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OSL dating of an inland dune along the lower River Scheldt near Aard (East Flanders, Belgium)

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Abstract

The chronostratigraphic position of aeolian dunes in East Flanders (Belgium) has been under debate for decades. Until now, the only available age information consisted of a limited number of radiocarbon dates, which provided indirect sediment deposition chronologies. This paper reports on the first direct determination, by quartz-based single-aliquot optically stimulated luminescence dating, of the time that dune sands were deposited along the Lower River Scheldt in Belgium. The sediments are dated at 12.0±0.9 ka (n = 5), which confirms that the time of inland dune formation in East Flanders dates from the Younger Dryas period and should not be constrained to the Holocene.

Introduction

Flood risk management in Flanders (Belgium) will transform a selection of areas along the lower River Scheldt and its tributaries to freshwater tidal flats and marshes. The most upstream selected area encloses the Kalkense Meersen (Fig. 1) which is situated between Wetteren and Schoonaarde. This area will be subjected to diurnal tides and is intended to serve as buffering zones against extreme storm events ('controlled flood basins'). The water regulation works are likely to disrupt or even obliterate the heritage that is preserved in the subsurface. In order to gauge the impact of these developments on the potential patrimony, an interdisciplinary survey of the area was carried out (Bogemans et al., 2008, 2009a, b). The reconstruction of the sedimentary palaeoenvironments formed the basic instrument of the archaeological and ecological research. The cultural – historical research made the link with the present day landscape. This paper aims to establish a robust chronological framework for the palaeoenvironmental and -climatic changes in the area; more specifically, it reports on the application of quartz-based single-aliquot optically stimulated luminescence (SAR-OSL) dating to constrain the time of dune formation near Aard (Fig. 1).

Quaternary geological context

The study area is situated at the most southern zone of the coversand area (Paepe & Vanhoorne, 1967), implicating that outside the alluvial plain the outcropping deposits are predominantly aeolian in origin. The facies have a bipartite constitution, with homogeneous sand deposits in the upper part, and an alternating bedding of sand and finer grained laminae or layers in the basal part. Both in Belgium and the neighbouring countries the accumulation of these aeolian deposits took place in the late phase of the Weichselian pleniglacial (see e.g. Paepe & Vanhoorne, 1967; Zagwijn & Paepe, 1968; Schwann, 1986, 1988; Koster, 1988; Bogemans, 1993; Vandenberghe et al., 1991; Huijzer & Vandenberghe, 1998; Bateman & Van Huissteden, 1999; Van Huissteden et al., 2001; Kasse, 2002).

The landscape in some parts of the alluvial plain and in the adjacent areas is marked by dune remains (see Fig. 1 near Aard and Hoge Berg). The height of the alluvial plain ranges between +3.5 to +4 m TAW (Belgian ordnance level), whereas the maximum elevation of the aeolian deposits found in the area is +16 m TAW, with heights of less than +8 m TAW being more common.

