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Research paper

Testing for sufficient signal resetting during sediment transport using a polymineral multiple-signal luminescence approach

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ABSTRACT

We present a multiple luminescence signal measurement procedure that simultaneously measures six different luminescence signals from a single polymineral aliquot (i.e. multiple-signal, short MS-SAR approach). The six signals show different bleaching rates in bleaching experiments, ranging from rapid bleaching for the quartz dominated blue stimulated luminescence signal (measured at 125 °C, BSL-125), to the slow-bleaching polymineral thermoluminescence signal. The bleaching rate of the infrared stimulated luminescence (IRSL) measured at room temperature (IR-25) and elevated temperature post-IR IRSL (pIRIR-90, pIRIR-155, pIRIR-225) signals decrease with increasing measurement temperature. Owing to these different bleaching rates, the MS-SAR approach allows inference of the degree of bleaching, and thereby information on the transport history of sediments. We test this approach by applying the MS-SAR to four coastal samples from a well-monitored sand-nourishment site at the Dutch coast. Our results show that the proposed MS-SAR approach can be utilised to construct bleaching plateaus which provide an independent and time-effective measure of the degree of poor bleaching in a sediment sample based on the measurement of only a few large aliquots. We propose that the MS-SAR protocol can be used to profile the age, luminescence properties and degree of bleaching of minimal prepared polymineral. This pre-profiling will allow the selection of suitable samples for full luminescence dating analysis in a target-orientated and time-effective manner.

1. Introduction

A crucial requirement for successful age determination in luminescence dating is sufficient resetting of luminescence signals by light exposure of mineral grains prior to deposition and burial. However, it is arguable whether this requirement has been fulfilled for sediments that were mainly transported under water-lain conditions (e.g. fluvial, marine, glacio-fluvial), especially when these sediments experience short transport and/or rapid deposition. Two methodological approaches to detect insufficient signal resetting (named poor bleaching) are proposed in the literature (see review by Wallinga, 2002a):

A. Interpretation of scatter in OSL results,

B. Comparison of different luminescence signals with different bleaching characteristics.

During the last decade the vast majority of studies on poor bleaching focused solely on the *ex post* evaluation of scatter in dose distributions (e.g. Olley et al., 1999, 2004; Bailey and Arnold, 2006; Arnold et al., 2007; Lüthgens et al., 2011; Kunz et al., 2013). Large over-dispersions as well as positively skewed dose distributions are commonly used as indicators for heterogeneous or partial luminescence signal resetting (e.g. Bailey and Arnold, 2006; Arnold et al., 2007). The shortcoming of this methodological approach – especially when used exclusively – is that the scatter in dose distributions is typically caused by numerous sources (e.g. Thomsen et al., 2005, 2007; Duller, 2008) which are not easily distinguished. Furthermore, detection of over-dispersion and positive skewness of dose distributions requires that intra-aliquot signal averaging is reduced to a minimal level. Signal averaging in multiple-grain aliquots can result in normal distributions showing the same features as a dose distribution derived from a well bleached sample (Wallinga, 2002b; Cunningham et al., 2011b),

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which may result in failure to identify poor bleaching if the size of the multiple-grain aliquot is not appropriate (e.g. Duller, 2008).

The alternative approach of comparing luminescence signals with different bleaching sensitivities to daylight exposure to detect insufficient bleaching in sediments has received far less attention, but nevertheless has been applied in a number of studies previously (e.g. Wintle et al., 1993; Fuller et al., 1994; Roberts et al., 1994; Bluszcz, 2001). Most of these earlier attempts compared quartz OSL signals (typically stimulated with blue light, BSL) or feldspar infrared stimulated luminescence signals (IRSL) with thermoluminescence (TL) signals. These methods use the well-established fact that OSL signals bleach an order of magnitude faster than the respective TL signals (Godfrey-Smith et al., 1988). More recently, Murray et al. (2012) used the difference in bleaching rate between quartz BSL and feldspar IRSL to identify well-bleached quartz samples.

Recently, dating protocols using the post-infrared infrared stimulated (pIRIR) signal have been developed (Thomsen et al., 2008; Thiel et al., 2011). Buylaert et al. (2013) suggested using the ratio of the conventional IRSL equivalent dose (measured by IR stimulation at 50 °C; IR-50) to the pIRIR equivalent dose (measured by post-IR IR stimulation at 290 °C; pIRIR-290), to identify samples for which the pIRIR-290 signal was reset at the time of deposition. This approach builds on recognition that the IR-50 signal bleaches more rapidly in daylight than the pIRIR signal that is measured at an elevated temperature (Thomsen et al., 2008; Reimann et al., 2011, 2012; Buylaert et al., 2012; Reimann and Tsukamoto, 2012; Kars et al., 2014). Li and Li (2011) recently proposed a multiple signal pIRIR approach where a sequence of IR feldspar signals is measured at gradually increasing IR stimulation temperature (MET-pIRIR). Each of these signals bleaches with a different optical decay constant (Li and Li, 2011; Kars et al., 2014).

