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IRSL dating of K-feldspars: Modelling natural dose response curves to deal with anomalous fading and trap competition

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ABSTRACT

We recently proposed a model that reconstructs the natural dose response curve for K-rich feldspars, using laboratory fading measurements and dose response as input parameters. The model is based on the relationship between recombination centre density and trap lifetime. In this study we test the working of the model by comparing modelled feldspar ages with known quartz OSL ages of the same samples and with anomalous fading-corrected feldspar ages. The modelled feldspar ages are in good agreement with quartz OSL ages and corrected feldspar ages, opening possibilities for future use of the model on samples without independent age constraints. Furthermore, we investigate the effects of trap competition on the build-up of IRSL signal using two new variations of the model. Results show that incorporating trap competition into the model reduces the agreement between feldspar IRSL ages and quartz OSL ages.

1. Introduction

The use of the infrared stimulated luminescence (IRSL) signal in feldspar is one of several approaches that are currently being explored to extend the age range of luminescence dating. The feldspar IRSL signal saturates at higher doses than the quartz fast-component optically stimulated luminescence (OSL) signal, allowing age determination on samples older than ~150 ka. However, feldspars are often affected by anomalous fading: loss of trapped charge from thermally stable traps during storage leading to underestimation of the burial age (Wintle, 1973). It has been accepted that this phenomenon is caused by quantum-mechanical tunnelling of trapped charge (Aitken, 1985, Appendix F).

For reliable IRSL dating on feldspars it is essential that anomalous fading is taken into account when comparing the natural IRSL signal to IRSL signals induced by laboratory irradiation. Several ways to do this have been proposed and tested (Lamothe and Auclair, 1999; Huntley and Lamothe, 2001; Lamothe et al., 2003). The Huntley and Lamothe (2001) method has been shown to work for Holocene samples, whereas the Lamothe et al. (2003) correction method has been applied successfully to samples of Eemian age (Buylaert et al., 2008). However, none of the proposed fading correction methods can be used for samples approaching field saturation (Morthekai et al., 2008).

We recently proposed a model that allows simulation of IRSL dose response curves (DRCs) and saturation levels at ambient dose rates, based on laboratory measured IRSL DRCs and anomalous fading measurements (Kars et al., 2008). The model is based on a description of fading by Huntley (2006) that formulates the relationship between recombination centre density (ρ') and trap stability. In the model it is assumed that the stability of a trap is determined by the distance (r') of that trap to the nearest recombination centre and that all recombination centres are available for recombination. The closer the trap and recombination centre pair, the higher the probability that an electron will tunnel and recombine without external stimulation.

The model as presented by Kars et al. (2008) assumes that the distribution of available charge depends solely on the trap-lifetime probability distribution (i.e. the probability that a trap of a certain lifetime exists). However, the matter may be further complicated if there is charge trapping competition between traps of different stability, as suggested by Huntley and Lian (2006) and Wallinga et al. (2007). Trap competition would lead to underestimation of the fading-corrected feldspar ages especially towards the high dose region of the DRC (Wallinga et al., 2007).

The first goal of this study is to test the Kars et al. (2008) model on a suite of samples spanning the Middle to Late Quaternary sedimentary record in the southern Netherlands (Schokker et al., 2005). We compare feldspar ages obtained using the model with reliable independent ages from quartz OSL dating and with feldspar ages corrected for anomalous fading following Lamothe et al. (2003). The second goal of this study is to investigate possible

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effects of trap competition on the build-up of the IRSL signal at environmental dose rates and their effects on equivalent dose estimation.

2. Materials and measurement conditions

We apply our methods to a suite of samples from a core through Middle to Late Pleistocene deposits in Boxtel, the Netherlands. The core contains stacked fluvial and aeolian sediments that accumulated in the tectonic low of the Roer Valley Graben. The geological setting and quartz OSL ages are presented by Schokker et al. (2005). Fading-corrected feldspar ages were obtained on the same samples by Wallinga et al. (2007) using the procedure proposed by Lamothe et al. (2003).

The environmental dose rates for feldspars used in this study are taken from Wallinga et al. (2007). The equivalent dose and fading rates on the feldspars were re-measured in this study, to use for modelling of the natural feldspar age. Wallinga et al. (2007) conclude that quartz OSL ages are valid for the samples in the top 12.35 m of the core and we limit this study to these top 11 samples. Because of the extremely low environmental dose rates (feldspar dose rates range from 1.34 to 1.92 Gy ka^{-1}; quartz dose rates range from 0.44 to 1.02 Gy ka^{-1}), quartz ages can be determined reliably up to 325 ka (Fig. 1).

IRSL dose response curves and equivalent doses were measured on a Risø TL-DA-15 TL/OSL reader with IR-diodes (870 nm) (Bøtter-Jensen et al., 2003). A single aliquot regenerative dose (SAR) protocol for feldspars (Wallinga et al., 2000) was used. The same preheat treatment was applied for regenerative dose and test dose (260 °C for 60 s) (Auclair et al., 2003; Blair et al., 2005) and a high temperature bleach (IRSL at 280 °C for 100 s) was included at the end of each regenerative cycle to avoid recuperation effects (Wallinga et al., 2007). IR stimulation was performed at 30 °C for 100 s. The net IRSL signal is obtained by subtracting the integrated signal of the last 10 s (background) from the integrated signal of the first 2 s. An LOT/Oriel 410/30 interference filter was used to select the K-feldspar emission around 410 nm (Krbetschek et al., 1997). During equivalent dose measurements a 3 mm diaphragm was added to avoid saturation of the photomultiplier tube as results of a too bright IRSL signal. Regenerative doses were measured up to 2220 Gy and a test dose of 50 Gy was used.

