Sensitization of TL signal by exposure to light

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Abstract

The regeneration method of obtaining the equivalent dose for polymineral loessic deposits has been shown to give rise to apparent TL ages which are far too young compared with known geological age over the period 50-700 ka. Debenham (1985) proposed that loss of luminescence centres over that time period was the cause of the underestimation. This conclusion was reached on the basis of the apparent exponential nature of the discrepancy between the TL dates (by regeneration) and the geologically estimated ages. This paper presents a different model which could give rise to a similar discrepancy in the dates. It proposes dose-dependent sensitivity changes occurring when the sample is exposed to light. It predicts a hyperbolic, rather than an exponential, discrepancy but it is difficult to differentiate between these two functions.

Introduction

Debenham (1985) has reported that when equivalent doses (EDs) are obtained by regeneration of the TL signal following exposure to a solar simulator, the TL ages obtained for loess from north-western Europe reach a limit of about 100 ka. He concludes that this effect is due to decay of the TL signal through time with a mean life, τ, of about 100 ka; hence the TL age, T, is obtained by $T = \tau\ (1 - \exp\{-t/\tau\}$ where t is the true geological age of the sample. Wintle et al. (1984) found ages in the range 75-139 ka for the loess and soil complex below the hiatus at 1.8 m at Saint Romain. They concluded that these represented the terrestrial climatic record equivalent to oxygen isotope stages 5e to 5a in the marine record in agreement with the geological interpretation (Lautridou, 1982). However, a later study by Wintle (1985) on soils deeper in the section did not show any increase of TL with depth. This thus confirmed the flattening off of TL age versus real age reported by Debenham and suggests that the interglacial soil at Saint Romain is pre-Eemian. Similar underestimates have been obtained for well-developed interglacial soils in Poland when this technique is employed (Proszynska-Bordas, 1985).

These results can be explained by the slow decay of luminescence centres over the period of interest as shown by Debenham. Fig. 1 shows the effect of such a decay (τ = 150 ka) on the measurement of TL ages. Loss of luminescence centres would affect not just the regeneration method of ED determination, but also the other methods, the total bleach ($N + \beta - I_0$) method and the partial bleach method (R-Γ) method, to the same extent. On the other hand, several authors (e.g. Buraczynski and Butrym, 1984) have obtained TL dates older than 150 ka using these methods. However, it should be emphasised that their dates could have been overestimated (thus fortuitously cancelling any loss of luminescence centres if the latter is occurring) because of non-linearity of the TL response as the dose is increased.

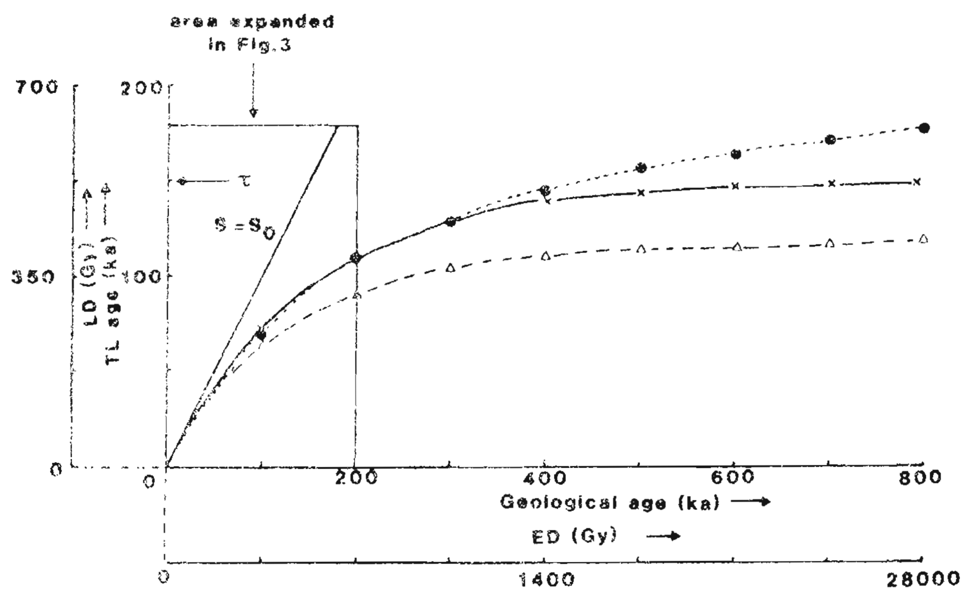

Figure 1: LD plotted versus ED (also converted to TL age versus geological age using a dose rate of 3.5 Gy/ka). x----x for loss of luminescence centres with τ *= 150 ka, ●....● for linear growth and sensitivity change △---△ for exponential growth with a sensitivity change which depends upon the fraction of filled traps.*