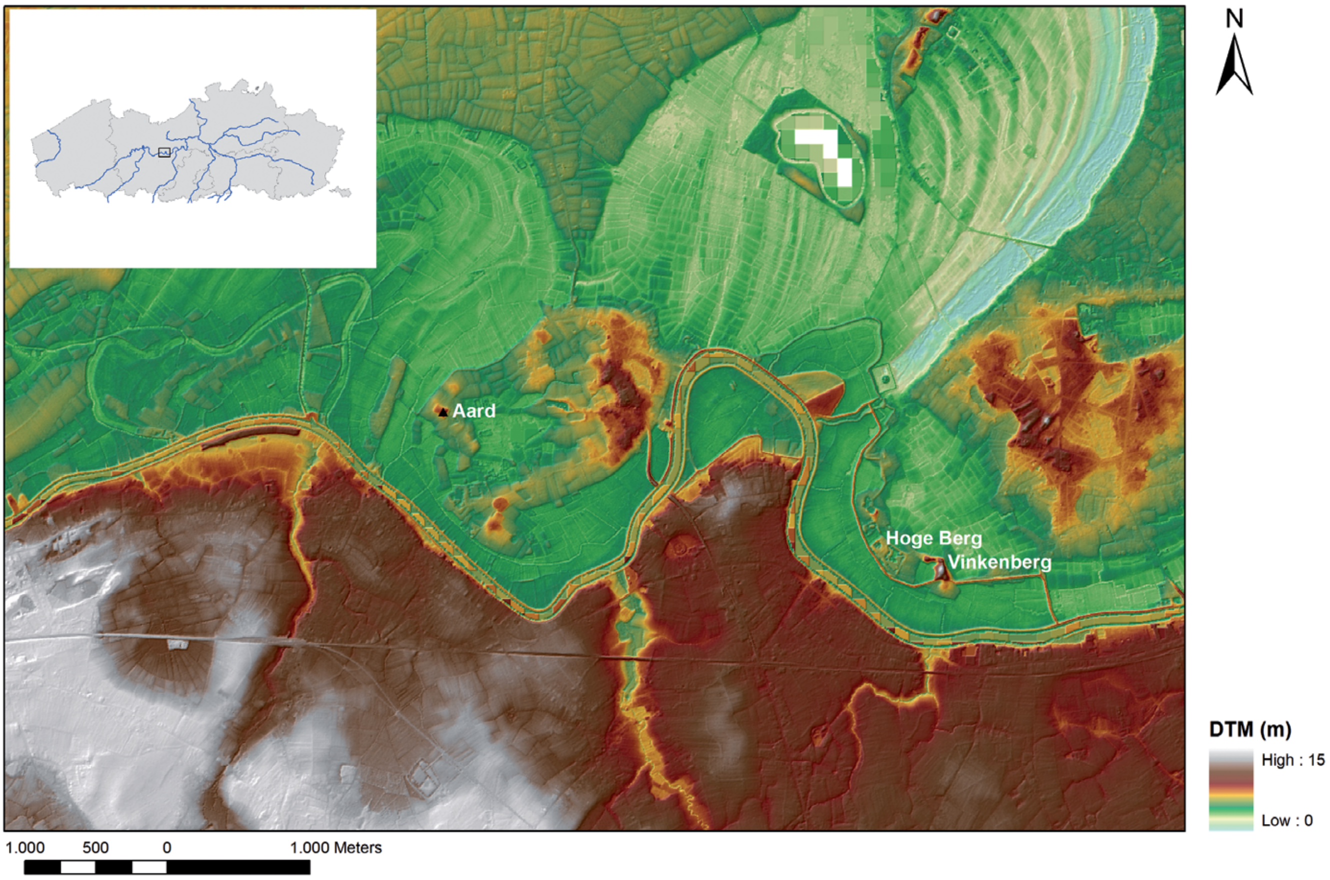

Fig. 1. The cluster of the Kalkense Meersen, the location of the river dunes and the sampling area Aard.

The associated deposits differentiate, according to Amerycks & Leys (1960), from the coversand deposits on basis of their slightly coarser grain size distribution and soil properties. Similar findings, but covering large areas in Lower Belgium, were already reported by Tavernier (1954). Vandenberghe (1977) recognized in the southern Campine area two types of dunes on basis of their texture. One group, with identical grain size distribution and a heavy mineral association like the coversand deposits was interpreted as relocated coversand deposits (see also Gullentops, 1957; De Ploey, 1977). The second group of dunes consists of coarser sand and was interpreted as reworked Weichselian fluvial deposits or even older Tertiary sediments.

Dunes are distinct morphological entities. Their form and scale is determined by factors like sand availability, suitable particle sizes, wind direction, -speed and -directional changeability, elements that favour deposition and trapping (like irregularities, and vegetation cover and -growth characteristics), and last but not least climate (Pye & Tsoar, 1990; Pye, 1993; Nickling, 1994). The dunes along the Belgian rivers are of the parabolic type and have been described by Peeters (1943), Gullentops (1957), Verbruggen (1971), Heyse & De Moor (1979) and Heyse (1984). Although most dunes in the study area are levelled or even destroyed by both agricultural practices and sand exploitation, Heyse still observed in 1984 prominent parabolic dunes at the Hoge Berg and Vinkenberg, situated on the left bank of the River Scheldt, west of Schoonaarde (Fig. 1). Now the dune morphology is completely disturbed. Essential for the development and growth of parabolic dunes are unidirectional winds and the presence of moderately developed vegetation anchoring the arms, while the central part is blown out (Lancaster, 1995). Their morphology and size is steered by wind strength, source and amount of sand and the distribution of the vegetation (Pye & Tsoar, 1990; Pye, 1993).

Existing chronology

Contrary to aeolian dune deposits in Limburg (Derese et al., 2009), those in East Flanders have only been dated indirectly, by applying radiocarbon dating to intercalated organic layers. This, however, provides only indicative 'time limits'. It does not allow, e.g., determining the rate of sedimentation or recognising hiatuses and the time interval that they represent. Moreover, organic material is rather scarce in dunes along the River Scheldt. Consequently, only limited age information was available and the timing of actual dune formation was poorly constrained.

