A model for sensitivity change of IRSL signals

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Introduction

Sensitivity increases or decreases of infrared stimulated luminescence (IRSL) signals after laboratory bleaching procedures have been reported (Li and Wintle, 1991, 1992a&b, Duller 1991, 1992b). It was found that the sensitivity change is related to the extent of laboratory bleaching, age of the sample and the extent of sunlight exposure which the sample experienced prior to deposition (Li and Wintle, 1991). This change in sensitivity was explained by the competition between hard-to-bleach (H-type) traps and easy-to-bleach traps during irradiation in an empirical model proposed by Li and Wintle (1992b). Here, we explore the competition in further detail.

The model

1. Two types of trapped charges and IRSL sensitivity.

We consider two types of trapped charges: E-type and H-type. It is hypothesised that the E-type are easy to bleach trapped charges, i.e. they are bleached easily by sunlight and correspond to the IRSL signal measured. The IRSL growth curves used in ED determinations represent the dose response of this type of trapped charge.

The other type, the H-type, are hard to bleach trapped charges, i.e. they are hard to bleach, but not non-bleached by sunlight. They can be bleached by prolonged sunlight exposure. The concentration of H-type charges increases with dose, but they do not contribute to the growth curves of the IRSL signal used for dating.

Both types of trapped charges build up with dose toward a maximum level.

In this competition model, it is hypothesised that there is competition between both types of traps during irradiation. The sensitivity of the IRSL signal (X) is related to the concentration of H-type charges (I). The higher the H-type charge concentration, the higher is the sensitivity of the IRSL signal. Hence, the sensitivity, X, can be empirically described as

$$X = \eta I + X_o \quad (1)$$

where η and X_o are constants relating to the competition and the minimum dose response respectively.

2. Sensitivity changes

Sensitivity change was observed experimentally by comparing the additive dose growth curve with the regeneration growth curve. The sensitivities may be expressed by the initial slopes of both curves. X_A and X_R (fig.1), and relate to the responses after deposition (A) and after laboratory bleaching (C) respectively. (B) represents the natural sample.

The sensitivity of the additive dose growth curve X_A relates to the concentration of H-type charges after the sample was last exposed to sunlight, I_a (fig.2). Hence, equation (1) can be written as

$$X_A = \eta I_a + X_o \quad (2)$$

and X_A is thus a function of the degree of sunlight exposure prior to deposition.

Similarly, the sensitivity of the regeneration growth curve X_R is related to the concentration of H-types charges after laboratory bleaching, I_c. This represents a portion of the charges in the natural sample, I_b (fig.2), which increased as a function of dose, F(D), and is added to the concentration I_a. Hence,

$$I_b = F(D) + I_a \quad (3)$$

After laboratory bleaching

$$I_c = f(S)I_b = f(S)F(D) + f(S)I_a \quad (4)$$

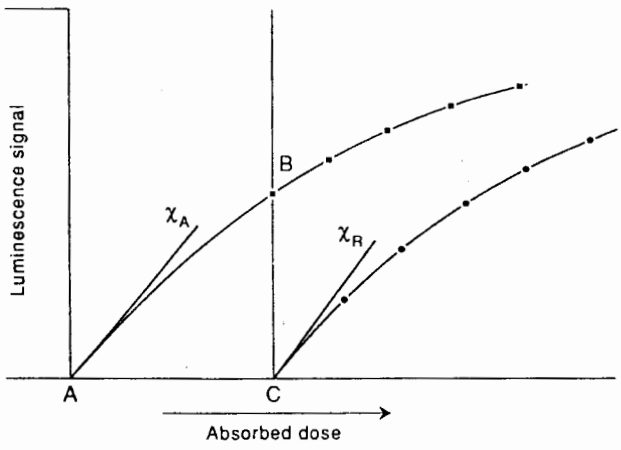

Figure 1.
Schematic diagram of luminescence signal growth curves: the response to added dose (filled squares) and response to dose after laboratory bleaching (filled circles).

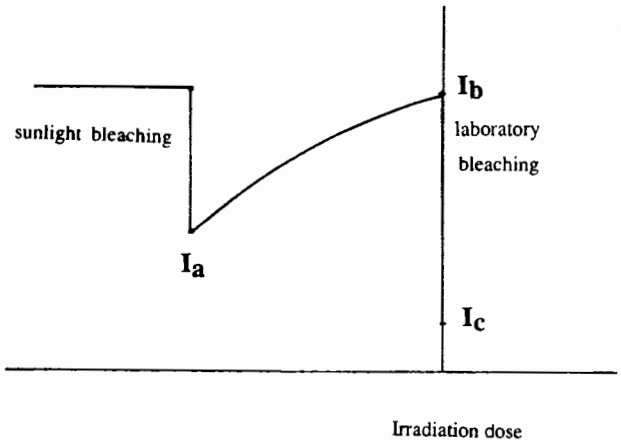

Figure 2.
Schematic diagram showing the change in concentration of H-type (the hard to bleach) trapped charges as a result of natural and laboratory bleaching procedures.

where f(S) is a bleaching factor, which depends on the bleaching time, spectrum and the strength of the bleaching light.

