Annales de la Société Géologique de Belgique, T. 112 (fascicule 1) - 1989, pp. 197-206 Août 1989

DATING OF QUATERNARY SEDIMENTS BY BETA THERMOLUMINESCENCE : INVESTIGATIONS OF A NEW METHOD[1]

by

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(4 figures and 2 tables)

RESUME.-Une nouvelle approche préliminaire pour la datation rapide et approximative en TL de sédiments est proposée (la méthode β-TL) basée sur le contenu en potassium (K) et le taux de dose beta infinie de l'échantillon.

L'équation d'âge est fondée sur un coefficient B, où $B = 0.244 - 0.024K$. L'âge est alors donné par la formule $Age = 0.0077D/B(K-0.35).a + D_c x\, 10^{-2} \times 0.77$ où D = dose équivalente totale, K = valeurs en % de K_2O, a = atténuation beta et D_c = dose cosmique. Les avantages de la version β-TL sont :

a) peu de mesures sont nécessaires;

b) la minimisation des erreurs environnementales dues aux rentrées d'eau.

L'application de cette nouvelle approche à 119 données publiées a donné des résultats tout à fait compatibles en âge.

ABSTRACT.- A new preliminary approach for swift and approximate TL inclusion dating of sediments is reported (the β-TL method) based on the potassium (K) content and the infinite beta dose-rate of the sediment sample.

The age equation is founded on a coefficient B, where $\log B = 0.244 - 0.024K$. The age is then given by the formula, $Age = 0.0077D/B(K-0.35).a + D_c \times 10^{-2} \times 0.77$ where D = total equivalent dose, $K = k_2O$ % values, a = beta attenuation and D_c = cosmic dose. The advantages of the β-TL version are:

a) fewer measurements are needed;

b) the minimisation of the environmental errors due to the water uptake.

The application of this new approach to materials from 119 published data produced highly compatible age results.

1.- INTRODUCTION

The possibility of dating sediments by TL was first recognized by Morozov (1968) and later by Shelkoplyas (1971) who obtained numerous dates for sediments from the Soviet Union. Real progress was not achieved until 1979 when Wintle and Huntley (1979) obtained a series of TL dates for a deep-sea core. Subsequently, several authors have reported on the TL dating of Quaternary sediments of different origin eg. aeolian (Loess), palaeosols, glacial and fluvioglacial deposits, sands, coastal dunes, beach dunes, peat bogs and river sediments (Singhvi & Mejdahl, 1985; Berger, 1986; see also fig. 1 for references per material).

The two fundamental techniques used are a) the fine (4-11 µm) polymineral grains technique, and b) the inclusion technique (coarse grains of quartz or alkali feldspar 100-300µm). Coarse grain samples can be separated into mineral groups

