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The hypothesis of mid-term fading and its trial on Chinese loess

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The model

To correct for fading of the TL signal in alkali feldspars Mejdahl (1988)uses a model based on a single trap-type with a single decay lifetime - determined as being between 800 ka and 5400 ka in the samples studied. Hütt and Jaek (1989) use a similar approach in discussing laboratory reconstruction of paleodose. While Mejdahl's model appears to fit the facts for a single trap-type in alkali feldspars we present here a modified model which seems to be appropriate for the optical dating signal obtained from polymineral samples of a long loess section at Duanjapo, near Xian, China. Application of the model to make correction for fading requires, as does the Mejdahl model, the availability either of a sample of known age - in the present case this is from the layer containing the Brunhes-Matuyama boundary (730 ka) - or of a sample having a minimum age sufficient for its expected paleodose to correspond to laboratory saturation.

The essentials of the model are:

(i) that the dating signal consists of an unstable component and a stable component,

(ii) that the lifetime of the latter is long compared to the age of the oldest sample, and

(iii) that the lifetime of the unstable component is 'mid-term', i.e. long compared to laboratory time but short compared to the ages being determined.

In the present instance a lifetime of several hundred years can be hypothesized - though its actual value does not enter into the correction calculations. It is further assumed that the luminescence characteristics of the loess are the same throughout the section.

In the postulation of two components the model is similar to that developed for zircon TL by Templer (1985) and successfully used for the TL dating of polymineral grains from pottery by Clark and Templer (1988). An earlier suggestion that a mid-term fading process might be operative was by Grün et al (1989).This was in respect of 30 - 40% underestimation of TL age, using K-feldspar (and a UG-11 filter in the detection system).

Procedure

As found by many workers on Chinese loess both TL and optical ages are very substantial underestimates for samples having expected ages beyond one or two hundred thousand years; typically an age of the order of 150 ka is obtained for a sample dated to 730 ka by its occurrence close to the Brunhes-Matuyama (B-M) boundary. Figure 1 illustrates the situation in principle - the actual experimental plot is less straightforward. As will be seen the observed signal from the B-M sample is some 37% lower than that expected on the basis of the laboratory growth curve obtained by dosing bleached aliquots of the sample. Then according to the model the unstable component constitutes 37% of the artificially-induced signal, and hence the growth of the stable component during antiquity can be represented by a curve derived by multiplying the laboratory curve by the factor 0.63.

Figure 2 illustrates the dating of a sample higher up in the section. The growth of the stable component during antiquity is obtained as just indicated and the intercept of the natural signal on the curve so obtained allows evaluation of the paleodose and hence the age.The essential difference from the Mejdahl approach is that because of assumptions (ii) and (iii) the fractional loss of signal by fading is assumed to be independent of the age of the sample (as long as that age is large compared to the hypothesized fading lifetime of the order of several hundred years); in the Mejdahl approach the fractional loss is assumed to increase with age.

Experimental

Signals were obtained using stimulation by 514 nm (green) light from an argon ion laser and detected using an EMI photomultiplier type 9635Q, preceded by four Corning filters type 7-59 and one Schott filter type BG39. Aliquots were presented for measurement as 'middle-grains' (20-50 μm) on aluminium discs, being pre-heated at 160 °C for 2 hours after irradiation. Before irradiation aliquots were bleached to a negligible level by means of a Hönle (SOL 2) solar simulator.

A $^{90}Sr/^{90}Y$ source was used for beta irradiation and the beta dose to middle grains was taken to be 1.08 times that to fine grains (4 - 11 μm). The a-value for the latter was found to be 0.07±0.01 using an Am-241 source in vacuum for alpha irradiation. It was assumed that uranium and thorium were distributed uniformly throughout all grains; since only about 20% of the signal is due to alpha particles the validity of this assumption it not too critical. Radioactivity measurement techniques included thick source alpha counting, potassium analysis and high resolution gamma spectrometry.

