Ancient TL

www.ancienttl.org · ISSN: 2693-0935

Mejdahl, V., 1985. *Further comments on extrapolation methods of dating sediments.* Ancient TL 3(2): 21-26. https://doi.org/10.26034/la.atl.1985.088

Further comments on extrapolation methods of dating sediments

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Debenham (1985) questions the TL dating result that I obtained for K-feldspar (lab. no. R-841008) from a marine sediment from Cape Copenhagen, Greenland (Mejdahl 1985) on the grounds that the procedures used for extrapolating the first glow growth curve may not be valid. He further presents a series of growth curves which he finds cannot be fitted by saturating exponential functions.

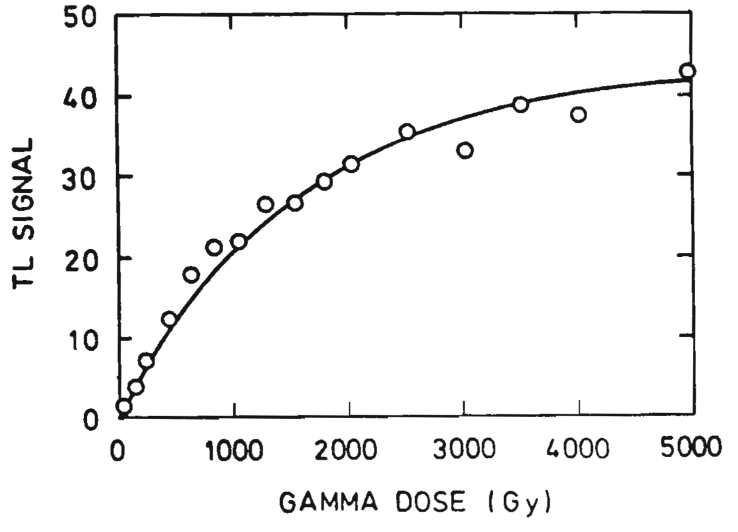
I agree that my work on the Greenland sample is still incomplete. The growth curve in question is given in Mejdahl (1985, Figure 1). Linear extrapolation based on three points gave an ED value of 4160 Gy while polynomial regression yielded ED = 3060 Gy. I have since studied the complete growth curve of a K-feldspar from a Swedish postglacial dune sand (lab. no. R-841611) by adding doses to the natural level (about 50 Gy). The growth curve (Figure 1) is approximately linear up to about 600 Gy after which it curves and approaches saturation. Polynomial regression gave a very poor fit to these points whereas a reasonably good fit was obtained by exponential regression as shown in Figure 1. The equation of the exponential is

$$y = 43.18\ (1 - \exp(-0.000650x)) \qquad \ldots(1)$$

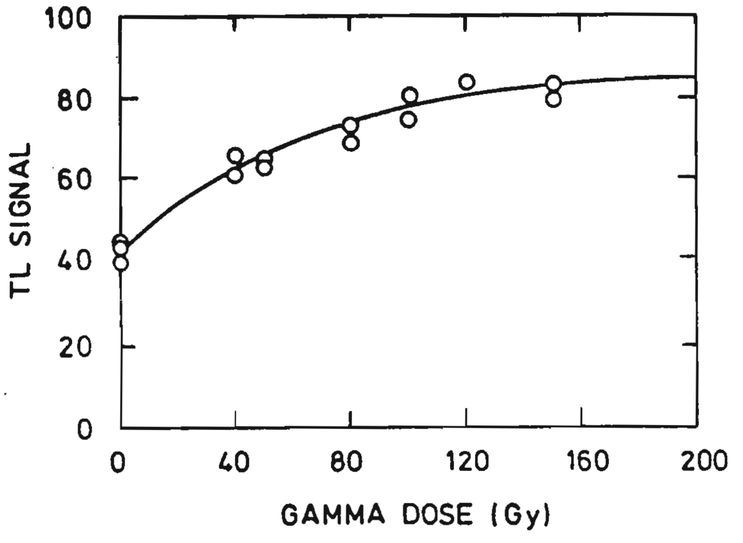
The exponential seems to underestimate the response in the range 600-1000 Gy, but gives a good fit below and above this region, apart from the two outliers at 3000 and 4000 Gy. A similar exponential fit for a quartz growth curve (Danish ice wedge cast, lab. no. R-32104) is shown in Figure 2. The equation is

