



# Quartz fast component optically stimulated luminescence: Towards routine extraction for dating applications



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## HIGHLIGHTS

- A simple mathematical method to extract quartz OSL fast component is presented.
- The method can be adopted in  $D_e$  calculation programs for routine extraction.
- The method leads to an increase in accuracy and precision of  $D_e$ .
- The method works for relatively dim samples with low signal-to-noise ratios.

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## ABSTRACT

Using an uncontaminated fast component is a key for improving the reliability of quartz OSL dating for many deposits. So far no approach to extract the fast component of quartz OSL has routinely been adopted for dating practice. Key challenges for extracting fast components are (1) the difficulty of finding a unique solution in curve-fitting deconvolution of OSL decay curves and (2) the relatively poor dating precision when using experimental fast component extraction. Here, a simple mathematic solution for fast component extraction is presented that is not relying on curve-fitting deconvolution and can easily be adopted into routine dating practices. By using specifically selected data points from smoothed OSL decay curves, the precision of equivalent doses calculated using the extracted fast component can be improved over equivalent doses calculated using bulk OSL. The fast component extraction is tested on a group of age-constrained samples containing both insufficiently bleached and sufficiently bleached deposits. Fast component OSL ages are as accurate as bulk OSL ages for the sufficiently bleached deposits, but more accurate for samples where bulk OSL is affected by insufficient bleaching. We also demonstrate how using a curve smoothing procedure can improve dating precision in case of both sufficiently and insufficiently bleached deposits.

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## 1. Introduction

Optically stimulated luminescence (OSL) dating of quartz has developed as one of the key techniques for dating the late Quaternary, especially since the advent of the single aliquot regenerative dose (SAR) protocols (Murray and Wintle, 2000). To establish the age of depositional events, green or blue light stimulation of quartz is used in a wide variety of environments to determine the

dose acquired since a crystal was latest exposed to sunlight. Quartz OSL has been shown to consist of multiple components (Smith and Rhodes, 1994). Following Bailey et al. (1997) and depending on optical sensitivity, fast ( $OSL_f$ ), medium ( $OSL_m$ ) and slow ( $OSL_s$ ) components can be differentiated. Routine practice in OSL dating utilizes signal from the initial part of OSL decay curves that is usually comprised of multiple components, though the SAR protocol has been shown to work particularly well for  $OSL_f$  dominated quartz (Wintle and Murray, 2006).

Two characteristics render  $OSL_f$  especially suitable for sediment dating: (1) the high thermal stability (e.g., Singarayer and Bailey, 2003; Shen et al., 2011) and (2) the high optical sensitivity. Large contributions of  $OSL_m$  and  $OSL_s$  in OSL dating can lead to inaccurate

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**Table 1**  
Samples and analytical results (all uncertainties are quoted at  $1\sigma$  uncertainty).

Sample	Expected age (ka) <sup>a</sup>	$\phi$ ( $\mu\text{m}$ ) <sup>b</sup>	$d$ (Gy/ka) <sup>c</sup>	Age model <sup>d</sup>	$\sigma$ (%) <sup>e</sup>	$D_e$ (Gy) <sup>f</sup>	Age (ka)
Wax Lake Delta I-1	<0.027	75–180	$2.13 \pm 0.09$	MAMUL	85	$0.075 \pm 0.007$	$0.035 \pm 0.004$
Wax Lake Delta I-2	0.036–0.069	75–180	$2.17 \pm 0.10$	MAMUL	85	$0.197 \pm 0.010$	$0.091 \pm 0.006$
Paincourtville I-4	<1.4	100–200	$2.47 \pm 0.21$	MAM	28	$2.60 \pm 0.30$	$1.05 \pm 0.15$
Chenier Perdue I-1	~2.5	125–180	$1.39 \pm 0.04$	CAM	8	$3.58 \pm 0.07$	$2.58 \pm 0.09$
Grand Chenier I-1	~1.15	125–180	$2.01 \pm 0.08$	CAM	8	$2.39 \pm 0.05$	$1.19 \pm 0.06$
Amite River I-1	N/A	180–250	$0.21 \pm 0.01$	CAM	12	$6.65 \pm 0.15$	$32 \pm 1$
					<b>11</b>	<b><math>6.65 \pm 0.14</math></b>	<b><math>32 \pm 1</math></b>

<sup>a</sup> Age constraints for Wax Lake Delta I-1 and I-2 are from Shen and Mauz (2012), Paincourtville I-4 from Törnqvist et al. (1996), Chenier Perdue I-1 and Grand Chenier I-1 from Gould and McFarlan (1959).

<sup>b</sup> Particle size of quartz used for OSL measurement.

<sup>c</sup> Natural dose rate.

<sup>d</sup> MAMUL: unlogged minimum age model of Arnold et al. (2009), MAM: minimum age model and CAM: central age model of Galbraith et al. (1999).