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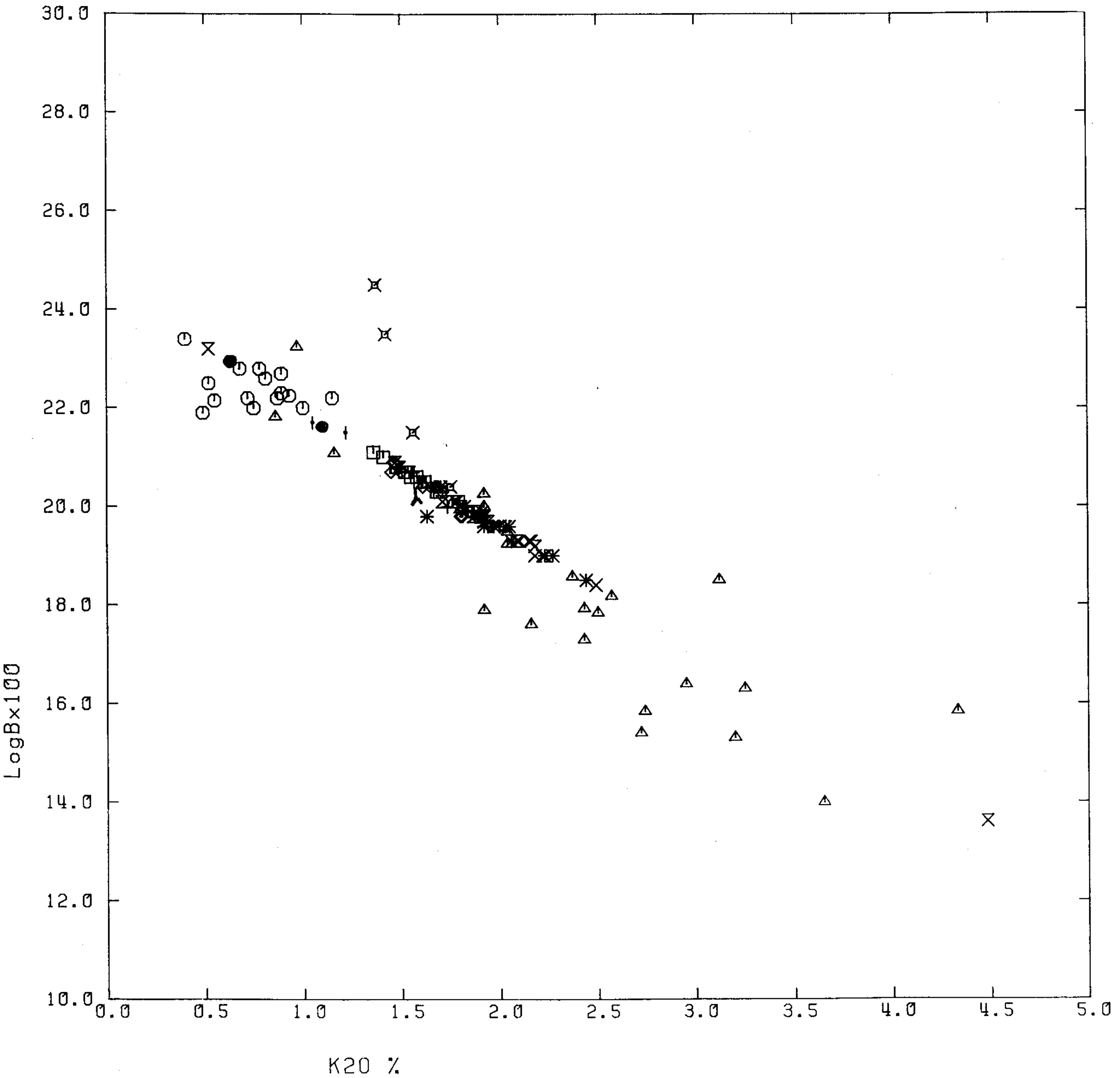

Fig. 1.- Plot of log B against K_2O % for various sediment types.

(⧫) cave sediments, Yokoyama *et al.* (1985); (×) soils in lòess. Wintle & Catt (1985); (○) ocean sediments, Siegele & Mangini (1985); (★) subaerial sediments, Proszynska (1983); (⧖) loess and soils, Proszynska (1985); (●) beach and dune sands, Southgate (1985); (◇) loess, Wintle *et al.* (1984); (△) vitrified forts, Sanderson *et al.* (1985); (□) loess, Bluszcz (1987); (+) loess, Proszynska *et al.* (1987); (X̄) Granite, sand pyroclastic flows, Shimakawa *et al.* (1987); (¤) Baked sediment of lava flow, Huxtable *et al.* (1978); (人) volcanoes, Guerin (1982); (Y) loess, Wintle (1985).

including quartz, Na-feldspar and K-feldspars. The procedures for the determination of total equivalent dose or palaeodose (D) in sediments are: a) the regeneration method, by prolonged exposure of the sample to light; b) the additive dose method; c) the quartz-feldspar mineral subtraction method. Depending on the extent of bleaching (total/partial bleaching), the (a), (b) methods above are appropriately modified to reproduce the original predepositional TL dose. These modifications refer to partial bleach version (R-B and R-Γ method) and to total bleach version respectively (Wintle & Huntley, 1982; Mejdahl, 1988; Singhvi *et al.*, 1985).

However, the slow progress of TL dating was caused primarily by a) the complex TL behaviour exhibited by the natural ubiquitous minerals (quartz, feldspars); b) the complexities of the microdosimetry of the natural radiation dose to these minerals. Emphasis has been given to methods for determining the palaeodose (D), whilst amongst the sources of error in the dating of sediments is still the water content. The water acts as an absorber of radiation, so that the radiation dose in the minerals will depend on the ratio of the stopping power of water to sediment type (Liritzis, 1985). This ratio is assumed to be 1.50, 1.25 and 1.14 for alpha, beta and gamma rays, respectively,

