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A NOTE ON THE PLATEAU TEST AS USED IN THERMOLUMINESCENCE DATING

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Abstract

Attention is drawn to effect of the presence of non-first-order TL kinetics upon the production of a TL "plateau".

1. Introduction - the "plateau test"

The "plateau test" is a useful criterion for determining if the localized energy levels (traps) associated with a given temperature interval thermoluminescence (TL) glow-curve are deep enough for long-term retention of the charge carriers (electrons of holes) during antiquity. In principle, the glow-curve of the natural TL (TLN) is compared with that of the TL resulting from artificial irradiation (TLA), and a plot is made of the ratio TLN/TLA against glow-curve temperature. Those traps which do not have the necessary stability are indicated by a non-constant value for the TL ratio with glow-curve temperature. The region of stable traps is indicated by a constant ratio - or "plateau" (Aitken, 1974).

In practice, however, samples tested in this fashion often produce poor plateaus, or may sometimes fail to show a plateau at all. One reason for this is a change in the TL sensitivity induced in the sample which has been heated prior to artificial irradiation. To circumnavigate this problem, the procedure most widely adopted is to artificially irradiate a previously undrained sample and a glow-curve corresponding to the artificial plus natural TL (TL(A+N)) is then produced. The plateau test is then carried out by plotting the ratio TLN/(TL(A + N) -TLN) against glow-curve temperature (e.g. Aitken and Fleming, 1972; Seeley, 1975; Aitken, 1978).

Other difficulties which may give rise to a poor plateau are supralinearity, anomalous fading, and non-radiation-induced ("spurious") TL. Indeed, the presence of spurious TL is often tested for by means of a "plateau test".

2. Second-order kinetics

Another, although perhaps as yet, not fully appreciated, effect arises as a simple consequence of the presence of non-first-order TL kinetics during the recombination process. A TL peak which is governed by pure first-order kinetics will always appear at the same glow-curve temperature, no matter to what level the traps are initially populated. Second-order kinetics, however, result in a shift in peak position with varying initial trap-populations, in particular the peak temperature T* increases as the initial trap-occupancy n_0 decreases (Garlick and Gibson, 1948). In general, TL peaks obeying non-first-order kinetics show an increase in T* with decreasing n_0, the degree of increase in T* depending upon the exact order of the kinetics.

The relevance of this to the "plateau test" is simply that a natural glow-curve (which may be the result of an absorbed dose in antiquity of 10^4 - 10^6 rad) cannot be compared with an artificial glow-curve when the artificial TL has been produced by irradiation with 10^2 - 10^3 rad only - if the kinetics of the TL process are higher than first-order. The differences in trap-occupancy are such that significant differences in T* will result, and thus by comparing the natural TL curve with the artificial curve we are not comparing "like-with-like". A plot of natural TL/artificial TL will thus result in a very poor plateau.

To demonstrate this I have constructed a glow-curve, shown in Figure 1, using the normal TL glow expression, assuming second-order kinetics (e.g. see Chen, 1976). The values used for the trapping parameters are $E_1 = 1.0$ eV; $S_1 = 1.3 \times 10^{13}$ s^{-1}; $n_0 = 5.0$ arbitrary units; $E_2 = 1.2$ eV; $S_2 = 1.0 \times 10^{13}$ s^{-1}; $n_0 = 10.0$ arbitrary units; $E_3 = 1.4$ eV; $S_3 = 8.7 \times 10^{12}$ s^{-1}; $n_0 = 8.0$ arbitrary units.

Curve (a) represents the "natural" glow-curve, in which there has been some thermal fading of the less stable traps during "antiquity" (equivalent to having heated the sample to 250^{o}C). Curve (b) represents the "artificially" irradiated sample, having been given a dose of radiation (D_A) equal to its natural dose (D_N). Curve (c) is that glow-curve obtained with $D_A = 2\ D_N$ and curve (d) is with $D_A = D_N/2$. Curve (e) is equivalent to superimposing an artificial dose $D_A = D_N$ on top of the natural dose. (Note that $e \neq a + b$).

The "plateau tests" obtained by dividing curve (a) by the other curves, is shown in Figure 2. Only when the natural curve is divided by an artificial curve which has an artificial dose equal to the natural dose, is a good plateau obtained. Poor plateaus, or no plateau at all, result with all the rest.

