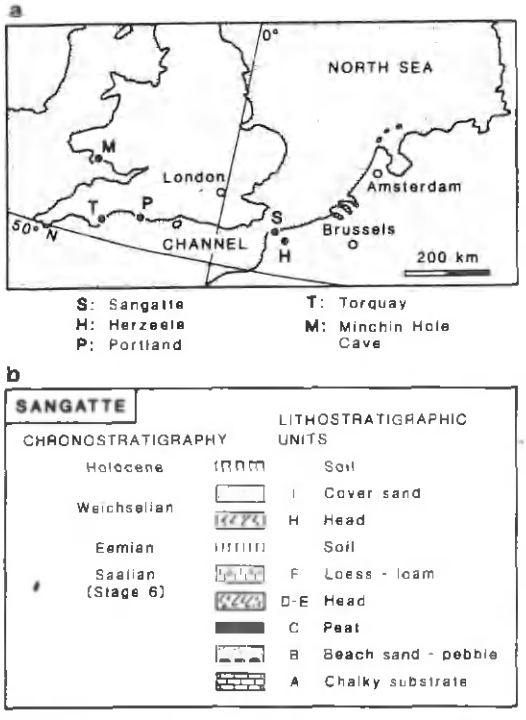

FIG. 1. (a) Map showing location of sites mentioned in the text. (b) Schematic lithostratigraphic succession of the Sangatte section, as observed along the present-day cliff (after Balescu and Haesaerts, 1984).

Two samples (SAN1, SAN2) were collected from the Sangatte raised beach, at a depth of about 15 m (below the surface) in the access pit of the Channel Tunnel (for the exact location see Antoine, 1989, Fig. 6, layer 12; the samples were taken from sublayers 12B and 12D, respectively). This glauconiferous beach sand yielded only a sparse and badly preserved molluscan fauna of boreal aspect, uncharacteristic of a specific interglaciation. No pollen has been found in the peat layer overlying the marine deposit. Palaeolithic Levallois artifacts have been reported from the upper 10 cm of the beach at this site (Antoine, 1989) and have also been found in an equivalent position along the present-day cliff (Sommé, 1977). The overlying sediments contain two soil horizons (Balescu and Haesaerts, 1984), the uppermost being Holocene. A sample was also collected from the nearby modern beach at Sangatte.

The principles of thermoluminescence (TL) dating have been described recently (Aitken, 1985; Berger, 1988). When quartz or feldspar grains are exposed to sunlight, previously acquired TL information is reduced to a stable, but non-zero, residual level. After being covered by more-recent sediment, the TL intensity grows as a result of radiation exposure. A TL age is derived from the ratio of the accumulated dose (ED) divided by the dose rate (D). The ED is determined by TL measurements (see below) and D is derived from the analysis of radioactivity in the sample and its surroundings.

The minerals used for dating the shallow-marine sand are quartz and K-feldspar coarse grains. Quartz was separated from the bulk sample using heavy liquids (2.58–2.70 s.g.) and the grains (150–250 μm) were etched with concentrated HF for 1 hr. Potassium feldspar grains (250–300 μm) were also separated using heavy liquid (<2.58 s.g.). The TL measurements of quartz were carried out in Cambridge with an automated TL reader (Botter-Jensen, 1988) using a blue-transmitting Corning 5-60 and a heat absorbing filter (340–500 nm). The first feldspar measurements were carried out in Cambridge with a UV-transmitting Schott UG11 filter (280–380 nm) (Balescu *et al.*, 1991). They were repeated in Montreal with an automated Daybreak TL reader using a blue-transmitting Corning 7-59/Schott BG39 filter combination (300–500 nm). The EDs were determined by the total bleach method (Singhvi *et al.*, 1982).

