Component resolved OSL dose response and sensitization of various sedimentary quartz samples

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Abstract

The structure of the linearly modulated optically stimulated luminescence (LM-OSL) signal was studied for four sedimentary quartz samples, collected from different sites around Istanbul, Turkey. Applying a computerized deconvolution analysis to the LM-OSL curves, at least six individual components of first-order kinetics were identified and photoionization cross-section of each component was evaluated. The OSL dose–response curve of each component for each quartz sample was obtained, showing a remarkable differentiation from component to component. The behavior of a highly dosed sample to successive LM-OSL measurements was also studied showing a stable recuperation signal in the position of the “slow” and “medium” components and high resistance to OSL bleaching of the “slow” component. The individual sensitivity of each component as a function of the activation temperature was obtained. The sensitivity of each component was normalized over the respective sensitivity of the glow-peak at 110\textdegree C of quartz in order to investigate the ability of the 110\textdegree C glow-peak to act as a correction factor for all components of the LM-OSL curves examined.

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1. Introduction

The linearly modulated optically stimulated luminescence (LM-OSL) method of measuring the OSL suggested by Bulur (1996) allows the application of a computerized deconvolution analysis to a multi-component LM-OSL curve in order to obtain the individual characteristics of each component. The use of LM-OSL allowed the easier isolation of the components of the quartz LM-OSL signal, termed “fast”, “medium” and “slow” (Bailey et al., 1997), because it enables the identification of donor defects with different optical cross-sections. Using LM-OSL Kuhns et al. (2000) reported three components, Bulur et al. (2000) four components, Schilles et al. (2001) and Singarayer and Bailey (2003) five components, whereas Jain et al. (2003) reported that the LM-OSL curve of quartz consists of at least seven components.

The LM-OSL signal of quartz can be analyzed into its individual component by the procedure of deconvolution, assuming that the signal is made up of a finite number of components (Wintle and Murray, 2006).

The LM-OSL intensity for first-order kinetics is given by the equation

\[ L(t) = n_0 \sigma q t \exp \left( -\frac{\sigma q t^2}{2} \right) , \]

where \( \sigma \) is the photoionization cross-section, \( n_0 \) is the initial number of trapped electrons, \( q \) is the linear modulation ramping rate and \( t \) the stimulation time (Bulur, 1996). The photoionization cross-section is a parameter in OSL phenomenon and of major interest to estimate its value. Huntley et al. (1996) derived an equation, which relates the photoionization cross-section with the ratio \( S_0/I_0 \), where \( S_0 \) is the initial slope of the CW-OSL decay curve and \( I_0 \) is the initial luminescence intensity. By combining simple equations to describe both LM-OSL and CW-OSL, Kuhns et al. (2000) evaluated the cross-section for the three components they found for an Aeolian quartz...
They showed that all OSL dose–response curves could be fitted for each component as a function of the "fast" component. Jain et al. (2003) also demonstrated, for a Korean sample of quartz, an "ultra-fast" OSL component appearing before the "fast" component. They calculated its cross-section, \( \sigma \), which is in very good agreement with the photoionization cross-section value of \( 7 \times 10^{-16} \) cm\(^2\) given by Singarayer and Bailey (2003) for their "ultra-fast" component. It is claimed (Choi et al., 2003a,b) that this "ultra-fast" component is partly responsible for the equivalent dose, \( D_e \), determination problems by the conventional SAR protocol, in the dating of some Korean sediment.

OSL dose–response curves for individual components were obtained by Bailey et al. (1997), using a multiple aliquot approach. The "slow" component they obtained using CW-OSL measurements, had a much higher dose saturation level than the "fast" and "medium" components. The same result was also reported by Bulur et al. (2000) in their study of LM-OSL signals from heated quartz. Singarayer and Bailey (2003) used a SAR protocol involving LM-OSL measurements to construct the dose–response curves for the four components they observed in quartz samples extracted from Moroccan dune sand. They showed that all OSL dose–response curves could be fitted by a single-saturating exponential function.