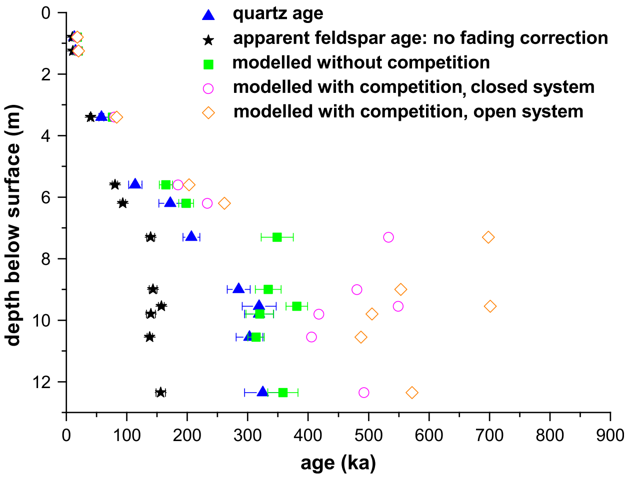

Fig. 1. Age plot showing the ages obtained for the Boxtel site: quartz OSL ages (triangles) (Schokker et al., 2005), the apparent feldspar ages (stars) and the modelled feldspar ages, using the Kars et al. (2008) model (squares). The feldspar ages modelled with trapping competition are given by the open circles (competition in a closed IRSL trap system) and open diamonds (competition in an open trap system).

The SAR protocol described above deviates in several aspects from the protocol used by Wallinga et al. (2007): 1) a longer preheat of 260 °C for 60 s (rather than 275 °C for 10 s) was used to avoid adverse effects due to thermal lag. This approach gave good results on samples from a nearby site (Kars et al., 2008). 2) Stimulation was performed at 30 °C instead of 50 °C in order to get a closer resemblance of the natural resetting conditions (Poolton et al., 2002). 3) We used an interference filter instead of a blue filter combination in order to select the area around 410 nm more accurately. The new SAR procedure gave a recycling ratio of 1.01 ± 0.01, a recuperation of $1.9 \pm 0.5\%$ and a dose recovery ratio of 0.96 ± 0.03 for all samples.

The same SAR protocol was used to measure fading rates, building in different storage times after administering a dose (15 Gy, test dose 7.5 Gy) and preheat, before IR stimulation (following Auclair et al., 2003). No diaphragm was added to the filter. We repeated the prompt measurement (230 s including preheat and half of the irradiation time) six times throughout the sequence to check recyclability and we used storage times of 1.7×10^3 s, 1.5×10^4 s and 1.6×10^5 s. Following Kars et al. (2008, eq. (5)) we obtained the recombination centre density (ρ') from laboratory fading rate measurements by fitting the data with the following equation:

$$\mathrm{IRSL}_{\mathrm{faded}} = \mathrm{IRSL}_{\mathrm{initial}} \exp\left\{-\rho'[\ln(1.8 \cdot s \cdot t)]^3\right\} \tag{1}$$

with $s = 3 \times 10^{15}$ s^{-1}, being the attempt-to-escape frequency (Huntley, 2006) and t the storage time, including half of the irradiation time. For clarity, fading rates are given in percentage loss per decade (g %, Aitken, 1985), obtained through fitting the data with eq. (1) in Wallinga et al. (2007), using a normalization time t_c of 2 days.

3. Results

We measured the dose response on all samples, but because all aliquots show similar DRCs, we use an average DRC for further analysis (Fig. 2; following Roberts and Duller, 2004). The measured

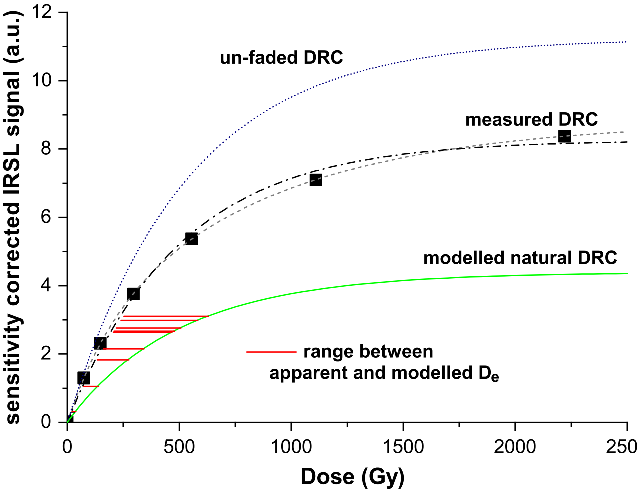

Fig. 2. IRSL dose response curves (DRCs) for the Boxtel samples. The measured regeneration points (squares, averaged for all samples; uncertainties shown but fall within the symbols) fitted with a single saturating exponential (dash–dotted line) and a double saturating exponential (dashed line). The regeneration points were extrapolated back to $t = 0$ (instantaneous irradiation and measurement) to construct an un-faded DRC (dotted line). Using the Kars et al. (2008) model a natural DRC was constructed (solid line). The natural signals of all samples are plotted on both measured and modelled DRCs (horizontal lines) to obtain the apparent D_e and modelled D_e respectively.