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THERMOLUMINESCENCE DATING OF BURNT CHERTS FROM THE ALICE BOER SITE (BRAZIL)

by

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ABSTRACT

More than 40 culturally burnt cherts from the Alice Boer site near Rio Claro, São Paulo State, have been studied by thermoluminescence (TL). Nine of these were found to be sufficiently heated by early man to reset the TL clock to zero and thereby be suitable for TL dating.

These cherts define, for the upper half of the uppermost cultural layer (layer III), a time scale for the presence of man from # 2,220 to 11,000 years. This time range is in essential agreement with the geological-paleoclimatological age estimate for the end of deposition of this layer, as well as with radiocarbon dates. In particular, it lends support to a radiocarbon age of 14,000 BP for a deeper level.

The overall geochronologic results are not in contradiction with earlier statements (Beltrão 1973, 1974, 1978) that the deepest cultural layer (layer V) at Alice Boer might have been deposited at least 20,000 years ago.

1. INTRODUCTION

The archaeological sites of Planalto Meridional in central Brazil present a rich lithic industry. In most of these sites, however, the cultural layers have a limited thickness, suggestive of short occupation times (Beltrão 1969). In this context, the Alice Boer site (São Paulo State) is of particular interest because of the wealth of its lithic industry, the great thickness of the archaeological layers and the time range they represent (at least 10,000 years), as well as the possible great antiquity of the lowermost tool-bearing level (Beltrão 1974).

Due to the low abundance of charcoal at the Alice Boer site, only a few levels from the tool-bearing layers have been radiocarbon dated (Beltrão 1974). The upper part of the cultural levels has been dated from 6000 to 14,000 radiocarbon years BP, while the timing of deposition of the lower levels remains largely speculative.

The artifact collection from Alice Boer consists of tools and flakes of locally abundant black chert. Careful examination by one of us (M.C. de M.C. Beltrão) of the fabric of these tools revealed that before being worked most samples had been thermally pretreated by early men, a technique known to improve their flaking properties (Crabtree 1964). Laboratory simulations suggest that thermal treatment may vary, depending on flint structure, from # 280 to # 500C (Inizan et al. 1975). An annealing temperature of about 380C is sufficient to reset the thermoluminescence (TL) chronometer to zero in cherts (Wintle and Aitken 1977), thus allowing eventually a *direct* dating of stone artifacts that have been adequately heated (intentionally or not) by early man. In a previous work (Danon et al. 1980), we have shown that indeed a few cherts from Alice Boer had been sufficiently heated in the past to allow TL dating. The Archaeological Doses of eight cherts from various levels were measured, and their variation with depth in the site appeared to be compatible with the radiocarbon data.

The transformation of these archaeological doses into TL ages requires the determination of additional parameters, including site gamma-dosimetry, not available in 1980. We have now measured these parameters and present here a first approach of the TL chronology at Alice Boer.

THERMOLUMINESCENCE DATING.

Principle of TL dating

Any archaelogical sample buried in a soil is continuously irradiated by a flux of ionising particles from cosmic rays and alpha, beta and gamma rays from natural radioactivity. These radiactions interact with matter mostly by ionisation (i.e., by ejecting electrons from their parent atoms). In any mineral, a fraction of the ionised electrons do not recombine immediately and becomes "trapped" in crystal lattice defects. The period of most natural radioactive isotopes being long enough, the radiation dose per unit of time is constant and the number of electrons trapped is therefore proportional to time. In some traps, electrons are stable for millions of years, unless the crystal lattice is given sufficient thermal agitation by heating, so that the electrons can acquire enough energy to leave their traps. For archaeological samples, the trap-emptying temperatures of interest to TL dating are in the range from 300C to 600C. In practical terms, a potsherd or a hearth stone baked at such temperatures will have all their traps emptied of the previously "geologically" trapped electrons, and then the traps will progressively fill again, the number of electrons at any time being proportional to the time elapsed since their last archaeological heating. An interesting property of the trapped electrons is that, upon heating, they will progressively leave their traps and recombine to their parent atoms while emitting some light. It is this thermally induced emission of light which is called *thermoluminescence*. As the number of electrons trapped is proportional to time, so is the height of the archaeological TL emitted at a given temperature (Fig. 1). The archaeological TL emitted a high temperature (say higher than 300C) corresponds to an absorbed *Archaeological radiation Dose* (AD). The principle of TL dating is, through the measurement of a TL signal, to determine this AD (Fig. 2) and deduce an age t from the relation ship:

