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BOLSTERSTONE GLASS HOUSE, STOCKSBRIDGE, SHEFFIELD, SOUTH YORKSHIRE
LUMINESCENCE DATING REPORT

SCIENTIFIC DATING REPORT

Ian Bailiff

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SUMMARY

Samples of heated sandstone associated with glass furnace sieges and the annealing furnace flue of the Bolsterstone Glass House, Stocksbridge, Sheffield, were tested using luminescence dating procedures, and conducted in parallel with an archaeomagnetic dating study of the structure (Karloukovski and Hounslow 2007). Six locations were sampled using a coring drill, four within the masonry forming the central lintel of the flue and the footings to the central arch support, and two taken from an excavation pit associated with the remains of the glass furnace sieges within the building. Quartz grains extracted from two of the six cores were found to have measurable luminescence signals (optically stimulated luminescence, OSL), whereas the OSL sensitivity of quartz from the other samples was insufficient for reliable dating measurements. The luminescence dates obtained for the samples from the central arch support footings and the sieges were AD 1745 ±23 and 1697 ±22, respectively (1σ). It is suggested that the luminescence and archaeomagnetic results obtained provide dates for two, and possibly three, phases of the thermal history of the structure related to glassmaking from the late 16th to mid-17th centuries and subsequent pottery production during the mid-19th century.

CONTRIBUTORS

Ian Bailiff and Scott Grainger, with contributions from D Dungworth, M Hounslow, P Linford, and J Meadows in comparing the luminescence results with other dating evidence.

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The samples examined were obtained by Vassil Karloukovski and Mark Hounslow of the Centre of Environmental Magnetism and Palaeomagnetism, Lancaster University.

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INTRODUCTION

The standing building that is now an outhouse adjoining Pot House Barn contains the remains of a 17th/18th century glasshouse (Fig 1; SK2660398029) which is thought to represent the earliest extant glasshouse structure in Britain. The furnace complex was excavated in 1986 (Ashurst 1987) and the standing elements of the original furnace, in particular the flues and sieges, are constructed with sandstone blocks. The latter, because of the nature of the use of the structure, were subject to repeated thermal treatments and hence are potentially suitable for application of archaeomagnetic and luminescence dating to determine the last use of the furnaces.

Figure 1: Map to show the location of Bolsterstone Glasshouse (based on the Ordnance Survey map with permission of the Controller of Her Majesty's Stationery Office, © Crown Copyright)

The results of the archaeomagnetic analysis have been reported by Karloukovski and Hounslow (2007), and the outcome of the luminescence measurements are reported here. Since the coring procedure used for archaeomagnetic samples (with some minor modifications) yields samples that are satisfactory for luminescence dating, a subset of the cores obtained for archaeomagnetic tests by the Lancaster University team was made available for luminescence tests. The sandstone blocks selected for sampling were located in regions of the furnace where the temperatures were expected to have greatly exceeded the temperatures required to zero the latent luminescence signal (*c.* 350 °C). The details of the locations discussed below are reproduced from the report of Karloukovski and Hounslow (2007).

METHODOLOGY

A quartz coarse grain technique (Aitken 1985; 1998) was applied to determine the luminescence age of the samples discussed in this report. The age, A, is calculated by determining experimentally the values of the palaeodose estimate, D_e, and the total dose rate, $\dot{D}_{tot}$:

$$A = \frac{D_e}{\dot{D}_{tot}} \pm \sigma_A; \pm \sigma_B, \quad (1)$$

where $\dot{D}_{tot} = a\dot{D}_{\alpha} + b\dot{D}_{\beta} + g\dot{D}_{\gamma} + \dot{D}_{cos}$ (2)

$\dot{D}_{\alpha}$ is the dose rate due to alpha-emitting radionuclide sources within the interior of the quartz grains (ie uranium and/or thorium); a is the a value (Aitken 1985) that accounts for the lower yield of luminescence per unit of absorbed dose; $\dot{D}_{\beta}$ and $\dot{D}_{\gamma}$ are the point-absorber infinite-medium β and γ dose rates respectively; b is a lumped correction factor that is applied to account for the attenuation of β radiation by the quartz grains, the reduction in grain size due to HF etching, and differences in the absorption coefficient between ceramic and water; g is a lumped correction factor related the geometry of the sources of γ radiation and to differences in the absorption coefficient between ceramic and water; $\dot{D}_{cos}$ is the cosmic ray dose rate calculated using the formula of Prescott and Hutton (1988). The process of HF etching quartz grains is assumed to reduce the dose rate contribution from external sources of alpha particles to a negligible level.

The age is given with two error terms ($\pm\sigma_A; \pm \sigma_B$) that are calculated using a procedure of error propagation similar to that described by Aitken (1985). The first error term, σ_A, is a type-A standard uncertainty (ISO 1993) obtained by an analysis of repeated observations. The second error term, σ_B, is a type-B standard uncertainty based on an assessment of uncertainty associated with all the quantities employed in the calculation of the age, including those of type A, and is equivalent to the overall error described by Aitken (1985). Unless stated otherwise, all the uncertainties discussed in this report are given at the 68% level of confidence ($\pm 1\sigma$).