Figure 2 shows the results for the quartz. Aliquots were each irradiated with increasing γ-doses (62, 186, and 310 Gy); higher doses were applied but the form of the curve indicated trap creation above 500 Gy (Chawla and Singhvi, 1989). Glow curves (Fig. 2a) were obtained using a heating rate of 5°C/sec in a nitrogen atmosphere. The residual level was reached after 4 hr exposure to a Hönle sunlight simulator (Fig. 2b). Each data point consists of 20 repeated measurements. The ED was determined ev-

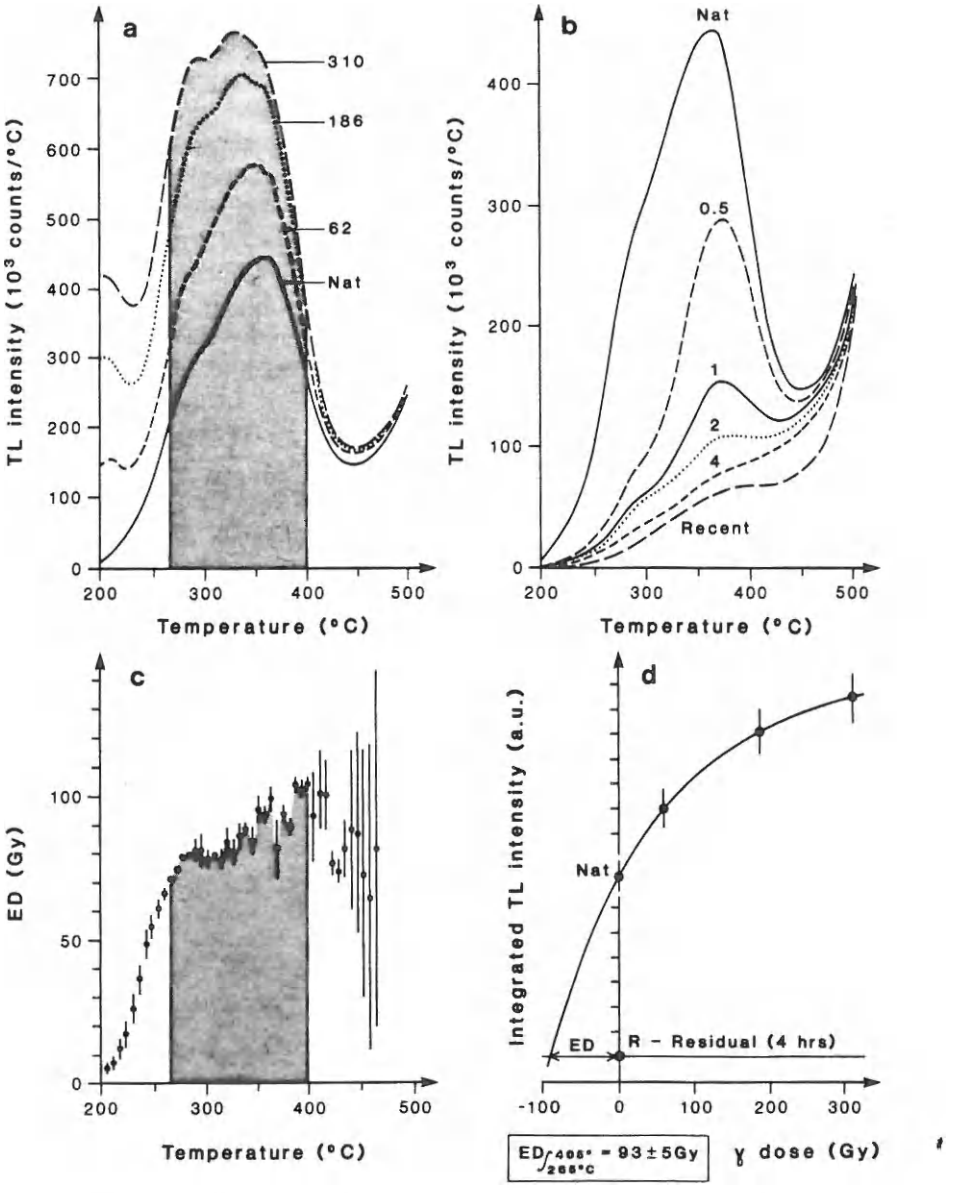

FIG. 2. (a) Glow curves for natural TL and that induced by additional doses of 62, 186, and 310 Gy for quartz extracted from the Sangatte raised beach (SAN 1). Corning 5-60 filter; 5°C/sec heating rate. (b) Natural TL (as in Fig. 2a) and glow curves showing the effect of exposure to the solar simulator for 0.5, 1, 2, and 4 hr compared with the signal from quartz from the recent beach at Sangatte (lowest curve). (c) ED for quartz from SAN-1 obtained as a function of glow curve temperature. (d) Additive growth curve for integrated TL (265°–405°C).