3. Importance of non-first-order kinetics in TL dating

It is fortunate that, with quartz (perhaps the most often dated archaeological material), the complications of second-order kinetics do not appear to be a problem. The results of both Aitken and Fleming (1972) and Levy (1978) imply that the kinetics of the TL process in quartz are almost pure first-order. Natural fluorite (Aitken and Fleming, 1972) also exhibits first-order kinetics. However, Levy (1978) finds second-order kinetics for the TL of albite and suggests that the TL from all other feldspars will follow second-order kinetics. Prôkic (1977) finds that a kinetic-order of 1.5 best describes the TL from natural barite. Wintle and Aitken (1977) observed that isothermal decay experiments on one of their flint samples caused the peak to shift to a higher temperature as the sample was thermally drained. In addition, when an artificial dose is superimposed on the natural dose, the resultant glow-curve shows a peak which is at a lower temperature than the corresponding peak in the natural glow-curve. This is strongly indicative of non-first-order kinetics and this, in turn, may be partially responsible for the lack of a plateau for this sample. (It should be pointed out that M. J. Aitken (private communication) considers that the shift in the TL peak, with isothermal decay, in this flint sample is more likely to be due to a spread in trap energies. However, non-first-order kinetics should not be ruled out.)

4. Conclusions

In addition to the effects of sensitivity changes on heating, supralinearity, anomalous fading and spurious TL, the presence of non-first-order kinetics may be a contributing factor in the difficulties met with when attempting a "plateau test" in some materials. Unless considered, non-first-order kinetics may give rise to misleading interpretations - for example, they may lead one to suspect the presence of spurious TL. Some samples, which may be otherwise suitable for TL dating, are often discarded on the basis of a poor plateau. Complications due to non-first-order kinetics should be borne in mind, and rejection of some samples may not prove necessary.

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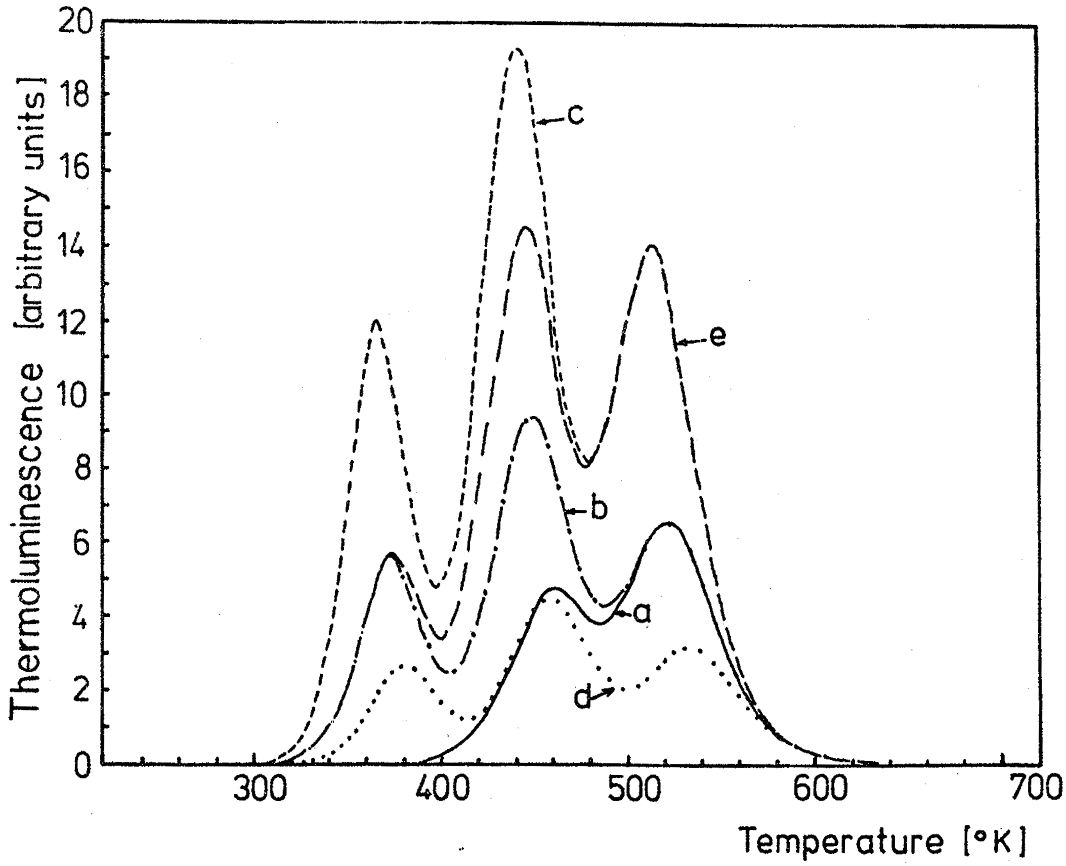