$$t = \frac{\text{archaeological dose}}{\text{annual dose}}$$

where the *annual dose* is the dose of radiation deposited per year in the mineral dated, by the radioactive impurities of the sample itself as well as by radiations originating from the embedding soil and cosmic rays. This annual dose is calculated from the U, Th and K content of the sample and its environments.

Although the principle of TL dating as summarized above is quite simple, various factors may intervene, which complicate its effective realization. For instance, the precision in the determination of the archaeological dose is limited by anomalous or saturation effects, supralinearity of the TL signal, etc...; those of the annual dose rate, by the state of disequilibrium of the U and Th series, the degree of homogeneity in the spatial distribution of the radioactive species throughout the sample, the relative efficiency of alpha and beta particles in producing TL, temporal variations of soil wetness, eventual leaching or deposition of radioactive species by running waters, etc...(Aitken and Fleming 1972; Aitken 1974). All in all, however, the best *overall* error limit (precision plus accuracy) achievable for the average date of a group of contemporaneous samples is of the order of ±7% at a 1 sigma (or 68%) confidence level. For a TL mean age of 10,000 years, this would therefore correspond to an overall error of ±700 years (Aitken and Huxtable 1980).

TL Dating of Cherts

TL dating of cherts was first attempted by Goksu et al. (1974). In order to eliminate spurious (triboluminescence and regeneration thermoluminescence) effects that had discouraged previous attempts, they used a "slice technique" for TL measurements. The same technique was then applied by Aitken and Wintle (1977) and Wintle and Aitken (1977) for the dating of a lower palaeolithic site. As noted by Wintle and Aitken, not too much weight was given to those ages, because there was as yet no control from other dating methods. Morever, the "slice technique" introduces an additional source of error to the TL age, of about ± 6%.

This led three groups to test again the feasibility of TL dating of flint/chert materials with more conventional sample preparations using careful grinding techniques. It was thus shown independently by Danon et al. (1980), Huxtable (1980) and Valladas (1980) that crushing cherts for TL measurements did not necessarily induce adverse effects. In fact, in more than 40 samples studied by Danon et al. (1980), all prepared with a crushing technique, none showed a recognizable spurious effect. It was further shown that either the archaeological doses measured in these samples (Danon et al. 1980) or their TL ages (Valladas 1980, from two Magdelenian flint artifacts), were compatible with the radiocarbon age of the same archaeological levels in their respective sites. The results reported here confirm this tendency and thereby the ability of the TL technique to give reliable ages for archaeologically burnt flints and cherts.

STRATIGRAPHY AND TL SAMPLING AT THE ALICE BOER SITE

The Alice Boer site, near to the town of Rio Claro (São Paulo), is situated on a flood terrace about 20m from the bank of the Rio da Cabeça. The elevation of this terrace above running water is less than 10m. Over an excavation depth of about 4m, five lithostratigraphic units have been identified, two of which (layers III and V) yielding lithic artifacts. A detailed description of the site and the results of sedimentological studies have been reported by Beltrão (1974) and Meis and Beltrão (1981,a,b).

A cross-section of the excavation is given in Fig. 3. Layer V, which corresponds to the older bed of the Rio da Cabeça, lies directly on bedrock composed of more or less altered silts. This layer, rich in gravels and blocs, contains a primitive tool industry of two different traditions. One of these consists of elaborated artifacts of elongated flakes, not laminates, probably obtained by indirect percussion and carefully retouched. The second tradition is represented by more rudimentary lithic tools, including one "chopping-tool", voluminous nuclei and poorly retouched massive flakes used as scrapers.