ery 6°C by exponential fitting (Apers *et al.*, 1981; Berger *et al.*, 1987) (Fig. 2c); the ED value for the age equation was obtained using the integral range of 265° to 405°C (Fig. 2d) which corresponds approximately to the half height of the TL signal of the natural sample. This region was used since it contained two TL peaks that overlap (commonly referred to as the 325° and 375°C peaks with lifetimes of $\sim 10^8$ yr; Aitken,

1985). No preheating treatment was performed. No anomalous fading was observed in this temperature range after 6 months.

Similar irradiation and TL measurement procedures were carried out on the K-feldspar grains in both Cambridge (Balescu *et al.*, 1991) and Montreal (Balescu and Lamothe, in press). Figure 3 shows the results for the K-feldspars obtained in Montreal. For each sample, SAN1 and SAN2, replicate ED determinations have been performed. Representative glow curves and growth curve for K-feldspars are shown in Figures 3a and 3b, respectively. The residual TL level was reached after 8 hr exposure to natural sunlight. The ED value for the age equation is averaged in the temperature range between 290° and 340°C. No anomalous fading was found. No correction for long-term fading (Mejdahl, 1988, 1989) has been made.

The results of the radioactivity and TL analyses are reported in Tables 1 and 2, respectively. Similar measurements for the quartz from the modern beach at Sangatte gave an age of <400 yr which agrees with an age of <600 yr obtained using the recently developed optical dating method for a recent beach sand from the same site (Smith *et al.*, 1990). This confirms the assumption that Pleistocene beach sands are easily bleached down to a residual level which is very close to the levels observed in a modern sample (Fig. 2b). This was achieved in quartz after about 4 hr exposure with a sunlight simulator (which corresponds to about 18 hr sunlight) and in K-feldspars after 8 hr exposure to natural sunlight. Longer bleaching did not significantly affect the residual level. The natural TL of the modern feldspar sample from Sangatte was less than 6% of the natural TL for the older beach sand. This was also found for other sands in this area (Balescu *et al.*, 1991).

The external β-dose rate and the environmental γ-dose rate were deduced from γ spectrometric analysis, neutron activation analysis, or plasma-emission analyses (Table 1). Dose rates were obtained using conversion factors (Nambi and Aitken, 1986). Allowances were made for β attenuation (Mejdahl, 1979). Dose rate values were corrected for measured water contents (10 ± 5%) and cosmic dose rates were estimated from the burial depth of the samples (Prescott and Hutton, 1988). The internal U and Th contents of the quartz grains were derived from neutron activation analysis; the internal K content of the K-feldspar grains was determined either using a Riso GM

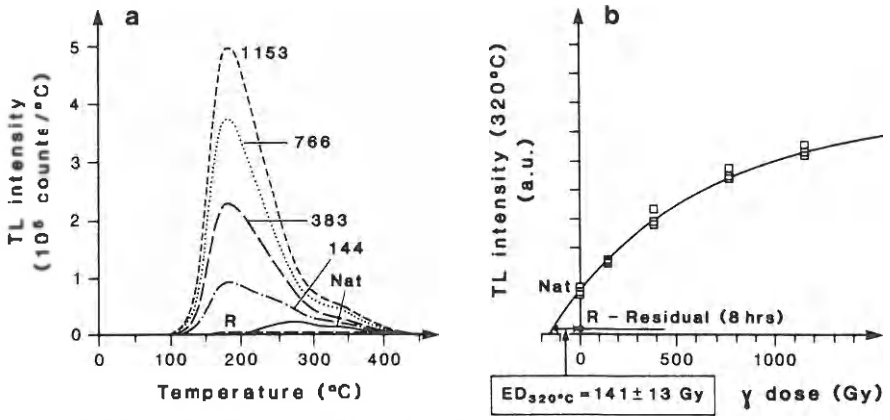

FIG. 3. (a) Glow curves for natural TL and that induced by additional doses of 144, 383, 766, and 1153 Gy for K-feldspar from SAN-1; R indicates residual TL signal after 8 hr exposure to natural sunlight. Corning 7-59/Schott BG39 filter combination; 2°C/sec heating rate. (b) Additive growth curve for the same K-feldspar subsample as in a. The TL signal is measured at 320°C.