$$y = 42 + 45.24(1 - \exp(-0.0152x)) \qquad \ldots(2)$$

Good exponential fits with exponential terms very similar to those in eqs (1) and (2) have been obtained for K-feldspar (with higher natural doses than the one in Figure 1) and quartz from a number of sediments from Finland, Norway and Sweden. For some quartz growth curves the exponential term was smaller, around 0.005x.



<u>*Figure 1:*</u> *Growth curve for K-feldspar from a Swedish postglacial sand dune (lab. no. R-841611). Gamma doses were added to the natural level; about 50 Gy. A saturating exponential function has been fitted to the points.*



<u>*Figure 2:*</u> *TL growth curve for quartz from a Danish ice wedge cast (lab. no. R-832104). Gamma doses were added to the natural level; about 40 Gy. A saturating exponential function has been fitted to the points.*

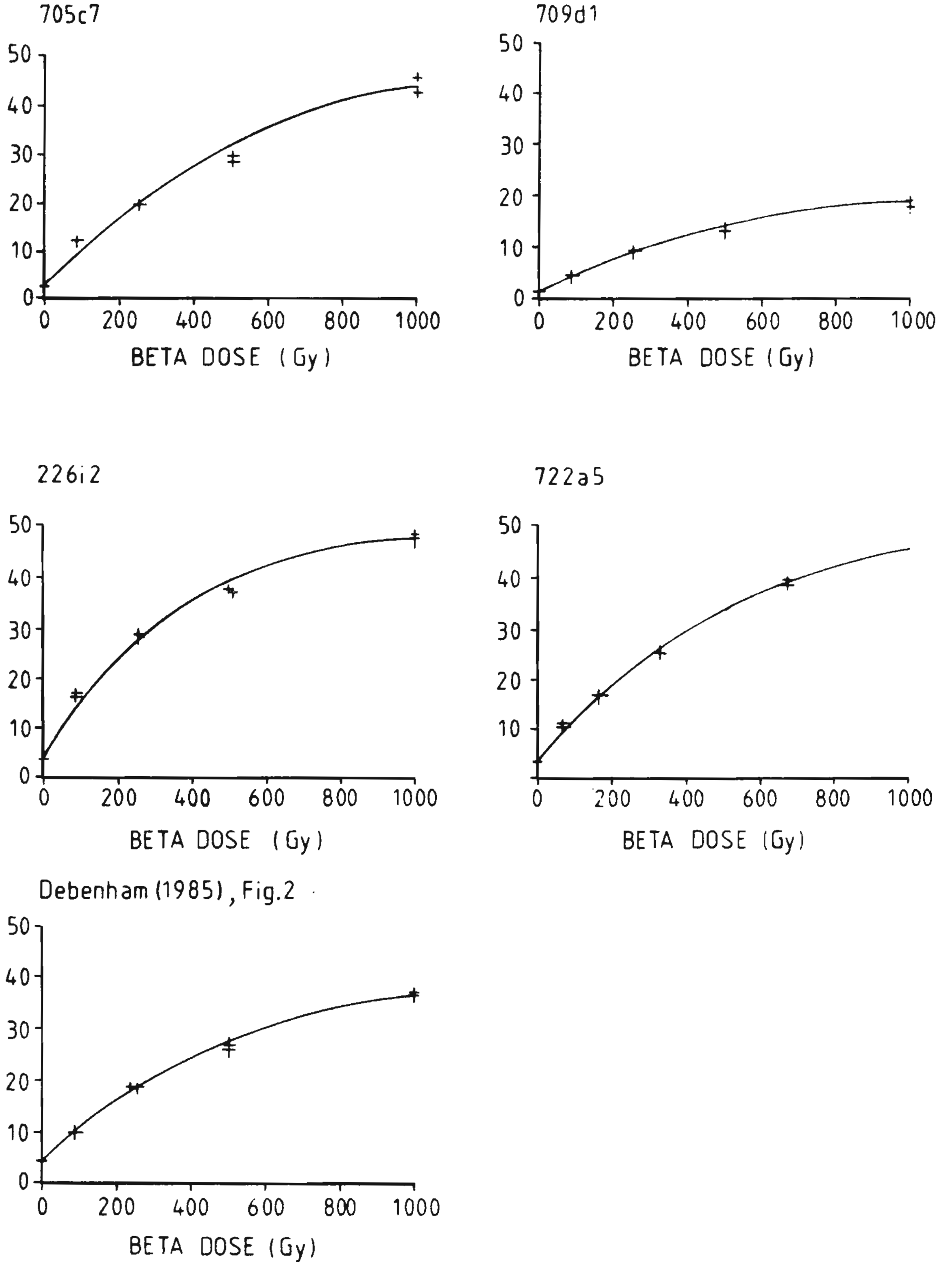


Figure 3: *Saturating exponential functions fitted to the TL growth curves given in Debenham (1985, Figs. 1 and 2).*

Editors note: *please note that curves were re-drawn free-hand by us from computer plots supplied by the author.*

The implication of these studies for the Greenland sample is that polynomial regression cannot be expected to give valid results, and linear regression will lead to an overestimate of the ED. Similarly, the linear extrapolation indicated by Debenham (1985, Figure 2) using only two groups of points will be invalid and his related discussion therefore unrealistic. Fitting an exponential to the growth curve of the Greenland sample (Mejdahl, 1985, Figure 1 plus a few more points, but none exceeding 2000 Gy) resulted in the following equation.

$$y = 85.4 + 48.15(1-\exp(-0.000818x)) \qquad \ldots(3)$$

which has an exponential term very similar to the one in eq.(1). The corresponding ED value is 1250 Gy which, with a dose rate of 2.86 Gy/ka, yields an age of 437 ka. This is considerably smaller than those reported earlier but still well above Debenham's 100 ka limit. More work on the Greenland samples is in progress to justify the procedure and verify the results; this includes adding doses above 2000 Gy and regenerating growth curves up to saturation.

