

A Regression Method for Evaluation of Paleodose in the Pre-dose Technique

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Abstract: A regression method for expanding the application range of the pre-dose technique is introduced. Comparing methods on the basis of a common acceptable prediction uncertainty, the limiting value of the allowable paleodose N in the regression method is found ($N \leq 1.2B$) to be at least twice that applicable to other methods. Uncertainties arising from the non-linear filling of R traps are also discussed.

I Introduction

The pre-dose technique in thermoluminescence (TL) dating was established more than twenty years ago following the reports of Fleming (1969, 1973) and Zimmerman (1971) and has attracted continuing study. Essentially Fleming reported that the 110°C TL peak in quartz retains a "memory" of previous irradiation and this "memory" can be used to evaluate the paleodose of archaeological samples. A model for the interpretation of the pre-dose effect was originally proposed by Zimmerman (1971). Studies and further developments of the potential for application of the method have since been reported (Chen, 1979, Aitken, 1985, Bailiff and Haskell, 1984). A detailed description of the procedure used in this technique and the proposed model are provided by Aitken (1985) and Bailiff (1991).

In Zimmerman's model, two electron traps are involved and two hole traps—the luminescence centre L and the reservoir trap R. Although a saturating exponential sensitivity change was pointed out long ago by Chen (1979), in most earlier reports about the practical evaluation of the paleodose it is assumed that both hole traps are linearly filled through the irradiation dose. As this assumption is correct only when the dose is very small, i.e. within the range of a few Gy, this significantly limits the age for archaeological samples suited to the pre-dose method.

In recent years, growing attention is being paid to the effects of non-linear filling of the hole traps. In the review paper of Bailiff (1991), techniques for reducing the experimental errors introduced by the non-linearity are presented.

A regression method that expands the range of application of the pre-dose technique is suggested and discussed in this work.

II Experimental Work

The natural quartz and the ancient brick samples used in this work are from China.

Two Sr^{90} β sources each 50mCi were used for the additive dose and test dose, set up at different irradiation distances. All TL measurements were performed on a 7188 thermoluminescence dating system manufactured by Littlemore Scientific Engineering Company, Oxford. Thermal activation temperatures are 500°C for the natural quartz and 470°C for the quartz extracted from the ancient brick (Fig. 1 shows the thermal activation characteristics). The test dose was 0.01Gy, the heating rate 10°C/s, and sensitivity was recorded by integrating the TL intensity from 80°C to 140°C.

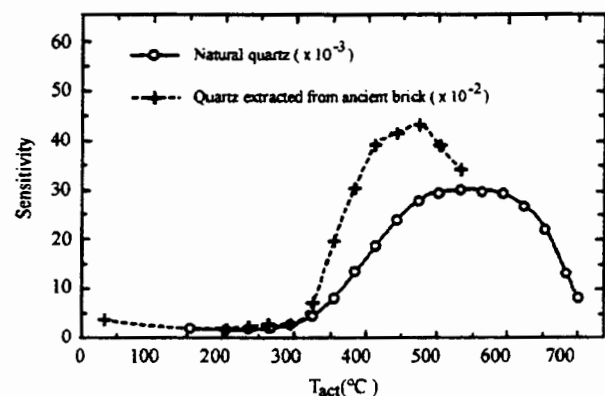


Figure 1. Thermal activation characteristic curves of natural quartz (solid line) and quartz extracted from the 1022 years old brick (dashed line)

III The Regression Method

1. Principle

If it is assumed that the reservoir traps are filled linearly, the sensitivity S can be represented as:

$$S = S_{\infty}(1 - e^{-D/B}) \quad (1)$$

where S_{∞} is the saturation value of S in the absence of quenching, B is a constant and D is the irradiation dose (Chen, 1979).

Quenching occurs if the sample has been successively irradiated and activated. The sensitization of one step in the dose/activation cycles, ΔS , is given by:

$$\Delta S = S_{\infty}(1 - S_{\downarrow}/S_{\infty})(1 - e^{-\beta/B}) \quad (2)$$

where S_{\downarrow} is the quenched value of S and β is the dose increment for this step (Bailiff, 1991).

Equation (2) can be written in an alternative form:

$$\Delta S = S_{\infty}(1 - e^{-\beta/B}) - (1 - e^{-\beta/B})S_{\downarrow} \quad (2a)$$

If β remains unchanged in the successive dose/activation cycles, $(1 - e^{-\beta/B})$ will be constant. Consequently, a linear relation between S_{\downarrow} and ΔS should be found with gradient $b = -(1 - e^{-\beta/B})$ and intercept $a = S_{\infty}(1 - e^{-\beta/B})$.