TABLE 1. RADIOACTIVITY DATA

Samples	Depth (m)	Mineralogy	Grain-size (μm)	External β dose rate (Gy/10³ yr)	External γ dose rate (Gy/10³ yr)	K int. (%)	U int. (ppm)	Th int. (ppm)	Internal dose rate (Gy/10³ yr)	Cosmic dose rate (Gy/10³ yr)	Total dose rate (Gy/10³ yr)
SAN1	15	K-Feld	250–300	0.204 ± 0.014[a]	0.130 ± 0.005[a]	6.5 ± 0.1[b]			0.452 ± 0.055	0.040 ± 0.020	0.826
SAN1	15	Quartz	150–250	0.208 ± 0.014[a]	0.130 ± 0.005[a]		0.08 ± 0.001[d]	0.19 ± 0.02[d]	0.028 ± 0.004	0.040 ± 0.020	0.406
SAN2	15.5	K-Feld	250–300	0.284 ± 0.017[c]	0.170 ± 0.010[c]	6.7 ± 0.1[c]			0.466 ± 0.057	0.038 ± 0.020	0.958

Note. Values deduced from: [a]neutron activation analysis (U–Th) and γ spectrometry (K); [b]Riso GM multicounter system; [c]plasma-emission analysis; and [d]neutron activation analysis.

multicounter system (Botter-Jensen and Mejdahl, 1988) or by plasma-emission analysis.

Due to the very low radioactive content of the Pleistocene beach sand, the natural TL level of the quartz grains has not yet reached saturation, and thus an age of 229,000 ± 18,000 yr can be obtained. This contrasts with the previous underestimated TL age estimate (130,000 ± 17,000 yr) obtained by Balescu *et al.* (1991) for the Sangatte raised beach, using the UV component of the K-feldspar TL signal. This problem of age underestimation has been recently overcome by the use of a blue-transmitting filter (Balescu and Lamothe, in press). As shown in Table 2, the blue component of the K-feldspar TL signal for both samples (SAN1 and SAN2) yielded significantly higher TL age estimates (200,000 ± 45,000, and 204,000 ± 14,000 yr, respectively). They are self-consistent and show good agreement with the quartz TL age estimate. This clearly demonstrates that internally consistent TL ages may be obtained from the quartz and the K-feldspar fractions of a Middle Pleistocene beach sand.

Moreover, these new self-consistent TL age estimates suggest a clear correlation of the Sangatte raised beach with oxygen-isotope stage 7. However, the associated errors do not allow a further classification into one of the substages. These results confirm the investigations of Sommé (1977) and Balescu and Haesaerts (1984) who attributed these deposits to the penultimate interglaciation, but contradict Antoine (1989) who derived a stage 9 assignment on the basis of the occurrence of an additional soil horizon which was also found at a nearby site. There is no evidence that this soil is interglacial and it may be equivalent to the Vaux soil (Haesaerts *et al.*, 1981) reported from the mid-Weichselian at Harmignies, Belgium.

These TL results suggest a correlation of the Sangatte raised beach with the stratotype for the stage 7 high sea-level event in southern Britain represented by the raised

TABLE 2. ED AND TL AGE ESTIMATES

Mineral	Filter	Laboratory	ED (Gy)	TL age estimates (10^3 yr)
SAN1				
K-feldspar	Schott UG11	C	105 ± 12[a]	130 ± 17[a]
	Corning 7-59 + Schott BG39	M	165 ± 35	200 ± 45
Quartz	Corning 5-60	C	93 ± 5	229 ± 18
SAN2				
K-feldspar	Corning 7-59 + Schott BG39	M	196 ± 5	205 ± 14

[a] Previously reported in Balescu and Lamothe (in press), uncorrected for the residual level. C or M: Cambridge or Montréal.

beach of Minchin Hole Cave (Gower) along the Bristol Channel, dated to stage 7 by the amino acid geochronology (Bowen *et al.*, 1985; Bowen and Sykes, 1988). Other beaches that have stage 7 amino acid ratios are Portland West (Davies and Keen, 1985) and Hope's Nose Torquay (Bowen *et al.*, 1985; Mottershead *et al.*, 1987) whose suggested sea levels (11 and 10.5 m, respectively) are close to that of Sangatte.