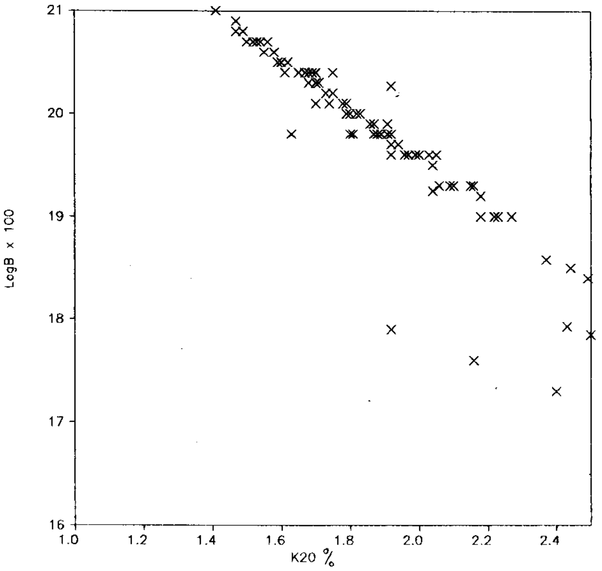

Fig. 2.- As per fig. 1, but expanded for the middle part, where overlapping of the points occurs.

for archaeological clays but can be used in otner sediment types too (Liritzis, 1985; Zimmerman, 1970).

Reviews for the TL of sediments have been made by Wintle and Huntley (1982) and Singhvi and Mejdahl (1985).

In the present paper, an alternative approach to the inclusion technique of TL dating of sediments is proposed which is based on an earlier preliminary work (Liritzis, 1985) which indicated a universal linear variation of K_2O percentage with beta-ray dose rates in ceramics. Due to lack of sufficiently published TL inclusion dates, the fine-grain age data are used but appropriately reduced to inclusion data. This new alternative relative dating method is called β-TL.

2.- RATIONALE OF THE NOVEL TL INCLUSION METHOD

Indeed, in geology it has beel repeatedly documented that there is an almost universal tendency for an increase in the concentration of uranium and thorium in proportion to the concentration of later members - potassium for example - in any «igneous or metamorphic differentiation series». That is, the separation of an igneous rock into two or more fractions, which can then consolidate as different rock types, for igneous processes and, the migration and concentration of elements during metamorphism so as to produce an inhomogeneous rock from an originally homogeneous one, for the metamorphic processes (HG, 1978; Heier & Carter, 1964; Heier & Rogers, 1963). The linear and/or hyperbolic partitioning nature of the three radioelements U, Th and K in the detrital rocks have also been extensively investigated by Quinif *et al.* (1982).

The K_2O % vs beta dose-rate ($D\beta$) relationships were derived for, a) geological materials and b) archaeological ceramics. For the latter TLD and alpha-counting plus K determination techniques were employed from results of Liritzis (1979) and Zimmermann (1970).

An average equation was deduced for such a linear relationship, given in eq. 1.

$$K = 0.35 + 0.77\ D_\beta \times 10^{-2}\ \left(\text{or } D_\beta = \frac{(K-0.35)}{0.77}\,10^2\right) \quad (1)$$
$$(\pm 22\%)\quad (\pm\ 3\%)$$

where, K is the K_2O % values. ($D\beta$ in mrads = 10^{-5}Gy).

From the inclusion technique TL age eq. (2),

$$\text{Age} = \frac{D}{aD_\beta + D_\gamma + D_c} \quad (2)$$

the denominator is written as in eq. (3)

$$\frac{D_\beta + D_\gamma}{D_\beta} = B \quad (3)$$

where (a) includes the beta ray attenuation through the grain and the etching effects; D_c is the cosmic-ray dose rate.

A plot of log B (for infinite matrix beta dose-rate) against K_2O % is shown in figures 1 and 2 for various sediment types. The linear distribution of figure 1 is expressed by eq. (4).

$$\log B = 0.244 - 0.24K \quad (4)$$
$$(\pm\ 4\%)\quad (\pm\ 3.6\%)$$

combining (1), (2), (3) and assuming a = 1, eq (2) becomes

$$A = \frac{D}{BD_\beta + D_c} = \frac{D}{\frac{B(K-0.35)}{0.77}\,10^2 + D_c} \Rightarrow$$

$$\text{Age} = \frac{D \times 0.0077}{B(K-0.35).a + D_c \times 10^{-2} \times 0.77} \quad (5)$$

where the coefficient (a) is included to correct the product $B(K-0.35) = D\beta$.