Layer IV above is a sterile level of river sands deposited in a torrential regime and lacking internal stratification. Layer III, with a total thickness of about 2m, is the richest archaeological layer, It is composed of clayey sands characteristic of a humid climatic phase. Sedimentological evidence suggests that the sedimentation rates toward the base of this layer may have been considerably slower than in the upper levels. The limit between layers III and IV corresponds to an unconformity, the top of layer IV being an erosional surface.

Again, no clear stratigraphy is discernible within layer III. As a consequence excavation was carried out by horizontal levels of an arbitrary thickness of 10cm each. Nineteen levels were defined, all of them bearing chert artifacts. Several hundred artifacts were recovered, most of them in levels 7 and 8. The description and illustrations of the most typical objects have been given in Beltrão (1974). Down to level 10, both bifacially flaked stone projectile points and biface tools are present. The last biface fragment was discovered at level 16. Below, only unifacially flaked artifacts were found. Whether the absence of bifacially flaked points below level 10 and bifaces below level 16 are a statistical effect or genuine is not clear because very few tools were found in the lower levels.

The two upper layers of the site are culturally sterile. Layer II is composed of 1.5m of colluvial deposits, capped by the present soil (layer I).

Radiocarbon dates were obtained on charcoal for four levels of layer III. Charcoal from levels 3, 5 and 8 gave similar ages (Table 2) which average 6090 ± 43BP. One small charcoal sample from level 10 gave a radiocarbon age of 14,200 ± 1150BP (SI 1208). From regional considerations, it seems that the sedimentation of layer II might have started a little less than 3500 years ago (Beltrão 1974). The beginning of the deposition of layer V was estimated by the same author, from sedimentological arguments, to be as early as # 20,000 years.

Burnt chert artifacts were present at all levels in layer III. On the contrary, no evidence of fire treatment was found on the tools from layer V. We have therefore concentrated our efforts on the layer III artifacts. Only chert artifacts showing signs of archaeological fire treatment were selected for TL dating. Special attention in the sampling procedure was given to samples from level 10 and below (i.e., to levels presumably older than ca. 14,000 years). Finally, cherts representative of all 19 levels (except levels 6 and 17) were studied. As far as we could judge from hand specimens, the chert material was homogeneous through all levels and apparently similar to the chert blocs now available in the nearby Rio da Cabeça bed, presumably the source of the archaeological fragments. Among the archaeologically burnt specimens, those presenting a reddish colour on some to all of their external surface (an indication of strong fire treatment), were especially selected. Our results are given in the next section.

TL AGE DETERMINATIONS

Forty-three chert artifacts showing evidence of fire treatment were selected for this study, and their TL measured with a coarse grain technique (Danon et al. 1980). The TLN of all cherts represent a single peak, centered in our heating conditions (10C/s) at # 375C. The TLA presents another peak centered at # 130C.

Of the 43 cherts, 34 were rejected for TL dating, either because of saturation (18 samples) and/or presence of anomalous fading (7 samples), non-reproducible TL signal (8 samples) or anomalous TL behavior (2 samples). The cherts with saturated TL (Fig. 4) correspond to samples archaeologically unheated. They were found at all levels, especially from level 7 downwards (Table 1) and correspond to samples that were never archaeologically heated enough to remove their geological TL. In effect, their "beta-equivalent-dose" at high temperature corresponds to saturation values of 10^4 to more than 10^5 rads (Fig. 5), which would require irradiation times in the Alice Boer site conditions of 60,000 to 500,000 years, which would contradict both geological and radiocarbon data.

Eight cherts are unsaturated and present a good plateau at temperatures greater than 300C. Fading tests showed no anomalous loss of TL over a period of three months. The archaeological doses and annual dose rates of these samples were determined with conventional procedures to ascertain their TL age.

Archaeological dose

The Archaeological Dose rates of the unsaturated cherts were determined from the TL lecture of powder aliquotes (100-500μm grain size) of the samples with the additive dose method. Supra-linearity effects are negligible for most samples.