The present study confirms the pre-Eemian age of the Sangatte raised beach and demonstrates the existence, along the southeastern coast of the North Sea Basin, of a high sea-level stand that can be correlated with oxygen isotope stage 7. The presence of a stage 7 beach at Sangatte demonstrates that the Strait of Dover was already open by this time, in agreement with the proposal by Sommé *et al.* (1978) and Gibbard (1988) of a middle Pleistocene age for the channel opening. Moreover, this study demonstrates, for the first time, the possibility of obtaining self-consistent quartz and feldspar TL ages on middle Pleistocene beach sand. Thus, TL dating of both quartz and K-feldspar opens the way for establishing a chronology for nonfossiliferous Pleistocene raised beaches, provided that the TL signals are not in saturation and that the blue emission of K-feldspars is used for dating.

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REFERENCES

Aitken, M. J. (1985). "Thermoluminescence Dating." Academic Press, New York.

Antoine, P. (1989). Stratigraphie des formations pléistocènes de Sangatte (Pas-de-Calais), d'après les premiers travaux du tunnel sous la Manche. *Bulletin de l'Association Française pour l'Etude du Quaternaire* 37, 5–17.

Apers, D., Debuyst, R., de Cannière, P., Dejehet, F., and Lombard, E. (1981). A criticism of the dating by electron paramagnetic resonance (ESR) of the stalagmitic floors of the Caune de l'Arago at Tautavel. *In* "Absolute Dating and Isotope Analysis in Prehistory. Methods and Limits" (H. de Lumley and J. Laheyrie, Eds.) pp. 533–550, CNRS, Paris.

Balescu, S. (1988). "Apports de la thermoluminescence à l'étude stratigraphique et sédimentologique des loess saaliens du NW de l'Europe." Unpublished Ph.D. thesis, Université Libre de Bruxelles, Belgium.

Balescu, S., Dupuis, Ch., and Quinif, Y. (1988). TL stratigraphy of pre-Weichselian loess from NW Europe using feldspar coarse grains. *Quaternary Science Reviews* 7, 309–313.

Balescu, S., and Haesaerts, P. (1984). The Sangatte raised beach and the age of the opening of the Strait of Dover. *Geologie en Mijnbouw* 63, 355–362.

Balescu, S., and Lamothe, M. (in press). The blue

emission of K-feldspar coarse grains and its potential for overcoming TL age underestimation. *Quaternary Science Reviews*.

Balescu, S., Packman, S. C., and Wintle, A. G. (1991). Chronological separation of interglacial raised beaches from Northwestern Europe using thermoluminescence. *Quaternary Research* **35**, 91–102.

Berger, G. W. (1988). Dating Quaternary events by luminescence. *Geological Society of America, Special Paper* **227**, 13–50.

Berger, G. W., Lockhart, R. A., and Kuo, J. (1987). Regression and error analysis applied to the dose-response curves in thermoluminescence dating. *Nuclear Tracks* **13**, 177–184.

Botter-Jensen, L. (1988). The automated Riso TL reader system. *Nuclear Tracks* **14**, 177–180.

Botter-Jensen, L., and Mejdahl, V. (1988). Assessment of beta dose rate using a GM multicounter system. *Nuclear Tracks* **14**, 187–191.

Bowen, D. Q., and Sykes, G. A. (1988). Correlation of marine events and glaciations on the northeast Atlantic margin. *Philosophical Transactions of the Royal Society of London Series B* **318**, 619–635.

