Ancient TL

A correction procedure for ambient activation in pre-dose dating

S. R. Sutton and C. M. Kornmeier
McDonnell Center for the Space Sciences
and
Center for Archaeometry
Washington University
St. Louis, MO 63130
U.S.A.

Introduction

The initial TL sensitivity of the 100°C peak, S_0, used in predose dating is often non-negligible compared to the sensitivity measured after activation of the palaeodose, S_n. The question then arises as to whether the measured initial has increased during burial due to "ambient activation" of the palaeodose. Described here is a procedure which can be used to estimate the degree of ambient activation experienced by such a quartz sample. The basic idea is that the thermal activation characteristic (TAC) for an ambiently activated sample will lie at higher temperatures than if the sample had not experienced this effect. In principle, the difference between natural and artificial TAC's can be used to quantify the magnitude of the activation.

Basic Principles

Consider some arbitrary TAC defined in relative terms using the nomenclature of Bailiff.

$$f_T = \frac{S_T - S_0}{S_{max} - S_0} \qquad (1)$$

If an identical aliquot of this sample were ambiently activated by some fraction f of the total possible $(S_{max} - S_0)$, the measured initial sensitivity, S_0^* would be greater and the measured TAC will instead be f_T^*

$$f_T^* = \frac{S_T - S_0^*}{S_{max} - S_0^*} \quad \text{for } S_T \geq S_0^* \qquad (2)$$

$$= 0 \qquad \text{for } S_T < S_0^*$$

where

$$S_0^* = S_0 + f(S_{max} - S_0) \text{ and } 0 < f < 1$$

The two-part solution is required by the condition that the new TAC cannot be negative. Substituting in the definition of S_0^* we get

$$\int_T^* = \frac{\int_T - f}{1 - f} \text{ for } \int_T > f \tag{3}$$

$$= 0 \qquad \text{for } \int_T \leq f$$

The difference $_T$ between the original and ambiently activated TAC's is

$$\triangle_T = \int_T - \int_T^*$$

$$= \left\{ \frac{f}{1-f} \right\} \{1 - \int_T\} \quad \text{for } \int_T > f \tag{4}$$

$$= \int_T \qquad \text{for } \int_T \leq f \text{ (since } \int_T^* = 0)$$

Thus, at increasing glow curve temperature, $\triangle_T$ increases as $\int_T$ until the temperature at which $\int_T = f$. From this temperature onward, $\triangle_i$ follows $(f/1-f)(1-\int_T)$. Since this function decreases with increasing temperature, it can be seen that $\triangle_T$ peaks at the temperature at which $\int_T = f$ and it has a maximum value of f. The maximum value of the difference between the two TAC's, therefore, gives the degree of ambient activation. It can also be seen that f is always less than or equal to S_0^*/S_{max} since

$$\frac{S_0^*/S_{max}}{\triangle_T(max)} = 1 + \frac{(1-f)S_0}{fS_{max}} \tag{5}$$

which is always ≥ 1.

Application to Natural Samples

The ambient activation correction is obtained from two TAC's - one for the natural dose $\int_{n,T}$ and one for a laboratory administered dose $\int_{\beta,T}$. The latter is actually from a "natural + artificial" TAC $\int_{n+\beta,T}$, rather than by measuring a second glow activation, to avoid modifications in the activation characteristic which can occur during the first heating. The "n+β" TAC is a weighted convolution of the "n" and "β" TAC's where the weighting factor is determined by the fraction of TL contributed by each. That is,

$$\int_{\beta,T} = \frac{\int_{n+\beta,T} - \alpha\int_{n,T}}{1 - \alpha} \tag{6}$$

and α = natural dose/(natural dose + lab dose). When a laboratory dose roughly equal to the natural dose is used, $\int_{\beta,T}$ is not very sensitive to α so only approximate knowledge of the natural dose is required. For highest accuracy an iterative approach must be taken.

