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GWITHIAN, CORNWALL
OPTICALLY STIMULATED LUMINESCENCE DATING OF SANDS FROM A BRONZE AGE ARCHAEOLOGICAL SITE

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Helen M Roberts

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Research Department Report Series 103/2007

Gwithian, Cornwall
Optically Stimulated Luminescence Dating of Sands from a Bronze Age Archaeological Site

Helen M Roberts

Summary

Two windblown sand units found at the Bronze Age site at Gwithian, near Hayle, West Cornwall, were dated using optically stimulated luminescence (OSL) applied to coarse (sand-sized) quartz grains. The quartz proved sufficiently sensitive to enable well-resolved dating using the Single Aliquot Regenerative dose (SAR) measurement protocol.

The OSL ages are indistinguishable within errors, showing that the two sand units were deposited in relatively rapid succession approximately 3500 years ago, with only a brief period of stabilisation due to cultivation in between. The OSL ages are in agreement with independent evidence from radiocarbon dating of intervening and overlying stratigraphic units.

Keywords

Optically Stimulated Luminescence
Bronze Age

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Gwithian, Cornwall: optically stimulated luminescence dating of sands from a Bronze Age archaeological site

H M Roberts

1. Introduction

This report describes the measurements and findings of an optically stimulated luminescence (OSL) dating study undertaken as part of a project undertaken by the Historic Environment Service of Cornwall County Council in collaboration with English Heritage, studying the Bronze Age archaeological site at Gwithian, near Hayle, West Cornwall (Fig 1). The site at Godrevy Towans was originally excavated during the 1950s and 1960s under the direction of Professor Charles Thomas. The present study forms part of a project re-examining the Bronze Age sequence at Gwithian, in which further samples were taken to enhance the original data sets, and reflect more recent developments in archaeological practice. In June 2005, samples were taken for palaeoenvironmental reconstruction, and also for dating using optically stimulated luminescence (OSL). This report discusses the findings of the OSL work.

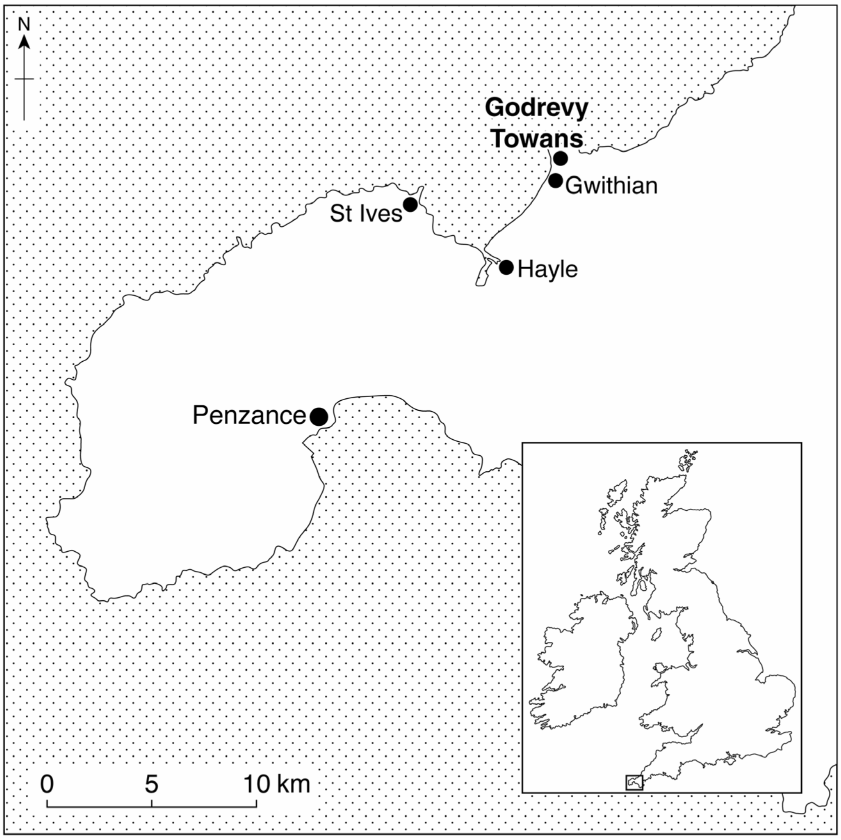

Figure 1: Location of study site at Godrevy Towans, Gwithian, near Hayle, West Cornwall

2. The principles of optically stimulated luminescence dating

Optically stimulated luminescence (OSL) dating examines the time-dependent signal that arises from the exposure of naturally occurring minerals, typically quartz and feldspar, to ionizing radiation in the natural environment. This dating technique can be applied directly to the mineral grains that make up sediment deposits, and here the event being dated is the last time the mineral grains were exposed to sunlight (ie the time the sediments were deposited and buried by further sediments). The technique relies upon the principle that any pre-existing luminescence signal contained in the sediment grains is lost on exposure to sunlight during transport, prior to deposition. Once the sediments are deposited and shielded from light exposure by the deposition of further sedimentary material, the luminescence signal re-accumulates over time through exposure to cosmic radiation, and to radiation from the decay of naturally occurring radioisotopes of uranium, thorium, and potassium located within the surrounding sediment. The luminescence signal is measured in the laboratory by stimulating small sub-samples, or aliquots, of prepared mineral grains with light – hence the term 'optically stimulated luminescence' or OSL. The size or intensity of the OSL signal observed in the laboratory is related to the time elapsed since the mineral grains were last exposed to sunlight. The OSL age is determined by calibrating the intensity of the OSL signal against known laboratory-administered radiation doses in order to determine how much radiation the sample was exposed to during burial (termed the equivalent dose, D_e, or the 'burial dose'). This value is divided by the radiation dose to which the sample was exposed each year since deposition and burial (termed the 'annual dose rate'), to give the OSL age (see Equation 1). Further details on OSL methods are given in Aitken (1998), and in recent reviews by Stokes (1999) and Duller (2004).

Equation 1

$$\text{OSL age (years)} = \frac{\text{Burial dose (Grays)}}{\text{Annual dose rate (Grays per year)}}$$

(1 Gray = 1 Joule/kg)

In this study, the D_e was obtained using the Single Aliquot Regenerative dose (SAR) measurement protocol (Murray and Wintle 2000), applied to coarse-grained quartz (ie grains > 90μm diameter). Working with quartz offers the advantage that it is not subject to anomalous fading, unlike some feldspars (eg Spooner 1994; Huntley and Lamothe 2001). The SAR protocol uses the response to a fixed test dose to correct for any change in luminescence sensitivity occurring in the sample during laboratory measurements (eg as a result of thermal pretreatments), with all of the measurements necessary for the determination of D_e being made on a single aliquot. By measuring several aliquots, many independent determinations of D_e can therefore be obtained. Figure 2 illustrates how D_e is obtained from the SAR measurements made. Following measurement of the natural luminescence intensity (denoted by the square symbol on the y-axis of Fig 2), the response (L_x) to a series of artificial radiation doses is measured, and normalised to the response (T_x) to a fixed test dose. A normalised dose-response or 'growth' curve can then be constructed by plotting the ratio L_x/T_x as a function of radiation dose. This enables the natural luminescence intensity to be calibrated to these responses to a given laboratory radiation dose, thereby determining the laboratory equivalent dose, D_e.