The Archaeological Dose received by the samples (Table 2) is the sum of the beta-equivalent dose + supra-linearity dose effect. The major source of error in the AD comes from the supralinear dose evaluation. This is why the older the sample and the smaller its supra-linearity, the better the precision on the AD. It may also be seen from table 2 that the AD increases as expected with depth below surface. An apparent anomaly occurs at level 4, where two samples show widely differing AD. It will be shown below that this is simply a consequence of their widely different internal radioactivity.

Annual dose rates

The annual radiation dose received by the cherts comes from their own radioactivity and the environmental flux of ionizing particles. The latter, composed of cosmic ray particles plus gamma rays of the soil radioactive isotopes, was measured from TL dosimeters (CaF_2) buried for about one year in various places in the Alice Boer excavation. No significant variation of the dose from place to place was observed and we have for the environmental dose an annual value of 200±25mrads. This value is also the average value determined from many soils in São Paulo State by Watanabe (pers comm.)

The internal dose in individual cherts has to be calculated from their U, Th and K contents. However, due to the small size and low radioactivity of our samples, individual determinations in our gamma-counting system were not possible. Therefore, groups of samples (up to 7) were measured together. Thorium and potassium were constantly below detection levels, setting upper limits for these elements of <0.1ppm and <100ppm, respectively. Uranium was on the average of 0.6ppm, but fission-track uranium content determinations revealed large variations from chert to chert on the range of 0.2ppm to 1ppm. Uranium fission track mapping also showed that the distribution of uranium within chert was very homogeneous, fission stars (corresponding to ponctual concentrations of uranium) having been observed only rarely (and only in a few cherts). The U content determinations by the fission-track method were made on small fragments and it is not certain they are representative of the whole cherts. Therefore, the annual dose rates were calculated as the average of two extremes, assuming a content of radioactive species of either (i) 0.2 ppm of U, with no Th or k; (ii) 1ppm U + 0.1ppm Th + 100ppm K.

Proper determination of the annual dose requires that the relative efficiency of alpha and beta particles for producing TL is known. Huxtable (1981) found, for flints from four different sites. a k-alpha relative efficiency factor of 0.094±0.03 (but with individual values extending from 0.57 to 0.14). Similar results are given in Valladas (1980). The k-alpha factor for one of our cherts was determined by Steve Sutton at Washington University to be 0.11. We have thus adopted a value of 0.10 for the calculation of internal radiation doses, using Bell's (1979) tabulation for U, Th and K annual dose rate data. Assuming that both U and Th radioactive series are at equilibrium, without loss of radon or thoron, we calculated an annual internal dose rate of 25 ± 10mrads.

The total annual dose rate received by the Alice Boer cherts amounts therefore to an average value of 225±21mrads/yr. The very large (90%) contribution of the environmental dose, the large uncertainties of the internal dose, and in a certain measure the k-alpha factor, do not affect critically the total annual dose. The average value arrived at above was used for all cherts except sample 4-109. In effect, sample 4-109 was found, from fission-track analysis and γ-spectrometry, to contain significantly more uranium than others. With 5.2±0.5ppm U, and Th and K respectively, less than 0.05ppm and less than 80ppm, the dose rate of the sample was taken at 422±23mrads/yr.

TL AGES

The TL ages, calculated from equation (1) for the eight dated cherts, are reported in table 2. The TL ages range from an average of 2190±185BP at level 1 to about 11,000BP at level 8. For those layers where two or three samples could be dated, the

TL ages of cherts are, in general, remarkably concordant, as expected for samples having had a similar environmental and cosmic ray exposure history. (Remember that in the Alice Boer cherts, the external dose accounts for ∿90% of the Archaeological Dose). Finally, it can be noted that the increase of TL age is correlative with stratigraphic depth.