<sup>e</sup> Overdispersion of dose distribution.

<sup>f</sup> Values in italic bold are based on the fast component analyses.

age estimates either due to thermal instability (Bailey et al., 2003; Jain et al., 2003; Li and Li, 2006; Shen and Mauz, 2009) or insufficient bleaching induced by the reduced optical sensitivity. The latter is of great concern particularly for dating sediments laid down after a short transport distance in turbid water where the intensity and wavelength of sunlight is significantly attenuated (Berger, 1990) and for relatively young deposits. Isolating  $OSL_f$  represents a key procedure to improving the accuracy of quartz OSL dating in such circumstances.

Existing techniques to identify and characterize OSL components are of limited use for dating applications. Curve-fitting deconvolution analysis of OSL decay curves is mathematically challenging and requires extensive tests to produce meaningful results (e.g., Choi et al., 2006). Experimental extraction of  $OSL_f$  by high temperature infra-red light stimulation often takes long measurement time (e.g., Jain et al., 2005) and yields a low signal/noise ratio (Bailey, 2010). In practice, all these  $OSL_f$  dating approaches result in a significantly reduced equivalent dose ( $D_e$ ) precision.

Here, a simple mathematic method is presented to extract  $OSL_f$  from continuous wave OSL (referred as OSL thereafter unless defined otherwise) using predefined parameters for OSL components (cf. Li and Li, 2006; Cunningham and Wallinga, 2009). The method is coded in Matlab® program (see supplementary file) to perform  $OSL_f$  extraction and equivalent dose ( $D_e$ ) calculation. We test the method with a range of waterlain deposits comprising of insufficiently bleached as well as sufficiently bleached samples. Compared to traditional OSL dating practice the proposed technique leads to an increase in accuracy, is not detrimental to equivalent dose precision, and can even be used for relatively dim samples with low signal-to-noise ratios.

## 2. Background

Assuming first-order kinetics, decay of quartz OSL,  $I(t)$ , under continuous wave optical stimulation can be described by the sum of multiple exponential decay components, commonly referred as  $OSL_f$ ,  $OSL_m$  and  $OSL_s$  (cf. Bailey et al., 1997):

$$I(t) = \sum_{i=1}^n I_i(t) \quad (1)$$

$$\ln I_i(t) = \ln I_{i0} - \frac{1}{\lambda_i} \times t \quad (2)$$

with  $I_i(t)$ ,  $I_{i0}$  and  $\lambda_i$  representing the OSL intensity at time  $t$ , initial OSL intensity and the decay constant of the  $i$ th component, respectively. The slow component shows minimal decay after a few tens of seconds of optical stimulation with blue light, as commonly used in quartz OSL dating, and can be removed from an OSL decay curve together with background signal through late-light background subtraction (Wintle and Murray, 2006). The resulting decay curve contains  $OSL_f$  and  $OSL_m$  only. Designate  $i = f$  for  $OSL_f$  and  $i = m$  for  $OSL_m$  and using a  $\ln(t)$  scale,  $OSL_f$  and  $OSL_m$  both decay linearly. Between OSL counting at time  $t_1$  and  $t_2$  ( $t_2 - t_1 = dt$ ), the slopes for the linear decays are:

$$s_f = \frac{\ln I_f(t_2) - \ln I_f(t_1)}{dt} = -\frac{1}{\lambda_f} \quad (3)$$

$$s_m = \frac{\ln I_m(t_2) - \ln I_m(t_1)}{dt} = -\frac{1}{\lambda_m} \quad (4)$$

The slope for  $\ln I(t)$  (bulk OSL) is:

$$S = \frac{\ln [I_f(t_2) + I_m(t_2)] - \ln [I_f(t_1) + I_m(t_1)]}{dt} \quad (5)$$

Assigning  $p_1 = \frac{I_f(t_1)}{I_m(t_1)}$  and  $p_2 = \frac{I_f(t_2)}{I_m(t_2)}$  as the ratios between  $OSL_f$  and  $OSL_m$  at time  $t_1$  and  $t_2$ , respectively. Replacing  $I_m(t_1)$  by  $I_f(t_1)/p_1$  and  $I_m(t_2)$  by  $I_f(t_2)/p_2$  in Eq. (5) and using Eq. (3) results in:

$$S = \frac{\ln \left( \frac{p_1}{p_2} \right)}{dt} + \frac{\ln \left( \frac{p_2+1}{p_1+1} \right)}{dt} + s_f \quad (6)$$

Replacing  $I_f(t_1)$  by  $p_1 \times I_m(t_1)$  and  $I_f(t_2)$  by  $p_2 \times I_m(t_2)$  in Eq. (5) and using Eq. (4) results in:

$$S = \frac{\ln \left( \frac{p_2+1}{p_1+1} \right)}{dt} + s_m \quad (7)$$

Resolving Eqs. (6) and (7) for  $p_1$  and  $p_2$  returns:

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