Tavernier (1954) correlated the river dune formations to the Late Dryas. His conclusion was based on the Allerød pollen assemblage of peat layers present underneath the aeolian deposits. Similar findings were reported by Snacken (1961), De

Smedt (1973), Verbruggen & Van Dongen (1976), Verbruggen et al., (1991, 1996) and Kiden & Verbruggen (2001) based on radiocarbon dating in combination with data concerning palaeovegetation, -climate and -environment. However, according to Ameryckx & Leys (1960), Jacobs (1974) and De Coster (1982) dune formation occurred in the Boreal and Preboreal. De Coster (1982) stated that the cut off of the meander of Overmere and the dune formation took place simultaneously during the Boreal based on the pollen analytic results of Verbruggen (1971) for peat present within the abandoned meander. De Moor (1981), De Moor & Heyse (1974, 1978), Heyse & De Moor (1979) and Heyse (1984) made a distinction between coversand ridges and dunes of local origin. On bases of pollen analysis and radiocarbon dating of peat layers, De Moor & Heyse (1978) and Heyse & De Moor (1979) placed the formation of the coversand ridges during the Late Glacial, and dune development at the beginning of the Holocene. The same authors indicate a continuation of dune forming processes throughout the Holocene.

The above illustrates that the chronology for both inland dune and sand ridge formation in Flanders is still uncertain as it is based on rather limited and indirect age information for the deposits. This emphasises the need for a reliable absolute chronology of dune sand deposition.

Optically stimulated luminescence (OSL) dating

OSL dating allows determining the time of sediment deposition and accumulation directly (see e.g. Aitken, 1998). The method uses sedimentary mineral grains (and not associated material) and has a wide dynamic range (from a few years to at least 100ka). The most robust luminescence dating procedure currently available involves the use of OSL signals from quartz in combination with the single-aliquot regenerative-dose (SAR) procedure (Murray & Olley, 2002; Wintle & Murray, 2006). This procedure has been successfully applied to Holocene and Pleistocene sediments in the West European lowlands (see e.g. Vandenberghe et al., 2004, 2009; Kasse et al., 2007; Buylaert et al., 2009; Derese et al., 2009, 2010; Van Mourik et al., 2010). Despite its undeniable potential, however, the method has seen relatively little application with respect to the timing of aeolian events in Flanders; this is in strong contrast to the situation in the Netherlands or Germany (see e.g. the reviews by Koster, 2005 and Wallinga et al., 2007)

Study site and sampling

It was mentioned earlier that, in restricted areas, some dunes form a morphological entity on the alluvial plain of the Scheldt river. Most of them, even the sampling site, are levelled or even destroyed by both agricultural practices and sand exploitation. Although the aeolian sequence was incomplete at the top, a dune in Aard (part of the municipally Schellebelle) (± 8.4 m TAW) was selected as it remained undisturbed for decades and translocation of the sediments because of root penetrations was minimal .

A profile pit of about 280 cm deep was dug, which did not reach the base of the C-horizon of the dune. Below a recently formed humic horizon, sediments consist of fine, slightly glauconitic loosely packed sand. Primary sedimentary structures are hardly visible. The sequence contains numerous clay enriched lamellae up to 1.5 cm thick, wavy to bifurcated wavy, locally even in the lower part of the excavated sequence. The distance between the lamellae ranges between 5 and 20 cm. For OSL dating, five samples in total were collected by hammering opaque PVC cylinders into the western profile wall. Sampling took place in between the lamellae in a well-defined vertical succession, starting at a depth of 97 cm and more or less at intervals of 40 cm. For each sample, about 0.75-1 kg of surrounding sediment was collected for dose rate determination. Two separate undisturbed sediment samples were taken for evaluation of the time-averaged moisture content.

Methods and luminescence characteristics

In the laboratory, coarse (180-212 µm) quartz grains were extracted from the inner cores of the sample cylinders in the usual manner (HCl, H_20_2, sieving, HF, HCl). The purity of the quartz extracts was confirmed by the absence of a significant infrared stimulated luminescence (IRSL) response to a large regenerative beta dose. The sensitivity to infrared stimulation was defined as significant if the resulting signal amounted to more than 10% of the corresponding blue light stimulated luminescence response (Vandenberghe, 2004) or if the OSL IR depletion ratio deviated by more than 10% from unity (Duller, 2003); no aliquots had to be rejected on this basis.