A heating procedure is almost always necessary before any OSL measurement in quartz optical dating. When the sensitivity of a sample is altered due to a heating treatment only, it is said that the sample is thermally activated, whereas the heating temperature is termed activation temperature. It is well known that the heating induces sensitization effects in both thermoluminescence (TL) and optically stimulated luminescence (OSL) signals. Aitken and Smith (1988) suggested that changes in the sensitivity of the 110°C TL glow-peak signal and the OSL signal might be attributed to a common mechanism. The very interesting relationship between the 110°C TL and the OSL sensitivity has been extensively studied (Murray and Roberts, 1998; Murray and Wintle, 2000; Chen et al., 2000).

Wintle and Murray (1998) studied the sensitivity changes of the initial part of the CW-OSL signal for a quartz sample collected from Australia. Using a computerized deconvolution analysis Jain et al. (2003) studied the relative changes in amplitude of all the components they obtained for the same quartz sample as that of Wintle and Murray (1998), along with other two quartz samples, collected from India and Denmark. According to their procedure, a single sample was heated to a temperature between 160 and 700°C, followed by a laboratory irradiation. Then the sample was pre-heated to 160 or 200°C for 10 s, in order to remove isothermal TL, and finally the LM-OSL was measured by ramping between 0 and 47 mW cm\(^2\) over 5 or 10 ks. Their conclusion was that sensitization of each component followed a different pattern in the three samples they studied. Furthermore, they suggested that the recombination centers used by the different OSL components and the 110°C TL glow-peak may depend on the quartz origin. They also argued that a correlation exists between the 110°C TL peak and the "fast" component for the cases of the Australian and Indian samples.

Sensitization of quartz’s TL signal depends strongly on the type of the quartz sample studied, as well as on its thermal and radiation history (Bailiff, 1994). It is reasonable to assume that similar kinds of sensitization effects should be present in the case of the OSL signal as well.

The aim of the present work is to obtain the OSL dose–response curves of all components of the LM-OSL curves of four sedimentary quartz samples, by applying a computerized deconvolution analysis, as well as to provide an estimation of the photoionization cross-section of each component. Furthermore we aim to analyze the LM-OSL signal in its individual components and to study the behavior of each one, as a function of the activation temperature. Finally, the possibility of the glow-peak at 110°C of quartz samples, to act as a correction factor of the OSL sensitivity variation of each component, due to activation temperature, is also investigated.

2. Experimental procedure

North-western Turkey is divided by a complex waterway that connects the Black Sea to the Sea of Marmara and the Aegean Sea. The channel, named the Bosphorus, connecting the Black Sea and the Sea of Marmara separates two continents, Asia and Europe, and Istanbul is positioned at the south end of the Bosphorus. This region is one of the most energetic earthquake zones in the world and has been struck by two massive earthquakes measuring over 7.1 on the Richter scale within three months in 1999. It is thought that the chain is not complete, and that an earthquake will soon strike further west along the fault—perhaps in the heavily populated city of Istanbul. Samples examined here were chosen as representative ones collected from four symmetric positions to the Bosphorus strait; two samples (Altınlıkum and Şile) were taken from the coastal area of the Black Sea and two samples (Ataköy and Pendik) were from the coastal area of the Sea of Marmara. Furthermore Altınlıkum and Ataköy are both positioned in European part and Şile and Pendik are in Asian part of the country (laboratory reference alt, atk, pdk and sle, respectively) (Kiyak and Canel, 2006). Although the study area is noted for earthquakes with destructive magnitudes, very little is known of the chronology of the neotectonic activity using luminescence dating techniques. Therefore luminescence studies on local quartz will provide valuable data that would be of interest to people working in this field.