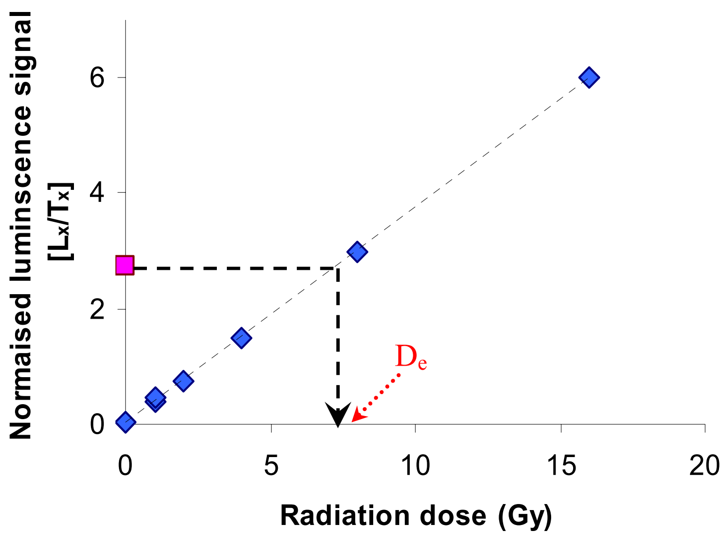

Figure 2: Dose-response or 'growth' curve (diamond symbols) generated from measurements made using the Single Aliquot Regenerative dose (SAR) measurement protocol, used in this study. The natural luminescence intensity (square symbol) of the aliquot is calibrated against the response to these known artificial irradiation doses to determine the laboratory equivalent dose, D_e

3. Sample site and OSL sample collection

In this project, OSL dating was to be used to date the wind-blown ('aeolian') sands lying between the archaeological units (including ploughed units) at one exposed section of the Gwithian site. For this pilot study, samples were selected from homogeneous sand units and taken as far away as possible from any change in stratigraphic unit, to minimise potential complications from any differences in dosimetry. Field gamma spectrometry measurements were also made at the point from which the OSL sample was taken to record the *in situ* dose rate to the sample.

One sample was taken from each of two sand units in the south facing section GMXVII using a 250mm length of 50mm diameter opaque plastic pipe driven horizontally into the sand units. The samples were taken from contexts 602a and 606, and given the laboratory codes Aber-101/GWT-4 and Aber-101/GWT-6, for the upper and lower units, respectively (Fig 3).

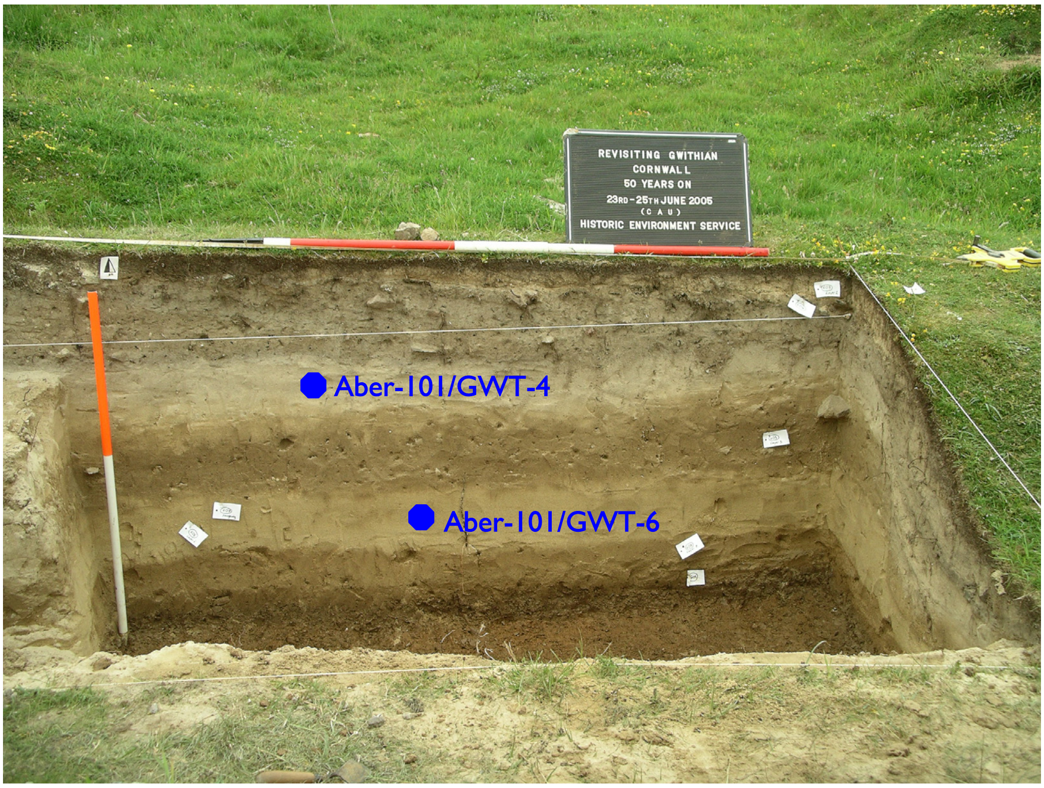

Figure 3: Section GMXVII at Gwithian, sampled 23–25 June 2005. The OSL sample locations are shown along with Aberystwyth Luminescence Research Laboratory codes; sample Aber-101/GWT-4 was taken from context 602a (part of 'Layer 4' in the original excavation), whilst sample Aber-101/GWT-6 was taken from context 606 (formerly termed 'Layer 6')

4. Methodology

4.1 Laboratory preparation

Samples were taken for preparation for OSL measurements by excavating material from the leading edge of the plastic sample tube (ie the material from deepest into the section) under subdued red lighting conditions in the luminescence laboratory. The first 10mm of the sample that had been exposed to daylight during sampling and retrieval was removed prior to the excavation of sample material for luminescence dating. Coarse-grained quartz was prepared using standard methods, outlined below.

