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Research paper

Instant luminescence chronologies? High resolution luminescence profiles using a portable luminescence reader

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ABSTRACT

Establishing a robust chronology is fundamental to most palaeoenvironmental studies. However, the number and positioning of dated points is critical. Using a portable luminescence reader, it is possible to rapidly generate high resolution down core relative age profiles. Profiles of portable luminescence data from two coastal dunes were evaluated and compared with the results of particle size analysis, stratigraphy, and an independent historical chronology. Results show that, even in young samples, portable luminescence data is dominated by an age related signal which in homogeneous sediment need not be corrected for moisture, feldspar content changes or grain size. Profiles therefore provide relative chronologies from which accumulation phases can be established, and from which better targeted sampling and comparison to other sites could be undertaken. Even though they do not provide instant absolute chronologies, field-based portable luminescence profiling of Late Quaternary sites hold much potential to improve the resultant chronologies.

1. Introduction

The time dimension is fundamental to most Quaternary studies. Without a means of determining a chronological sequence, timing and duration of events, hiatuses within sequences, and correlation between sites is difficult or impossible to interpret. Most, if not all chronological techniques applicable to the Quaternary period rely on point sampling of appropriate material for a given technique. Yet, as has been shown, the location and number of samples taken from a stratigraphic sequence can have a profound impact on the resultant chronology. For example, Blaauw (2010, Fig. 5), in his review of age-modelling, showed how very different age-depth models could be constructed depending on how ages were interpolated between actual dated points. Likewise, Telfer et al. (2010), in the context of regional-scale dune systems, showed that very different interpretations of externally-forced events could be made, depending on the number of dated samples used. Even where good bedding structures, bounding surfaces or archaeological features have been preserved and are visible in a sediment profile, as demonstrated by Leighton et al. (2013) at Rub' al Khali, Saudi Arabia, the preserved features may not have temporal significance and may lead to inappropriate sample collection. Obtaining an instant chronology of a profile while still at a field site would eliminate many of these errors that occur in the sampling and analyses of Quaternary sediments. The availability of an immediate chronology would allow for an initial assessment of the importance of specific sampling sites relative to the scientific questions the research aims to address. It would also inform where samples for other proxy records should be taken, allow focussing and higher resolution sample of areas which prove to be critical, and depending on the chronology developed, raise further questions about a site which could be addressed in the field.

Although vast improvements have been made to the methodologies of absolute dating (i.e. radiocarbon dating, luminescence dating, dendrochronology, etc.), and absolute chronologies can be available in as little as two days in the case of radiocarbon, these methods all require laboratory-based protocols that are not available during field sampling. Significant technological and methodological advances have also been made with luminescence dating over the last 30 years. There has been a shift in methodology from the slower to reset thermoluminescence signal, to faster optical stimulated luminescence (OSL) signal. There has also been a move from multiple aliquots individually loaded into measurement

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machines to produce a single palaeodose (D_e; e.g. Bateman, 1995) to automated machines and protocols capable of generating a D_e from a single aliquot or single grain (e.g. Bateman et al. 2010). However, rather than producing ages quicker, these advances have been mostly used to generate more sample data to better understand and improve data and age quality (e.g. Bateman et al. 2010). As a result, whilst in principle it is possible to generate an OSL age based on a single aliquot measurement of D_e and by determining the dose-rate, it is highly unlikely that it would be viewed as acceptably robust. Most OSL ages are based on measurements of at least 24 replicates to check reproducibility and take steps to avoid incorporation of any antecedent (pre burial) signal and the effects post-depositional disturbance (e.g. Bateman et al. 2003, 2007), all of which takes time to attain the required laboratory precision.

Until recently, instantly derived chronologies remained largely aspirational. In terms of luminescence, it is technically possible to undertake measurements of luminescence in the field. One such instrument that enables this is the Scottish Universities Environmental Research Centre (SUERC) portable OSL reader (Sanderson and Murphy, 2010). This machine uses pulsed or continuous wave stimulation either by infrared light (IRSL; IR LEDs at 880 nm with RG780 filters) or by blue light (OSL; Blue LEDs at 470 nm with CG420 filters) with signals detected through UG11 filters by a photon counter (Sanderson and Murphy, 2010). The availability of IR and OSL measurements allows for the potential to target either feldspar or quartz related signals. Each measurement takes 60 s (or other set control time), during which time the photon counter collects and calculates the IR or OSL signal and measurement. Actual age determinations are not possible with this method, as the instrument lacks a radiation source and heating system, both necessary to thermally assist OSL signals and to quantify sample specific sensitivities. Instead, the total luminescence count measurements can be viewed as a rough proxy for time, with older samples having a higher luminescence signal than younger samples.