The samples were taken from a depth of 5–10 cm below the earth’s surface. They were subjected to wet sieving to obtain grains of dimensions 90–180, 180–250 and 250–325 μm. The grains obtained in the size range of 90–180 μm were treated first with HCl (10%) to remove carbonates and then with H\(_2\)O\(_2\).
The transformed form given by Polymeris et al. (2006) is

\[ I(t) = \frac{T}{\sigma I_0}, \]  

where \( T \) is the total illumination time, \( I_0 \) is the maximum stimulation intensity (W/cm\(^2\)) and \( \sigma \) the cross-section.

Solving towards \( \sigma \) one obtains

\[ \sigma = \frac{T}{c_I I_0 t_m^2}, \]  

where \( c_I \) is a conversion factor, which converts \( I_0 \) into number of photons.

In the case of LM-OSL the illumination light intensity is linearly increased and therefore each peak position with an individual value of \( t_m \), corresponds to a unique light intensity, \( I_{0m} \), between zero and \( I_0 \). Therefore, for the evaluation of the cross-section, the \( I_0 \) of the later equation must be replaced by \( I_{0m} \), in W cm\(^{-2}\), which is given by

\[ I_{0m} = \frac{I_0}{T} t_m. \]  

Therefore

\[ \sigma = \frac{T^2}{c_I I_0 t_m^2}. \]  

For the evaluation of \( \sigma \), one has to convert the intensity of the stimulation \( I_0 \) into photon number, i.e. to obtain the value of the coefficient \( c_I \). If the stimulation light intensity is expressed in W/cm\(^2\), then one obtains

\[ c_I = \left( \frac{\text{Joule}}{\text{s cm}^2} \right) = \left[ \frac{6.24 \times 10^{18} \text{eV}}{\text{s cm}^2} \right]. \]  

For a given stimulation photon energy \( E_\phi \),

\[ c_I = \frac{6.24 \times 10^{18}}{E_\phi} \left( \frac{\text{eV}}{\text{eV s cm}^2} \right). \]  

Eventually

\[ \sigma = 3.82 \times 10^{-20} \frac{E_\phi T^2}{I_0 t_m^2} \text{(cm}^2\). \]  

Eq. (10) is an expression, which relates to the photoionization cross-section, \( \sigma \), with experimental parameters such as the total stimulation time, \( T \); and the stimulation intensity used, \( I_0 \), (expressed in W/cm\(^2\)), the photon energy of the stimulation light, \( E_\phi \), (expressed in eV) and with the fitting parameter \( t_m \).

### 3. Method of analysis

The first-order kinetics equation describing an LM-OSL peak proposed by Bulur (1996) was used. However, the original equation (1) of Bulur (1996) was transformed, so that instead of the parameters \( n_0 \) and \( \sigma \), it contains the parameters \( I_m \) and \( t_m \) which can be obtained directly from experimental curves. The transformed form given by Polymeris et al. (2006) is

\[ I(t) = 1.6488 \frac{I_m}{t_m} t \exp \left( -\frac{t^2}{2t_m^2} \right), \]  

where \( I_m \) and \( t_m \) are the values of OSL intensity and time at the maximum of the LM-OSL peak and \( t \) the time of the stimulation. Eq. (2) was used for the deconvolution of all experimental data. The curve fitting was performed using the MINUIT program (James and Roos, 1977), whereas the goodness of fit was tested by the figure of merit (FOM) of Balian and Eddy (1977), given by

\[ \text{FOM} = \sum_i \left| \frac{Y_{\text{Exper}} - Y_{\text{Fit}}}{A} \right|, \]  

where \( Y_{\text{Exper}} \) is the experimental glow-curve, \( Y_{\text{Fit}} \) is the fitted glow-curve and \( A \) is the area of the fitted glow-curve.