Since the H-type charges can be bleached by prolonged sunlight exposure, their concentration will decrease with bleaching time. Hence, f(S) will be smaller for longer bleaching. The spectrum of light used in laboratory bleaching is likely to be either similar to sunlight, e.g. solar simulator, or a relatively narrow wavelength band. In the latter case, a particular light may or may not reduce the H-type charges when the E-type charges are removed by the light exposure. Since the model assumes that there is no charge migration into the H-types traps during bleaching, f(S) can be defined in the range of $O \leq f(S) \leq 1$.

Hence, substituting (4) into (1), the sensitivity of the regeneration curve is,

$$X_R = \eta I_c + X_O = \eta f(S)F(D) + \eta f(S)I_a + X_O \quad (5)$$

Comparing equations (2) and (5), the sensitivity change after laboratory bleaching is given as,

$$X_R - X_A = \eta f(S)F(D) + \eta f(S)I_a - \eta I_a \quad (6)$$

The sensitivity change is thus related to the age of the sample F(D), laboratory bleaching f(S) and the bleaching prior to deposition as represented by I_a. The sensitivity can increase or decrease depending upon those three conditions.

Predictions of the model

Various predictions can be made from this model for the response of different types of sediments.

1. Shortly bleached sediments (colluvial deposits).
For sediments which have experienced only short sunlight exposure prior to deposition, the H-type charges have not been removed at deposition, because of the short sunlight exposure. The concentration I_a is very high, and may even be close to saturation, $I_a = I_{max}$. For these sediments the H-type charge is likely to be close to its maximum value and hence $F(D) \approx 0$, and $I_b = I_a$. Therefore equation (6) becomes

$$X_R - X_A = \eta I_a[f(S) - 1]$$

As $O \leq f(S) \leq 1$ by definition, a sensitivity decrease will be observed after laboratory bleaching which releases H-type charges. The longer the bleaching, the greater is the sensitivity decrease expected.

One exception of this behaviour will occur when bleaching of the IRSL signal is carried out using the wavelength that is used for stimulation, i.e. IR. The H-type traps will remain full because this wavelength will remove only the E-type charges and will not affect the population of H-type charges, i.e. $f(S) = 1$. This can be seen from the large TL signal which remains after the IRSL is reduced to <1% by 1000 seconds of IR exposure (Li and Aitken, 1989; Duller, 1992a). In this case the E-type traps will fill under the same competing regime as in nature and the sensitivity of the signal response to dose when regenerated will be the same for a sample of any age.

2. Well bleached sediments (aeolian deposits).
Since aeolian sediments were well exposed to sunlight at deposition, H-type traps were empty at deposition, $I_a=O$. Hence, equation (6) becomes

$$X_R - X_A = \eta f(S) F(D)$$

Since F(D) is positive $X_R - X_A \leq 0$, the sensitivity will always increase after laboratory bleaching, unless a prolonged bleaching is applied or a zero age sample is studied (F(D)=O). The degree of increase is dependent upon f(S) and F(D), which relate to the degree of laboratory bleaching and the natural irradiation of the sample respectively. After a short bleach, i.e. fixed f(S), a sensitivity increase would be expected for different age samples; the older the sample, the greater the sensitivity increase expected after the same short bleach. However, for a young sample, F(D) is relatively small and may be negligible; in this case no significant sensitivity change should be observed after any laboratory bleaching. For samples of the same age, i.e. fixed F(D), the sensitivity change will decrease with increased light exposure.

These predictions are in agreement with data reported in the literature (Li and Wintle, 1991; Duller, 1991; 1992b) and in particular with the results of an experimental programme designed to test this simple but predictive model (Li and Wintle, 1992b).

Conclusions

A change in sensitivity of an IRSL signal brought about by laboratory bleaching can be explained in terms of a competition model involving two trapped charge populations. Either increase or decrease in sensitivity can occur after laboratory bleaching and irradiation. Such a model has important implications for laboratory procedures used to determine the equivalent dose. The regeneration method is not suitable without careful consideration of the most appropriate bleaching procedure. When using the regeneration method, it is necessary for the IRSL signal to be bleached to a negligible level and for the H-type trapped charges to be bleached to the level they occupied at deposition.

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