The main goal of this study is to investigate the potential of comparing multiple luminescence signals with different bleaching characteristics to detect and quantify the degree of bleaching for sediments. Towards this goal we develop a novel luminescence measurement procedure that examines six different luminescence signals from the same polymineral sub-sample (aliquot). In the procedure we detect conventional luminescence signals (IRSL, BSL and TL) as well as luminescence signals that have only recently been proposed for dating purposes (pIRIR, MET-pIRIR). Each of these signals potentially shows a different bleaching rate upon daylight exposure. In this paper we thoroughly test the potential of this polymineral multiple-signal approach to infer sufficient signal resetting of sediment samples prior to burial.

The main advantage of a multiple luminescence signal approach compared to other methods is that information on poor bleaching can be derived from only a few multiple-grain aliquots of minimally treated or untreated material. Thereby the approach is more time-effective than luminescence analysis of dose distributions and provides the potential to profile the degree of bleaching prior to full sample preparation and luminescence dose measurements.

2. Site and samples

The study site is situated in the Netherlands (inset Fig. 1A). Large parts of the Dutch coast are prone to erosion and with global sea-level rise it is expected that the pressure on the coastal defence will significantly increase over the next century (Kabat et al., 2009). To protect the coast against flooding and erosion the Dutch government, research institutes and companies are currently developing a new coastal protection scheme in which huge sand-nourishments play a key role (Stive et al., 2013). The “Zandmotor” (in English: Sand Engine) is a unique pilot mega-nourishment project situated near the locality Ter Heijde, near The Hague. An

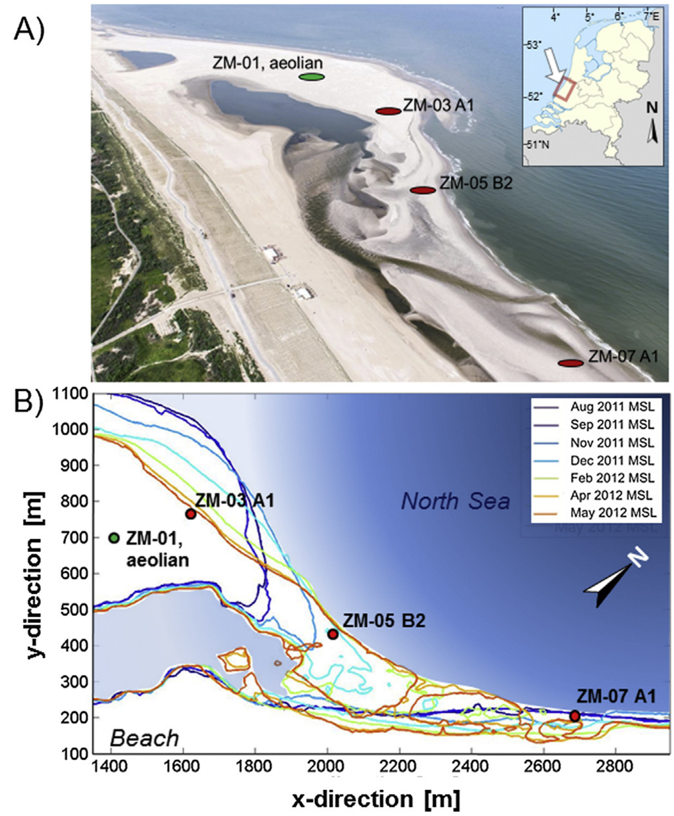

Fig. 1. Aerial photograph A) and map B) of the *Zandmotor* with sample locations (green and red circles). The aerial photograph A) was taken 2nd of June 2012, thus at the time of sampling. The map B) shows the changing position of the coastline over time, i.e. the mean sea level (MSL) contour lines are shown from August 2011 (after construction of the Zandmotor) to May 2012 (month of sampling). Topographic data and aerial photograph was collected by the Dutch Ministry of Infrastructure and the Environment (Rijkswaterstaat). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

aerial photograph of the Zandmotor is shown in Fig. 1A and a map of the location is provided in Fig. 1B. The Zandmotor was constructed within four months in spring 2011. The material for the nourishment is fluvial sediment that was deposited by the river Rhine when it transversed the exposed continental plain between the Netherlands and England during the Pleistocene (e.g. Hijma et al., 2012). 21.5 million m^3 of sediment was dredged from these off-shore deposits and dumped and sprayed along a 2.5 km long coastal stretch. The Zandmotor provides a source of sediment and is expected to feed the adjacent coastal sections for the next 15–20 years (Stive et al., 2013). This pilot project incorporates an elaborate monitoring program which provides a unique opportunity to gain valuable insights regarding coastal sediment dynamics and morphological processes. We selected the Zandmotor as natural laboratory to test our novel bleaching detection approach.

Sampling of the Zandmotor sediment was carried out 12 months after construction in May and June 2012. In the first year since implementation, the original hook shaped peninsula has spread in both alongshore directions. The most seaward parts of the peninsula have eroded and a spit-like feature has formed on the northern side (Fig. 1). In Fig. 1B the changes of the mean sea level (MSL) coastline position are shown for the period from August 2011 (immediately after summer construction) to May 2012 (immediately before sampling). For light-tight sampling of water-logged sands from the subsurface, we used a *Van der Staay* suction corer (Wallinga and van der Staay, 1999).