Still, only the upper half of layer III could be dated. In effect, it is remarkable that only cherts from levels 1 to 8 were found to be convenient for TL dating: nearly half of the 20 samples from these levels were categorized as "saturated" (table 1). On the contrary, the 23 cherts from levels 9 to 19 (the deepest level in layer III) were mostly (15 samples) in the latter group, and none was burnt to temperatures high enough to cure totally the geological TL. As throughout the whole stratigraphic column we have kept constant our sampling criteria (from visual observation), we are led to conclude that below level 8 (i.e., before about 11,000yrs BP) none to possibly a very few chert artifacts were strongly heated in hearths at the excavated site. Earlier, we have (Danon et al. 1980) suggested that among the possible explanations to this observation can be included either a change in fire technology or a change in utilization of the site. Whatever the actual answer, it is a fact that heating of cherts at temperatures above 380C was absent before 11,000BP.

DISCUSSION

Chronology of the Alice Boer site

In order to discuss the overall chronology of the Alice Boer site, we have reported in table 2, along with our TL measurements, all previously available data. From the comparison of columns 4 and 5 from table 2, it turns out that the time-scale defined by thermoluminescence dating of the upper levels of layer III is in general agreement with other (geological and radiocarbon) scales. Still, some discrepancies occur between TL and radiocarbon ages at levels 3-4 and 8.

In agreement with regional geological data, Beltrão had conservatively estimated that the beginning of sedimentation of layer II had started less than 3500yrs ago. A lower limit to the age of this sedimentation can be set by a drastic climatic change toward an arid regime that took place some time between 2400 and 2700 years ago. The dating of chert artifacts from the top level of layer III at 2190±185BP (error standard on the mean age of three cherts) is in satisfying agreement with the above boundaries. Similarly, the TL ages of 6350±1220BP for level 7 is concordant with the average radiocarbon age of 6090±43BP for levels 3 to 8. Finally, the two remarkably concordant TL ages of 11,000BP for level 8 are significantly older than the above dates and younger than the radiocarbon age of the underlying level 10.

The only TL data apparently incompatible with the radiocarbon ages are the two concordant TL ages of level 4, apparently "too young" by about 2000 years. To understand this dis crepancy, it is important to remember that the archaeological excavation levels were defined purely geometrically as horizontal 10cm thick layers, while contacts between layers suggest a slightly inclined stratigraphy (Fig. 3). Moreover, some parts of the site could not be worked conveniently and were not investigated due to obvious stratigraphic disturbance by burrowing animals. In the absence of other evidence, we tend to believe that the slight but significant differences between radiocarbon and TL ages at level 4 might result from either the obliquity or irregularity of stratigraphy over the "geometric" definition of sampling or sediment disturbance by nearby (unseen) animal reworkings.

In this respect, it is interesting that in a subsequent excavation at Alice Boer, a few meters from the one described here, one burnt chert artifact, sample 54, from a topographic level (nivel 1.30) roughly equivalent to level 5 of layer III yielded a TL age of 3800±350BP quite compatible with those of chert 4-109, of 3400±200BP.

All the TL ages have been calculated by assuming that the present level of soil humidity was representative of average conditions since the beginning of burial of the chert artifacts. The agreement of TL ages with other ages (i) at the top of layer III; (ii) at levels 5-7 with radiocarbon ages, suggest that hypothesis is not an unreasonable one and that the overall error in our TL ages (including radioactive source calibration and other systematic errors) is of the order of 10%.

The TL chronology at Alice Boer appears therefore to be in *essential agreement* with the radiocarbon time scale, and suggests that the deposition of the earliest flaked artifacts at Alice Boer at the bottom of layer III and especially in layer V may have started significantly earlier than 14,000 years ago. In fact, from geological evidence, Beltrão (1973, 1974, 1978) suggested that the deposition of layer V occured more than 20,000 years ago and possibly as long as 40,000 years ago. From the coarseness of sedimentation products (including rocky blocs), it may be inferred that the deposition was made under a high energy regime. As a consequence, the tools in this layer cannot be considered as *in situ*, and therefore the estimated age of 20,000 to 40,000 years must be considered only as a *minimum* age for the two different artifact cultural traditions found in layer V.