Equations (4) and (5) provide the inclusion grain age from only two measured parameters, the D and K_2O, the D_c and (a) being estimated quite well.

The water uptake correction factors do not seem to significantly alter eq. (5). In fact, taking into account the water uptake correction formula by Zimmerman (1970), for the determination of actual beta and gamma dose rates, eq. (3) becomes

$$B = 1 + \frac{D_\gamma(1.25\ w - 0.25)}{D_\beta(1.14\ w - 0.14)} \qquad (6)$$

where w is the ratio of weights of the sediment sample in saturated with water and in dry states.

For a sample saturated with 80 % water, the error introduced to the B factor is around 5 %. Lower water uptake values would induce insignificant errors to the age result. Due to the principal involvements of beta dose rates and potassium content (a major beta-ray contributor) in this investigation this approximate dating approach is abbreviated to β-TL.

3.- TESTING THE β-TL METHOD

TL age data from the literature were used, to which the β-TL age results are compared. Due to lack of sufficient ages derived from the «inclusion technique», an attempt was made to subtract the alpha dose contribution from those employing the «fine grain technique». Appropriate calculations were also made to bring the corrected published data to original forms (see comments, table 1). The β-TL was also applied to feldspars taking into account their internal beta dose (see table 1 results by Kronborg; comment no. 11). Table 1 and figures 3 and 4 show the comparison of the dates. A total of 119 published dates were employed, 79 of which referred to «fine grain technique» and 40 to «inclusion technique». Table 2 shows the degree of age agreement as percentage difference between β-TL and TL for certain error limits.

The TL age errors were lying between 10-20 % though on average were 12 %. For inclusion data, 90 % of the TL and β-TL pairs were in agreement to within 0-20 % of the respective published TL errors.

For fine grain data, 63 % of the TL and β-TL pairs were in agreement to within 0-20 %.

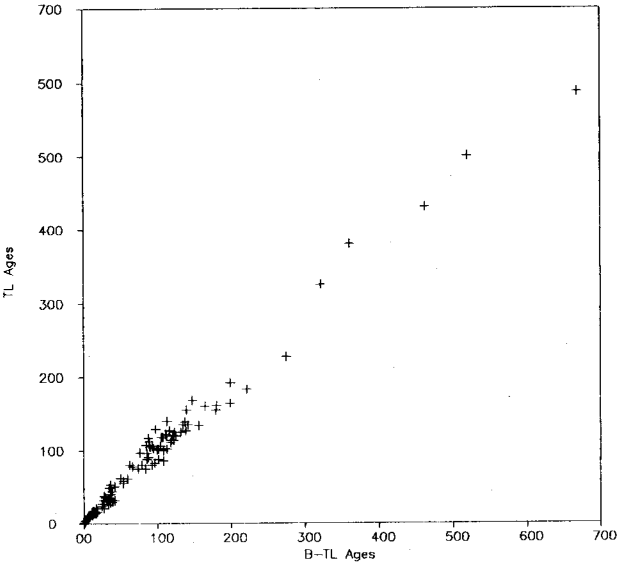

Fig. 3.- Plot of TL versus B-TL ages from Table 1. The ages are in thousand years.

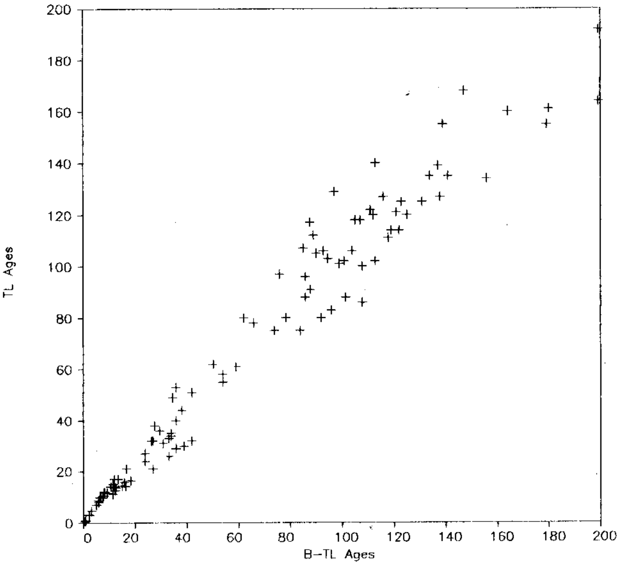

Fig. 4.- As per fig. 3, but for the first 200.000 years.