Bowen, D. Q., Sykes, G. A., Reeves, A., Miller, G. H., Andrews, J. T., Brew, J. S., and Hare, P. E. (1985). Amino Acid Geochronology of Raised Beaches in South West Britain. *Quaternary Science Reviews* **4**, 279–318.

Chawla, S., and Singhvi, A. K. (1989). Limits in quartz based thermoluminescence chronology: Possible relevance of sensitivity change." Synopses from a Workshop on "Long and Short Range Limits in Luminescence Dating"; The Research Laboratory for Archaeology and the History of Art, Oxford University, April 1989. Occasional Publication 9.

Davies, K. H., and Keen, D. H. (1985). The age of Pleistocene marine deposits at Portland, Dorset. *Proceedings of the Geological Association* **96**, 217–225.

De Heinzelin, J. (1966). Falaise et plage suspendue de Sangatte. *Bulletin Société Belge Géologie* **75**, 292–296.

Gibbard, P. L. (1988). The history of the great northwest European rivers during the past three million years. *Philosophical Transactions of the Royal Society of London Series B* **318**, 559–602.

Haesaerts, P., et Dupuis, C. (1986). Contribution à la stratigraphie des nappes alluviales de la Somme et de l'Avre dans la région d'Amiens. *Supplément au Bulletin de l'Association Française pour l'Etude du Quaternaire* **26**, 171–186.

Haesaerts, P., Juvigné, E., Kuyl, O., Mucher, H., and Roebroeks, W. (1981). Compte rendu de l'excursion du 13 juin 1981, en Hesbaye et au Limbourg Néerlandais, consacrée à la chronostratigraphie des loess du Pléistocène supérieur. *Annales Société Géologique Belgique* **104**, 223–240.

Martinson, D. G., Pisias, N. G., Hays, J. D., Imbrie, J., Moore, T. C., and Shackleton, N. J. (1987). Age Dating and the Orbital Theory of the Ice Ages: Development of a High-Resolution 0 to 300,000-Year Chronostratigraphy. *Quaternary Research* **27**, 1–29.

Mejdahl, V. (1979). Thermoluminescence dating: beta-dose attenuation in quartz grains. *Archaeometry* **21**, 61–72.

Mejdahl, V. (1988). Long-term stability of the TL signal in alkali feldspars. *Quaternary Science Reviews* **7**, 357–360.

Mejdahl, V. (1989). "How Far Back: Life Times Estimated from Studies of Feldspars of Infinite Ages." Synopses from a Workshop on "Long and Short Range Limits in Luminescence Dating"; The Research Laboratory for Archaeology and the History of Art, Oxford University, April 1989. Occasional Publication 9.

Mottershead, D. N., Gilbertson, D. D., and Keen, D. H. (1987). The raised beaches and shore platforms of Tor Bay: A re-evaluation. *Proceedings of the Geological Association* **98**, 241–257.

Nambi, K. S. V., and Aitken, M. J. (1986). Annual dose conversion factors for TL and ESR dating. *Archaeometry* **28**, 202–205.

Prescott, J. R., and Hutton, J. T. (1988). Cosmic ray and gamma ray dosimetry for TL and ESR. *Nuclear Tracks* **14**, 223–227.

Singhvi, A. K., Sharma, Y. P., and Agrawal, D. P. (1982). Thermoluminescence dating of dune sands in Rajasthan, India. *Nature* **295**, 313–315.

Smith, B. W., Rhodes, E. J., Stokes, S., Spooner, N. A., and Aitken, M. J. (1990). Optical dating of sediments: Initial quartz results from Oxford. *Archaeometry* **32**, 19–31.

Sommé, J. (1977). "Les plaines du Nord de la France et leur bordure." Ph.D. thesis, Université de Paris I (Librairie Honoré Champion, Paris, Ed.).

Sommé, J., Paepe, R., Baeteman, C., Beyens, L., Cunat, N., Geeraerts, R., Hardy, A. F., Hus, J., Juvigné, E., Mathieu, L., Thorez, J., et Vanhoorne, R. (1978). La formation d'Herzeele: Un nouveau stratotype du Pléistocène moyen marin de la Mer du Nord. *Bulletin de l'Association Française pour l'Etude du Quaternaire* **54–56**, 81–149.