Concerning Debenham's second point, viz., the shape of the growth curves presented in his Figures 1 and 2 (Debenham 1985), I can not agree on his interpretation that an initial non-linear portion is followed by a linear one. Except for 705 c1, which is linear throughout, nowhere can one find more than two groups of points that lie on a straight line. In my opinion all curves show a saturating behaviour which would be even more pronounced if they were continued to higher doses. In Figure 3 below I have fitted saturating exponentials to all of Debenham's curves except 705c1. The fit is not quite satisfactory for 226i2 and 705c7 but excellent for 722a5, 709d1 and Debenham's Figure 2. It is interesting to note that the deviating points in the two samples deviate in the same way; this shows that the deviation is not random. The exponential equations are given in Table 1.

It is interesting to note the similarity of the exponential term for all samples. The saturation behaviour appears to be intermediate between what I find for K-feldspar and quartz. In Table 2 I have compared this behaviour, taking the saturation dose to be that for which 90% saturation is reached. An average exponential factor of 0.002 and an x-axis intercept of 30 Gy have been assumed for the samples in Table 1 and an x-axis intercept of 50 Gy has been included for the quartz sample.

Debenham does not state what his samples are, but it is evident that their TL growth is different from that of either of the K-feldspar and quartz samples discussed above. There seems to be no basis, therefore, for assuming that dating limitations found for his samples would automatically apply to samples from other regions. On the other hand, it must be admitted that as yet there is no definitive proof that this 100 ka barrier can be exceeded.

References

Debenham, N. C. (1985) Comments on extrapolation methods of dating sediments by TL. Ancient TL 3 (2), 17-20.