An important aspect of the measurement procedure was that all samples were subject to identical preparation and pre-heating conditions. To this end two or more samples were prepared, preheated, and measured in parallel in such a way as to 'normalize' to the B-M sample. Further details of the procedures used are given elsewhere (Xie and Aitken, 1991).

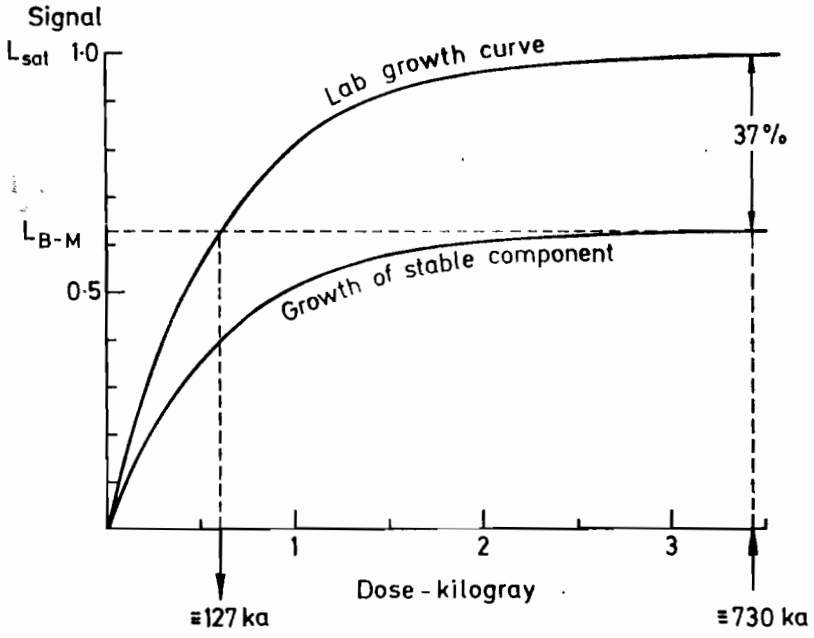

Figure 1.
Illustration of how the size of the mid-term fading component is evaluated using the known age of the sample from the B-M boundary. The regenerated laboratory growth curve is of the form

$$L = L_{sat}\,(1 - exp\,(-D/D_s))$$

where D is the laboratory dose and D_s = 600 Gy. The natural signal is L_{B-M}, and L_{B-M} is experimentally found to be 0.63 times the value of L at D = 3.4 kGy; the latter is the predicted paleodose corresponding to an age of 730 ka, the annual dose being 4.7 Gy/ka. The hypothesized curve for the growth of the stable component is drawn so that at each dose value it is 0.63 times the co-ordinate of the laboratory curve at that dose value. The age obtained for this sample if it is assumed that there has been no fading is 127 ka.