This suggests a method enabling the paleodose N to be evaluated. Serial measurements of S_{\downarrow} and ΔS separated by equal dose increments β will give $(S_{\downarrow}, \Delta S)$ data pairs. Regression of the data will give gradient and intercept values from which S_{∞} and B can be obtained. The paleodose N can then be found from the equation:

$$\Delta S_N = S_N - S_0 = S_{\infty}(1 - S_0/S_{\infty})(1 - e^{-N/B}) \quad (2b)$$

2. Examples

(i) *Natural quartz* - the natural dose of an archaeological sample cannot be precisely known so, to test the method, fine grain natural quartz annealed at 800°C for 15 hours is used. The "natural" dose is replaced by a laboratory dose, giving an equivalent paleodose N followed by warming to 150°C. It has been found that the characteristics and range of linearity varies widely in quartz with various origins. More than ten groups of quartz samples found in China, either natural or extracted from ancient pottery, were tested. The linear range of these samples was found to be 2-3Gy only.

First, an equivalent paleodose $N=3.38$ Gy was used to test the proposed method.

Measurements of the sensitivities of the 110 °C peak in the successive dose/activation cycles were performed with a 2.70Gy dose increment. Results are given in Table 1.

Dose(Gy)	S (x10 ⁴)	S _↓ (x10 ⁴)	ΔS (x10 ⁴)
N	3.56	2.37	1.84
N+2.70	4.21	3.08	1.51
N+5.40	4.58	3.51	1.31
N+8.10	4.82	3.89	1.08
N+10.80	4.97		

Table1. Sensitivities and sensitizations of natural quartz samples with a "paleodose" administered in successive dose/activation cycles. ($S_0 = 0.14 \times 10^4$)

The $\Delta S \sim S_{\downarrow}$ curve is shown by the solid line in Fig. 2. As predicted, there is a good linear relation between ΔS and S_{\downarrow} . The regression parameters from eqs. (2a) and (2b) give $S_{\infty} = 6.11 \times 10^4$; $B = 3.94$ Gy and $N = 3.35$ Gy.

It can be seen that the calculated value of N lies very close to the actual laboratory "paleodose" — 3.38Gy. Repeated examinations have been performed with similar quartz samples but varying the "paleodose" and the dose increment β . The largest "paleodose" used was 4.73Gy. It is shown by the experimental results that the uncertainty in the calculated N can be kept within 10% by using an appropriate value of β (this will be discussed in the following section).

(ii) *Quartz extracted from ancient brick* - measurements were also taken with fine grain quartz extracted from an ancient brick sample produced in the Five Dynasties. The age of the sample is 1022 years. The results are given in Table 2.

Dose(Gy)	S(x10 ³)	S _↓ (x10 ³)	ΔS(x10 ³)
N	4.55	3.77	1.97
N+4.75	5.74	5.03	1.17
N+9.50	6.20	5.66	0.73
N+14.25	6.39	6.15	0.33
N+19.00	6.48		

Table2. Sensitivities and sensitizations of quartz samples extracted from ancient brick in successive dose/activation cycles ($S_0 = 0.22 \times 10^3$)

The $\Delta S \sim S_{\downarrow}$ curve of this sample is shown by the dashed line in Fig. 2. The values obtained by

The $\Delta S \sim S \downarrow$ curve of this sample is shown by the dashed line in Fig. 2. The values obtained by regression are: $S_\infty = 6.69 \times 10^3$; $B = 4.15 \text{Gy}$; $N = 4.54 \text{Gy}$.

This result appears reliable as the average annual dose of Chinese ceramics for pre-dose method, in which the α -dose should be neglected, is about 4.23mGy (Stoneham, 1987), then the age of that ancient brick obtained from the result $N = 4.54 \text{Gy}$ is about 1073 years.

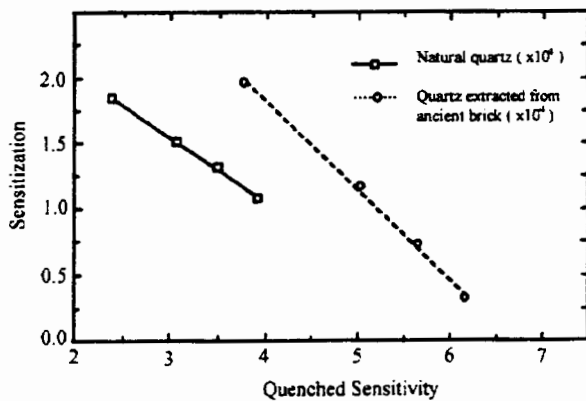


Figure 2. Regression curves of the sensitization and quenched sensitivities of natural quartz (solid line) and quartz extracted from 1022 years old brick (dashed line) in the dose/activation cycles

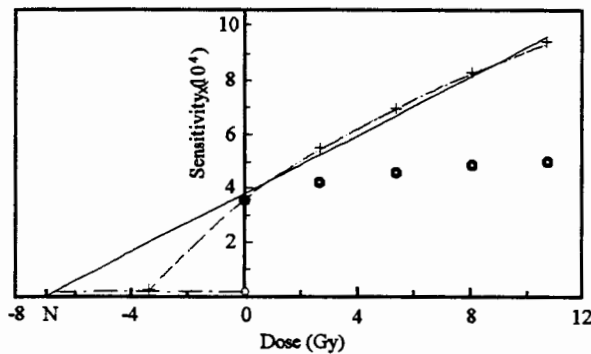


Figure 3. The relation between sensitivity and irradiation dose, details in text.

