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The fast ratio: A rapid measure for testing the dominance of the fast component in the initial OSL signal from quartz

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ABSTRACT

The signal from the fast component is usually considered preferable for quartz optically stimulated luminescence (OSL) dating, however its presence in a continuous wave (CW) OSL signal is often assumed, rather than verified. This paper presents an objective measure (termed the fast ratio) for testing the dominance of the fast component in the initial part of a quartz OSL signal. The ratio is based upon the photo ionisation cross-sections of the fast and medium components and the power of the measurement equipment used to record the OSL signal, and it compares parts of the OSL signal selected to represent the fast and medium components. The ability of the fast ratio to distinguish between samples whose CW-OSL signal is dominated by the fast and non-fast components is demonstrated by comparing the fast ratio with the contribution of the fast component calculated from curve deconvolution of measured OSL signals and from simulated data. The ratio offers a rapid method for screening a large number of OSL signals obtained for individual equivalent dose estimates, it can be calculated and applied as easily as other routine screening methods, and is transferrable between different aliquots, samples and measurement equipment.

1. Introduction

The optically stimulated luminescence (OSL) signal from quartz has been used as the basis for many geochronological studies in Quaternary Science, particularly since the development of the single-aliquot regenerative-dose (SAR) protocol (Murray and Wintle, 2000; Wintle and Murray, 2006), which greatly improved the accuracy and precision of equivalent dose (D_e) estimates. The OSL signal from quartz is composed of a number of components (e.g. Bailey et al., 1997; Jain et al., 2003; Singarayer and Bailey, 2003), each of which has different optical and thermal luminescence properties (Bailey, 2010). The fast component is usually of most interest for dating quartz, as it is stable over a timescale of millions of years (Singarayer and Bailey, 2003) and is readily bleachable in nature (Li and Li, 2006). The presence of a dominant fast component is preferable for accurate and precise D_e calculation (Wintle and Murray, 2006), although other components have been utilised for dating in some studies (e.g. Rhodes et al., 2006).

The SAR protocol (Murray and Wintle, 2000; Wintle and Murray, 2006) incorporates a number of internal checks to ensure that the luminescence signal is being accurately measured. These have been summarised by Roberts (2008), and include the repeated measurement of a regenerative dose (the recycling ratio), the measurement of a zero dose to check for recuperation, and the inclusion of an infra-red (IR) stimulation prior to blue stimulation of the final repeated dose (the OSL IR depletion ratio; Duller, 2003) to check for contamination of the signal by minerals other than quartz. However, the presence of a dominant fast component is commonly assumed or judged visually on a qualitative basis.

There are a number of techniques that have been adopted to measure and isolate the fast component, but these are often complex and time-consuming. Both the continuous wave (CW) and the linearly modulated (LM) OSL signal can be mathematically deconvolved, providing a measure of the physical properties of the components, such as the photo ionisation cross-section (σ) and the initial trapped charge population (n_0), and thus the relative contribution of each component to the OSL signal (e.g. Bailey et al., 1997; Bulur, 2000). However, the curve fitting of both the LM- and the CW-OSL signal is time-consuming, but more significantly curve fitting is both technically complex, and can introduce errors that are difficult to quantify. An alternative approach for isolating the fast component from quartz has been described by Singarayer and Bailey (2004), who stimulated with IR at elevated temperatures (above 125 °C), although the relative inefficiency of stimulating quartz with IR requires long measurement periods. Bailey (2010) proposed a method for using IR to measure the fast component

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from quartz that avoids the use of long stimulation times, but the technique is only applicable to bright samples. Whilst these methods are successful techniques for component separation in some samples, their complexity and time-consuming nature mean that they are not routinely applied to samples where the primary aim of analysis is age estimation.

Integration of the OSL signal from the initial part of an OSL decay curve will maximise the contribution from the fast component in quartz, but inevitably, it will also include signals from the medium and some slower components. To increase the relative contribution of the fast component within a CW-OSL quartz signal, Ballarini et al. (2007) applied the early background (EBG) subtraction method to single grain signals, where the background signal is taken immediately after the initial signal integration interval, instead of later in the decay curve as is normally done. Ballarini et al. (2007) report that using the EBG method, the contribution of the medium and slow components to the composite signal are reduced by 83% and 99% respectively (in comparison to taking a late background). However, the net signal used in D_e calculation is also lower, resulting in reduced precision on D_e. For single aliquot signals, Cunningham and Wallinga (2010) developed the EBG subtraction method further using four young samples. They concluded that for signals that were assumed to be dominated by the fast component, D_e precision was not adversely affected by taking a background approximately two and a half times the length of the initial signal and immediately following it.