Samples were pretreated with a 10% vv dilution of concentrated (37%) hydrochloric acid (HCl) to remove carbonates and surficial coatings, then washed three times in distilled water. Samples were then treated with 20 vols hydrogen peroxide (H_2O_2) to remove organic material, and then washed as previously. Samples were dried and then sieved using the following mesh sizes: 355, 300, 250, 212, 180, 150, 125, and 90μm diameter mesh.

Grains of 180–212μm diameter were selected for OSL dating, and refined using a solution of sodium polytungstate ('heavy liquid') to separate out the quartz material from the feldspar and heavy mineral fractions of the sediments, on the basis of differences in density. The quartz-rich fraction of the sediments (density between 2.62–2.70 gcm^{-3}), was treated with 40% hydrofluoric acid (HF) for 45 minutes, to remove the alpha-irradiated surface of the quartz grains and to dissolve any remaining feldspar material, followed by a further 45 minutes in concentrated (37%) HCl, to dissolve any fluorides formed during the etching procedure. The samples were rinsed a minimum of three times in distilled water, centrifuging between washings, and then dried at 50°C, prior to re-sieving. This final sieving acts as a further quartz purification step, as it removes feldspar grains which have not been totally dissolved with HF, but which have been significantly etched and therefore reduced in diameter. The final quartz is then ready for OSL measurements to determine the 'burial dose' or equivalent dose, D_e.

The light-exposed material removed from the end of each OSL sample tube was suitable for laboratory-based measurements of water content and dosimetry as these measurements do not require unexposed sample material. The light-exposed portion of each OSL sample was weighed, prior to drying at 50°C. Drying continued until a constant mass was recorded, to establish the field water content at the time of sampling. These measurements of conditions at the time of sampling provide a benchmark for the water content values employed in the final age calculations (shown in Table 3). After drying, the light-exposed material was then crushed to a fine powder using a ball mill, prior to beta counting (*see* section 4.2).

4.2 Equipment and Methods

All OSL measurements were conducted using an automated *Risø* TL/OSL reader, equipped with a combined high-power blue LED/ infra-red laser diode OSL unit, and a beta source for irradiations. The combined OSL unit was employed at 80% of full diode current, providing approximately 17mW/cm^2 power from the blue LED unit (470nm), and 370mW/cm^2 from the IR laser diode (830nm). All measurements were made whilst holding the sample at 125°C, and OSL was detected using 7.5mm Hoya U-340 filters.

Measurements of OSL were made on coarse-grained quartz, using the Single Aliquot Regenerative dose (SAR) protocol of Murray and Wintle (2000). The advantage of SAR over previous measurement protocols is that it uses a measurement of the luminescence production per unit dose to monitor and correct for changes in luminescence sensitivity that have occurred as a function of time, temperature, and past-radiation exposure (Wintle and Murray 2000). The SAR procedure permits the determination of an equivalent dose (D_e), and hence potentially an OSL age, for each aliquot examined.

As part of the sequence of OSL measurements made, outlined in Table 1, a minimum of four regenerative beta doses were applied to each aliquot, bracketing the expected natural dose. Two zero beta doses were also included towards the beginning and end of the measurement cycle to monitor recuperation, and the first regenerative dose was repeated at the end of the measurement protocol to monitor the sensitivity correction applied (this is sometimes referred to as monitoring of the 'recycling'). Following measurement of each natural or regenerative-dose signal, a fixed test dose was applied, with a cut-heat of 160°C, to monitor and correct for sensitivity change during the measurement procedure. Measurements were made for a range of preheat temperatures (held for 10s) to enable D_e to be obtained as a function of preheat temperature: 24 aliquots were examined at preheat temperatures ranging between 160–300°C in 20 °C step intervals, with three aliquots at each temperature.

Dose-rates were determined using a *Risø GM-25-5* beta counter for laboratory-based beta counting, applied to finely ground bulk sample material, and a portable MicroNomad gamma detector fitted with a 50mm crystal was used in the field (section 3). The cosmic ray dose was estimated from the burial depth (Prescott and Hutton 1994). Water contents were determined in the laboratory from sealed field samples (section 3), and the values employed in the calculation of ages are presented in Table 3. Moisture and beta attenuation factors are given in Aitken (1985). The beta and gamma counting results, cosmic dose rates, water content values, and the dose rates calculated using the conversion factors of Adamiec and Aitken (1998), are given for each sample in the final age table (Table 3).

Table 1: Outline of the SAR measurement protocol applied to each aliquot in this study. A minimum of four regenerative doses were employed in this study, designed to characterise the dose-response curve and bracket the natural signal

Step Number	**SAR sequence description**
1	Preheat: (160–300°C), heating rate 5°C/s, hold at temperature for 10s
2	Measure natural or regenerative dose signal (‘L_x’): 100s OSL @125°C
3	Apply Test Dose
4	Cut heat: 160°C, heating rate 5°C/s
5	Measure test dose signal (‘T_x’):100s OSL @125°C
6	Apply 0Gy dose (‘recuperation’ check)
7–11	*Repeat steps 1–5*
12	Apply regenerative dose 1
13–17	*Repeat steps 1–5*
18	Apply regenerative dose 2 (larger than dose 1)
19–23	*Repeat steps 1–5*
24	Apply regenerative dose 3 (larger than dose 2)
25–9	*Repeat steps 1–5*
30	Apply regenerative dose 4 (larger than dose 3)
31–5	*Repeat steps 1–5*
36	Apply 0Gy dose (‘recuperation’ check)
37–41	*Repeat steps 1–5*
42	Apply regenerative dose 1 (‘recycling’ test)
43–7	*Repeat steps 1–5*

5. Results of experimental tests

As part of the OSL measurements made in this project, a series of tests were undertaken to monitor the OSL measurement procedure, the response and behaviour of the samples, plus the choice of grain size and aliquot size. These experimental checks are discussed below.

5.1 Aliquot size

Prepared quartz grains for each sample were presented for OSL measurements by mounting the grains in a monolayer onto 10mm diameter aluminium discs, sprayed lightly with Silkospray™ silicone oil to hold the grains in place during measurement. The discs, or aliquots, may be prepared using various amounts of sample. In this study, initial tests showed that signal levels were low due to the material being relatively insensitive and/or due to the relatively young age of the material. Large aliquots (8mm diameter, giving >1000 grains per aliquot) were therefore examined throughout this study, to maximise the luminescence signal observed from each aliquot.

5.2 OSL signal checks

The OSL signal of each aliquot measured was examined visually, to check the initial signal intensity and the form of the decay curve. A typical decay curve is shown in Figure 4, and shows a rapid decrease in signal which is characteristic of the decay of a signal from quartz. Routinely, the D_e values were calculated using the first two data channels (0.8s stimulation) and the background was taken from the end of the decay curve (channels 230–250, the final 8.4s stimulation). This maximised the contribution of the fast component of the OSL signal (Bailey *et al* 1997; Murray and Wintle 2003), and typically represented ~15–35% of the total OSL signal.