Since, the final values of \( t_m \) and \( I_m \) are directly evaluated from the curve fitting procedure an estimate of the photoionization cross-section is possible as follows; according to Bulur (1996) the value of \( t_m \) is given by

\[ t_m = \sqrt{\frac{T}{\sigma I_0}}, \]  

where \( T \) is the total illumination time, \( I_0 \) is the maximum stimulation intensity (W/cm\(^2\)) and \( \sigma \) the cross-section.
in order to find the number of components and their kinetics order, which give the best fit, in a consistent way, to all experimental data. It was found that this could be achieved by using six first-order kinetics components. First-order kinetics was also exclusively used in the de-convolution analysis performed by Kuhns et al. (2000), Singarayer and Bailey (2003, 2004) (see also Wintle and Murray, 2006 and references therein). The number of components depends on the kind of material used, as well as, on the experimental conditions used like, for example, preheat treatment, stimulation time and stimulation temperature.

LM-OSL curve shapes analyzed and resolved into their individual components are shown in Figs. 1–4, for the quartz samples with reference names alt, atk, pdk and sle, respectively. In all figures (a) corresponds to a low dose of 5 Gy, whereas (b) the one to the high dose of 1 kGy. Based on LM-OSL curve fitting analysis six first-order kinetics components were identified for each of the four quartz types (see previous section). The FOM values obtained, giving the goodness of fit, were better than 1% for all cases, which ensure excellent fits. The values of $t_m$ obtained from the best fitting procedure for each component of all quartz samples are given in Table 1. The very interesting result is that although the LM-OSL curve shapes varied from sample to sample and especially for low and high doses, the resulting values of $t_m$ are almost similar for the four quartz samples studied, with a slight exception for the quartz samples of sle. The $t_m$ position of each component is also the same for all doses justifying thus the choice of first-order kinetics for the deconvolution procedure (see previous section).

The relative uncertainty in the $t_m$ values of the first and sixth components are rather higher than the rest of the values in Table 1. Concerning the “first” component the reason is that this component is restricted to the very short times of the OSL glow curve, which corresponds to no more than 4–5 experimental points. In all cases, however, it was not possible to achieve a best fit without including this component. Another reason for the possible higher errors in the “first” component is the poor resolution across the time scale due to the very long duration of each measurement (3600 s). Since 250 channels
were used to record the OSL during 3600 s the time resolution was 14 s and although this resolution is poor for the “first” component it is less of a problem for the components appearing at higher stimulation times. Whereas the smaller number of experimental points makes the massive deconvolution analysis of all experimental results to be achieved in convenient times.

Concerning the case of the “sixth” component, as seen from Table 1, its time maximum $t_m = 3800$ s is greater than the total measuring time of 3600 s, it is clear that this component is not completed (see Figs. 1–4).

The terminology used in literature to describe LM-OSL components are “fast”, “medium” and “slow”. In the present work the deconvolution analysis gave exact characteristics for each component like, for example, the peak time maximum $t_m$, which can be used to give a name for each component. From the results of Table 1, one can see that the time maximum position $t_m$ can distinguish very well each component. So, the component 1 can be termed $C_1$ or “UltraFast” in the terminology of Jain et al. (2003) at $\sim 22$ s, the component 2, $C_2$ or “fast” at $\sim 65$ s, the component 3, $C_3$ or “medium” at $\sim 165$ s, the component 4, $C_4$ or “slow 1” at $\sim 410$ s, the component 5, $C_5$ or “slow 2” at $\sim 1000$ s and the component 6, $C_6$ or “slow 3” at $\sim 3800$ s, under, of course, the experimental conditions used.

Once the values of $t_m$, given in Table 1, were obtained from the best fit procedure, an estimation of the photoionization cross-section was possible using Eq. (11). The photoionization cross-section values obtained in the present work, as given in Table 2, are in very good agreement with the photoionization cross-section values reported by Singarayer and Bailey (2003). Indeed it is very interesting to observe that the $\sigma$ values listed in Table 2 almost coincide, within the errors, with the respective $\sigma$ values reported by Singarayer and Bailey (2003) for their sedimentary quartz measured at 160°C stimulation temperature. The fact that the experimental LM-OSL measuring protocol used in the present work is similar to that used by
Singarayer and Bailey (2003) is a basic reason for the very good agreement.