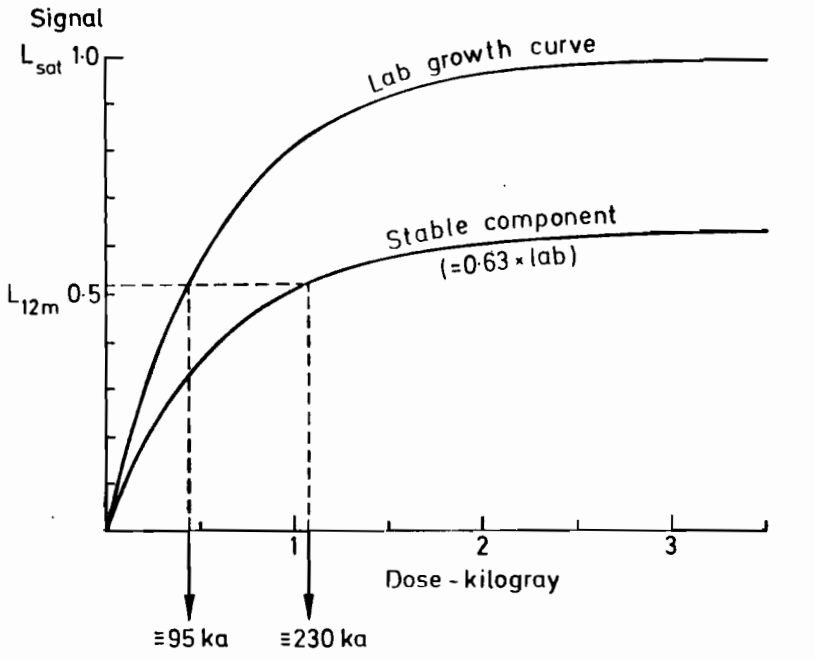

Figure 2.
Illustration of dating procedure for sample from 12 m. As in figure 1, the growth curve of the stable component is taken to be 0.63 L_{sat} (1 - exp(-D/D_s)). On this basis the age of the 12 m sample is 230 ka whereas if no correction is made for fading the age is 95 ka.

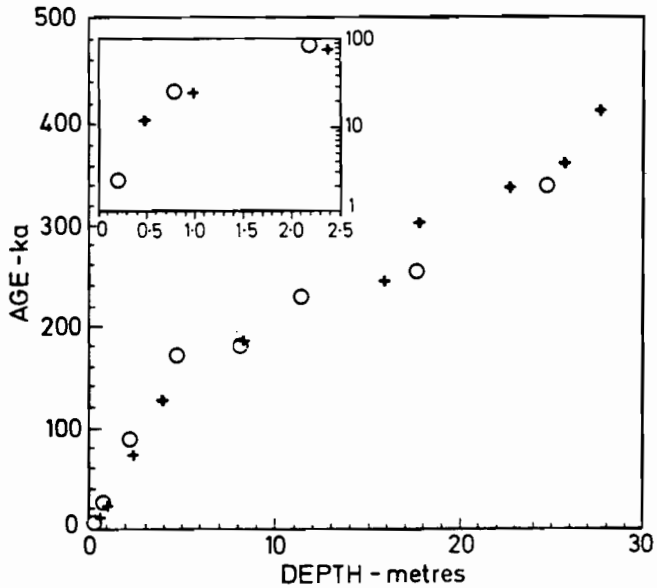

Figure 3.
Ages obtained for samples from the upper 25 m of the section - indicated by circles. Crosses show the ages according to the astronomical chronology for the oxygen-isotope stages assumed to correspond to the various palaeosol-loess boundaries of the section. The inset is a semi-log plot of the younger dates.

Results of application

Figure 3 shows ages derived on the above basis for 8 samples from the upper 25 m of the section. Also shown are the ages obtained by matching the successive palaeosols to oxygen-18 climatic stages and hence to the astronomical timescale. It will be seen that the agreement with the latter is encouraging. On the other hand the corresponding ages obtained in an attempt to use the Mejdahl method of correction were substantially too low - as is inherent in any model in which the fractional loss becomes small for young ages; of course the Mejdahl method is strictly applicable only where a single trap-type and lifetime is involved.

Discussion

The purpose of this note is primarily to call attention to a possible model for fading that has not so far been considered (except for the mention by Grün et al noted above). Secondly it is to report that in application to one section of Chinese loess at any rate the fading correction based on the model yields ages consistent with the section's interpretation in terms of oxygen-18 isotope stages. Clearly confirmatory measurements and estimation of error limits need to be done before consistency can be claimed definitively. It would also be interesting to apply the method to sections having more direct age constraints and to try it using TL.

In conclusion it must be stressed that it is necessary to have a layer of known age, or an undated layer having a minimum age limit sufficient for saturation to have been reached; also that the luminescence characteristics have to be the same throughout the section. It should also be borne in mind that the upper layers of the section may be too young for the validity of the assumption that the lifetime of the fading component is substantially shorter than sample age.

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PI Reviewers comments (Ann Wintle)

The model of Xie and Aitken assumes that:

(a) The unstable component has the same growth characteristic D_S as the stable component. If it is a totally separate luminescence signal, the values of D_S are likely to be different, which would invalidate the simple approach of multiplying the laboratory growth curve by 0.63.