For analysis, quartz grains were spread out on the inner 8 mm of 9.7 mm diameter stainless steel discs using silicon spray as adhesive. Luminescence measurements were performed using an automated Risø TL/OSL DA-12 reader equipped with blue (470±30 nm) LEDs and an IR laser diode (830 nm). All luminescence emissions were detected through a 7.5 mm thick Hoya U-340 UV filter. Details on the measurement apparatus can be found in Bøtter-Jensen et al. (2003).

The equivalent dose was determined using the single-aliquot regenerative-dose (SAR) protocol (Murray & Wintle, 2000). Optical stimulation with the blue diodes was for 40 s at 125° C. The initial 0.32 s of the decay curve minus a background evaluated from the 0.8-1.28 s interval was used for the calculations. Preheating of regenerative and test doses was for 10 s at 240° C and by a cut-heat to 220° C, respectively. After the measurement of the response to the test dose, a high-temperature cleanout was performed by stimulating with the blue diodes for 40 s at 280° C (Murray & Wintle, 2003). The suitability of the SAR measurement conditions was confirmed through a dose recovery test (Murray & Wintle, 2003). In this test, aliquots were bleached at room temperature using the blue diodes (2 times 250 s, with a 10 ks pause in between) and given a dose close to the expected natural dose; they were then measured using the SAR protocol. The overall average measured to given dose ratio is 1.02±0.01 (n = 30, i.e. averaged over all samples and aliquots); the corresponding values for the recycling ratio and recuperation (expressed as % of the sensitivity-corrected natural signal) are 0.97±0.01 and 0.14±0.06%, respectively. The results from the dose recovery test indicate that the SAR protocol is suitable to measure a laboratory dose given prior to any heat treatment.

For each sample, 24 replicate measurements of the equivalent dose (D_e) were made. Values were accepted if the recuperated signal did not exceed a threshold set at 5% of the corrected natural signal, and if the recycling ratio was within 10% from unity. Of the 120 aliquots measured in total, three had to be rejected on account of not meeting the recycling criterion. Figure 2 shows a representative dose-response curve for an aliquot of sample GLL-080720. It illustrates the generally good behaviour of the samples in the SAR protocol; recycling ratios are close to unity (indicating that sensitivity changes occurring throughout the measurement procedure are accurately corrected for) and the growth curves pass close to the origin (demonstrating that recuperation is negligible).

Determination of the dose rate was based on low-level gamma-ray spectrometry in the laboratory. The sediment was oven dried (at 110° C until constant weight), and homogenised and pulverised. A subsample of ~140 g was then cast in wax (De Corte et al., 2006) and stored for at least one month before being measured on top of the detector. The samples were counted for 2-3 days. Details on instrumentation, spectrum evaluation and radionuclide concentration calculation can be found in Vandenberghe (2004). The measured radionuclide activities were converted to dose rates using the factors tabulated by Adamiec & Aitken (1998). The external beta dose rate was corrected for the effects of attenuation and etching following Mejdahl (1979). Both the beta and gamma contributions were corrected for the effect of moisture; the moisture content as found at the time of sampling was assumed to be representative for the time-averaged degree of wetness; increasing the water content with 1% increases the optical age by ~1%. The contribution of cosmic radiation was calculated following Prescott & Hutton (1994), while an internal dose rate of 0.013±0.003 Gy/ka was assumed based on the U and Th concentrations reported by Vandenberghe et al. (2008).

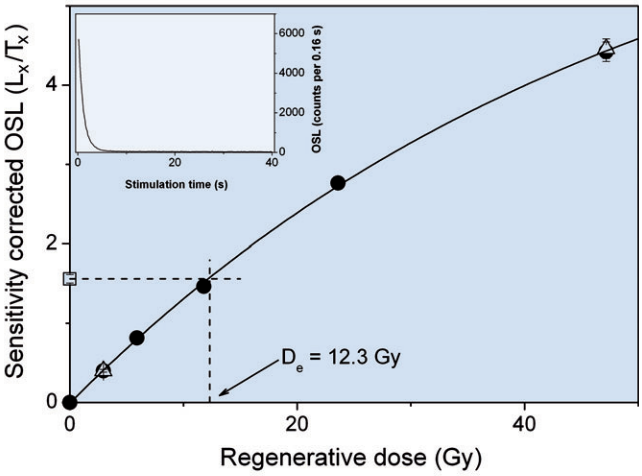

Fig. 2. Illustrative SAR growth curve and natural luminescence decay curve (inset) for an aliquot of quartz grains extracted from sample GLL-080720. The solid line is the fit of the data to a single saturating exponential function; the equivalent dose (D_e) is obtained by interpolation of the sensitivity-corrected natural signal (open square) on this dose-response curve. The open triangles represent recycling points.