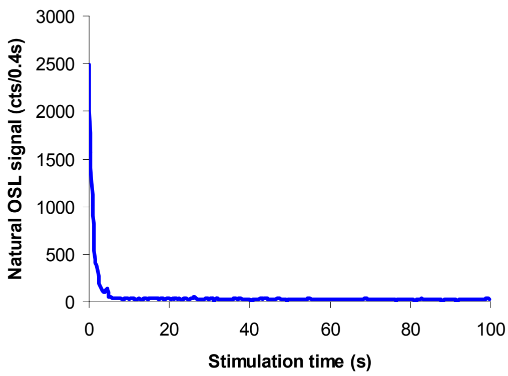

Figure 4: Typical OSL signal for aliquots in this study. The example shown is from an aliquot of sample Aber-101/GWT-6 which was preheated to 220°C/10s. The very rapid decrease in signal, quickly reaching a steady low background is a form which is frequently observed in the study of quartz aliquots. The signal integrated to derive the value of D_e is that from the first 0.8s of optical stimulation

The form of the dose-response or 'growth' curve was also examined, and a minimum of four artificial irradiation doses were used to define the growth curve for each aliquot, designed to bracket the 'natural' signal and hence determine the value of D_e. Figure 5 shows a typical growth curve; error bars are shown, calculated following Banerjee *et al* (2000) and Galbraith (2002), and generated by *Analyst* (written by Dr Geoff Duller, Aberystwyth University).

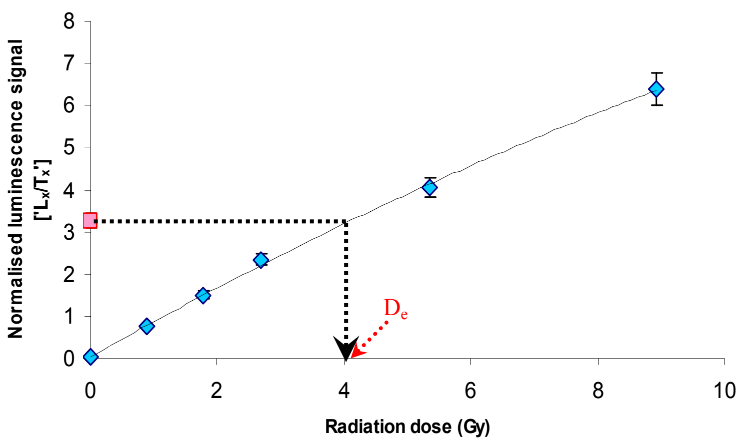

Figure 5: Typical growth curve constructed for aliquots in this OSL dating study. The example shown is from an aliquot of sample Aber-101/GWT-6 which was preheated to 220°C/10s

Once the sequence of dating measurements was completed, each aliquot was irradiated and then stimulated using infrared (IR) laser-diodes at a temperature of 125°C to check the purity of each aliquot. Stimulation with IR was proposed as a check on the purity of prepared quartz material by Stokes (1992). Feldspathic minerals respond to simulation with IR, giving a rapidly decaying signal, however, quartz does not appear to respond to stimulation with IR (Spooner and Questiaux 1989). There was little evidence of any response above background signal levels to stimulation with IR for any aliquot in this study (a typical IR stimulated luminescence signal response is shown in Fig 6). No feldspar contamination was therefore considered to be present in any quartz separates prepared for this OSL dating study.

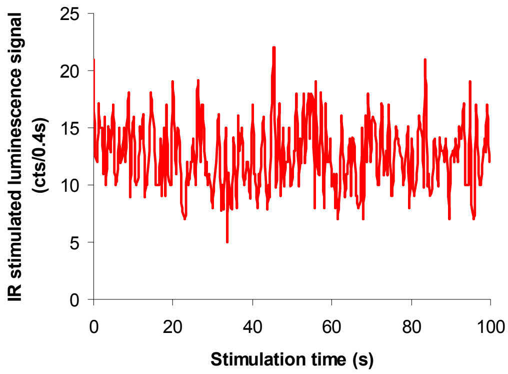

Figure 6: Typical response to stimulation with IR. The signal level is very low, being approximately at background levels, thereby suggesting that no feldspar is present in the quartz material prepared for OSL dating. The example shown is from an aliquot of sample Aber-101/GWT-6 which was preheated to 220°C/10s

5.3 Recovery of a known laboratory irradiation dose

An important test of any luminescence dating protocol employed is whether the value of a previously delivered laboratory irradiation dose can be accurately and precisely determined. This is sometimes referred to as a 'dose-recovery' test and should be conducted on material which has not previously received any thermal pretreatments. This fundamental test was conducted for both samples in this dating study using three aliquots of unheated material at each preheat temperature to study the dose recovery across a range of preheat temperatures (160–240°C for sample Aber-101/GWT-4, and 160–300°C for sample Aber-101/GWT-6).

The laboratory beta dose chosen for the dose-recovery experiment was 2.7Gy. Between 15 and 24 aliquots of each sample were prepared in the same way as the aliquots used for dating. The natural signal was removed from each aliquot by 2 × 1000s stimulation with blue diodes at room temperature, with a 10,000s pause between each stimulation; a beta dose was then applied to each of the aliquots in the dose recovery experiment. The SAR protocol was then applied using regeneration and test dose values of the same size as used in the dating measurement sequences, and applying a preheat of between 160–300°C for 10s, and a cut heat of 160°C.

The beta dose recovered for each set of sample aliquots is shown in Figure 7 relative to the beta dose applied, and is also shown numerically in Table 2 as mean dose recovery values for each preheat temperature. With the exception of one aliquot of sample Aber-101/GWT-6 which is clearly anomalous (Fig 7b), the ratio of the beta dose applied to the dose recovered is within ±10% of unity for both samples using a range of preheat temperatures. The SAR measurement protocol therefore seems to be appropriate and working well for the sample material used for dating in this study, even at high and low preheat temperatures.