Effect of dose-dependent sensitivity change on regenerated growth curves

Another phenomenon which could give rise to an apparent flattening off of the TL age versus geological age plot is now considered. It concerns the effect of a sensitivity change produced by the laboratory light exposure. It is constrained by the experimental knowledge that for young European loesses the sensitivity after bleaching, S, differs negligibly from that for an unbleached sample, S_0. Let us assume that the sensitivity after bleaching depends upon the radiation dose that the sample has received since it was last exposed to sunlight, in a way which is analagous to the pre-dose sensitisation found for quartz and feldspars from pottery when they are heated in the laboratory (e.g. Mejdahl, 1985).

(a) <u>Linear growth curve</u>

In the simplest case, where the growth curves are linear let us assume that the sensitivity after bleaching is given by the equation $S = S_0\ (1 + \dot{D}t/B)$ where t is the geological age, $\dot{D}$ is the annual dose rate, and B is a constant, taken as 800 Gy. The effect on laboratory growth curves is shown in Fig. 2 for samples of various EDs. When the natural TL intensity produced by ED is matched to that induced by laboratory dose LD, we can write

$$S_0 \cdot ED = S \cdot LD$$

and hence $S_0 \cdot ED = S_0\ (1 + \dot{D}t/B).LD = S_0\ (1 + ED/B).LD.$

The unique points obtained when the light levels are matched fall on the hyperbola LD = ED (1 + ED/B). This function is also plotted in Fig. 1, with $\dot{D}$ maintained as 3.5 Gy/ka, a fairly typical value for loess. It can be seen that for samples up to 400 ka there is negligible difference between this function and the exponential proposed for decay of luminescence centres with τ = 150 ka. Above 400 ka the curves deviate as the hyperbolic nature of the above equation becomes more pronounced. For the dose region below 200 Gy the responses of these two curves can be seen better in the expanded plot in Fig. 3.