IV Discussions

1. Comparison between the regression method and the standard methods

In previous work (Aitken, 1985, Bailiff, 1991), several methods for evaluating the paleodose N have been reported. The equivalent paleodose in example 1 presented in the above section is also evaluated with those methods for comparison.

(i) by the multiple activation technique Data processing of example 1 is shown in Fig.3, where the

empty cycles represent the data of S given in Tab.1, the plus symbols represent the points corrected from quenching. The principle of the correction for quenching is described by Aitken(1985).

It is found from the solid line and the dots in Fig.3 that the calculated paleodose N is about 7.0Gy. Comparing with the true paleodose $N=3.38 \text{Gy}$, the error is larger than 100%.

(ii) by putting the first two rows of Table 1 in the equation:

$$N = \frac{S_N - S_0}{S_{N+\beta} - S_{N\downarrow}} \cdot (\beta - \beta_T) \quad (3),$$

where β_T is the test dose. The calculated value of N is 4.97Gy — this is 50% above the actual value.

For the discussion of those errors, equation (1) $S = S_\infty (1 - e^{-D/B})$ is rewritten:

$$S = S_\infty [D/B - 1/2(D/B)^2 + 1/6(D/B)^3 - \dots] \quad (1a)$$

i.e. the linear relation only holds when $D \ll B$, then $S \approx S_\infty (D/B)$.

The multiple activation technique and eq.(3) are both based on the assumption of a linear relation between S and D , though a pseudo non-linearity is introduced by quenching when multiple activations are employed.

The real relation between sensitivity and dose in example 1 is shown by the dashed line in Figure 3, which indicates that the dose used in this example is far beyond the linear range. Large errors were introduced by the non-linearity. The error in method (ii) is smaller than that in method (i), as less non-linear part of the S - D curve is used in method (ii) case.

It can be shown from equation (1a) that the error produced when using equation (3) will be larger than 20% when $D/B \geq 0.7$. That means that equation (3) is properly valid only for the case of $D/B < 0.7$, i.e. $(N+\beta) < 0.7B$ or $N < 0.5B$. And in the case of multiple activation technique, the value of N is even more limited.

In the regression method, the paleodose N is evaluated from the values of the intercept a and the gradient b . The uncertainties in a and b in the present work are about 5%. It can be shown that the main contribution to the uncertainty of the final result is caused due to the uncertainty in B . As $b = -(1 - e^{-\beta/B})$, i.e. $-\beta/B = \ln(1+b)$, it follows that:

$$|\Delta B/B| = |\Delta b/b| \left| \left[(1+1/b) \ln(1+b) \right]^{-1} \right| \quad (4)$$

where $-1 < b < 0$. It is seen from eq.(4) that the relative error in B increases with the increase of the absolute value of b . For example, suppose $|\Delta b/b| \approx 5\%$. If $b = -0.7$ then $|\Delta B/B| \approx 10\%$; if $b = -0.8$ $|\Delta B/B| \approx 12.5\%$; and $|\Delta B/B|$ will be about 45% when $b = -0.97$.

It is suggested that $|b|$ should not be larger than 0.7 (i.e. $\beta/B \leq 1.2$) if the error of the final result is expected to be within 15%. As discussed in the following section, the value of β should in fact be as close as possible to the paleodose N. Thus the regression method would give acceptable results within the range $N \leq 1.2B$.

This expands the application range by a factor of at least two compared to the standard method.

(ii) *The effects of non-linear filling of the reservoir traps*

Equation (1), which is the foundation of the regression method, is based on the assumption that the traps R are filled linearly. In fact the population of R traps themselves would be better described by an expression similar to equation (1) (Chen, 1979). The assumption of linearity is in fact only correct when the irradiation dose is small. In the work reported here both N and β are outside this condition.

The non-linear filling of R traps will give a further contribution E_R to the estimated uncertainty. It can be shown that E_R is determined largely by the ratio $|(N-\beta)/\beta|$ and also the ratio between the natural dose N and the saturation (i.e., 90% of R traps are filled) dose of the R traps, D_s^R .

Table 3 gives an indication of the relationships involved.

N/D_s^R	$ (N-\beta)/\beta $	E_R
17%	0	0
	10%	2%
	20%	5%
33%	0	0
	10%	4%
	20%	10%
67%	0	0
	10%	7%
	20%	15%

Table3. The relation between E_R , N/D_s^R and $|(N-\beta)/\beta|$

It can be seen from Table 3 that E_R increases with the ratio $|(N-\beta)/\beta|$. Obviously its value can be reduced if β is close to N, and can even be neglected when $\beta \approx N$. This is in agreement with Bailiff's report (1991). This indicates that, before measurements are taken for an archaeological sample, the approximate natural dose should be estimated in order to select the appropriate dose increment β . When the pre-dose technique is used for a paleodose outside the linear range, the result should be considered unreliable if the calculated value of N in the final result is much larger or much smaller than β . In this case it is advisable to use an adjusted dose increment closer to the value of the obtained N and reiterate the whole experimental procedure until the difference obtained between N and β is within 20%.