EXPERIMENTAL METHOD

Sampling

Six samples were submitted for luminescence dating. They formed part of the samples collected on 24 March 2006 by Lancaster University (Karloukovski and Hounslow 2007). The samples were in the form of cores (six cores, OSL 1–6, *c.* 26mm dia) that had been extracted using a water-lubricated diamond-tipped core drill and promptly wrapped in foil following extraction. Although a subsequent visit had been planned to place luminescence dosemeters in the core holes, access became unavailable and hence *in situ* measurements of the dose rate could not be performed.

Sample locations

The sampling focused on two areas of the structure:

A. Feature BSA, comprising the annealing furnace flues located to the rear of the standing building (Fig 2a), built using blocks of sandstone (Fig 3a). Cores BSA16 (OSL-1), BSA26 (OSL-2), BSA14 (OSL-3), and BSA34 (OSL-4) were drilled horizontally from the external surface, yielding cores of up to 125mm in length.

B. Feature BSB, comprising the remains of glass furnace sieges located in the interior of the building within a small excavation pit (Fig 2b). The sieges were constructed using sandstone blocks. Cores BSB15 (OSL-5) and BSB16 (OSL-6) were drilled vertically (~85mm length) into a block of fine-grained sandstone an overlying section of which had been removed before sampling. The cores were assigned Durham sample codes as indicated in Table 1, together with the depth of the section of each core used to prepare the luminescence sample.

Table 1. Sample list

Context	Sample Cores			
	Lancaster	Lancaster	Durham	Depth sample (mm)
Annealing furnace flue	BSA16	OSL-1	324-1	60–80
	BSA26	OSL-2	324-2	90–110
	BSA32	OSL-3	324-3	70–90
	BSA34	OSL-4	324-4	80–100
Glass furnace siege	BSB15	OSL-5	324-5	45–55
	BSB16	OSL-6	324-6	75–85

Figure 2a. Close-up of external wall containing the annealing furnace flues showing the locations of cores within feature 'BSA' obtained for archaeomagnetic dating, and including sample OSL -1. Samples OSL-3 and -4, located in an adjacent section of the wall, are shown in Fig 3 (reproduced from Karloukovski and Hounslow 2007)

Figure 2b. Close-up of excavated pit associated with glass furnace siege located inside the building, referred to as sampling feature BSB, containing samples OSL -5 and -6. All the cores taken in this feature are shown in Fig 4 (reproduced from Karloukovski and Hounslow 2007)

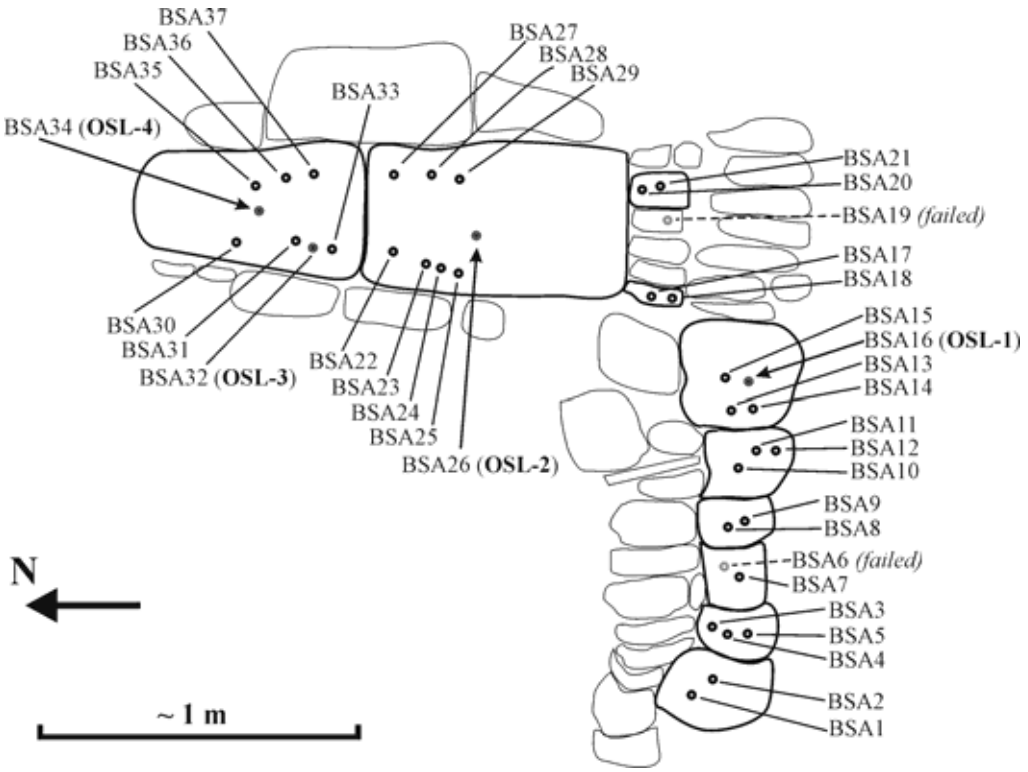


Figure 3: Sampling feature BSA. Schematic side-view showing samples BSA1–37 from the central lintel of the flue and from the southern support of an arch (reproduced from Karloukovski and Hounslow 2007)