Comparison with other sites

Both leaf-shaped and contracted-stemmed points are found in the lithic industry at Alice Boer at various depths in layer III, from levels 1 to 10 for the stemmed points and 4 to 9 for the leaf-shaped points. Bifacially flaked stone projectile points are known in a number of places in South America. Following Hurt (1983, in this volume), similar contracted-stemmed points occur by about 8000 radiocarbon years BP at EL Inga (Ecuador) and Las Casitas (Venezuela). The results at Alice Boer indicate that both types of points were present in central Brazil by about 14,000 years ago and that their production without major stylistic change continued up to about 2000 years ago.

Another kind of tool was found in layer III. From layer V to layer III (up to level 3), Beltrão (1978) identified a series of burins (identification confirmed by J. Tixier), of which the more elaborate ones were found in the upper levels. There is therefore a suggestion here that, as in Europe, the stylistic evolution through time of burins could serve to establish a relative chronology of sites from central Brazil. Accordingly, careful typological studies of burins and further absolute dating at Alice Boer might be of paramount importance.

Another site, at Itaboraī (Rio de Janeiro) being excavated by one of us (see report in this volume by M.C. de M.C. Beltrão), might also shed some light on the early man occupation of southeastern Brazil. Over a stratigraphic section of # 7 metres, this site has two archaeological layers with a lithic industry (typologically different from that Alice Boer), interbedded between sterile deposits. The stratigraphy at Itaboraī is reminiscent of that at Alice Boer, in that it suggests that here too some archaeological materials might have been deposited more than 14,000 years ago. Intensive work on this site is in progress, and excavated burnt stones associated with charcoal fragments will be analysed by radiocarbon and TL methods.

Evidence for the early presence of man in northeastern Brazil is presented by Guidon (in this volume). Three sites in the state of Piauī have been radiocarbon dated 17,000 or more years, and one of these has dates greater than 25,000 BP. If the evidence of human occupation and the early dates are verified, these sites would be the oldest radiochronologically dated archaeological sites in Brazil.

CONCLUSION

Ten years ago, evidence for an early (more than 12,000 years ago) arrival of man in Brazil were very faint. The Alice Boer site and its radiocarbon dating suggested strongly that early man was present in central Brazil by 14,000 years ago, and probably significantly earlier. The TL chronology established from the dating of archaeologically burnt chert artifacts for the upper part of the major cultural layer (layer III) confirms the radiocarbon time scale. These results demonstrate clearly that a lithic industry characterized by contracted-stemmed points was already in place by about 14,000BP, and persisted for more than 11,000 years. Rather inexplicably, no chert artifacts were found sufficiently reheated in the deepest half of layer III to allow TL dating below the levels attributed to a radiocarbon age of 14,200±1150 years. Whether this unfortunate (for TL dating purposes) lack of reheating of the most deeply buried chert artifacts is a consequence of some change in fire technology or for some other reason is still unresolved.

Other sites (Itaboraī, and three recently radiocarbon dated sites in Piauī) also suggest that early man may have been present in Brazil significantly earlier than 12,000BP. Although much archaeological and geochronological work remains to be done at these sites, there are now at least four sites in Brazil at which evidence exists in favor of the presence of man more than 17,000 years ago.

Precisely dating these and similar sites in Brazil, and elsewhere in America, where now a number of quite ancient localities is supected (cf. Bryan 1978) will be a major task of the next few years. Recent developments of existing techniques, as radiocarbon (with the use of accelerator dating) and TL (with the use of new datable materials, as calcite and chert), as well as the emergence of new methods (as electron spin resonance dating), open fascinating possibilities in this respect.