When the dose is near the saturation dose of R traps, a small difference between N and β will induce a serious error in the final result. This is the main reason to limit the values of the paleodose and the dose increment in the regression method. It is not easy to estimate the saturation dose of R traps. However in all the measurements reported in this work no serious error caused by the non-linear filling effects of R traps has been detected within the conditions of $N \leq 1.2B$ and $\beta = (1 \pm 20\%)N$.

V Summary

Using the pre-dose technique, the paleodose can be evaluated from the parameters obtained in the regression of the the sensitizations and quenched sensitivities recorded during the dose/activation cycles. Compared with the standard method, the range of application is expanded by a factor of at least two using the regression method. The conditions $N \leq 1.2B$ and $\beta = (1 \pm 20\%) N$ are suggested for obtaining reliable predictions.

Acknowledgement

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Reviewer

Ed Haskell

Optical detrapping of charge from the 110°C quartz TL region

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Abstract : A series of experiments has shown that the mechanism responsible for the enhanced rate of decay under illumination of PTTL (photo-transferred thermoluminescence) in the ~110°C region is most likely to be optical detrapping of charge. It has been demonstrated that an alternative explanation for the decay, related to changes in acceptor site concentrations, is unlikely to be the cause. An optical half-life of ~600s is deduced for the ~110°C PTTL emission for the conditions described (420-560nm, 12 mW.cm⁻² stimulation).

Introduction

The aim of this work was to investigate the optical stability of electrons held in the quartz TL peak found at ~110°C. More specifically, the main concern was the issue of whether or not the decrease in PTTL as a function of OSL exposure time is due to optical bleaching (of the 110°C PTTL) or to a change in the concentration of available acceptor sites (such as the loss of luminescence centres or an increase in competition from non-radiative centres or electron traps) during optical exposure.

Basis of experiments

Following an exposure to the OSL stimulation light of 75s (at 20°C, stimulating with 2.2-2.9eV photons (420-560 nm) at ~12mW.cm⁻², within a standard automated TL-DA-12 Risø reader) the measurable OSL signal is generally depleted to a level of ≤1% of the initial intensity (I_0). During such an OSL shinedown a proportion of the mobile charge is transferred to the TL trap responsible for the ~110°C PTTL emission (Aitken and Smith, 1988). As the OSL signal has been reduced to such a low level, any further light exposure after this point (75s) will add only a minute fraction to the PTTL already present. If following 75s OSL the excitation light is turned off, the thermal decay of the PTTL (at 20°C) can be measured by making TL measurements of individual aliquots following time t . A plot of PTTL versus t both with and without illumination will show the effect of the light exposure on the PTTL.

Sensitivity change as a function of optical exposure time

It is necessary to quantify the degree to which the apparent loss of PTTL upon optical exposure (after

the initial 75s shinedown) is due to changes in the concentration of available acceptor sites. An attempt to indirectly measure such effects, as a function of OSL measurement time, was made using the ~110°C TL response. Individual aliquots of natural Chaperon Rouge (724g2) quartz (a sample chosen for its relatively strong TL / PTTL peaks at ~110°C), having a natural dose of ~12 Gy, were given ~0.1 Gy of beta dose and then immediately heated to 160°C (2°C.s⁻¹) to measure the TL at ~110°C (this procedure will be termed the *standard sensitivity test*). The aliquots were then exposed to the OSL excitation light for a range of times at 160°C. Following the OSL shine, the standard sensitivity test was performed again, the rationale being that during OSL shinedown a proportion of the de-trapped electrons recombine at the available L-centres (luminescence centres), hence the OSL, and the OSL traps are substantially depleted. Therefore, following the OSL measurement, the probability of any free electron moving around the lattice recombining at an L-centre is lessened, (both because of the reduced concentration of available L-centres and the increased competition for charge from the empty OSL traps), which should be expressed as a loss of sensitivity. This assumes that electrons released from the OSL and 110°C TL/PTTL traps recombine at the same L-centres - a view supported by the spectral emission work of Franklin *et al.* (1995).

The results (shown in Figure 1) are interpreted to mean that the loss of luminescence centres following OSL shinedown (to < 1% of I_0) is only a small fraction of the total, in the order of 9%. This is consistent with the findings of Bailey *et al.* (1997) who report an effectively constant charge transfer

rate throughout the OSL shine-down. There is a slight dose dependency in the results, showing less of a drop in sensitivity for aliquots dosed (see Figure 1 for details of administered doses) and preheated (220°C for 300s) prior to measurement. This can be tentatively interpreted in a number of ways (including thermal sensitisation via the mechanism described first by Zimmerman (Zimmerman, 1971) or there being an increased likelihood of trapping holes in the appropriate L-centres during dosing rather than trapping electrons at the OSL source traps). More work however is needed here and this is a relatively subsidiary point.