Mejdahl, V. (1985) Thermoluminescence dating of loess deposition in Normandy. Ancient TL 3 (1), 14-16.

Table 1. Saturating exponential functions fitted to the growth curves given in Debenham (1985, Figures 1 and 2)

Sample No.	Equation
705c7	$y = 2.35 + 48.83\ (1 - \exp(-\ 0.001783x))$
709d1	$y = 1.35 + 21.46\ (1 - \exp(-\ 0.001886x))$
226i2	$y = 3.65 + 45.72\ (1 - \exp(-\ 0.002936x))$
722a5	$y = 3.65 + 48.55\ (1 - \exp(-\ 0.001938x))$
Fig. 2	$y = 8.30 + 75.51\ (1 - \exp(-\ 0.001895x))$

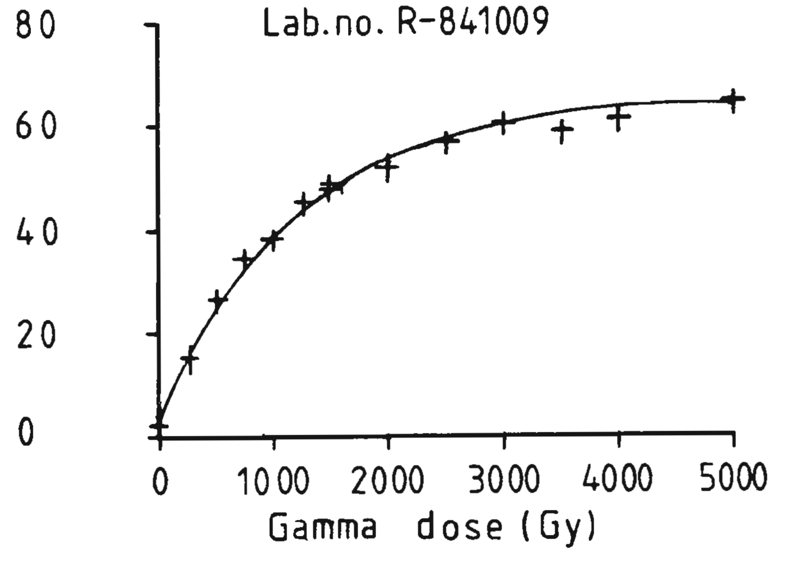
Table 2. Comparison of saturating behaviour of growth curves from Debenham (1985, Figures 1 and 2) and K-feldspar and quartz from Sweden and Denmark assuming exponential regression.

Sample	Lab no.	Exponential term	Dose for 90% saturation (Gy)
K-feldspar[1]	R-841611	$0.000650x$	3500
Quartz	R-832104	$0.0153(x - 50)$	200
Debenham	see Table 1	$0.0020(x - 30)$	1180

1. Quartz contamination less than 5%. Signal from quartz negligible.

Postscript

I have since completed regeneration measurements for a K-feldspar from a Greenland sample (lab. no. R-841009) taken from the same locality but 25 m above that represented in eq (3). The sample was bleached by exposure to sunlight for two days. The resulting regenerated growth curve is shown below.



Regeneration curve for K-feldspar from a Greenland sample, lab. no. R-841009. Bleaching was achieved by exposing the sample to sunlight for two days. An exponential function has been fitted to the points. The equation of this exponential is

$$y = 2.44 + 62.8(1 - \exp(-0.000822x))$$

The exponential term, and thereby the shape of the curve, is identical with that in eq. 3. This indicates that the extrapolation based on eq. 3 and described in the paper is a valid approach

Reviewer's comments (A. G. Wintle)

It seems that much more experimental work on a wide range of samples needs to be done to look at the non-linearity of different types of feldspars and quartz and fine grain mixtures of these minerals.

Also, these questions could be answered in part by further studies on a range of known age material, greater than 100 ka. However, such samples are very hard to find.

We must ask again whether there are any laboratory experiments which might prove, or disprove, Debenham's hypothesis that the problem is caused by loss of luminescence centres with time.