Jain et al. (2003) reported a deconvolution of the LM-OSL curves, measured at 125 °C, in sedimentary quartz using seven first-order kinetics components. The values of \( \sigma \) found by these authors for their first three components, termed by them “ultrafast”, “fast” and “medium”, respectively, are lower by almost one order of magnitude compared to the values for components C1, C2 and C3 of the present report. On the other hand, the \( \sigma \) values for components “slow 2”, “slow 3” and “slow 4” (in the terminology of Jain et al., 2003) are in good agreement with the respective \( \sigma \) values of components C4, C5 and C6 of the present work (Table 2).

### 4.2. Dose–response of individual components

The OSL dose–response curve of the component 1 at 22 s is shown in Fig. 5 where one can see that the behavior is similar for all kinds of quartz. The response seems to be sub-linear at lower doses, supra-linear above 10 Gy, saturating at about 200 Gy.

The behavior of the OSL dose–response curves of the second component C2 (or fast) at 65 s, shown in Fig. 6, is similar, but different to that of the component 1 at 22 s. Component resolved dose–response curves of the “fast” component for all samples can be fitted with a single saturating exponential function at about 200 Gy, comparable with published results using LM-OSL deconvolution technique (Singarayer and Bailey, 2003; Bulur et al., 2000).

The very interesting and surprising results obtained were that the OSL dose–response curves of the component 3 at 165 s, of the component 4 at 410 s and of the component 5 at 1000 s appear not be in saturation, in the dose range up to 1000 Gy, as shown in Fig. 7. We may expect a behavior of saturating dose response at relatively higher doses. As it is seen that these components behave exactly similar both as components and as quartz kinds, with almost the same order of magnitude in all samples studied. They show a significantly higher dose response but relatively low intensity, initially, a sub-linear behavior, which turns slightly to be supra-linear above 100 Gy.

The OSL dose–response curves of the component 6 at 3800 s, shown in Fig. 8, show different behavior from that of the components 3–5, but exactly similar, except for the last dose, with the behavior of component 2 at 65 s. OSL intensity, however, in magnitude is significantly higher than the second component C2. Dose–response curves of this component for all quartz types could be approximated by using a saturating exponential plus a linear function.

As it was mentioned in the Experimental Procedure section the samples of each kind of quartz, which were irradiated with the highest dose of 1 kGy, were subjected to successive LM-OSL measurements, without new irradiation, in order to study the recuperation level and as discussed above, the residual OSL left. The deconvolution analysis of these LM-OSL curves gave excellent fits with FOM values much better than 1%, whereas
in the cases of the Şile quartz (sle) the FOM values were better than 0.4%. It is interesting to note that in order to obtain excellent fits, it is necessary to include all components 1–6. For the case of components 1–5 the best fit was achieved with the $t_m$ values found previously and given in Table 1. Concerning the $t_m$ value of the component 6 at $\sim 3800$ s, it was found in analysis of these data that it is continuously increased as a function of the illumination cycle. This result is due to the fact that, as it was discussed above, only the half part of this component is obtained during the 3600 s duration of the OSL measurement, which may result in a higher inaccuracy in the value of $t_m$ of this component. It must be noticed that such a shift is also compatible with a higher order kinetics component, because as the illumination cycle number increases, the electron concentration $n_0$ in the respective OSL trap decreases. However, the available data are not enough for a final argument.

The first cycle corresponds to a measurement immediately after the measurement of 1 kGy. The ratio, in %, of the OSL of the first cycle over the OSL of the last dose of 1 kGy, is given in Table 3. The components 1–4 are treated as a sum, because the statistics in this time region is low, so that, the accuracy of the integral of each component is low too in order to follow them separately. Anyway, these components are obtained to a level below 4% of the original signal corresponding to the dose of 1 kGy, whereas the component 5 at 1000 s is obtained to a level equal to almost 60% of the original signal, because, as it was discussed above, the illumination time of 3600 s is not capable to deplete completely the responsible OSL trap.