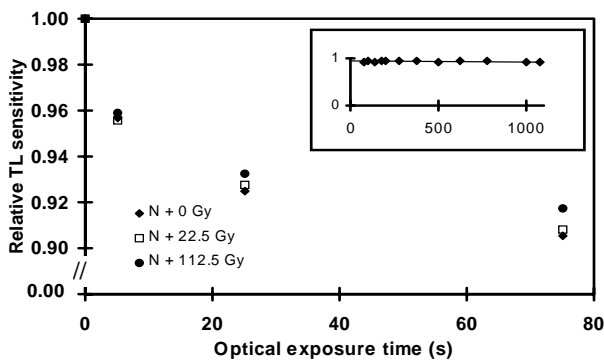


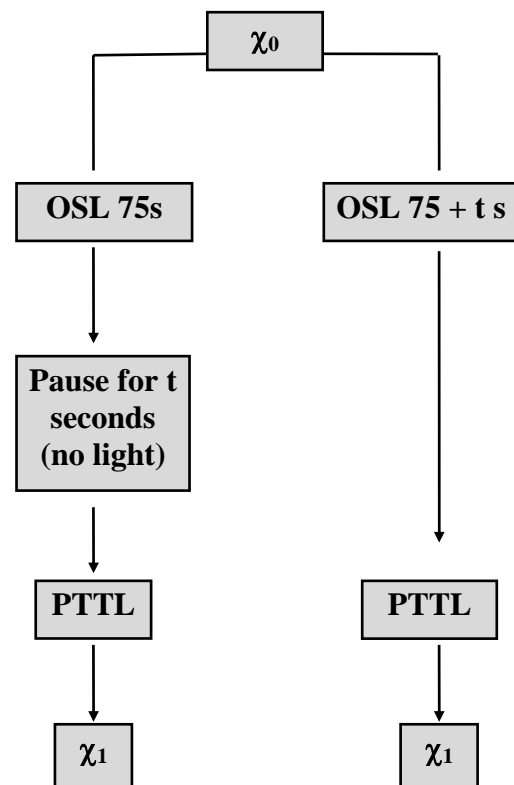
Figure 1: Relative sensitivity of the $\sim 110^\circ\text{C}$ TL emission as a function of OSL measurement time. Individual aliquots (of Chaperon Rouge quartz, 724g2) were β -irradiated with the doses shown and preheated (220°C for 300s). A standard sensitivity test was then made (see main text for description). The individual aliquots were then exposed to the OSL excitation light (as described in main text) whilst held at 160°C. Following light exposure a further standard sensitivity test was administered. The relative sensitivity is defined as the ratio of the two sensitivity measurements. Each data point is the mean of four individual aliquots. The standard errors are smaller than the size of the symbols. The inset box shows similar data for a natural sample of the same quartz with the optical exposure times extended to 1075s. Again each point is the average of at least two similar aliquots. A linear fit to the data is shown, which confirms the constancy of the relative sensitivity between 75 and 1075s of optical exposure (the gradient of the fit is less than 1 in 10^5).

The results from the present work show the same ca.9% drop in sensitivity following a shinedown to <1% for the same sample illuminated this time at

20°C. As expected the drop in sensitivity as a function of optical exposure appears to be proportional to the measured OSL signal. Consequently the change in sensitivity for OSL exposure times >75s (at either 20°C or 160°C), where the OSL signal has dropped to very low levels, are imperceptible, with no change in sensitivity seen for OSL exposure times between 75 and 1000s. Effectively all of the loss in sensitivity (as a function of optical exposure) has been completed by the 75s measurement time (i.e. where $t = 0$).

Procedure

A diagram for the experimental procedure is shown below. The same sample (natural Chaperon Rouge, 724g2) used for the experiment previously described was also used here. The characters χ_0 and χ_1 are the standard sensitivity tests, performed at the beginning and end of the procedure respectively. The TL measurements (of both PTTL and dose induced TL signals) were made at $2^\circ\text{C}\cdot\text{s}^{-1}$, heating to 160°C. During illumination with the OSL excitation light, and for the subsequent hold for t seconds (where applicable), the samples were maintained at room temperature ($\sim 20^\circ\text{C}$).



Discussion of results

Figure 2 shows the integrated PTTL (20-150°C integral) remaining as a function of t , for both conditions (i.e. light on during t and light off during t). Each point represents the mean of at least two individual measurements, with the standard deviation shown. The data were normalised using the initial standard sensitivity measurement.

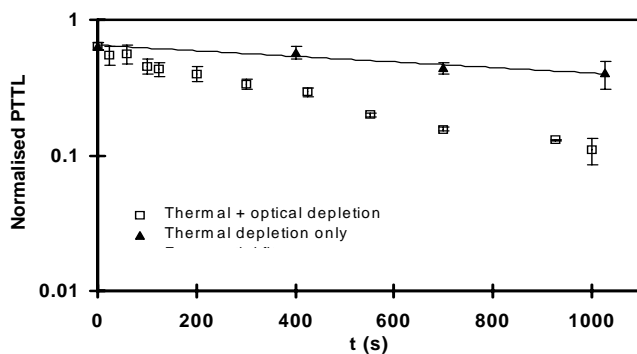


Figure 2: Comparison of thermal and combined thermal and optical decay of PTTL (see main text for details). Each data point is due to at least two replicate measurements. The thermal decay data has been fitted to a single exponential decay.