The above imply that β-TL can indeed be a valuable version of and of comparable precision to the conventional «inclusion technique». The attempts to convert fine grain age data in a form appropriate for β-TL age calculation include several assumptions regarding cosmic ray dose, alpha efficiency, water uptake values, etc. as adopted from original publications. Also, the degree of disequilibrium and unhomogeneous distribution of radionuclides around the dated sediment sample was not thoroughly examined in original publications. All these reasons may explain the observed difference between the β-TL and fine grain TL data. Nevertheless, over half of the cases the results were compatible within the attributed standard (random and systematic) errors.

4.- DISCUSSION - CONCLUSION

The β-TL method produces dates which are highly compatible to the published ones, considering the total error estimate of each result. The β-TL version assumes homogeneous environment around the dated sample for the use of a fixed infinite gamma ray dose rate.

Table 1.- Comparison between β-TL and TL dates
The data were derived from various authors. (Errors in β-TL are ± 20 %)

Mineral/Sediment	TL (Age years x 10^3)	B-TL	Author	Comment
Loess; soil, / quartz Feldspar	12.6 ± 1.3	12.3	Wintle et.al. (1984)	1
	14.4 ± 1.1	15.1		
	13.7 ± 1.2	16		
	14.2 ± 1.3	16.4		
	11.1 ± 1.0	11.5		
	16.4 ± 1.5	18.3		
	75 ± 6.5	84		
	80 ± 7.0	92.7		
	88 ± 8.0	101.4		
	86 ± 8.0	108.1		
	83 ± 7.0	95.5		
	120 ± 19	125		
	111 ± 10	118		
	114 ± 10	119		
	125 ± 11	131		
	139 ± 12	137		
Loess/feldspar, quartz	13.6 ± 1.5	12.6	Wintle (1985)	2
	14. ± 1.2	12.1		
	129 ± 1 1	96.7		
	13.9 ± 1.5	11.5		
	11.6 ± 1.9	9.3		
	103 ± 10	94.5		
	140 ± 13	112.6		
	117 ± 10	87.4		
Loess/soils, feldspar	44 ± 5	37.6	Proszynska (1985)	3
	15 ± 2	11.4		
	36 ± 4	29.4		
	38 ± 4	27.6		
	49 ± 5	34.5		
	53 ± 5	35.9		
	62 ± 7	50.2		
	80 ± 9	62		
Baked sediment of lava flow / quartz, fine grain	24 ± 2.7	23.8	Huxtable et.al. (1978)	4
	34 ± 3.6	33.8		
	26 ± 2.7	33.5		
	21 ± 1.8	27		
	32 ± 3.2	41.9		
	29 ± 2.8	36.4		
	30 ± 2.6	38.7		
Dune sands / quartz inclusion	192.2 ± 3.3	199.4	Southgate (1985)	5
	227 ± 20	274.5		
	164.4 ± 13	199		
	183.2 ± 18	221.5		

Table 1 (continued)

Soils in loess deposits/quartz fine grain	0.7 ± 0.1	0.51	Wintle and Catt (1985)	6	
	9.8 ± 0.9	6.7			
	9.9 ± 0.9	6.5			
	8.6 ± 0.8	6.04			
	3.1 ± 0.3	2.2			
	4.6 ± 0.4	3.2			
	7.4 ± 0.7	5.0			
	12.2 ± 1.4	8.3			
	11.7 ± 1.1	7.8			
	8.0 ± 0.7	5.7			
	9.8 ± 0.7	7.4			
	10.5 ± 0.9	7.8			
Subaerial sediments / quartz, fine grain	14 ± 2	10.7	Proszynska (1983)	7	
	21 ± 3	16.7			
	40 ± 6	36			
	17 ± 3	13.5			
	32 ± 5	26.5			
	107 ± 16	84.8			
	32 ± 5	27.3			
	78 ± 12	65.9			
	112 ± 17	88.4			
	17 ± 2	12			
	58 ± 9	54			
	97 ± 15	76			
Cave sediments / quartz, fine grain	380(ESR) ± 80	460	Yokoyama et.al. (1985)	8	ESR age error is ± 20-25%
	430 ± 85	462			
ceramic/feldspar inclusion	0.892 ± 5%	0.886	Mejdahl (1983)	9	
	0.89 ± 5%	0.881			
	0.951 ± 5%	0.941			
	0.879 ± 5%	0.874			
	0.971 ± 5%	0.965			
	0.912 ± 5%	0.901			
volcanoes/feldspar, inclusion	1695 ± 34 AD	1560 ± 30 AD	Guerin (1982)	10	Historical age expected 1669 AD
					Expected
sand/lake silts cave clay/diatomite/ sandy till, feldspar inclusion	31	30.7	Krönborg (1983)		20-30
	35.2	34.2			35.3-37.4
	74.8	74			20-30
	80	78.3			75-125
	87.6	85.8			75-125
	102	100.6			75-125
	101	99.2			75-125
	325	320.8			300-600
	500	520			300-600
				11	