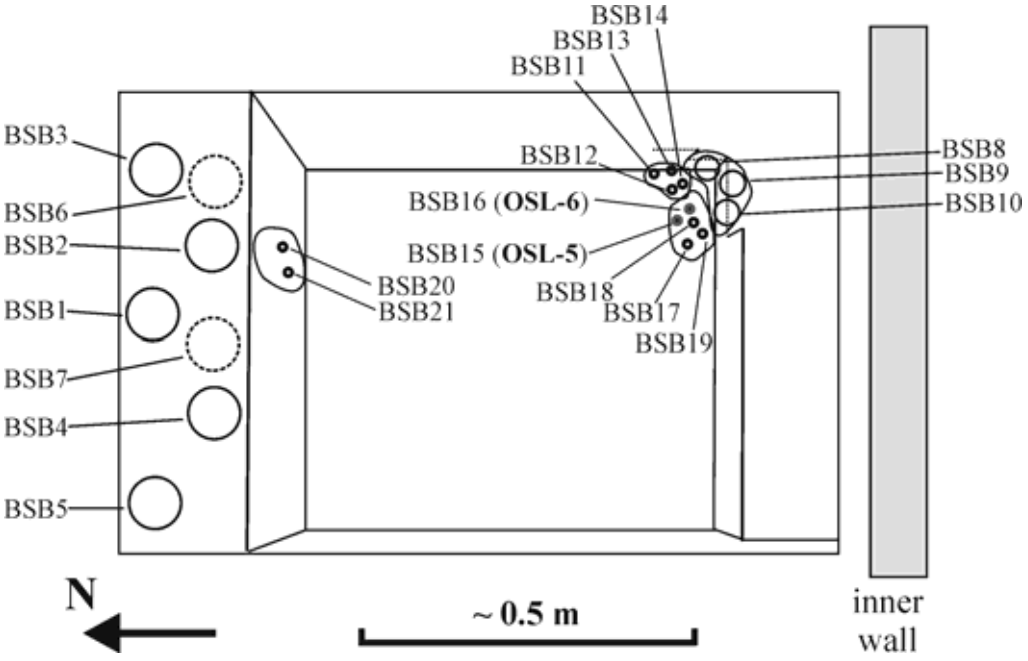


Figure 4: Sampling feature BSB. Schematic plan-view (looking down) showing samples BSB1–21 from the glass furnace sieges in the interior excavation pit, inside the building (reproduced from Karloukovski and Hounslow 2007)

Sample preparation

A general assessment of the composition of the stone fabric was made using a low-power stereo microscope.

Quartz grains in the size range 90–150μm were extracted for luminescence measurements by following a procedure based on that developed for the quartz inclusion technique (Aitken 1985). All sample preparation was performed under subdued red lighting conditions. A subsample of material was extracted from the inner part of the core (Table 1) and dried at 50 °C before being mechanically crushed and sieved to isolate grains within the size fractions <90μm, 90–150μm, and 150–355μm. The 90–150μm range is preferred because it corresponds to the grain size range used in the primary β source calibration.

Following removal of any carbonates (using HCl), the sieved fraction was etched in HF (40%, 45min), immersed in HCl for 45 minutes to remove fluoride precipitates, and finally resieved, with appropriate washing procedures being applied at each stage. The quality of the etched material was assessed by visual examination of one or more aliquots under a low-power microscope. The presence of feldspars in the etched material was tested by measuring the response of aliquots to infra-red stimulation following the application of a laboratory β dose and preheat treatment – no significant infra-red stimulated luminescence (IRSL) was detected with the samples discussed in this report. On the basis of visual inspection of randomly selected aliquots and the results of IRSL tests (see below), heavy liquid separation was considered not to be necessary.

Dose rate assessment

The components of the total dose rate, $\dot{D}_{tot}$, were determined by direct measurement of the contemporary external β dose rate and by the use of indirect methods employing high-resolution γ spectrometry. β TLD measurements (Bailiff 1982; Aitken 1985) were performed using a 10mm-diameter calcium fluoride dosemeter to measure externally the β dose rate close to the surface of the sample, with a mylar screen interposed to absorb alpha particles. The measurements were performed with a) aliquots (~2cm^3) of a pulverised portion of sample taken from a section of core adjacent to that used to extract the etched quartz and b) solid stone samples cut to form a cylinder (~1cm^3).

The average concentrations of ^{238}U, ^{232}Th, and ^{40}K in the sandstone samples were measured using a high-resolution γ ray spectrometer configured with shielding for low background (Canberra high purity germanium coaxial detector type GR2018 of 20% efficiency and with a beryllium window). The spectrometer was calibrated using silica-rich sands containing lithogenic radionuclides of certified concentrations (New Brunswick Laboratories, USA and NCS DC73374 standard supplied by LGC Promochem). The γ spectra were recorded with samples in both crushed and solid form (standard

measurement weight is 25g). In the case of solid samples, a geometry correction factor was obtained by performing measurements with analysed sands placed into a container of dimensions similar to a cut core section weighing ~25g. Crushed and solid samples were placed into sealed containers and stored for at least five days before measurement. The specific activities of the ^{232}Th and ^{238}U decay series were determined by measurement of the γ ray emissions by ^{228}Ac, ^{212}Bi, ^{212}Pb, and ^{206}Tl (^{232}Th series), and ^{226}Ra, ^{214}Pb, ^{214}Bi, and ^{210}Pb (^{238}U series).

The saturation moisture uptake of the cores was measured by soaking core sections in water until a constant weight was achieved.