(b) The filling of the electron traps giving rise to the stable component is unaffected by the fact that the electron traps giving rise to the unstable component remain empty, i.e. there is no competition for electrons during natural irradiation of the sample.

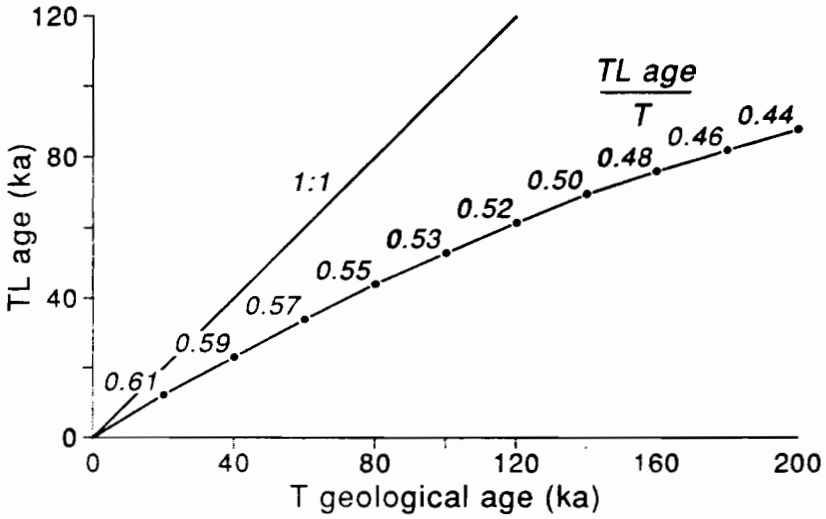
(c) The fraction of the signal which is unstable is constant for all samples. If this were the case, then the correction proposed for the measured ED would be irrespective of the measured dose rate for the sample.

The model suggests that substantial underestimation will be encountered irrespective of which method of ED determination is used.

In an attempt to assess the potential of this hypothesis as the explanation of apparent age underestimations encountered whilst dating loess sections, I have plotted the luminescence age that would be obtained if no correction were made against the true age. In this way it is analogous to that produced by Debenham (1985) for TL age estimates for European loess from different sections and indeed bears a general resemblance to it. The curve was calculated for a dose rate of 4.7 Gy/ka, with D_S = 600 Gy and a fractional stable component - 0.63, as specified by Xie and Aitken.

The underestimation of the luminescence age will initially be 40%, but because the growth curve is a saturating exponential, this underestimation will be larger for older samples, reaching 53% by 100 ka and 56% by 200 ka. Within the range of radiocarbon dating (<40 ka) the systematic underestimation would be 39±2%. An underestimation of this order of magnitude should have been reported from TL studies; however, apart from a number of radiocarbon dates on secondary carbonates nodules within the uppermost loess unit (the Malan loess), there are no independent dates with which to compare the results of the model. Very few useful radiocarbon dates on suitable material have been reported from loess sections which have been sampled for luminescence dating. (It should be noted that Debenham's youngest age estimates were for samples with indirect and incorrect age control (Debenham, 1985).) In general no such systematic underestimation has been obtained for loess in the range 13 - 30 ka (Wintle, 1990). Hence a fading component with a lifetime of only a few hundred years is unlikely.

Although the correlation of the Brunches/Matuyama boundary is well dated (by potassium-argon dating of lavas flows) at 730 ka, the correlation of the boundaries of the palaeosols with particular oxygen isotope stage boundaries is open to debate. Hence care should be taken when such correlations are used as a test for another dating method. This criticism is particularly true for the first major palaeosol, S_1. In this paper it is taken to date 74 ka to 130 ka (from figure 3) with loess deposition commencing at the 5/4 Oxygen Isotope



Stage boundary, rather than at the 5e/5d Substage boundary at 108 ka (see Wintle, 1990 for discussion), a possible alternative. Correlations for all soils are based on a "count down from the top" approach. No other studies have been published for the 30 m loess section at Dunajapo. It is therefore difficult to confirm the interpretation of the loess/palaeosol sequence at this site.