Table 1 (continued)

Loess, quartz fine grain	27 ± 5	23.6	Proszynska et.al. (1987)	12
	118 ± 19	106.6		
	96 ± 10	85.8		
	55 ± 8	54.1		
	125 ± 14	123		
	105 ± 12	90		
	51 ± 6	42.2		
		46.2		
	106 ± 12	87.8		
		92.8		
	118 ± 19	104.6		
	122 ± 19	100		
		110.4		
	120 ± 20	105.2		
		112.3		
	155 ± 35	138.7		
	168 ± 27	135.3		
		146.7		
	127 ± 14	116.3		
loess/quartz inclusion	33 ± 7	33 (34.2)	Bluszcz (1987)	13
	61 ± 9	57 (59)		
	100 ± 17	108 (113)		
	102 ± 13	113 (118)		
	114 ± 21	122 (128)		
	102 ± 15	113 (118)		
	106 ± 10	104 (108)		
	127 ± 22	138 (142)		
	91 ± 13	88 (92)		
	135 ± 37	134 (140)		
	121 ± 18	121 (126)		
	135 ± 36	141 (149)		
	134 ± 36	156 (164)		
	155 ± 23	179 (187)		
	161 ± 36	180 (190)		
	160 ± 26	164 (172)		

	TL	B-TL	K_2O %	Th: U: K	Author	Comments
Granite	1.89×10^6 yrs	1.58×10^6	2.18	6.9:1.6:1	Shimokawa et.al. (1987)	14
Sand	1.32×10^6	1.56×10^6	4.48	2:0.5:1		
I Pyroclastic	0.587×10^6	0.668×10^6	1.49	4.7:1.8:1		
II flows	0.175×10^6	1.25×10^6 (?)	0.52	38:9.4:1(?)		

Table 2.- Number of pairs and percentage differences between the TL-published dates and β-TL, for inclusion (INCL) and fine grain (FG) techniques, which fall between certain range limits from 0 to 30 %

	Percentage limits (%)				
	0 to ±5%	±5 to ±10%	±10 to ±20%	±20 to 30%	Total number of data
(TL, ß-TL) pairs for INCL	22 (55%)	7 (17.5%)	7 (17.5%)	4 (10%)	40
(TL, ß-TL) pairs for F.G.	11 (14%)	13 (16.5%)	26 (32.9%)	29 (36.7)	79

From preliminary computations, the estimated fraction (d_γ^r) of infinite matrix gamma-ray dose-rate ($D_\gamma^{r=\infty}$) expected at a centre of a sphere of radius, r, is about $d_\gamma^{r=1.4} = 0.15\ D_\gamma^{r=\infty}$ and $d_\gamma^{r=12} = 0.5\ D_\gamma^{r=\infty}$ for two different r (in cm) and for $E = 1.0$ MeV, $g = 1.8 g.cm^{-3}$ (Liritzis, 1986b).

Therefore i) the variable (U: Th : K) ratios in proximal layers, ii) the semi-infinite matrix d_γ variation. That is, a sediment layer initially receives a semi-infinite d_γ, which gradually becomes infinite by time (dependant on the rate of deposition) during which time subsequent deposition, of around 30 cm thickness, overlies the initial layer, and iii) any U-disequilibrium in adjacent thin depositional layers of the dated sample, all are expected to contribute different and non-constant d_γ dose-rates with time, with a result to change the validity of eq. (3) and (4) and consequently the age result. The above apply to the conventional TL dating procedure as well.

To circumvent such an error in stratigraphies of quite different natural radioactivity by depth an average K-content value is taken in our approach to produce approximate ages, within ± 30 cm of the dated horizon. This has been made in table 1 with satisfactory results. Otherwise, the quartz-feldspar subtraction technique has to be employed, where the environmental factor of water uptake is not required, but with no better accuracy.