Luminescence measurements

A TL-DA-12 semi-automated reader (Risø National Laboratory, Denmark) with a blue diode (470nm; ~50 mW cm^{-2}) stimulation source was used to record the optically stimulated luminescence (OSL), detected after passing through a Hoya U340 filter (7.5mm). The TL signal was also measured using a heating rate of 5 °C s^{-1} and with a minimal set of optical filters inserted in the detection system (Schott BG39) to maximise sensitivity. Laboratory β doses were administered to luminescence samples using a ^{90}Sr/^{90}Y β source mounted on the reader that had been calibrated against a secondary standard ^{60}Co source (Göksu *et al*1995).

Sample aliquots, typically 1mg of quartz, were deposited within a diameter of 3–4mm as a near monolayer onto stainless steel discs that previously had been coated with a thin layer of silicone oil. Initial tests were performed to establish the basic OSL characteristics of each sample and the OSL decay curve was measured for typically ~20s, with a sample temperature of 125 °C during stimulation. Preheating (PH) was performed by heating the aliquot (5 °C s^{-1}) to a maximum temperature selected in the range 200–240 °C and maintaining the sample at that temperature for 10s.

The absorbed dose, D_e, to quartz grains was determined using a single aliquot OSL regenerative procedure (Table 2), similar to the SAR procedure described by Murray and Wintle (2000; 2003), but where the corrections for sensitization effects and thermal transfer are handled differently. The 'test' dose is replaced by the use of a monitor dose that is comparable to the size of D_e (Table 2, steps 3, 7, 11, 15, and 19). A second OSL decay curve is recorded at each stage of the regenerative procedure (steps 2, 4, 6, 8, 10 and rpt) to monitor the OSL signal due to thermal transfer, referred to as a preheat monitor (PHM), and this is used to define the background signal. The preheat treatment, (10s hold at the selected temperature, T_P) was applied with temperatures between 200 and 240 °C to establish the form of the palaeodose-preheat characteristic (D_e vs T_P).

The pattern of sensitivity change with cumulative dose was measured by repeating a series of regeneration cycles using the same dose and preheat temperature. The same procedure was applied to separate aliquots using a different preheat temperature. The β

doses administered in regeneration measurements typically range from ~0.7 to ~1.5 of the estimated cumulative dose (D_e), and this range is extended if further investigation of the growth characteristic is required. Steps 21 and 22 were used to check for the presence of feldspar contaminants by measurement of the IRSL response.

Table 2. Summary of OSL measurement procedures

Step	Procedure	Measurement
1	PH; OSL	Preheat using a selected temperature in the range 200–240 °C; measure OSL.
2	PH; OSL	Preheat monitor (PHM)
3	+0.8 ß; PH; OSL	1st dose point / Sensitivity Monitor
4	PH; OSL	PHM
5	+ ß; PH; OSL	2nd dose point
6	PH; OSL	PHM
7	+0.8 ß; PH; OSL	Sensitivity Monitor
8	PH; OSL	PHM
9	+1.5 ß; PH; OSL	3rd dose point
10	PH; OSL	PHM
11–18		Repeat Steps 3–10
19	+0.8 ß; PH; OSL	Sensitivity Monitor
20	PH; OSL	PHM
21	+ ß; PH; IRSL	Test for feldspar contamination
22	+ ß; IRSL	Test for feldspar contamination

Notes

1. The OSL decay curve was measured for 50s with the sample temperature held at 125 °C during stimulation.
2. The preheat (PH) was performed by heating the aliquot (5 °C s^{-1}) to a maximum temperature selected in the range 200–240 °C and holding at that temperature for 10s.
3. The symbol ß represents the administration of a laboratory beta dose corresponding to the value of the estimated palaeodose , D_e.

Additive dose measurements were also performed to test for potential changes in luminescence properties during the first OSL measurement (only). The additive beta dose was administered before Step 1 (Table 2) and two levels of additive dose were applied ($\beta^+ = D_e$ and $2D_e$) to separate sets of aliquots. The additive dose procedure followed the SAR sequence except that a laboratory beta dose, $ß^+$, was administered before step 1. The value of ß in the subsequent steps (3, 5, 7, etc) was adjusted to reflect the combined dose ($D_e + ß^+$) applied before the first OSL measurement, and one preheat temperature (220 °C) was used.

RESULTS

Palaeodose determination, D_e

Results from initial tests with HF-etched quartz indicated that all samples exhibited very weak natural TL signals and that only samples 324-1 (BSA16) and 324-5 (BSB15) had sufficiently bright OSL emission, while the OSL and TL sensitivity of the quartz from samples 324-2, -3, -4 and -6 was too weak for reliable absorbed-dose evaluations. It is

surprising that cores taken from the same section of stone (OSL 5 and 6) had markedly different levels of sensitivity, and tests with a larger group of unheated stone samples would be needed to investigate whether highly variable sensitivity is a characteristic of the sandstone used. Heating of quartz for prolonged periods at temperatures in excess of 1200 °C in air can cause severe quenching (reduction) of the luminescence sensitivity, and this may have occurred within some of the stone blocks used in the flue structure.

The results of preliminary TL measurements performed with HF-etched quartz extracted from samples 324-1 and -5 were examined for evidence that the sandstone had been heated to temperatures sufficient to zero the latent OSL. Figure 5a illustrates the TL glow curves measured following the measurement of the natural TL (N), and subsequent regenerated glow curves following administration of laboratory doses of 6Gy (β, β'') and 12Gy (2β). The growth characteristic (Fig 4b; integrated TL, 320–400 °C) indicates strong supralinear growth of the regenerated TL signal with dose and this gives rise to the very weak natural signal, while measurable signals for doses >3Gy. The growth characteristics for aliquots of sample 324-5 exhibited much lower intercept values but the intensity of the natural signals was also very low. The indicative value of the palaeodose obtained from 324-5 of -0.4±1.9 Gy, albeit imprecise, supports the assumption of sufficient heating of the sandstone.