Fundamental to the use of the portable OSL reader is that the measured signal must be dominated by a luminescence signal which relates to age since sediment burial. Luminescence signal is potentially a function of a wide range of variables, including mineral composition, particle size, colour, moisture content and age. Different minerals contribute not only luminescence in different wavelengths but also accumulate luminescence and are bleached at different rates; even within the same mineral, the ability of grains to accumulate dose (i.e. their sensitivity) can vary. The luminescence signal derived from a sample from any given location is generated by the background dose-rate, which is a function of not only uranium, thorium, and potassium levels, but also of whether pore spaces are filled with water or precipitated cements, which attenuate the ionizing radiation. Sediment size and depth from the surface also affects the cosmogenic dose. Thus when comparing multiple down profile measurements to establish a relative chronology, as for example presented by Munyikwa et al. (2012), it is necessary to know whether differences in the total luminescence signal do reflect age or these changes in sediment/luminescence characteristics.

This study aimed to generate portable OSL (POSL) profiles in order to test whether data changes reflect depositional events or other factors, and if the data reflects other factors, which factors other than age affected the luminescence signal. In order to avoid any substantial changes in sediment type, single dunes were selected. To rigorously test the approach, rather than apply it to ancient dunes with long durations and large temporal hiatuses, historical to modern dunes were sought. The availability of historical records was also required, so that these could be used as a known comparative chronology. To this end, the coastal dunes at Holkham, Norfolk fulfilled all of these criteria.

North Norfolk has a low-lying coast with a moderate to low wave regime from the north-east, a westerly longshore drift and macro-meso tidal ranges (Andrews et al. 2000). Its wide sandy beaches and/or subtidal sand flats have given rise to extensive coastal dunes that form multiple coast parallel barriers up to 10 m high. The coast at Holkham is known to have been prograding during the Holocene (Andrews et al. 2000). Historic maps (1st series ordnance survey) and aerial imagery (Crown copyright Royal Air Force aerial photographs 1946, Norfolk County Council aerial survey 1988 and Get Mapping imagery 2007 via Google Earth) show the coast to have continued to prograde and the back beach dunes are still actively accumulating sediment today. Two dunes were selected for this study. Site 1 is located at the back of the present beach, on dunes presumed to be the mostly recently formed; site 2 is located on a line of dunes parallel to the coast, approximately 300 m inland, and interpreted as an older formation than the dunes around site 1 (Fig. 1).

2. Methods

At both dune sites sampling was carried out on the dune crest using a Dormer engineering sand drill. This was used to core each dune from crest to dune base. At ~25 cm intervals, samples for POSL measurements were collected in light-tight chemical photographic film canisters (Fig. 2). Samples for full OSL dating were also collected from near the dune surface, mid core and base of core (Fig. 3). Light-contaminated sediment from the ends of the sample from these were also used to supplement the samples for POSL measurements and to provide direct comparison between the two measurement methods. This resulted in the collection from Site 1 and 2 of a total of 35 samples for POSL measurement and 6 for OSL dating. Results of the OSL dating form part of a wider study; this paper will only summarise the results of the quartz based single aliquot regeneration based OSL ages.

Whilst POSL measurements could have been conducted on site, to achieve more controlled measurements and better evaluate signal changes, samples were transported to the Sheffield University luminescence laboratory. In the dark room, the sediment from the top and bottom of the canister (potentially light contaminated during sampling) was removed and used to evaluate moisture content and for particle size analysis. The remaining sample material was dried at 30 °C for 24 h before POSL measurement was conducted.

To factor out the POSL signal variability due to changing sample volume and changing geometry in respect to the portable reader, a small amount of each sample (~5 g) was placed as a monolayer across the entire base of a 5 cm diameter petri dish. This dish was then placed in the portable reader for measurement. Repeat measurements using this approach were able to produce good reproducibility in terms of both IR and post-IR OSL signal measurements (Fig. S1). Each sample underwent 60 s continuous wave stimulation with IR followed by 60 s continuous wave stimulation with blue light. Data in both cases was integrated 1 s bins. The initial IR measurement should have been collecting the luminescence dominated by feldspars, whilst the post IR OSL measurement should have targeted the quartz dominated signal. Repeat IR measurements of the same sample without removing it from the machine between measurements revealed that full feldspar depletion was not achieved within 60 s. This is in part due to the limiting of the IR stimulation power to only ~90 mW in order to allow the portable reader to be powered by batteries (Sanderson and Murphy, 2010). It also reflects the much larger sample size being measured. A standard 9 mm OSL aliquot typically measures approximately 1800 grains of 200 μm diameter simultaneously,