Other problems involved with the β-TL are those common to the conventional TL inclusion dating, that is; long/short term fading, signal stability, determination of palaeodose, radon emanation, U-disequilibrium etc.

At any rate, the β-TL inheres at present a ± 20% error, due mainly to the poor estimation of the intercept of eq. (1). This error figure derives also from the comparison of β-TL with the published TL ages, which makes β-TL compatible to the conventional TL inclusion dating, regarding accuracy. It should be mentioned here the particular care exercised in the determination of palaeodose (D), which is appropriately assessed and accepted only after the application of appropriate criteria, (Wintle & Huntley, 1982, Singhvi & Mejdahl, 1985). The errors involved for this measurement (by the TL apparatus) are of the order of 10 - 15 %.

Further refinement of eq. (1) and eq. (4) is an ongoing project, which is made with the examination of the partitioning character of U-Th-K in certain sedimentary formations.

Preliminary results seem to indicate different distributory patterns regarding K vs. D_β and log B vs. K. (e.g. some outliers in figs 1 and 2).

Our proposed TL dating version can, however, at present provide approximate but satisfactory age results that may be used at first instance without the undertaking of many measurements. Although it does not intend to replace the meticulous approach developed by many TL groups, it can, however, be developed to a potentially very effective swift dating tool in Quaternary geology with a quite acceptable approximation.

ACKNOWLEDGEMENTS

I am grateful to the National Bank of Greece for a Conference travel grant, and the NHRF, Greece and the Royal Society, London for help in the initial stage.

I much appreciate the swift response of Dr. A. Wintle to my request for her TL results as well as to Dr. Shimokawa and Dr. Bluszcz for providing their unpublished data during the TL/ESR dating seminar in Cambridge, 1987. Particular thanks to Dr. A. Wintle for practical assistance in Cambridge.

I am indebted to Onassis Foundation for financial assistance for the completion of this project, and to Dr. D.F.O. Russel and the Russell Trust for assistance in a critical stage of my work.

COMMENTS NOS (Table 1)