If loess deposition commenced at 74 ka and if the hypothesis of Xie and Aitken was correct, then it would imply that no TL age estimate over 40 ka would be obtained for the Malan loess by the straightforward interpretation of the TL data (and no age over 85 ka would be obtained for loess within Oxygen Isotope Stage 6). However, published TL ages for the base of the Malan loess range from 65 - 94 ka (Zhou LiPing, pers. comm.). This would suggest that the lifetime for a single fading component comprising 37% of the luminescence signal could not be on the timescale of a few thousands of years.

Although TL age estimates for 100-300 μm feldspar grains from cover sands in Northwest Europe (Dijkmans and Wintle, 1991; Grün, Packman and Pye, 1989) have been systematically about 40% low when compared with reliable radiocarbon dates from the same sections, the results cannot be taken to support the hypothesis of Xie and Aitken. In those cases, and also for older samples measured in the same way (Balescu et al, 1991), the underestimation only occured when ultraviolet pass filters were used for the TL measurements. The effect of the choice of filter was demonstrated by Balescu and Lamothe (1991) and is clearly caused by a different phenomenon.

Though the laser stimulates OSL from both feldspar and quartz, the TL also comes from both mineral components, but the relative intensities may be different and may not allow direct comparison of the dating information. Having criticized the hypothesis on the basis of a world-wide data base of TL results, I will conclude with a evaluation of the OSL results presented by Xie and Aitken (figure 3). For the three samples, from 0.7 to 5 m, the corrected ages appear to be overestimated compared with the palaeosol/$\partial^{18}O$ correlation, implying that the correction over-compensates. For older samples it is difficult to judge the agreement since the age uncertainty becomes very large and asymmetric.

In conclusion it should be noted that the approach suggested by Xie and Aitken is highly sensitive to the numerical value for the fractional stable component, i.e. the ratio of the natural luminescence signal for a very old sample (e.g. from the B/M boundary) to its asymptotic signal reached after prolonged laboratory irradiation. An error of only a few % would have a large affect on the calculated age. The error in the age obtained in this way will be even larger after taking account of the scatter in the natural luminescence signal for the sample being dated.

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Reply by the authors

First we would like to reiterate that the primary purpose of our note is to call attention to mid-term fading as a phenomenon that may need to be considered. Currently, with polymineral grains at any rate, we have the impasse that samples which are given a clean bill of health on the basis of laboratory fading tests nevertheless give gross underestimate of age. A mid-term fading component could be the explanation (or at any rate part of the explanation) and the fact that there are difficulties in making correction by means of the relevant model, such as the rather wide error limits that result (as the reviewer points out), is hardly an argument that the phenomenon does not exist. The reviewer's conclusion that the lifetime of the fading component would have to be in excess, not only of a few hundred years, but of a few thousand years, is in the same category of being a difficulty in making correction. As we say in the paper '... the upper layers....may be too young for the validity of the assumption that the lifetime .... is substantially shorter than sample age.' Our suggested lifetime of a few hundred years may indeed be too short - but this does not invalidate the basic hypothesis that a mid-term fading component is present. We accept the possibility of alternative interpretations of the section but those suggested by the reviewer do not destroy the broad agreement between corrected age and the oxygen-18 timescale. We take this broad agreement as encouragment for the basic hypothesis to be given further consideration, henceforth bearing in mind the various caveats that the reviewer has put forward - and we are appreciative of her critical assessment. In conclusion we would emphasize that in the first place we see the hypothesis as applicable to optical dating of polymineral grains from the loess section concerned; whether or not it is applicable to the TL signal from those grains will be investigated by one of us (JX). From the reviewer's comments in respect of TL dating of K-feldspar it is good news that age underestimation can be avoided by wavelength selection. Unfortunately there is no encouagement so far to think that this is also the case for optical dating of polymineral grains (e.g. Spooner and Questiaux, 1989).

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