For the majority of studies using the OSL signal from quartz to date sediments, complex approaches, such as curve deconvolution and measurement using IR stimulation, are not routinely used and the dominance of the fast component is assumed but rarely verified. A particular problem occurs where the medium component makes a significant contribution to the initial part of the decay curve used for dating quartz (e.g. Steffen et al., 2009), because a number of studies have indicated that the medium component may have a much shorter lifetime than the fast component (e.g. Li and Li, 2006; Steffen et al., 2009).

The aim of this study is to develop a simple numerical measure for assessing the dominance of the fast component in the initial part of the OSL signal, which can be routinely applied to a large number of aliquots measured using CW-OSL. This measure characterises the signal measured under CW stimulation and could be used to inform further analysis of the signal, such as the most appropriate integration intervals to use for dating or as a rejection criterion that can be applied as part of a suite of checks routinely applied to CW-OSL signals used for dating. It also provides the means to compare the dominance of the fast component between different samples. The measure is a ratio based upon one devised by Madsen et al. (2009), where the photon count rate over a period of time dominated by the fast component (minus the background signal) was divided by the photon count rate of a time period dominated by the medium component (again with the background subtracted) (Fig. 1). However, Madsen et al. (2009) did not provide any clear rationale for their choice of integration intervals, nor how they selected the threshold value that they chose as a criterion for accepting an aliquot. Their approach cannot therefore be easily applied to other studies. The ratio presented in this paper takes into account the stimulation power of the measurement equipment used and the photo ionisation cross-sections (σ) of the quartz OSL components. This ensures that results are comparable with measurements made on other aliquots (and samples) and/or made with other measurement equipment. To achieve this, it is first necessary to determine whether σ values are consistent between quartz from different samples. In the first part of this paper this will be explored by measuring the σ values of quartz from a variety of geographical locations, and based upon this, the integration

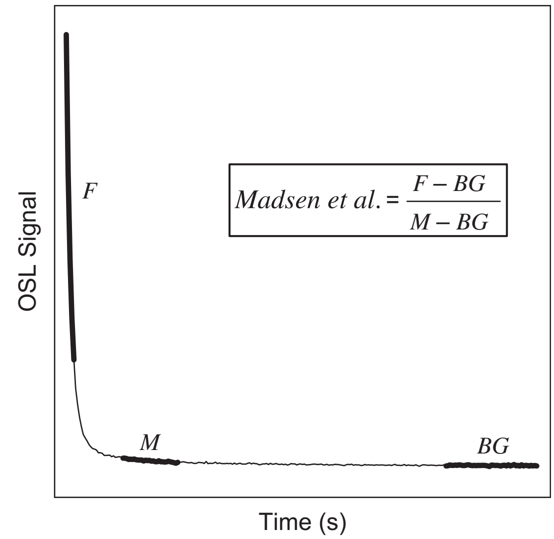

Fig. 1. A schematic view of the ratio presented by Madsen et al. (2009). F refers to the period selected to represent the fast component, M, the medium, and BG, the background.

intervals required to characterise the fast and medium components, and the background will be considered. In the second part of this paper these integrals will be defined, and the relationship between the fast ratio and the relative dominance of the fast component within a signal will be investigated.

2. Measuring the photo ionisation cross-section

The decay of signal during the OSL measurement of quartz does not form the simple exponential that would be expected if a single trap system with first-order kinetics was in operation (Chen and McKeever, 1997). Bailey et al. (1997) suggested that the most probable explanation for this is that the composite quartz OSL signal originates from a number of distinct traps which have different photo ionisation cross-sections. Each of these components can be described by an exponential decay (Eq (1)), and where first-order kinetics are assumed (see Chen and McKeever, 1997) can be described by the equation (Bulur, 2000)

$$L_{(t)} = n_0 \sigma I_0 \exp(-\sigma I_0 t) \quad (1)$$

where, $L_{(t)}$ is the luminescence intensity as a function of stimulation time t (s), n_0 is the initial trapped charge population, σ is the photo ionisation cross-section (cm^2), and I_0 is the light intensity (photons s^{-1} cm^{-2}).

The purpose of the fast ratio is to provide a rapid, easily applicable method of assessing whether the fast component is dominant in the signal from an aliquot measured with continuous wave (CW) stimulation, without prior knowledge of the sample specific σ parameters. A number of studies have published absolute and relative values for σ (see Table 1) and if σ values are consistent between samples, a set of standard σ values could be used for the calculation of the fast ratio. To test this, a number of samples were measured using LM-OSL, and from this, the σ values were calculated by deconvolution.

2.1. Experimental design and measurement

Ten samples were chosen for analysis and 2–3 aliquots of each were measured. Samples were chosen to reflect a variety of depositional settings, to be geographically dispersed (Table 2),