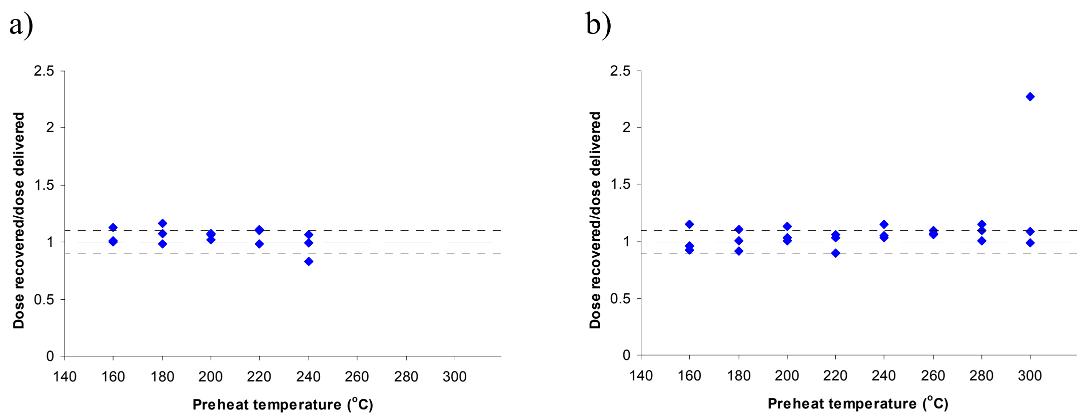

Figure 7: Dose recovery test results for sample a) Aber-101/GWT-4 and b) Aber-101/GWT-6, showing the dose recovered relative to the dose applied for each of the three aliquots measured using a range of different preheat temperatures. Unity and the error limits at ±10% are indicated as dashed lines

Table 2: Recovery of a known beta dose for three aliquots prepared from each sample dated in this OSL study. The dose applied to sample Aber-101/GWT-4 for recovery was 74% of the natural D_e, and for Aber-101/GWT-6 the dose to recover was 71% of the natural D_e

Sample	Dose applied (Gy)	Dose recovered / Dose applied (mean and s.d. of 3 aliquots)
101/GWT-4 160°C	2.68	1.05 ±0.07
101/GWT-4 180°C	2.68	1.07 ±0.09
101/GWT-4 200°C	2.68	1.05 ±0.03
101/GWT-4 220°C	2.68	1.06 ±0.07
101/GWT-4 240°C	2.68	0.96 ±0.12
101/GWT-6 160°C	2.68	1.01 ±0.12
101/GWT-6 180°C	2.68	1.01 ±0.09
101/GWT-6 200°C	2.68	1.06 ±0.07
101/GWT-6 220°C	2.68	0.99 ±0.09
101/GWT-6 240°C	2.68	1.08 ±0.06
101/GWT-6 260°C	2.68	1.07 ±0.02
101/GWT-6 280°C	2.68	1.08 ±0.07
101/GWT-6 300°C	2.68	1.04 ±0.07*

* The anomalous dose recovery point shown in Fig 7b and discussed above is omitted here; the mean shown is therefore that of two aliquots for this preheat temperature

5.4 OSL dating measurements and checks

The SAR measurement sequence employed in this study has several checks built into it to monitor the behaviour of the sample and the efficacy of the sensitivity correction. For each sample, 24 aliquots were examined to establish D_e values for use in determining an OSL age. The advantage of working with single-aliquot, rather than multiple-aliquot methods, is that each of the 24 aliquots measured gives rise to an independent assessment of D_e, and hence, potentially to an OSL age.

Working with a number of aliquots offers the advantage of making measurements using a range of thermal pretreatments, to compare the D_e values determined for aliquots using different preheat temperatures. Thermal pretreatments are employed in order to remove any unstable trapped charge prior to measurement of either the natural or an artificially irradiated OSL signal. However, high preheat temperatures are sometimes problematic for young samples, and can lead to erroneously high D_e values being determined due to thermal transfer of trapped charge from relatively stable yet optically-insensitive traps into OSL traps during preheating (eg Bailey *et al* 2001). Given the likely young age of the samples in this study, it was therefore of particular importance to make OSL measurements using a range of preheat temperatures to try to establish a preheat plateau where common values of D_e could be identified and any erroneously high D_e values could be discounted. A range of preheat temperatures was therefore investigated during OSL dating measurements of each sample, increasing to the given temperature at a rate of 5°C/s and held for 10s on reaching the required temperature; a minimum of three aliquots were examined at each of 8 preheat temperatures (160–300°C).

The preheat plots generated for the samples in this study are given in Figure 8, showing D_e values for each of three aliquots measured using one of eight preheat temperatures. All aliquots measured are shown in Figure 8, including those rejected from the final age determination (Table 3). Aliquots were rejected on the basis of several criteria: where recycling ratios exceeded ±10%, where the maximum error on the test dose or the D_e exceeded 10%, and where signal intensities were <1000 counts/0.8s stimulation. The plateau test suggests that a wide range of preheat temperatures are suitable for dating these samples; furthermore, thermal transfer of trapped charge does not seem to be a problem here.

a) b)

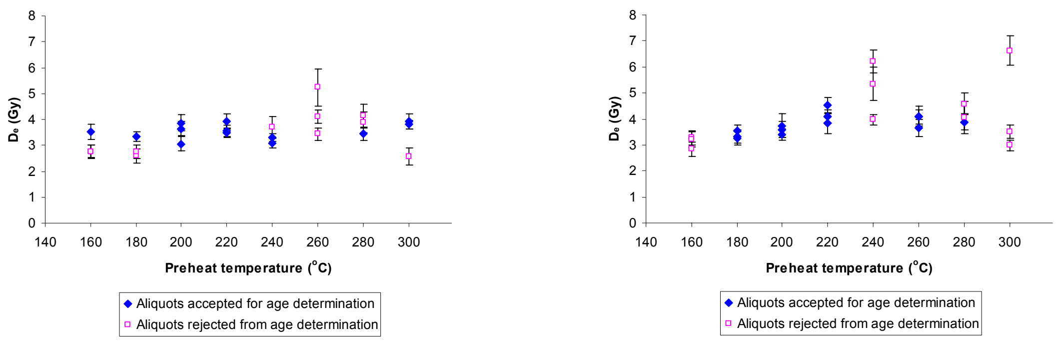

Figure 8: Preheat plots for a) sample Aber-101/GWT-4, and b) sample Aber-101/GWT-6, showing the D_e value determined for each of the three aliquots measured using a range of different preheat temperatures. The associated error in D_e is from the error on 'n' as defined by Galbraith (2002) from counting statistics and the error associated with curve fitting as used in *Analyst* (written by Dr Geoff Duller, Aberystwyth University)

Other criteria may also be used to evaluate the behaviour and reliability of the aliquots used for dating. One of the most powerful of these tests arises from the use of the SAR protocol for the OSL dating measurements. In this measurement procedure, the natural luminescence signal is measured, followed by the response to a series of artificial laboratory beta doses of increasing magnitude designed to bracket the intensity of the natural signal (Table 1). In the SAR measurements made in this study, a low irradiation dose was repeated, or recycled, and applied at the end of the measurement cycle for all aliquots to test how well the sensitivity correction procedure is working. If the sensitivity correction is adequate, then the ratio of the signal arising from this repeated regenerative dose at the end of the measurement sequence to that of its earlier regeneration dose (eg Table 1) should fall within the range of 1.0 ±0.1 (Murray and Wintle 2000). Only two of the 48 aliquots examined for OSL dating failed this 'recycling test', indicating that the sensitivity correction in the SAR measurement procedure is working well for these samples in monitoring and correcting for changes in luminescence sensitivity that may have occurred as a function of time, temperature, and past-radiation exposure.