The optical stimulation source was adjusted to 90% of maximum power to improve the resolution of the OSL decay curve above the instrumental background signal. A high proportion of the OSL decayed within several seconds and the decay curves were dominated by a single decay component (Fig 5a,b) judged to be 'fast'/'medium' (Bailey 2001); a 'slow' component was either absent or not resolved above the background signal. The OSL signal was measured by integrating the photon counts recorded during the first 1–2 seconds of stimulation, which were sufficient to account for at least 80% of the OSL. Once selected, the same period of integration was used for all measurements performed with one sample.

The OSL data were used to generate a growth characteristic, providing there was no significant change in the form of the decay curve within the integration range throughout the series of regeneration measurements. In the case of samples 324-1 and 324-5, none of the aliquots measured was excluded from the calculation of D_e, due to change in the form of the decay curve. An estimate of D_e for each aliquot was obtained using the interpolation procedure applied in the standard regenerative technique and included corrections for changes in sensitivity during the repeated measurement cycles. A linear curve was fitted to the growth characteristic using a Monte Carlo (MC) simulation procedure combined with a least-squares algorithm and the uncertainty in D_e calculated as the standard deviation of D_e distribution obtained using the MC procedure (50 cycles).

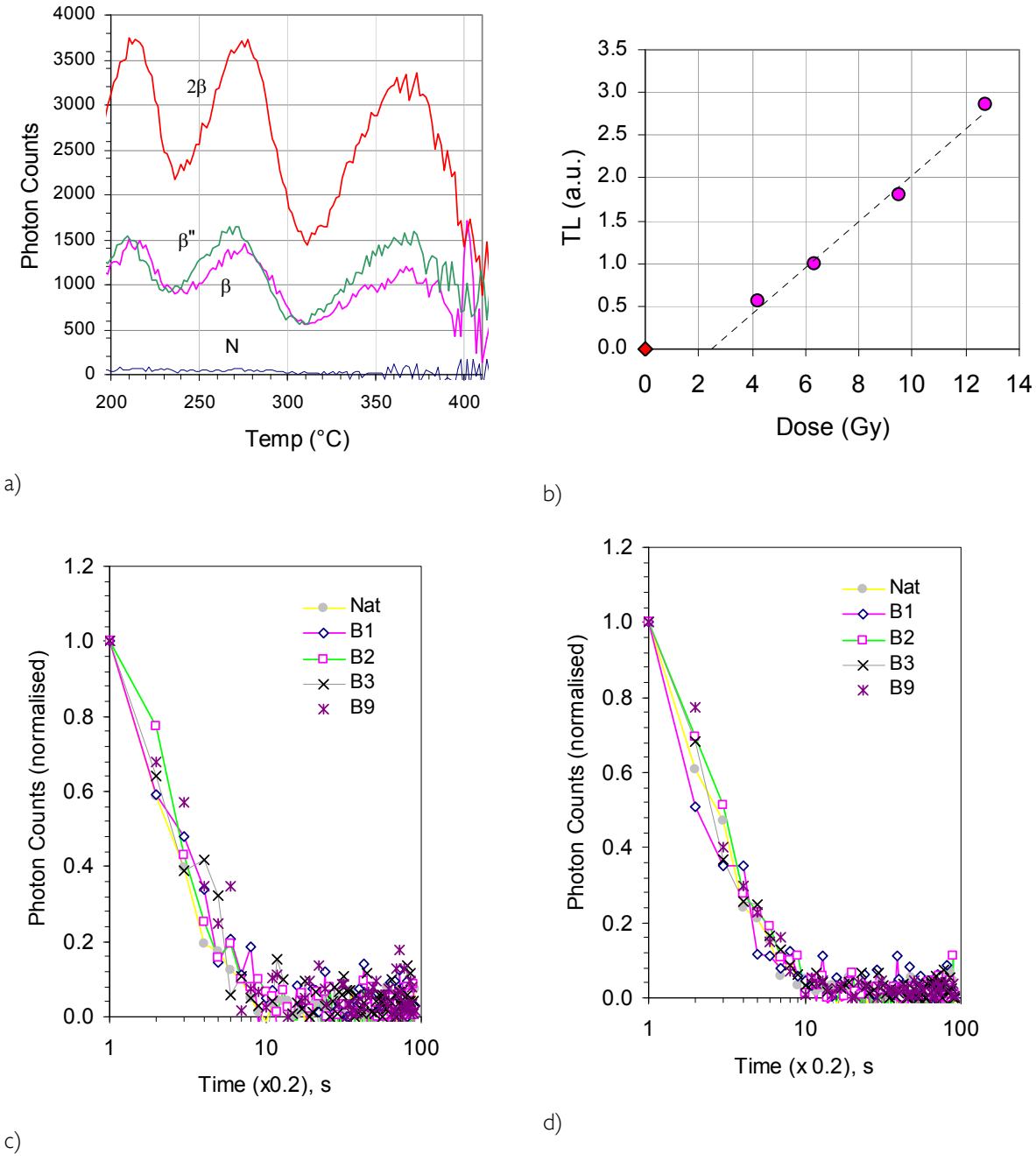
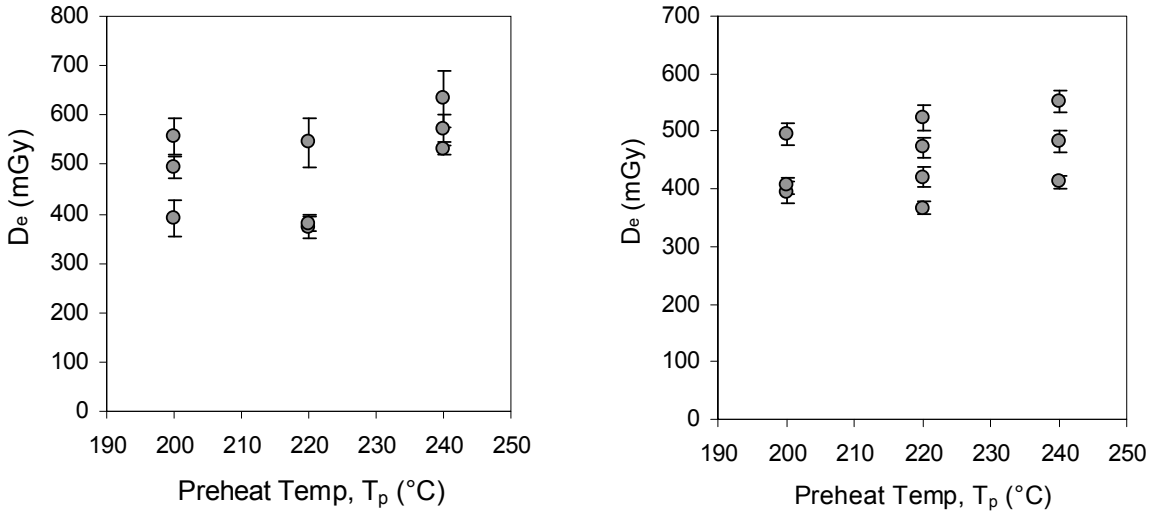