The behavior of the sum of the components 1–4, of the component 5 at 1000 s and of the component 6 at 3800 s as a function of the illumination cycle is shown in Fig. 9 for all quartz kinds, with almost the same order of magnitude in all samples studied, initially, a sub-linear behavior, which turns slightly to be supra-linear above 10 Gy.
The ratio (first residual/OSL at 1 kGy)*100, for the sum of components 1–4 shown in Fig. 9, respectively. However, after the seventh illumination cycle after the OSL measurement of 1 kGy. The normalization is done over the first illumination cycle of the four quartz samples. The normalization factor of unity corresponds to the percentage (%) level given in Table 3 for each component and material. The sum of the components 1–4 for alt quartz, which correspond to the curve (a), decays slowly as a function of the illumination cycle. This means that the OSL in time region of these components is always present and they are always recuperated at the level of 1%. On the other hand, the components 5 at 1000 s and component 6 at 3800 s, which correspond to curves (b) and (c), respectively, decay rapidly as a function of the illumination cycle. The similar behavior of atk, pdk and sle samples are also shown in Fig. 9, respectively. However, after the seventh illumination cycle a fraction of about 20% of the original signal of the OSL at 1 kGy is not removed.

4.3. Sensitization

The 110°C TL peak of quartz, which is obtained by the step 3 of the measuring protocol for sensitization, can be used to correct for the sensitivity changes. Since the glow-curve region around the 110°C TL glow-peak contains low intensity satellite peaks, all the TL glow-curves were analyzed using a first-order kinetics equation (Kitis et al., 1998) in order to obtain the clear integral, as well as, the kinetics parameters of the glow-peak for all kinds of quartz. A characteristic example (sle quartz, the Black Sea sample from Asian side) is shown in Fig. 10, in which one can see the low intensity satellites around the main peak. The values of the parameters of each glow-peak are listed in Table 4, where one can see that there are not appreciable differences between the four kinds of quartz. In fact, the real peak maximum is found to be between 132 and 142°C, and not at 110°C.

The behavior of the sensitivity of the 110°C glow-peak as a function of the activation temperature is shown in Fig. 11. It is normalized over the sensitivity of the lower activation temperature of 100°C. In fact the measuring protocol is quite similar to the procedure used in TL to obtain the single aliquot thermal activation curves (SA-TAC) for the pre-dose sensitization of the 110°C glow-peak (Kitis et al., 1998). The pre-existing natural dose is considered to be the pre-dose. As it is seen in Fig. 11, there is no sensitization up to an activation temperature of about 300°C. Above 300°C, the observed sensitization, although qualitatively the same, is differentiated for each quartz kind concerning the maximum sensitization factor and the activation temperature at which the maximum appears.

In order to examine the normalization efficiency of the 110°C peak, the behavior of each LM-OSL component is investigated as a function of the activation temperature. In Figs. 12b, 13b, d, 14b and d, the individual behavior of each component is shown for a direct comparison with the respective one of the 100°C TL peak, as well as, their normalized over the 110°C TL sensitivity.

The component C1 at 22 s, which could be correlated with the component termed “ultra-fast” in literature (Jain et al., 2003), is unfortunately, poorly resolved during deconvolution analysis shown in Figs. 1–4, since it decays rapidly, so that it corresponds to very few, in fact three, experimental points. However, it is not possible to fit the initial part of the LM-OSL curve without including this component. The only possible conclusion for this component is that it is sensitized. However, due the high uncertainties it is not possible to argue safety if it match point per point that of the 110°C TL.