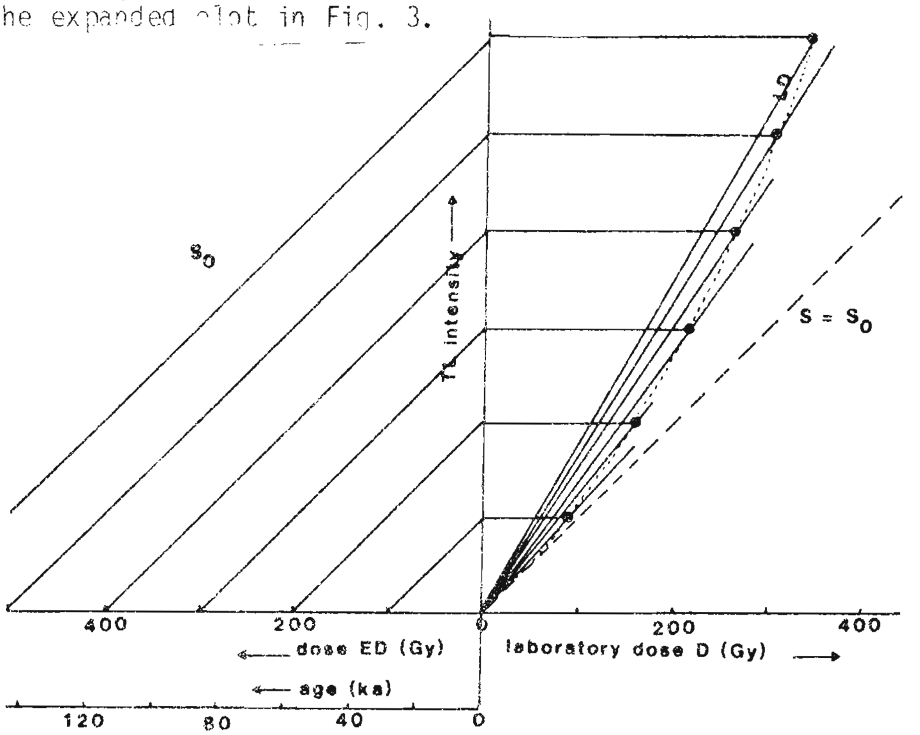

Figure 2: TL intensity plotted as a function of dose for a theoretical sample having linear growth but for which the sensitivity after laboratory bleaching depends upon the equivalent dose ED. This results in an underestimate of the TL age, since the laboratory dose LD which matches the natural TL intensity is systematically smaller than the ED as shown by ● .... ● .... ●

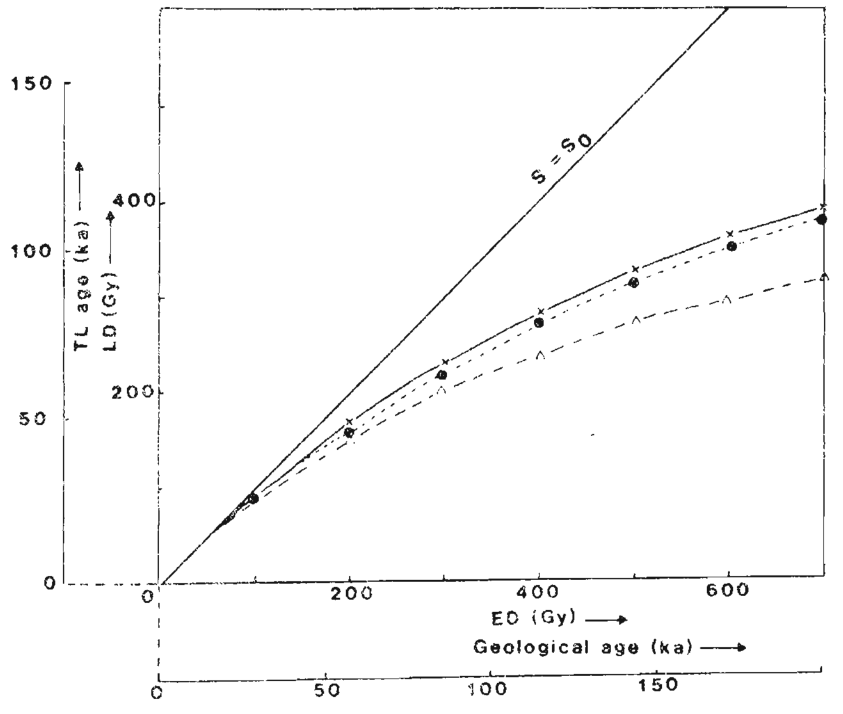

Figure 3: Expansion of the box in Figure 1.

(b) Exponential growth curve

The above linear growth curve model may be insufficient since it has been demonstrated that the growth curve for fine grain loess after bleaching becomes noticably non-linear for doses greater than 200 Gy (Debenham, 1985). Fig. 4 shows a composite regenerated growth curve obtained by matching data for two samples from Saint Romain and two much older ones from Paks and Stranzendorf (H. Proszynska-Bordas, personal communication 1985); normalisation of the data was performed by matching the light level at particular doses assuming that only the sensitivity and not the shape is dose dependent. These data can be fitted reasonably well by a saturating exponential of the form $I/I_0 = (1-\exp[-D/D_0]$ with $D_0 = 600$ Gy. An equation of this form is preferred since it is that predicted as the finite number of electron traps becomes filled.