1. The cosmic-ray dose contribution (D_c) was 30 mrads/yr throughout the section. The β-TL age result is calculated as follows : the dose-rate for betas and gammas is computed from K, U, Th (corrected for water absorption) and subtracted from total dose-rate. This gives the alpha dose rate which includes the corrected 20 % value of water uptake and has been corrected for attenuation. This alpha dose-rate value times the TL age, gives the alpha dose contribution which is subsequently subtracted from the total dose value. In this way, the total inclusion dose along with equation (5) in the text was used to calculate the β-TL age. The B-values were calculated from respective β- and γ-dose rate data, using eq. (3); while the same value was calculated alternatively from eq. (4) too.
   The latter comparison indicated that the different ways in the calculation of B was satisfactory (see also comment 13).
2. The cosmic ray dose-rate was 15 mrads/yr. From U, Th contents the alpha dose-rate was calculated which when multiplied with the TL age gives the alpha dose contribution to total dose. Their subtraction provides the total dose due to beta and gamma doses.
   The B-value were computed from eq. (4). The errors in the TL ages were approx. 10 %.
3. The water uptake values were 20 ± 5 %. The cosmic ray dose rate was calculated in proportion to the depth. The dose due to betas and gammas and the B-values were calculated as above in (2). The error in TL ages were around 10 - 12 %.
   The k-ratio coefficient (beta dose contribution relevant to alpha dose) was chosen by the authors arbitrarily as 0.1. If the water uptake values were different from the assumed in the paper; say, higher, the difference in the age results could be more compatible. The water-uptake values assumed in original publication, naturally, affects alpha dose calculation, which subsequently affects the calculation of the total dose due to β- and γ-doses, and thus the β-TL age result.
   Four results were calculated from mean U, Th values from α-counting and γ-spectrometry (1st, 3rd, 5th, 6th). The other results were calculated from either of these methods, whichever was uniquely quoted by the authors.
4. The gamma dose rate value included D_c as well. A D_c value of 10 mrads/yr was assumed. The total dose for eq. (5) was calculated as above. The mean TL age for Chaîne des Puys was 25.8 ± 2.2 Kyrs while for the β-TL was 33.6 Kyrs. One should note that the TL age for the Lanschamp event was 33 ± 4 Kyrs (Valladas *et al.*, 1977) and for Lake mungo hearths 33.5 ± 4.3 Kyrs (Huxtable & Aitken, 1977) (for references and further informations see the paper Huxtable & Aitken, 1978, cited herein).
5. The first sample was 150-250 μm and the second one 250-355 μm in diameter.
   The a-coefficient (beta attenuation) was calculated as 0.93 and 0.92 respectively, based on Mejdahl (1979).
   The etching factor, that is, the attenuation due to the etched layer was calculated as 0.99 on 100 μm. The error in original TL age was ± 3.3 Kyrs for the first and ± 13-20 Kyrs for the last three ages. The D_c was 14 mrads/yr. The B-factor was calculated as in previous comment 1.
6. The samples were in order of presentation in the table i.e. surface topsoil, hillwash, soils.
   The errors in U, Th determination were 20-30 %.
   The k-coefficient was 0.1. The D_c was assumed as 14 mrads/yr.
   The water uptake values were assumed 35 %.
   The alpha dose and B-values were calculated as above. There was found a consistency in the B evaluation by eq. (4) and eq. (3).
7. The D_c was 14 mrads/yr. Other calculations are as in the former cases. k-coefficient = 0.1. Water uptake values = 20%. TL age errors were around 12-15 %.
8. D_c = 6 and 4 mrads/yr respectively. a-coefficient = 0.95 and 0.96 respectively. The authors assumed removal efficiency of a particle dose rate = 0.5 ± 0.3. The palaeodose was measured by ESR.
   The U-disequilibrium in these sediments was not checked for by Yokoyama *et al.*
9. The minerals were alkali feldspars and plagioclase. The γ-dose from the environment was small. The B-values were consequently low.
   Although inhomogeneous the environment of the dated ceramics, the agreement of the TL and β-TL ages were good, because the higher total-dose which could have been obtained from the gamma-doze of the ceramic, cancels-out with the high beta dose from the ceramic and the B-ratio. The beta dose from feldspars were taken into account too, in the calculation of the β-TL ages.
10. The grain size was 80-125 μm of plagioclase feldspars, with internal alpha radioactivity due to U-Th impurities. The total dose was calculated as in earlier cases, by subtracting the alpha dose contribution.
11. Feldspar grain size 0.1 - 0.3 mm. The B-values were calculated from the ratio of eq. (3), incorporating internal-β from K_2O too. The K_2O % values were calculated from eq. (1). The D_c was assumed as 10 mrads/yr. No corrections for beta attenuation and water uptake were made, as they were cancelled out.
12. The alpha-dose contribution to fine grain was subtracted from total dose data. The K_2O % values were used to derive B-ratio factors. The a-coefficient = 0.95 was used throughout. The original TL dates were corrected for water uptake by measuring this content in respective depths. The D_c was evaluated by depth.
    Occasionally and average K_2O % value was estimated from the K-content of the dated layer plus the K-content on either sides. this was done in cases where the radioelements were significantly different. The obtained ages are given below the respective β-TL results.
    The second age is deduced by employing an average potassium content in the three consecutive layers including the one which is dated. The use of an average K-content provides a better age, compared to the original TL age. This is due to the more representative dose-rate data regarding the partitioning nature of U-Th-K (see section 2 of text).
13. For the same loess strata as above, Dr. A. Bluszcz has applied inclusion TL dating. The agreement between TL^{incl} and β-TL was remarkable. All the differences were less than the TL^{incl} errors quoted, that is, less than 15-20 %. Appropriate attenuation factors were applied to the quoted grain sizes. Gamma dose-rates were measured *in situ* with a portable scintillometer. Number in parenthesis is the age deduced using B from eq. (4). The other number is the average age using an average B from eq. (3) and eq. (4). The deduction of the age using the two equations for the calculations of B is presented as an example, which shows the effect that has on age the choice of either eq. (3) or eq. (4) (see also comment 1).
14. Dr. Shimokawa kindly provided data on inclusion TL dating of sand, granite and two pyroclastic flows (grain size 125-250 μm).
    As expected, for some igneous materials, the distribution of U, Th and K does not follow a particular partitioning function as other sedimentary and homogeneous materials do. This anticipation was furthermore reinforced from their U:Th:K ratio. One thus would expect an around 10-fold higher K-content for pyroclastic II sample (Shimokawa

et al., 1987, ESR dating of volcanic and Baked Rocks, 5th Specialist Seminar on TL and ESR Dating, Cambridge). However, the age disagreement for flow II could also be due to an erroneous measurement of total dose or to fading.

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