The behavior of the component C2 at 65 s, which in literature is termed “fast” component, is shown in Fig. 12. The left-hand side of Fig. 4 shows the sensitization as a function of the activation temperature. It is impressive to observe how much the behavior of this component agrees, not only qualitatively but also quantitatively, with the respective behavior of the TL glow-peak at 110°C, shown in Fig. 11. For this reason its normalized sensitivity in the right-hand side of Fig. 12 shows a very good stability up to an activation temperature of almost 350°C. This is a result, which makes this component ideal for the SAR protocol.

The behaviors of the component C3 at 165 s and the component C4 at 410 s which can be correlated with the component “medium” and “slow 1” of literature are shown in Fig. 13. The sensitization of both components C3 and C4 shown in the left-hand side of Fig. 13, (a) and (c), shows the same pattern as that of the TL glow-peak at 110°C. On the other hand, their normalized response shown in the right-hand side of Fig. 13, (b)

![Fig. 8. OSL dose–response curves of the sixth component or “slow 3” at 3800 s of (a) alt, (b) atk, (c) pdk and (d) sle quartz samples. They show significantly higher dose response similar, except for the last dose, with the behavior of component 2 at 65 s.](image-url)
and (d), are very well stable, at least, up to an activation temperature of 350°C, indicating that these components meet very well the requirements of the SAR protocol. Since, the behavior of the component C4 is very similar to that of the component C3, termed “medium”, it is considered that C4 must be included in the series of “medium” component as “medium 2”, instead in the series of the “slow” components.

The behavior of the component C5 at 1000 s, termed “slow 2” of literature, is shown in Fig. 14a as a function of the activation temperature. This component is also sensitized but its sensitization follows poorly the respective behavior of the TL glow-peak at 110°C. One possible reason is due to the deconvolution analysis. This component is like a satellite of the component C6 at 3800 s, which has much higher intensity, so that a small error at the \( t_m \) of the component C6 will result a high influence to the component C5. However, despite the influence from the higher component C6 the general characteristics of the component C5 are clearly closer to those of the components C3 and C4. From its normalized sensitivity, shown in Fig. 14b, this could be useful for the SAR protocol at least for the cases of alt and pdk quartzs. The behavior of this component can be considered that it is closer to those of component C3 and C4. So, it is concluded that it must be included in the series of the “medium” components as “medium 3” instead of the series of the “slow” components.

The behavior of the component C6 at 3800 s is also shown in Fig. 14. This component can be correlated with the component termed “slow 3” in literature. Fig. 6c shows the sensitization
as a function of the activation temperature, where one can see that this component does not follow the respective behavior of the glow-peak at 110°C. Its behavior can be separated into two regions. In the first region between 100 and 300°C, it is desensitized, whereas the sensitivity of the glow-peak at 110°C is stable. In the second region between 300 and 500°C, it is sensitized in a manner qualitatively the same as that of the glow-peak at 110°C. Finally, its normalized response, shown in Fig. 14d, is initially decreased in the first activation temperature region, noted above, and then turns into stability above the activation temperature of 400°C. The net conclusion is that this component does not meet the requirements of the SAR protocol.

5. Conclusions

The analysis of the LM-OSL curves of four sedimentary quartz samples using a computerized deconvolution analysis, resulted in six first-order kinetics individual components centered at \( \sim 22, \sim 65, \sim 165, \sim 410, \sim 1000 \) s and at \( \sim 3800 \) s, under the experimental conditions used. The first-order kinetics was verified by the fact that the time maximum position of each OSL component is the same for doses 1 Gy up to 1 kGy. The OSL dose–response of each component separately is exactly the same in the four sedimentary quartz samples studied. Individually, the OSL dose–response curve of the component 1