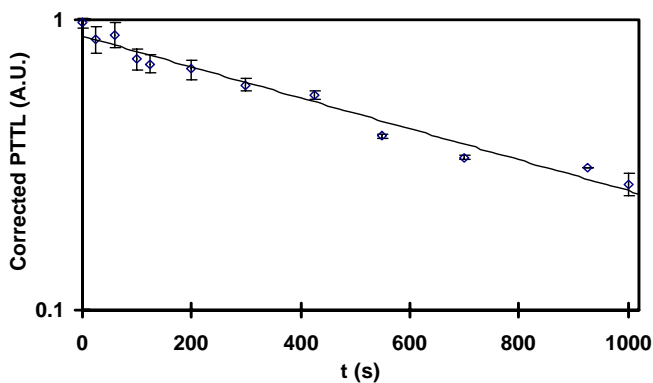


Figure 3: Optical decay of PTTL, corrected for thermal decay at 20°C and fitted to a single exponential decay. Data are normalised to the initial sensitivity value and are due to at least two replicate measurements (see main text for details).

There is a clear difference between the two sets of data shown in Figure 2. The increased rate of signal decay in samples exposed to the OSL excitation light during the hold for t seconds is easily apparent. As shown in the previous section, the sensitivity of the ~110°C TL peak is not subsequently affected by light

exposure past 75s and hence the subsequent changes in the availability of electron acceptors after this time are taken to be minimal. The drop in PTTL signal level as a function of illumination time therefore strongly suggests that optical bleaching of the PTTL is taking place.

An exponential fit to the thermal depletion data (see Figure 2) can be used to correct for the thermal loss of the PTTL signal during illumination, yielding the data shown in Figure 3. These data represent the true optical depletion of the ~110°C PTTL signal. The data cannot be particularly well fitted with a single exponential decay and there are a number of possible reasons for this. Smith and Rhodes (1994) have shown that the TL emission at ~110°C (for the same sample as that used here) comprises two components, with TL peak positions possibly corresponding to the 85°C and 110°C TL emissions (Smith *pers.comm.*). Other kinetic effects such as charge re-trapping (both to the traps responsible for the ~110°C PTTL and the OSL emissions) may also contribute to the overall form of optically induced decay. However if the data in Figure 3 are fitted to an exponential decay an optical half life for the ~110°C PTTL peak of ~600s is obtained (for the conditions described above). Wintle and Murray (1996) have also concluded that optical stimulation of electrons from the 110°C TL trap gave rise to a decrease in the PTTL signal under green light stimulation. They obtained a shorter optical decay lifetime of ~130s for the first 90% loss of signal decay for their sample of Australian quartz.

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Reviewer

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The K content of the K-feldspars being measured in optical dating or in thermoluminescence dating

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Mejdahl (1983, 1985) suggested the use of separated potassium feldspars for dating, and showed the feasibility of this. We address here the question of what is the correct potassium content to use to evaluate the β dose rate from the potassium within the grains.

Pure K-feldspar, KAlSi_3O_8 , has 14.0 wt. % K. The grains in a sediment generally consist of a highly inhomogeneous collection and one can expect grains to be present with a range of K contents between 0 and 14%. The laboratory procedures designed to separate K-feldspars are not perfect and usually result in the presence of other minerals such as quartz and plagioclase feldspars. The situation is further complicated by the fact that different mineral grains have different luminescence sensitivities and it is not unusual to find that most of the light that is being measured arises from a small fraction of the grains of an aliquot. The one observation that appears to make the problem tractable is that it is generally observed that there is a positive correlation between luminescence sensitivity and potassium content.

Our approach to the problem has been to note that 14% is the maximum possible value of the K content, and that a minimum value can be determined from the average K content of the separated grains.

The grains are separated using standard procedures. These are an HCl treatment to dissolve carbonates, sieving to select a grain size, a 6 minute HF etch to clean, but not dissolve the grains, an HCl treatment to dissolve precipitated fluorides, sieving to remove small fragments, selection of the $< 2.58 \text{ g cm}^{-3}$ fraction using an aqueous solution of sodium polytungstate, and magnetic separation. After optical dating measurements the grains are recovered and about 0.3 g sent for commercial atomic-absorption analysis; the K contents so obtained for a variety of samples are given in the table.

We have sought to obtain the fraction of the separated grains that is K-feldspar by making maps of element concentrations of Si, Al, Na and K using a

scanning electron microscope. A monolayer of grains is sprinkled onto an aquadag-coated carbon target, the element maps are made, and then an ordinary white-light photograph made. About 100 grains are then identified and classified. Grains showing only Si are classified as SiO_2 . Those with Si and Al usually contain either K or Na or both. Such a grain is classified as K-feldspar if K is clearly dominant and Na feldspar if Na is clearly dominant. Where neither is dominant a grain is classified as mixed. Some grains showed Si and Al but neither K nor Na, and these are listed as "other Si & Al" and may be low-Na plagioclases. The table shows the grain counts and fraction identified as K-feldspar; the latter ranges from 15% to 97%. Here a mixed K & Na grain is counted as 1/2 a K-feldspar grain.