In this case, $\triangle_T$ is taken as $f_{\beta,T} - f_{n,T}$ so that equations 4 are used after substituting $f_{\beta,T}$ for f^*. A hypothetical case for "f=0.3" is shown in figure 1. $\triangle_T$ peaks at the temperature where $f_{\beta,T} = f$. The function "$(f/1-f)(1-f_{\beta,T})$" intercepts the sensitivity axis at $f/(1-f)$ in the limit that $f_{\beta,T} = 0$.

Fig.1: An Hypothetical Example
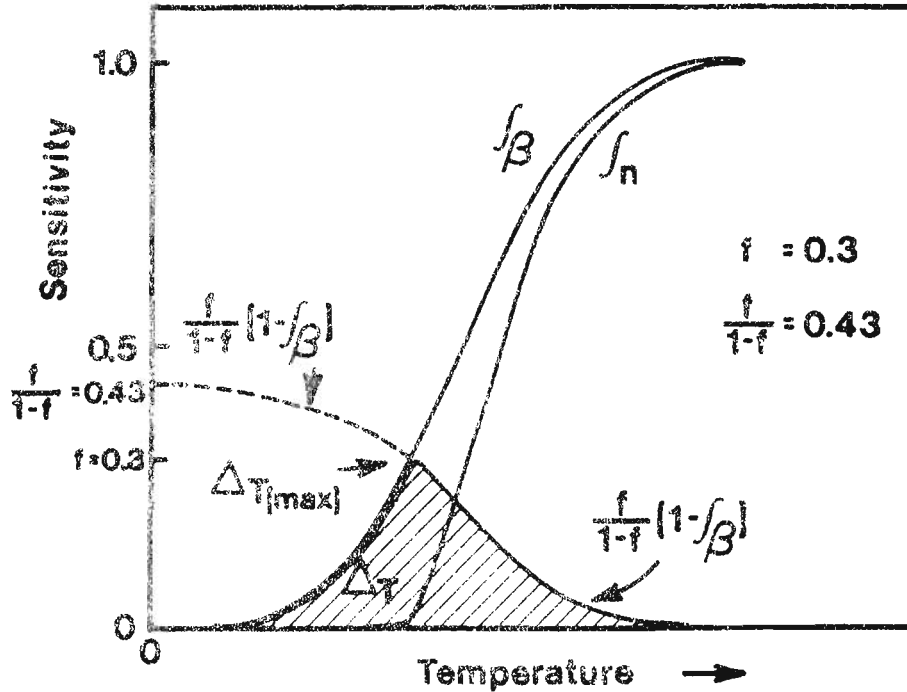
Correction of Natural Dose Determinations

The fractional error in the uncorrected natural dose determination D_n^* due to ambient activation is equivalent to the fractional error in the measured sensitivity enhancement. The true natural dose D_n, that obtained after correction for ambient activation, is then

$$D_n = \frac{(S_{n,max} - S_0)}{(S_{n,max} - S_0^*)} D_n^* = \frac{D_n^*}{1 - \triangle_{T(max)}} \tag{7}$$

Simulation Experiment

A simulation experiment was performed to test this method. Two aliquots of pottery quartz (WU-1160, S. Missouri) were given add-on beta doses equivalent to the uncorrected natural dose (using the full value S_0^*) of 100 rads. For the first aliquot, $f_{n+\beta,T}$ was measured at 50°C intervals up to 450°C. $f_{\beta,T}$ was then computed as described above. From this TAC, it could be seen that the laboratory dose was activated to 40% of maximum by an activation to 312°C. Accordingly, the second aliquot was pre-activated to 312°C to simulate an ambient activation, and $f_{\beta,T}$ determined as for the first aliquot. $\triangle_T$ computed from these two TAC's peaked at 0.4 in agreement with the prediction.

Ambient Activation Corrections for Some Pottery Quartz

This correction method has been applied to ceramic artifacts from site 23BU10 in the Ozark National Scenic Riverway. The site correlates with the Powers Phase which has 30 associated C14 dates between 630 and 705 years. TL dating results are shown in table 1. Measured ambient activation correction factors ranged from 0.06 to 0.38 and figure 2 shows representative TAC's. In general, the corrected dates are in better agreement with C14 than the uncorrected dates.