A further test of the reliability of the sensitivity corrected growth curve generated using the SAR measurement protocol is a check on the 'recuperation' of signal (Murray and Wintle 2000) following the application of a regeneration dose of 0Gy at both the beginning (following measurement of the natural signal) and towards the end of the measurement cycle (following the largest regeneration dose and prior to the application of the recycling regeneration dose). No significant net OSL signal should be observed following this 0Gy beta dose if the sensitivity correction is working correctly. For the two samples in this study, no recuperation in OSL signal was observed at low through to high preheat temperatures, and the dose-response or 'growth' curve generated passed through the origin (eg Fig 9a and b). This suggests again that thermal transfer of charge from optically insensitive traps into OSL traps is not a factor in this study.

(a) (b)

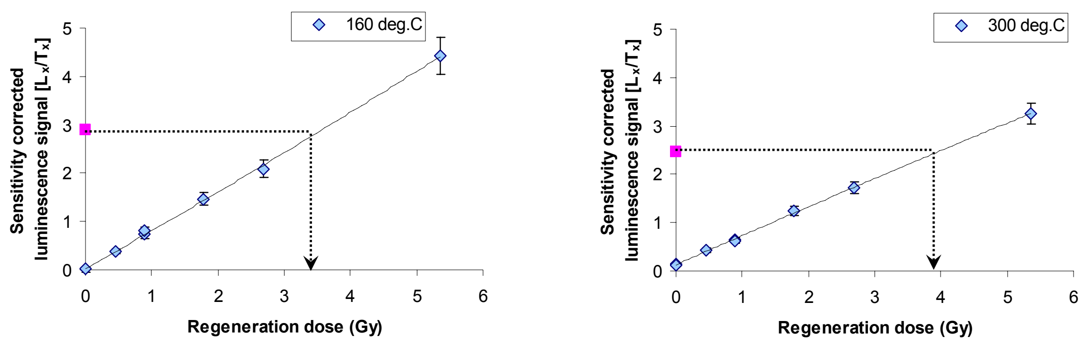

Figure 9: Sensitivity corrected dose-response or 'growth' curves measured following (a) low (160°C) and (b) high (300°C) preheat temperatures for the aliquots shown in the preheat plot of Figure 8a (sample Aber-101/GWT-4). In both cases, the dose-response curve passes through the origin, and no increase in recuperation of the OSL signal is observed between the beginning and the end of the measurement sequence. The aliquot also passes the recycling ratio test (repeating a regeneration dose at the end of the measurement sequence, here of ~0.9Gy)

5.6 Determination of the equivalent dose for use in the final OSL age calculation

The aliquots on which OSL dating measurements were conducted were screened for their suitability for use in the final age equation using the series of tests described and discussed above. These checks included examination of signal intensity levels, decay curve shape, growth curve shape, recycling ratio, recuperation, preheat plots, and feldspar contamination checks using IR stimulation. The most common reason for rejection of aliquots (accounting for 91% of the aliquots rejected) was on the basis of low signal levels, causing errors on the test dose and D_e to exceed 10%. In spite of this, the number of acceptable aliquots combined to determine a final OSL age for each sample was 13.

For each sample, the D_e values of the aliquots accepted following screening were normally distributed (an example is shown in Fig 10). The simple arithmetic mean of these D_e values was therefore taken for calculation of the final OSL age. The error on each determination of D_e was calculated using the standard error (ie the standard deviation divided by the square root of the number of estimates of D_e). The D_e and standard error are given for each sample in the final OSL age table (Table 3).

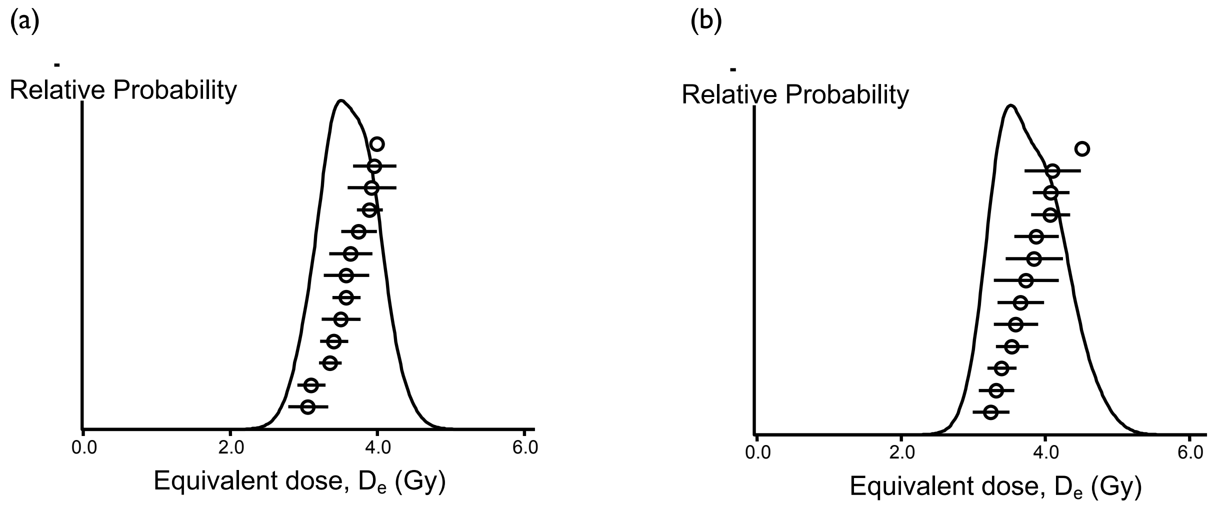

Figure 10: The distribution of D_e values obtained for a) sample Aber-101/GWT-4, and b) sample Aber-101/GWT-6. Each of the 13 points shown is an individual aliquot, which is plotted with the associated error. The probability density plots demonstrate that the D_e values of both samples are normally distributed

The aliquots which were accepted following all the screening tests (Fig 10) are also shown replotted for both samples in this study in Figure 11. Here, the distributions of D_e values are presented as radial plots (Galbraith 1990), with the D_e of each aliquot being shown as a single point on the plot. These plots are presented as a visual aid to the data only, and displaying the data on such plots offers the advantage of showing the precision to which each data point is known. The precision is displayed on the x-axis, with data of high precision being plotted towards the right hand side of the plot. The y-axis shows the number of standard deviations away from a central value for each D_e value, whilst the radial scale displays the D_e value. The horizontal dotted line extending from 0 on the y-axis is the mean D_e calculated for the sample. The dotted lines extending from the y-axis to the radial scale in Figure 11 are placed at two standard deviations, and any points falling within these limits (indicated by infilled circles) therefore lie within two standard deviations of the mean D_e value. Ideally, the data for all aliquots will fall within this band indicated on the diagrams, indicating one population of D_e values. The data for both samples in this study show very little scatter in the distribution of D_e values obtained following screening (Fig 11), suggesting only one population of D_e values for each sample.