Optical ages and discussion

Table 1 summarises the analytical results relevant to the age and uncertainty calculation. Uncertainties on the luminescence ages were calculated following the error assessment system proposed by Aitken & Alldred (1972) and Aitken (1976). It can be seen that the systematic uncertainty is dominant in the overall uncertainty on the ages, which typically amounts to 8-9%.

To evaluate the internal consistency of the age results, only the random uncertainties are to be considered. Within this uncertainty, the dataset shows no increase with depth and the observed variation in age results is not much larger than is expected from the individual uncertainties. This suggests that all sources of random uncertainty have been properly accounted for.

The OSL dates are clustered around a mean value of 12±0.9 ka, indicating that at least ~1.5 m of sediment accumulated during a short period of time (i.e. within the given limit on the time-resolution) in the Late-Dryas (13-11.7 ka calBP; Hoek, 2001).

Conclusion

The optical dates indicate that at least part of the river dunes near Aard formed in the Late Dryas. This corroborates the statements of Tavernier (1954) and Kiden & Verbruggen (2001), amongst others (see section 'Existing Chronology'). The obtained dates of Late-Dryas age are also in agreement with those obtained for similar deposits in neighbouring countries (e.g. Teunissen, 1983; Vandenberghe et al., 1991; Bohncke et al., 1993; Kasse, 1995, 1999, 2002; Isarin et al., 1997, 1999; Kasse et al., 2007; Vandenberghe et al., 2004).

It remains to be established when the dune formation actually started and ended. As the samples were, most probably, collected in the central part of the original dune sequence, it cannot be excluded that sedimentation continued into the Holocene. The optical dates do demonstrate, however, that dune formation in East Flanders is not limited to the

Table 1. Radionuclide activities, time-averaged moisture content, calculated dose rates, D_e values, optical ages, and random (σ_r), systematic (σ_{sys}) and total uncertainties (σ_{tot}). The uncertainties mentioned with the De and dosimetry data are random; all uncertainties represent 1.

Sample	Depth	^{234}Th	^{226}Ra	^{210}Pb	^{232}Th	^{40}K	Water content	Total dose rate	D_e	Age	σ_r	σ_{sys}	σ_{tot}	
GLL-code	(cm)	(Bq kg^{-1})	(Bq kg^{-1})	(Bq kg^{-1})	(Bq kg^{-1})	(Bq kg^{-1})	(%)	(Gy ka^{-1})	(Gy)	(ka)	(%)	(%)	(%)	(ka)
080717	97	3.3±0.7	4.9±0.2	4.2±0.6	4.9±0.2	166±3	4±1	0.86±0.01	10.7±0.3	12.5	2.75	7.45	7.94	1.0
080718	137	5.9±0.9	6.0±0.3	5.8±0.7	6.2±0.1	188±2	4±1	0.97±0.01	12.0±0.5	12.4	4.06	7.50	8.53	1.1
080719	173	6.6±1.2	6.7±0.3	7.1±0.9	6.4±0.1	192±2	4±1	1.00±0.02	11.2±0.6	11.2	5.34	7.52	9.22	1.0
080720	209	6.7±1.1	6.9±0.5	6.1±0.6	6.5±0.2	197±3	4±1	1.00±0.01	12.2±0.4	12.3	3.71	7.54	8.41	1.0
080721	247	5.5±0.8	7.0±0.4	7.6±0.7	6.4±0.2	196±2	4±1	1.00±0.01	11.8±0.2	11.7	2.13	7.55	7.84	0.9

Holocene, such as was previously hypothesised by Ameryckx & Leys (1960), Jacobs (1974) and De Coster (1982).

This work illustrates the considerable potential of SAR-OSL dating to determine the time of inland dune formation. Future studies that aim at gaining an improved understanding of the spatial and temporal relationship between fossil river dunes in Flanders, and of their significance as archives of palaeoenvironmental and palaeoclimatic changes, will benefit by including SAR-OSL dating. Resolving the issue concerning the final phase of dune building, on the other hand, may prove quite a challenge, because of the artificial levelling of most of the remaining dunes and/or soil formation in the top of the sequences.

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