Two caveats should be pointed out. First, it is assumed that the TAC's are identical except for ambient activation effects. Second, high accuracy is difficult to attain in practice. This is because high precision temperature control is essential and values are determined by subtracting sensitivities of similar magnitude.
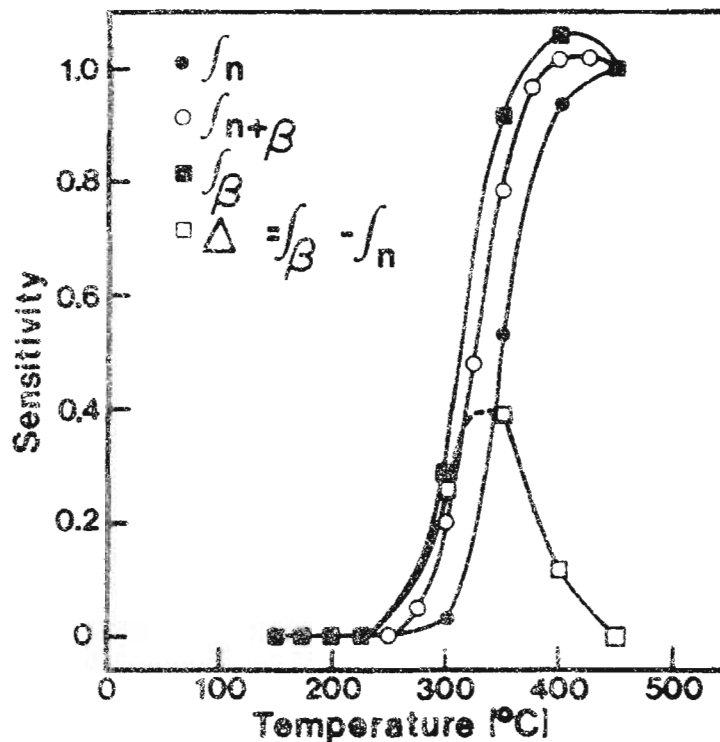
Fig.2: 116D Quartz TAC's

Table 1

Sample	D_n^* (rads)	S_o^*/S_n	Age using S_o^* (years)	$\Delta_T(max)$	Corrected D_n (rads)	Age using correction (years)
116A	125	0.30	465	0.12	140	530
116B	145	0.20	515	0.20	180	650
116C	150	0.12	540	0.10	165	600
116D	100	0.42	495	0.38	160	800
116E	95	0.14	405	0.14	110	470
116F	210	0.12	680	0.06	225	720
116J	180	0.47	615	0.30	255	880

$$C14 = 630\text{-}705 \text{ years B.p.}$$

Reviewer's Comments (IKB)

The paper provides a good exposition of the quantitative use of TACs to approach the problem of activation of the accrued dose at ambient temperatures during antiquity. High initial sensitivity is one of the remaining stumbling blocks of the technique that can give rise to significant uncertainty in the evaluation of the accrued dose. Consequently, any procedure that can be used to reduce such error is of importance. However, from our experience in this laboratory we would question its practicability for reasons which are mentioned as caveats by the authors. It is commonly the case that TAC form alters significantly with dose and annealing treatments and these effects will complicate the evaluation of the true initial sensitivity, in addition to the problem of obtaining high precision. The authors do not discuss the use of UV reversal and it would be interesting to test whether; (i) all samples except 116 D, F, and J, where it appears the true initial sensitivity is negligible, are fully UV reversible and (ii) the remaining samples, where ambient activation accounts for part of the measured values of initial sensitivity, are similarly partial UV reversible.

For archaeological samples the possibility of secondary heating should be considered. If it can be excluded there remains the question of whether the measured extent of activation is to be expected at ambient temperatures.

Author's Response

Clearly, additional work is required to test the general applicability of the proposed correction procedure. Comparisons of UV reversibility with activation correction factors would indeed be informative. Errors due to alteration of TAC's by annealing treatment are avoided by using "first glows" as described; however, alteration with dose remains a potentially serious complication. In principle, the correction procedure properly evaluates the integrated effect of any post-firing thermal activation of the initial sensitivity including minor secondary heatings.