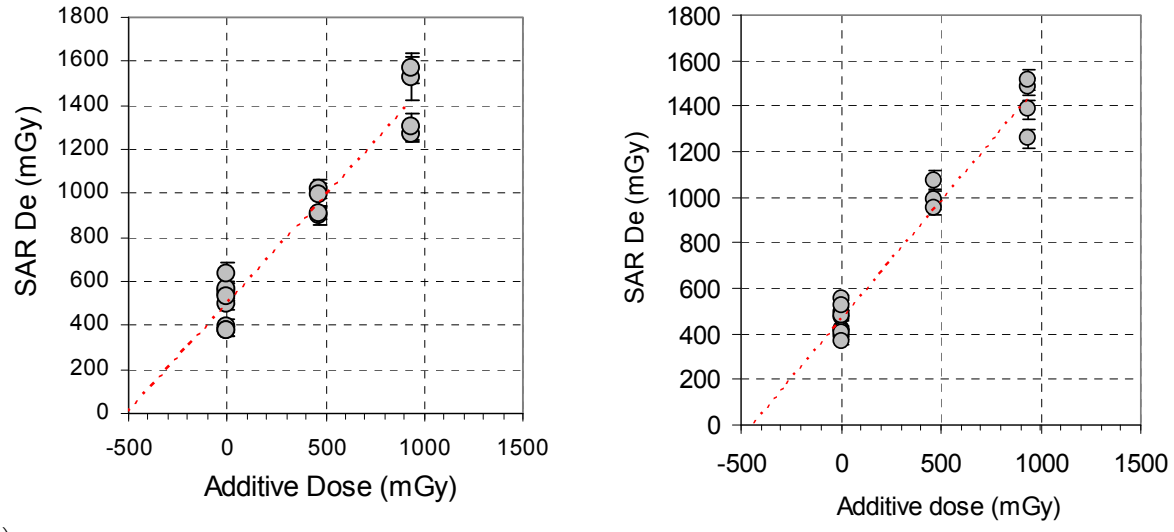
Figure 5. a) Examples of TL glow curves for aliquots of 324-1 where measurement of the natural TL (N) was followed by a series of glow-curve measurements following the administration of beta doses (β=~6Gy) to test for sensitization and growth of TL; b) growth characteristic for the same sample, showing strong supralinearity; c) and d) examples of OSL decay curves for aliquots of c) 324-1 and d) 324-5 measured at various stages of the SAR procedure. The data for each decay curve are normalised to the initial intensity to enable comparison of the form of decay

All values of palaeodose obtained using the three preheat temperatures (Fig 6) were used to calculate the mean value of D_e (Table 3a). The dispersion is significantly larger (ranges of ~40% and ~50% of the mean value for samples 324-1 and -2 respectively) than the best observed with ceramic brick samples (Bailiff 2007) but similar to other bricks where spatial non-uniformity in the beta dose rate was suspected. The values are approximately normally distributed; the uncertainty in the average beta dose rate ($\dot{D}_\beta$ in Eqn 2) was increased to ±5% to make allowance for this factor in the age calculation. The values of D_e determined using the additive procedure (Fig 7; Table 3a) are in good agreement with those obtained using the conventional SAR procedure and confirm the absence of a change in luminescence characteristics during the first laboratory measurement (Bailiff 2007).



a) b)

Figure 6. De vs Tp characteristics for samples a) 324-1 and b) 324-5



a) b)

Figure 7. Additive dose characteristics for samples a) 324-1 and b) 324-5

Dose rate

The values of the components of the total dose rate, $\dot{D}_{tot}$ (Eqn 2), are given in Table 3b, together with other relevant parameters. The experimentally derived value of the infinite medium beta dose rate was corrected for attenuation (1-ϕ= 0.93) and moisture content (3±1%). A value of 0.06mGy a^{-1} was assumed for the internal grain dose rate – this value is an average derived from previous analyses of HF-etched quartz extracted from ceramic materials tested in the laboratory.