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Table 4

<table>
<thead>
<tr>
<th>Sample</th>
<th>( T_{\text{max}} ) (K)</th>
<th>( E ) (eV)</th>
<th>( S ) (s(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>alt</td>
<td>405.5 ± 1.7</td>
<td>0.835 ± 0.018</td>
<td>(3.43 ± 2.50) ( \times 10^{10} )</td>
</tr>
<tr>
<td>atk</td>
<td>409.8 ± 0.3</td>
<td>0.792 ± 0.005</td>
<td>(6.13 ± 0.90) ( \times 10^{9} )</td>
</tr>
<tr>
<td>pdk</td>
<td>414.9 ± 0.5</td>
<td>0.796 ± 0.010</td>
<td>(5.24 ± 1.70) ( \times 10^{9} )</td>
</tr>
<tr>
<td>sle</td>
<td>409.8 ± 0.4</td>
<td>0.810 ± 0.008</td>
<td>(1.05 ± 0.24) ( \times 10^{10} )</td>
</tr>
</tbody>
</table>

The values are the average of all (about 30 for each kind of quartz) obtained glow-peaks.
at 22 s seems to be sub-linear at lower doses, supra-linear above 10 Gy, saturating at about 200 Gy. The OSL dose–response of the component 2 at 65 s should be described by a saturating exponential. The OSL dose–responses of the component 3 at 165 s, of the component 4 at 410 s and of the component 5 at 100 s, are exactly similar consisting on an initial sub-linear behavior, which turns to be supra-linear above 10 Gy. The OSL dose response of the component 6 at 3800 s is also similar, except for the last dose, with the behavior of component 2 at 65 s.

The LM-OSL measurements at 160°C for 3600 s, of a sample irradiated with 1 kGy, are able to deplete the OSL traps responsible for the components 1–4 (recuperation level ∼ 1%) and for the component 5 (recuperation level ∼2–4%) but it is not able to deplete the OSL trap responsible for the component 6 (residual level ∼ 60%). After seven successive LM-OSL measurements at 165°C for 3600 s, the recuperation level for components 1–5 is below 1%, whereas the residual level of the component 6 drops to 20%.

The sensitization as a function of the component C2 at 65 s, which should be correlate with the so-called “fast” component, is in excellent agreement both qualitatively and quantitatively with the sensitization as a function of the activation tempera-

Fig. 13. (a) and (c) show the sensitization of the component C3 at 165 s and C4 at 410 s, termed “medium” and “slow 1” of literature as a function of the activation temperature, normalized over the 100°C activation temperature. It shows the same behavior as that of the TL glow-peak at 110°C. (b) and (d) are the normalized behavior of the left-hand side figures (a) and (c). They are very well stable up to an activation temperature of 350°C, indicating that these components meet very well the requirements of the SAR protocol.

Fig. 14. (a) Normalized sensitization of the fifth component C5 of the LM-OSL curve at 1000 s as a function of the activation temperature. It follows poorly the respective behavior of the TL glow-peak at 110°C. (b) The corrected for sensitivity changes of the fifth component C5 in (a), dividing by the response of the 110°C glow-peak given in Fig. 11. (c) Normalized behavior of the sixth component C6 of the LM-OSL curve at 3600 s as a function of the activation temperature. This component does not follow the respective behavior of the glow-peak at 110°C. (d) The normalized behavior of C6 after dividing by the response of the 110°C glow-peak given in Fig. 11. It is initially decreased in the first activation temperature region, and then turns into stability above the activation temperature of 400°C.

deture of the glow-peak at 110°C of quartz. The stability of its normalized, over the TL of 110°C up to about 350°C, response makes this component to fulfill very well the requirements of the SAR protocol.

Similarly the components C3 at 165 s and C4 at 410 s, which are correlated with the “medium” and “slow 1” of literature fulfill also the requirements of the SAR protocol. Their normalized, over the TL of 110°C up to about 350°C, response make these components suitable for the SAR protocol. The component C6 “slow 3” at 3800 s is not suitable for SAR protocol, whereas the components C1 at 22 s “ultra-fast” and C5 at 1000 s “slow 2” are poorly resolved.

References