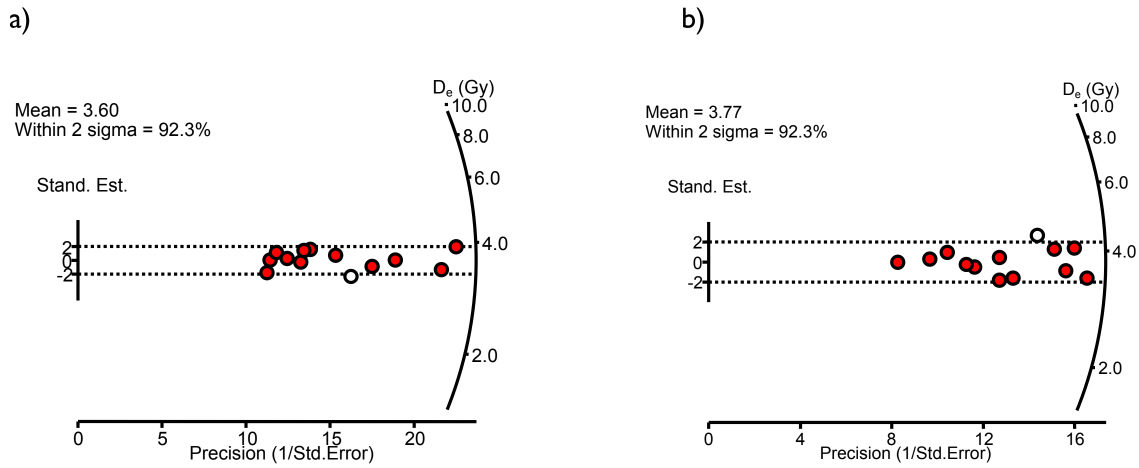

Figure 11: Distribution of equivalent dose (D_e) values used for the determination of OSL ages for a) sample Aber-101/GWT-4, and b) sample Aber-101/GWT-6

6. OSL age determinations

The equivalent dose (D_e) data (discussed in section 5) and the results of laboratory dosimetry measurements were combined for each sample, with corrections being made for attenuation by water and for grain size, to give an OSL age for both samples in this study. These data, including the final age determinations, are presented in detail for each sample in Table 3. The error shown for the D_e determination of both samples (Table 3) is the standard error (*see* section 5.6) (ie the standard deviation divided by the square root of the number of independent estimates of D_e). The average percentage error on the OSL ages is small, being < 5.0%.

The finalised OSL ages are also shown in Figure 12, superimposed on a photograph of the Gwithian section. Although the ages are not in stratigraphic order, they are consistent with each other within 1σ errors. The fact that the ages cannot be resolved, in spite of their high precision, suggests that the sand deposition was rapid, with only a brief period of stabilisation due to cultivation occurring in between, as indicated by the intervening Bronze Age ploughsoil (Phase 3 in Hamilton *et al* 2007, formerly 'Layer 5'). The OSL ages are in agreement with radiocarbon dates obtained from this phase (SUERC-6167: 3180 ±35 BP, 1520–1400 cal BC) and from deposits sealing 'Layer 4' (ie from Phase 5 in Hamilton *et al* 2007, eg OxA-14590: 2836 ±32 BP, 1120–900 cal BC).

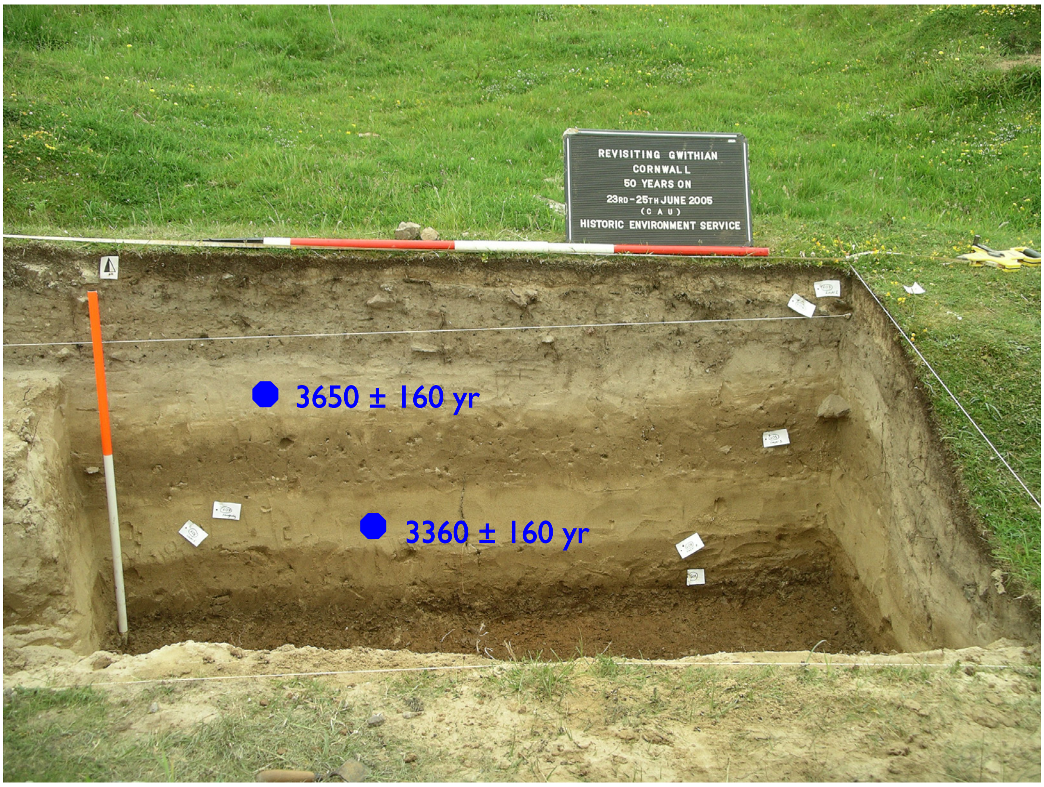

Figure 12: The OSL ages of the two sand units dated for Gwithian (see Table 3 for full details of the OSL age determinations). The uppermost sample, Aber-101/GWT-4, was taken from context 602a (part of 'Layer 4' in the original excavation), whilst the lower sample, Aber-101/GWT-6, was taken from context 606 (formerly termed 'Layer 6')