In the absence of dosemeter measurements, the gamma dose rate was assessed on the basis of the radionuclide concentrations determined by γ spectrometry (Table 3c). The values of specific activity were combined with published dose-rate conversion factors (Adamiec and Aitken 1998) and geometry factors, calculated using the Monte Carlo radiation transport code MCNP for general building configurations, to obtain estimated gamma dose rates for the two sample locations.

At location 1 (BSA-16) the sampled volume was located at a depth of *c.* 60–80mm from the outer surface of the stone block. In calculating the γ dose rate it was assumed that this section of wall had remained exposed to air since last use of the furnace. If there had been a layer of external stone cladding, it is estimated that the gamma dose rate would be up to ~5% higher. The measured γ activity of two cores at this location (Table 3c; BSA16 and 13) is lower than the activity of BSB13b, giving rise to a ~4% lower γ dose rate, and suggests that any heterogeneity in the sandstone block sampled is slight and on a scale relevant to the assessment of the gamma dose rate. The measured $^{210}Pb/^{226}Ra$ ratios (0.83±0.24; 0.74±0.30) indicate that some disequilibrium may exist in the solid condition.

At location 1 (BSA-16) the sampled volume was located at a depth of *c.* 45–55mm beneath the sandstone surface exposed in the interior excavation pit. An overlying block had been removed to reveal the surface into which the cores were drilled (Fig 2b). In estimating the gamma dose rate to the sampled volume, it was assumed that the sandstone was the dominant contributor to the gamma dose rate. Since the gamma spectrometry measurements indicate that the radioactivity of the sandstone blocks within this section of the sieges varies (Table 3c; BSB 12, 15, and 16), an average of the activities of the three samples was used to calculate the gamma dose rate (Table 3b) assuming that an infinite medium was established within the sandstone (see also notes to Table 3b).

DATE CALCULATION

The calculated luminescence dates (Table 3d) for the last heating of the sampled locations are:

Annealing furnace flue	324-1	AD 1723–67 (68% confidence)	AD 1701–89 (95% confidence)
Glass furnace siege	324-5	AD 1675–1719 (68% confidence)	AD 1653–1741 (95% confidence)

COMPARISON WITH OTHER DATING EVIDENCE

The luminescence date (AD 1653–1741; 95% confidence) for sample 324-5 from the glass furnace sieges (feature BSB) is in excellent agreement with the archaeomagnetic date of AD 1710 (AD 1680–1730, 95% confidence Karloukovski and Hounslow 2007) for samples taken from the sieges and the moulding floor. It is consistent with the archaeological assessment of when the glassworks was in operation, from its foundation during the mid-17th century until its closure in *c.* 1758, as indicated in surviving documentary records (Ashurst 1987). The luminescence date (324-1; AD 1701–89, 95% confidence) for the last heating of a block (BSA16) that forms the upper part of the footing of the central lintel associated with the furnace flue overlaps the date for the siege, with a central value that is younger by some 50 years; using Ward and Wilson's (1978) test statistic, T, the difference is statistically significant ($T=8.0$; $T'(5\%)=3.84$, $\nu=1$).

While the date range for 324-1 is consistent with the period of demise of glass production, it is significantly earlier than the archaeomagnetic date (AD 1800–70; 95% confidence; Karloukovski and Hounslow 2007) obtained for blocks forming the lower section of the same footing (BSA 3-12) The archaeomagnetic date was tentatively associated with the later use of the structure for pottery production during the mid-19th century. This raises the question of whether the luminescence and archaeomagnetic dates obtained for cores within the same feature are inconsistent.

The magnetic characteristics of the cores from the sample blocks (BSA13-37) above the block containing BSA10-12 indicate that the blocks had not been heated sufficiently to reset the geologically acquired magnetization, and no archaeomagnetic dates were produced for cores taken from them (Karloukovski and Hounslow 2007). In Figure 8,

Q_{NRM} values, which reflect the extent of past heating, show a sharp change between the block containing the OSL sample (BSA16) and the underlying block (BSA11-12; the cores which were included in the archaeomagnetic date calculation). The onset of significant enhancement of the magnetic susceptibility in the type of sandstone used in the structure is expected to require temperatures of *c.* 400–450 °C, but could be lower, depending on the concentration of clay in the rock (Hounslow pers comm). Such temperatures are sufficient to reset the quartz in the luminescence samples, but the low Q_{NRM} values for cores BSA 13–15 suggest the absence of strong heating of this block.