Figure 1 An imaginary glow-curve consisting of three peaks, constructed using $E_1 = 1.0$eV; $E_2 = 1.2$ eV and $E_3 = 1.4$ eV. Values for S and n_o are given in the text. Second-order kinetics are assumed for each peak. Curve (a) represents the "natural" glow-curve; curve (b) represents the "artificial" glow-curve obtained after imparting an "artificial dose" D_A equal to the "natural dose" D_N. Curve (c) is obtained with $D_A = 2D_N$ and curve (d) is with $D_A = D_N/2$. Curve (e) is equivalent to superimposing an artificial dose $D_A = D_N$ on top of the natural dose. (Note that $e \neq a + b$)

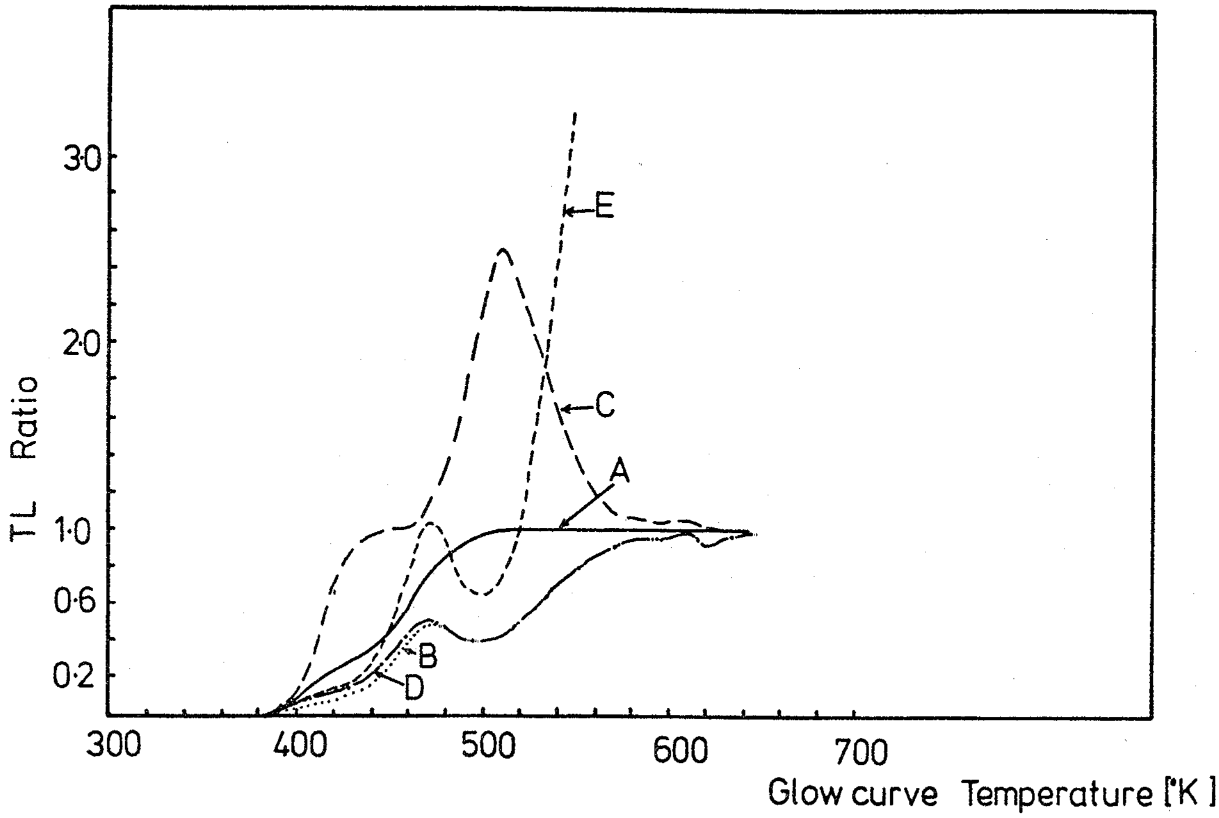

Figure 2 The "plateau tests" obtained by dividing curve (a) from Figure 1 by each of the other curves. A = a/b; B = a/c; C = a/d; D = a/e; E = a/(e-a).

[Editor's Note: Measurements by Singhvi and Zimmerman (Archaeometry, Volume 21 (1), 1979, p. 73-77) indicate that the dominant luminescent mineral in some fine grain pottery samples is feldspar. Such samples may exhibit non-first-order kinetics and, as a result, have poor plateau characteristics as described above.]

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