On the assumption that all the K is in the grains identified as K-feldspar, the K content of these grains is calculated, and given in the last column of the table. With two exceptions these figures cluster about a value of about 13% and this figure would appear to be generally appropriate. Two considerations, however, indicate that this value may be too high. The classification of the grains causes bias because of any K in those grains classified as Na feldspar. For some samples this cannot be a large effect because when there is a large fraction that is not K-feldspar, this is mainly quartz. The second consideration is that analyses of single mineral samples of K-feldspar generally yield K contents in the range 10-13% K (Huntley et al, 1988; Spooner, 1992, Prescott and Fox, 1993), and unless museum samples have lower K contents than K-feldspar grains found in sediments, a typical value of 13% for the latter seems unlikely and a slightly smaller value is warranted.

Although this establishes typical K contents of K-feldspar grains it does not take into account the fact that most of the measured luminescence often arises from a small fraction of the grains, and these could have lower or higher K contents. Prescott and Fox (1993) have shown that there is a high degree of correlation between thermoluminescence sensitivity

and K content for a range of K-feldspars, those with over 11% K being the brightest. A similar indication was found by Spooner (1992) for the 1.4 eV

(infrared) - excited luminescence. Thus one can expect that the light will be coming from high-K feldspars.

Sample	Separated grains K wt. %	grain counts						K-feldspar fraction	K of K-feldspar grains wt. %
		total	SiO ₂	K- feldspar	Na- feldspar	mixed K&Na	other Si&Al		
TTS	4.8	97	19	43	35	0	0	0.44 ± 0.05	10.9 ± 1.2
TTS3	9.05	102	23	69	10	0	0	0.68 ± 0.05	13.3 ± 1.0
PATSI	7.2	71	11	26	21	11	2	0.52 ± 0.06	13.8 ± 1.6
CBTS2	9.6	113	9	77	19	8	0	0.68 ± 0.05	14.1 ± 1.0
NRTS	8.29	185	49	82	27	17	10	0.49 ± 0.04	16.9 ± 1.5
FHTS-3	4.7	184	14	42	76	45	7	0.35 ± 0.04	13.4 ± 1.7
KHTS-1	5.7	160	22	61	35	24	18	0.46 ± 0.04	12.5 ± 1.2
KHTS-2	3.9	160	14	33	78	25	10	0.28 ± 0.04	13.4 ± 1.7
ZCTS	3.8	192	28	64	50	43	6	0.44 ± 0.04	8.4 ± 0.8
SW6-01	7.6	100	38	55	6	1	0	0.55 ± 0.05	13.8 ± 1.2
SAW94-32	6.2	107	45	39	7	11	5	0.47 ± 0.05	13.2 ± 1.4
SAW94-37	8.3	106	29	42	5	26	4	0.64 ± 0.04	13.0 ± 0.8
SAW94-62	2.4	83	41	29	9	4	0	0.37 ± 0.05	6.5 ± 0.9
MELVL93-5	10.7	128	9	95	24	0	0	0.74 ± 0.04	14.5 ± 0.8
CPIW	6.0	98	37	32	2	11	16	0.44 ± 0.05	13.6 ± 1.5
TAG2	7.9	60	20	33	3	15	9	0.60 ± 0.06	13.2 ± 1.3
CTL2	2.3	72	31	11	21	0	9	0.15 ± 0.04	15.3 ± 4.0
DY24	11.5	117	3	104	1	9	0	0.93 ± 0.02	12.4 ± 0.3
SN30	11.9	88	0	83	1	4	0	0.97 ± 0.02	12.3 ± 0.3
SN55	11.4	74	0	69	1	4	0	0.96 ± 0.02	11.9 ± 0.3
SN4d	3.4	96	63	27	2	4	0	0.28 ± 0.05	12.1 ± 2.2

Table: Grain counts, K contents, and deduced K contents of the K-feldspar grains for 21 sediment samples from 7 geographically distinct areas. The first 8 samples are tsunami-laid sands from British Columbia and Washington State (Huntley and Clague, 1996; Baril, 1997). ZCTS is a fluvial sediment from the same region. SW6-01, SAW94-32 & -37 are interdune and dune sands from the Great Sand Hills, Saskatchewan. SAW94-62 is a loess from the Cypress Hills nearby. MELVL93-5 is from California. CPIW and TAG2 are a sand wedge and buried fluvial deposit respectively from the Mackenzie River delta. CTL2 is from near Merritt, British Columbia. DY24 is from a site by the Lena River near Yakutsk, Siberia. The SN samples are from Sandy Neck, Cape Cod, Massachusetts, U.S.A.