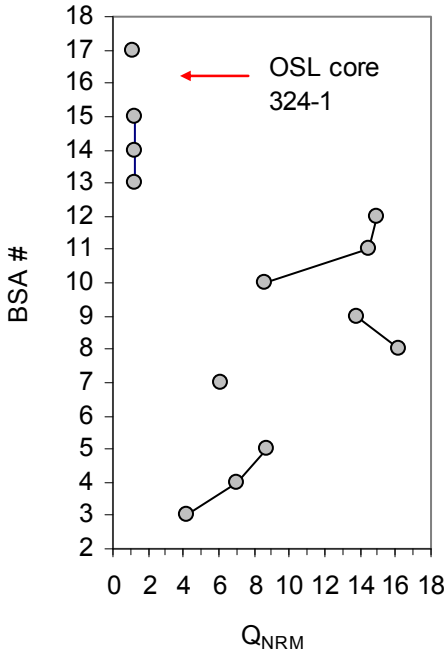


Figure 8. Values of Q_{NRM} (Koenigsberger factor) for cores taken from the furnace flue feature BSA (see Fig 2). Values for cores taken from the same block are linked. In this sequence, the core taken for OSL measurements (324-5) is BSA 16. Data values taken from Karloukovski and Hounslow (2007)

While it is not possible to obtain more precise indicators of thermal history, it is plausible that, following use of the furnace for glassmaking, the block containing BSA16 (324-5) was not heated to temperatures sufficient to reset the luminescence chronometer (*c.* 200–300 °C), whereas in the underlying blocks the heating caused by the relatively low temperature firing for the later pottery production (*c.* 700–800 °C) was sufficient to allow magnetic alignment in the prevailing field at that time. Hence it is suggested that the luminescence and archaeomagnetic results obtained provide dates for two, and possibly three, phases of the thermal history of the structure, related to glassmaking from the late 16th to mid-17th centuries and subsequently to pottery production during the mid-19th century. In reaching this interpretation, we assume that no repairs involving the replacement of the blocks occurred following the use of the structure for glassmaking.

Table 3. Data related to assessment of (a) palaeodose , (b) dose rate, (c) activity and (d) age calculation

a)

Sample ref.	Preheat range (°C)	D_e (SAR) ± s.e. (mGy)	D_e (SAR) range (mGy)	n	D_e (ADD) ± s.e. (mGy)	n
324-1	200–240	497±31	373–633	9	508±28	17
324-5	200–240	452±19	367–553	10	446±11	18

b)

Sample ref.	$\dot{D}_{\beta+ig}$ (mGy a^{-1})	$\dot{D}_{\gamma}$ mGy a^{-1})	$\dot{D}_{cos}$ (mGy a^{-1})	$\dot{D}_{tot}$ (mGy a^{-1})
324-1	1.06	0.64	0.20	1.90±0.05
324-5	0.74	0.54	0.18	1.46±0.04

c)

Sample ref.	Th (Bq kg^{-1})	U (Bq kg^{-1})	K (Bq kg^{-1})	Ratio $^{210}Pb/^{226}Ra$
Feature BSA				
BSA16 (OSL1)	19.0±2.7	13.8±1.7	411±7	0.83±0.24
BSA13b	20.9±2.9	12.1±1.6	368±7	0.74±0.30
BSA10	18.6±4.2	22.0±2.5	375±10	0.54±0.16*
Feature BSB				* short seal period
BSB15 (OSL5)	14.7±3.2	11.8±1.8	312±8	1.07±0.37
BSB12a	12.5±2.7	9.4±1.5	463±7	0.81±0.32
BSB16	17.0±3.4	13.9±1.9	281±8	0.76±0.17

d)

Sample ref.	D_e ± s.e. (mGy)	$\dot{D}_{tot}$ ± s.e. (mGy a^{-1})	Luminescence Date (AD) $\pm\sigma_A$; $\pm\sigma_B$
324 qiOSL -1	497±31	1.90±0.05	1745 ±19; ±23
324 qiOSL -5	452±19	1.46±0.04	1697 ±17; ±22

Notes Table 3b:

1. The values of the point absorber beta dose rate within the tested material, obtained using β-TLD, were reduced (by 7% for 90-150 μm grains) to account for the effects of attenuation due to the finite size of the quartz grains using data published by Brennan (2003)
2. Corrections for moisture content (assumed to be 3±1% for both contexts) were applied to both beta and gamma dose rates using factors (ratio of absorption coefficients for water and ceramic) of 1.25 and 1.14 for the beta and gamma dose-rates respectively, as calculated by Zimmerman (1971).
3. An allowance of 0.06 mGy a^{-1} was made for the internal grain dose rate (alpha and beta) arising from radionuclides within the quartz.
4. The gamma dose rate at each location was calculated by using average radionuclide concentrations for the surrounding medium to calculate the infinite medium dose rate and applying a geometry factor for the sampled location derived from Monte Carlo modelling of the variation of dose rate with depth in planar structures. In the case of location 1, the estimated geometry factor was 0.85 and a 10% contribution from sources within the ground facing the external wall was also included using typical radionuclide concentrations in soil to calculate the dose rate. For location 2 the dose rate was assumed to be derived from equal contributions of the three stone fabrics tested using γ spectrometry and that an infinite medium was obtained within a sandstone environment.
5. The cosmic dose rate was calculated (Prescott and Hutton 1988) assuming an average overburden of 50 and 200 g cm^{-2} for locations 324 -1 and -5 respectively.
6. Palaeodose determinations were performed during 2007.

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