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TABLE I+

CALSSIFICATION OF ALICE BOER CHERTS ACCORDING TO THE RESULTS FROM TL MEASUREMENTS

Saturated	Fading	Inhomogeneous	Anamalous	Prehistoric heat-treated
AB III 1-10	AB III 8-132	AB III 2-53	AB III 8-62	AB III 1-1
AB III 7-502	AB III 8-213	AB III 4-47	AB III 12-5	AB III 1-11
AB III 8-200	AB III 10-37	AB III 5-78		AB III 1-22
AB III 9-6	AB III 13-37	AB III 7-37		AB III 4-53
AB III 9-13	AB III 15-3	AB III 7-387		AB III 4-109
AB III 9-40	AB III 16-4	AB III 8-8		AB III 7-212
AB III 10	AB III 19-1	AB III 13-16		AB III 8-339
AB III 10-1		AB III 14-4		AB III 8-340
AB III 10-36				
AB III 11-4				
AB III 11-9				
AB III 11-34				
AB III 13-2				
AB III 14-11				
AB III 18-4				
AB III 18-13				
AB III 18-8				
AB III 19-2				

Saturated - TLN is saturated or near saturation. The equivalent dose is typically 10^4 to 10^5 rads.

Fading - Do not fulfill the plateau test of TL storage stability over archaeoligi cal time.

Inhomogeneous - Very poor reproducibility of TL measurements. Possibly partilly heated samples.

Anamalous - Unexpected behaviour of TL measurements.

Prehistoric Heat-Treated - The equivalent dose is in the range 10^2 to 10^3 rads; fulfill the plateau test and can be dated

+Modified from Danon et al., 1980.

TABLE 2

TL AGES OF BURNT CHERTS FROM THE UPPER PART OF ALICE BOER LAYER III

Stratigraphy	Sample	Archeological[+] Dose Rads	TL age[§o] yrs	Remarks[o]
<u>Layer II</u>				Sedimentation of layer II starts <3500 yrs
<u>Layer III</u>				^{14}C ages
level 1	1-1	499 ± 43	2200 + 280	
	1-11	533 ± 3	2370 + 220	
	1-22	452 ± 16	2000 + 200	
2				
3				6050 ± 100
4	4-53	646 ± 87	2870 ± 450	
	4-109	1435 ± 29	3400 ± 200	
5				6135 ± 160
6				
7	7-212	1534 ± 150	6350 ± 1220	
8	8-339	2468 ± 2	10970 ± 1020	6085 ± 160
	8-340	2462 ± 6	10950 ± 1020	
9				
10				14200 ± 1150

[+] error calculated from regression line (see Fig. 2) calculation

[§] includes error on annual dose calculation as given in text. This does not take into account a possible variation with time of the external dose due to variable soil water content.

[o] ^{14}C and TL ages are given ± 1 sigma.

LEGEND OF FIGURES

Fig. 1- TL behaviour of a typical unsaturated (see text) chert artefact from Alice Boer: sample 4-109.

a) TL glow curve versus temperature (heating rate 10°C/second). Full line: natural TL (TLN), with a single peak centered at ∿375°C; dashed line, natural TL + a laboratory β-irradiation dose of 468 rads. Note the appearance of a second peak at 130°C (unseen in the TLN, due to the low thermal stability of electrons in the corresponding low-energy traps), and especially the increase of the 375°C peak; dotted line, artificial TL (TLA) released after emptying the TLN by heating and irradiating by a β-dose of 936 rads.

b) Plateau test: the ratio of TLN/TLA with temperature increases from zero at temperatures <200°C to a stable (±15%) value above ∿300°C. This suggest that above this last temperature no loss of TLN occured since the last firing of chert 4-109 and that TL dating is feasible on this sample.

Fig. 2- Determination of the archaeological dose of radiation to an archaeological sample, chert 4-109 from Alice Boer. As a result of the plateau-test (Fig. 1), the TL in this sample was measured between 330°C and 400°C, with the additive radiation dose method (Aitken, 1974).

Upper curve: increase of the TL level with laboratory β-doses (from 468 to 1560 rads) for aliquotes having kept their TLN.