There is, however, usually a small fraction of high-Na feldspar (albite) amongst our separated grains, and the same authors show that these can be as bright as the high-K feldspars. There is thus the possibility that these may contribute significantly to the measured luminescence, and in one sample for which we obtained spectra we found this to be the case (Ollerhead et al, 1994). There is, fortunately, an easy remedy for this; since the main K-feldspar emission is at 3.1 eV (400 nm), whereas that of Na-feldspar is at 2.2 eV (570 nm), the use of a blue filter in the measuring system can readily eliminate the latter. In this respect, the quantum efficiency of the

photomultiplier tubes commonly used is significantly lower at 2.2 eV than 3.1 eV and this goes some way to accomplishing the same objective.

From the combination of information above a suitably conservative estimate of the K content to use would appear to be 12.5 ± 0.5%. At 95% confidence this covers the range 11.5 - 13.5% which would seem to cover the possible range. The β dose rate from the potassium within the grains can be calculated using the table of Mejdahl (1979).

The two low values of 6.5 and 8.4% K in the table are cause for concern. If we assume that the K analyses are correct they indicate that for some

sediments the K-feldspars are not 13% K; for such samples one will have to assume the relevant K content could lie anywhere between the determined value and 14%, but recognize that most of the luminescence could still be from feldspars with ~ 13% K.

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Reviewer

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Comments

The paper deals with the intricate problem of determining the correct K concentration in K and Na feldspar when the separation of feldspars from other minerals, especially quartz, is incomplete. The procedure described is a mapping of minerals in five groups: SiO₂, K-feldspar, Na-feldspar, mixed K + Na, other (Si and Al) by means of a scanning electron microscope.

This method seems to work well and as a result of their discussion the authors conclude that a typical, suitably conservative estimate of the K content in K-feldspar would be $12.5 \pm 0.5\%$;

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Notices

TLDATE : a program for the TL age estimation of archaeological samples

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A program, TLDATE, has been developed for the thermoluminescence (TL) age estimation of archaeological samples. The salient features of the package are :

1. It is simple, very specific and interactive at every stage of the analysis.
2. It plots smoothed, background subtracted and auto scaled glow curves in single and multi-mode.
3. A novel method of plateau estimation, based on two software packages (koul and Bhat, 1994 ;Koul,1995) Data is screened, point by point, from either side of the chosen window to see the relevance of individual points vis-a-vis the plateau. The set of selected inputs has absolutely no impact on the results. There is also provision for identifying the common plateau region.
4. Equivalent dose estimation is carried out by extrapolating the least square fit of the data to the point of intersection with the time or dose axis.
5. In non-linearity estimation the user has to identify the point up to which the supralinear portion extends. There-after, again, a least squares fit is made for points which include this point and all other point above it. The intersection with time or dose axis yields nonlinearity correction.
6. A subroutine for annual dose estimation which takes care of all relevant parameters (Nambi and Aitken, 1986).
7. Age estimation and errors involved in it are calculated in a conventional way (Aitken, 1985).
8. All data management is in-built in the package.

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Note :

For any information about this package please contact D.K.Koul or Director, Centre for Advanced Technology, Indore 452 013, India.

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Thesis Abstract

Thesis title : Optical Dating of Tsunami Deposits.

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degree : Master of Science

speciality : Physics.

Abstract:

A tsunami generated by a Cascadia subduction zone earthquake deposited sands in marshes on Vancouver Island and the coast of Washington 300 years ago. Similar deposits were left in marshes on Vancouver Island by the tsunami produced by the 1964 Alaska earthquake. Samples of one or more of these and other sand layers were collected from marshes on Vancouver Island at Fair Harbour, Koprino Harbour, Neroutsos Inlet and Zeballos, and at the Niawiakum River in Washington State. At some sites samples of material considered to be analogous to the source material for the sand layers were also collected.

A new luminescence detection chamber was constructed for the measurement of these young samples and an improvement in detection efficiency over 4 times that of the old chamber was attained.

The two samples collected from Koprino Harbour yielded optical ages of 60 ± 20 years and 270 ± 50

years, consistent with the known ages of 32 and 300 years respectively. The remaining samples all yielded ages considerably older than the independent age estimates. Optical ages for the 300-year-old sands at the remaining sites were: 920 ± 170 years at Fair Harbour, 2100 ± 500 years at Neroutsos Inlet and 540 ± 90 years at the Niawiakum River. The purported 300-year-old tsunami layer at Zeballos yielded an optical age of $11,700\pm 700$ years. At Fair Harbour, a sand layer that was probably deposited by a flood less than 500 years ago yielded an optical age of 5300 ± 700 years. Samples of modern tidal-channel sediments at Fair Harbour and Koprino Harbour yielded near-zero equivalent doses. A non-zero equivalent dose was obtained for modern river bottom sediment at the Niawiakum River.

These and previous results indicate that some of the sands received poor exposure of sunlight prior to burial whereas others were sufficiently exposed. The discrepancy is probably due to the differing depth of tsunami scour of the source sediments at different sites. A correlation is also suggested between sites at which anomalously old ages were obtained and the extent of the mud flats fringing the marsh.