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An investigation of pulsed-irradiation regeneration of quartz OSL and its implications for the precision and accuracy of optical dating (Paper II)

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Abstract

An essential part of the laboratory procedure associated with optical dating is the irradiation of sample aliquots with known doses of ionizing radiation. Only if laboratory irradiation faithfully reproduces the effects (within the dating sample) of natural irradiation (during burial) will the dates obtained be accurate. Modelling of quartz luminescence suggests that the usual practice of administering laboratory doses at room temperature, and in single exposures, may lead to both equivalent-dose overestimation and increased levels of scatter in individual age estimates for samples with palaeodoses greater than ∼40 Gy. In the model, this effect is due to the large differences between laboratory and natural dose rates. A modification to standard irradiation practices is suggested as a remedy to this problem, whereby laboratory regeneration doses are administered in 10 Gy pulses, with the aliquot then being heated to 240 °C following each pulse. Empirical measurements of 12 sedimentary samples support the theoretical findings, with significant differences in dose response being observed between single-irradiation and pulsed-irradiation OSL regeneration data. Results are also presented in which the problem of the laboratory dose response failing to reach the level obtained through natural irradiation is remedied by the pulsed-irradiation procedure. It is possible that the application of pulsed-irradiation regeneration may in future lead to a more accurate means of dating the deposition of quaternary sediments, although this remains to be demonstrated empirically by the dating of known-age samples.

Keywords: Quartz; Optical dating; Dose-rate; Pulsed-irradiation; Accuracy; Precision

1. Introduction

A fundamental requirement of all current trapped-electron based dating procedures (of which optical dating methods are a subset) is that equivalence exists between the radiation dose delivered to the sample naturally (during burial) and that delivered during laboratory irradiation (i.e. irradiation in both cases gives rise to the same trapped charge distribution). Without this equivalence, it would not be possible to obtain accurate age estimates. One of the significant differences between natural and laboratory doses is the rate at which the dose is delivered. Natural dose rates to sedimentary quartz are typically ∼1 Gy/ka (that is $\sim 3 \times 10^{-11}$ Gy/s), whilst during laboratory irradiation dose rates of $\sim 10^{-1}$ Gy/s are common. Results from a numerical model of quartz luminescence presented previously (Bailey, 2004) indicate that dose-rate effects do indeed affect the dose response of quartz

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OSL. Simulations of natural irradiation rates and standard laboratory measurement procedures point to a potential overestimation of D_e (by ~10%) for samples with palaeodoses (P) between 40 and 100 Gy.

1.1. The mechanism responsible for simulated dose-rate dependence

In the model (Bailey, 2004), the observed dose rate effect arises due to competition for charge (electrons), during laboratory irradiation, from relatively thermally unstable (hole-trapping) R_1-centres (Bailey, 2004) which are effectively absent at natural irradiation rates.[1] The effect on dating can be reduced by limiting the concentration of holes trapped at this centre during laboratory irradiation. In practice this might be achieved by irradiating samples at raised temperature (~200 °C), in which case the low residence time of charges trapped in the R_1-centre would lead to a very low equilibrium population. Similarly, the unwanted competition effect may be reduced by separating the irradiation period in to a series of shorter pulses, and heating ('preheating') the sample following each pulse, thus reducing competition from the R_1-centre prior to the next irradiation pulse (Bailey, 2004). For this latter procedure, modelling results suggest that laboratory irradiation in 10 Gy pulses with intervening heats to 240 °C is likely to be adequate for most samples.

1.2. Dating accuracy

In a preliminary experiment, the dose response characteristics of aliquots of sample BA14, a last interglacial-age (~120–130 ka, Marine Oxygen Isotope Stage 5e) coastal dune deposit from Mozambique, Africa, were examined. Regenerated dose-response curves were measured using both the 'standard' (single irradiation steps) SAR and the pulsed irradiation procedure in which regeneration doses were administered in 10 Gy pulses, with a heat to 240 °C following each pulse (Bailey, 2004). As predicted from the model, the dose response measured using the two approaches (single- and pulsed-irradiation) were different (Fig. 1). The pulsed-irradiation procedure produced a reduction in the estimate of D_e compared to the standard single-irradiation procedure. The calculated ages were 149 ± 12 ka and 126 ± 8 ka using single- and pulsed-irradiations, respectively. While this result appears encouraging with regard to pulsed-irradiation,

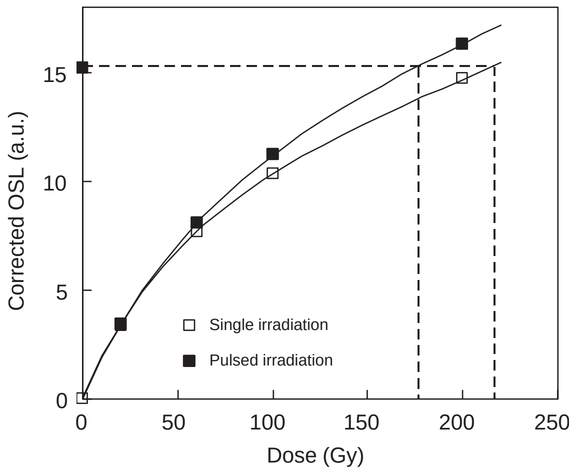

Fig. 1. Comparison of dose response measured using standard (single irradiation) and pulsed-irradiation regeneration doses ($PH_P = 240$ °C, $R_P = 10$ Gy) (sample BA14; see Bailey, 2004 for further details).

recent studies aimed specifically at assessing the accuracy of optical dating (using the SAR method), have not reported any systematic age overestimation (e.g. Murray and Olley, 2002; Murray and Funder, 2003).

1.3. The context of this paper

The numerical model (Bailey, 2004) makes definite predictions of a dose-rate effect that leads to an inaccuracy in D_e estimates for samples with $P > 40$ Gy (Section 1.1). However, as mentioned in the previous section, this does not tally with already-published empirical observations of dating accuracy (Section 1.2). A logical response in this case is that the model must be wrong. This may of course be true although some reflection is necessary before the model is abandoned or significantly modified. The model has been constrained using a wide range of comparisons to laboratory measurement (e.g. Bailey, 2001). In the present case, the model was used to predict that the same mechanism as that responsible for the dose rate effect would also produce an effect that could be observed in laboratory measurements (namely, the difference between pulsed-irradiation and single-irradiation dose response). Laboratory measurements subsequently confirmed this prediction, showing concordance between theoretical and measured data. The model also predicts that for ~90% of the variants on the standard model (see Bailey, 2004), the natural OSL intensity (for a palaeodose of 500 Gy) exceeds the maximum OSL intensity obtainable from laboratory regeneration. This inability of OSL signals to be regenerated to the level of the natural signal has reported by several authors (see Bailey, 2004) although has not yet been explained in terms of known theory. To summarize these apparently contradictory lines

[1] Several authors have previously predicted dose rate effects using relatively simple models (e.g. McKeever et al., 1980; Chen and Leung, 2001). It is difficult to relate these previous studies to the present work as typically the simulated dose-rate dependence was observed when both traps and centres had zero population at the onset of irradiation (unlike the case of natural materials). Nonetheless, it is interesting to note that far simpler systems than that simulated in the present paper can produce dose rate effects and that care must be taken when interpreting the behaviour of more complex systems.