Table 3: OSL sample details, equivalent dose and dose rate data, and OSL ages

Gwithian OSL samples		
Aberystwyth Lab. number	101 GWT 4	101 GWT 6
Sample description	Context 602a	Context 606
Depth down-section (m)	0.45 ±0.02	0.85 ±0.02
Material used for dating	quartz	
Grain size (μm)	180–212	180–212
Preparation method	Heavy liquid separation (sodium polytungstate); 40% HF etch 45 mins	
Measurement protocol	SAR; OSL 470nm; detection filter 7.5mm Hoya U-340	
Aliquots measured	24	24
Aliquots used for D_e	13	13
Equivalent Dose, D_e (Gy)*	**3.60 ±0.09**	**3.77 ±0.10**
Water content (% dry mass)	7 ±5	7 ±5
U (ppm)	0.62 ±0.04	0.63 ±0.04
Th (ppm)	1.71 ±0.11	2.49 ±0.14
K (%)	0.65 ±0.05	0.73 ±0.05
Layer removed by etching (μm)	10 ±2	10 ±2
Infinite β dose rate (Gy/ka)	0.599 ±0.008	0.734 ±0.015
External β dose rate 'wet' (Gy/ka)	0.484 ± 0.029	0.593 ± 0.036
External γ dose rate 'wet' (Gy/ka)	0.287 ± 0.020	0.340 ± 0.022
Cosmic (Gy/ka)	0.214 ±0.002	0.189 ±0.002
Total dose rate (Gy/ka)	**0.99 ±0.04**	**1.12 ±0.04**
OSL Age#	**3650 ±160**	**3360 ±160**

Ages are expressed as years before AD 2005, rounded to the nearest 10 years. All calculations were performed before rounding.
* The error shown is the standard error on the mean.

7. Summary and Conclusions

Two sand units, interpreted to be aeolian in origin, found at the Bronze Age site at Gwithian were dated using OSL applied to coarse-grained quartz. The OSL measurement procedure employed was the Single Aliquot Regenerative dose (SAR) protocol which corrects for sensitivity change. Several checks and screening criteria were applied to the OSL dating aliquots and also to additional aliquots prepared from the samples to ensure that the data included in the final age calculation were of the highest quality. The SAR measurement protocol was appropriate for these samples and the sensitivity correction worked well. Using large aliquots, the samples studied proved sufficiently sensitive and responsive to facilitate well-resolved dating using OSL.

The final OSL ages generated were both accurate and of high precision, being supported by other independent dating evidence from radiocarbon (Hamilton *et al* 2007; Nowakowski in press; Nowakowski *et al* forthcoming). The OSL ages of the two units dated were indistinguishable, in spite of the high precision obtained. This implies that the deposition of the two wind-blown sand units was rapid, and took place at approximately 3500 years ago, with only a brief period of stabilisation due to cultivation in the intervening time.

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References

Adamiec, G and Aitken, M, 1998 Dose-rate conversion factors: update, *Ancient TL* **16**, 37–49

Aitken, M J, 1985 *Thermoluminescence Dating,* London (Academic Press)

Aitken, M J, 1998 *An Introduction to Optical Dating*, Oxford (Oxford Univ Press)

Bailey, R M, Smith, B W, and Rhodes, E J, 1997 Partial bleaching and the decay form characteristics of quartz OSL, *Radiation Measurements*, **27**, 123–36

Bailey, S D, Wintle, A G, Duller, G A T, and Bristow, C S, 2001 Sand deposition during the last millennium at Aberffraw, Anglesey, North Wales as determined by OSL dating of quartz, *Quat Sci Rev*, **20**, 701–4

Banerjee, D, Bøtter-Jensen, L, and Murray, A S, 2000 Retrospective dosimetry: estimation of the dose to quartz using the single-aliquot regenerative-dose protocol, *Applied Radiation and Isotopes*, **52**, 831–44

Duller, G A T, 2004 Luminescence dating of Quaternary sediments: recent advances, *J Quat Sci*, **19**, 183–92

Galbraith, R, 1990 The radial plot: graphical assessment of spread in ages, *Nuclear Tracks and Radiation Measurements*, **17**, 207–14

Galbraith, R, 2002 A note on the variance of a background-corrected OSL count, *Ancient TL*, **20**, 49–51

Hamilton, D, Marshall, P, Roberts, H M, Bronk Ramsey, C, and Cook, G, 2007 Gwithian: scientific dating (AMS) programme, in *Excavations of a Bronze Age landscape and post-Roman industrial settlement 1953–61, Gwithian, Cornwall. Assessment of key datasets 2005–6* (ed J A Nowakowski), **II**, 249–63 (Historic Environment Service, Cornwall County Council), HES Rep 2007R017

Huntley, D J and Lamothe, M, 2001 Ubiquity of anomalous fading in K-feldspars and the measurement and correction for it in optical dating, *Canadian J Earth Sci*, **38**, 1093–106

Murray, A S and Wintle, A G, 2000 Luminescence dating of quartz using an improved single-aliquot regenerative-dose protocol, *Radiation Measurements*, **32**, 57–73

Murray, A S and Wintle, A G, 2003 The single aliquot regenerative dose protocol: potential for improvements in reliability, *Radiation Measurements*, **37**, 377–81

Nowakowski, J A, in press Living in the sands – Bronze Age Gwithian, Cornwall, revisited, in *Land and People: papers in Honour of John G Evans*, Prehist Soc Res Papers

Nowakowski, J A, Quinnell, H, Sturgess, H, Thomas, C, and Thorpe, C, forthcoming Return to Gwithian: shifting the sands of time, *Cornish Archaeol*

Prescott, J R and Hutton, J T, 1994 Cosmic ray contributions to dose rates for luminescence and ESR dating: large depths and long-term time variations, *Radiation Measurements*, **23**, 497–500

Spooner, N A, 1994 The anomalous fading of infrared-stimulated luminescence from feldspars, *Radiation Measurements,* **23**, 625–32

Spooner, N A and Questiaux, D, 1989 Optical dating – Achenheim beyond the Eemian using green and infrared stimulation, in *Proceedings of a Workshop on Long and Short Range Limits in Luminescence Dating*, RLAHA Occ Publ 9, Oxford Univ

Stokes, S, 1992 Optical dating of young (modern) sediments using quartz: results from a selection of depositional environments, *Quat Sci Rev*, 11, 153–9

Stokes, S, 1999 Luminescence dating applications in geomorphological research, *Geomorphol*, **29**, 153–71

Wintle, A G and Murray, A S, 2000 Quartz OSL: effects of thermal treatment and their relevance to laboratory dating procedures, *Radiation Measurements*, **32**, 387–400