Assuming the same exponential growth for the natural TL and for the post-bleaching TL measurements (i.e. no change in growth curve shape caused by bleaching), we can examine the effect of a sensitivity change which depends upon the degree of trap filling i.e. $S/S_0 = 1 + [1 - \exp -ED/D_0]$. The effect of this sensitivity change is shown in Fig. 3, where the relationship between LD and ED is obtained by matching the TL level. This results in

$$(1 - \exp\text{-}ED/D_0) = [1 + (1 - \exp\text{-}ED/D_0)]\ [1 - \exp\text{-}LD/D_0].$$

However, this model predicts that LD will not reach a value greater than about 410 Gy and it also produces a sensitivity enhancement of $S_R / S_N = 2.3$ for a regeneration dose of 270 Gy when the slope of the regenerated curve (S_R) and the N + β curve (S_N) are compared at the same light levels.

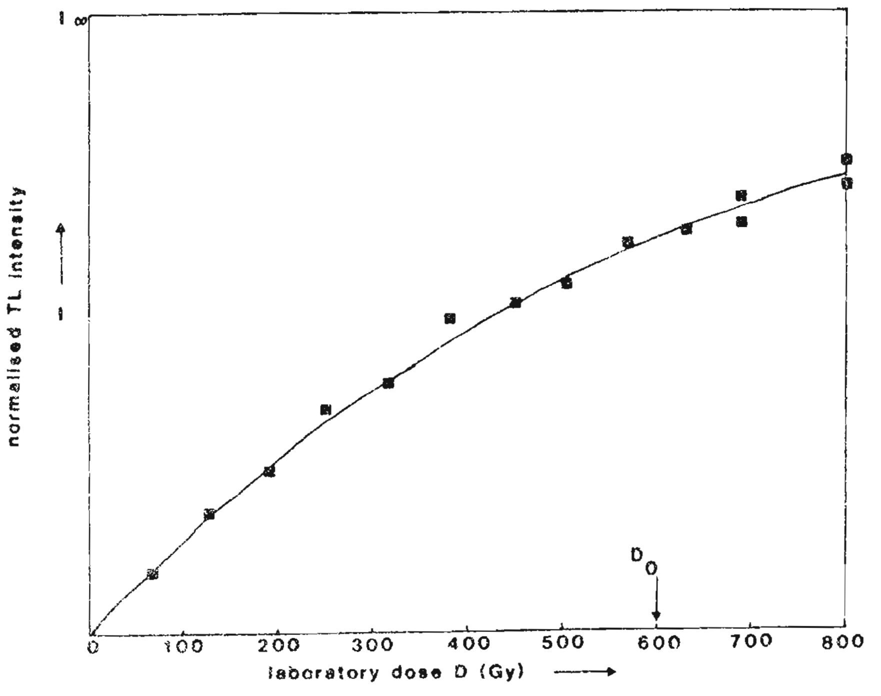

Figure 4: Composite, normalised growth curve data obtained after 450 min. unfiltered sunlamp exposure showing exponential growth for 300-310°C TL signal.

Discussion

Unlike Debenham's hypothesis, the model described above can be tested in the laboratory. Debenham's data implied that S_R / S_N does not increase above 1.6 for regenerated doses up to 400 Gy in his study of a number of geological samples. However, the best test of the model will be a series of experiments of a young loess.

Sensitivity changes after bleaching have been reported in a bleaching study on polymineral fine grains by Rendell et al. (1983) for loess from Pakistan. In their work they found the gradient of the regenerated TL (i.e. S) varied in a non-linear way with the length of bleaching time. If this is a general phenomenon then it adds an additional variable to the evaluation of existing data and to proposed experimental procedures.

References

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Reviewers' comments:

The virtue of the model presented in this paper is that experiments may be devised to test it. Nevertheless the two problems that can never be resolved are (i) the possibility of dose rate effects and (ii) defect migration either by normal thermal diffusion or by optically enhanced diffusion, because the laboratory to natural dose rates vary by some 10^6:1, and diffusion times of 100 ka could allow defects to migrate throughout the silica or silicate grains of the loess. The familiar demonstration of these problems occurs in the photographic process, and there is no justicication in assuming that the loess presents us with a simpler problem. We should add that in addition to the paper cited (Rendell et al., 1983), we have more recent experimental data indicating that post-bleaching sensitivity changes are extremely complex, at least as far as the Pakistan loess is concerned.

Finally, contrasting TL and geological age estimates is really only helpful if the geological age estimates are related to absolute age determinations - unfortunately geological age estimates often have a flimsier base than those of TL.

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