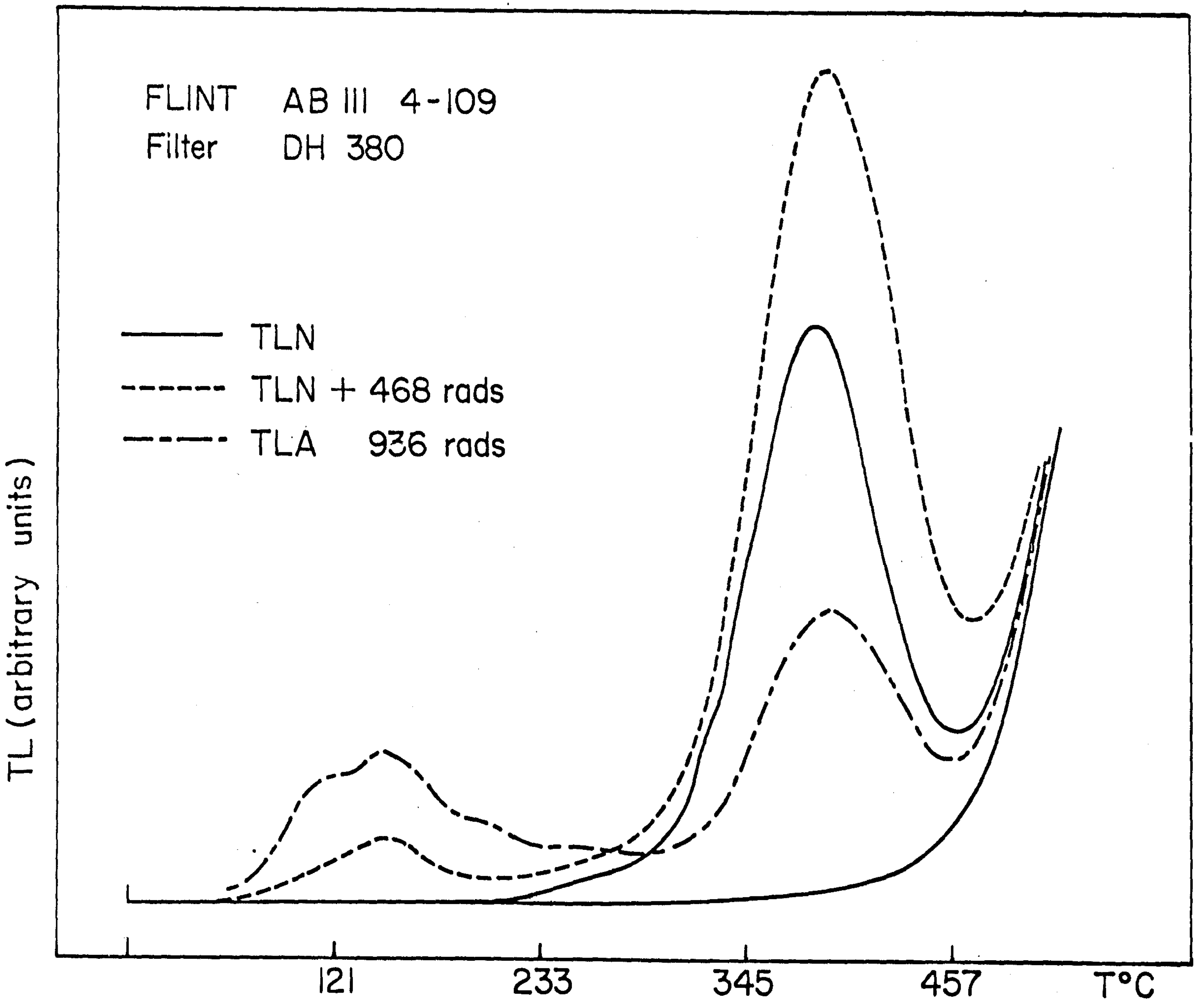
The linearity of TL increase with dose indicate that we are still far from saturation. Extrapolation backwards the "equivalent β-dose" to which sample was submitted since last firing ("first glow growth curve").

Lower curve: The artificial TL of aliquotes reirradiated after TLN + dose emptying is again linear with dose. Extrapolation backward to the zero TL level allows to determine a "supra linear" effect. The sum of the β-equivalent dose and supra linearity dose effect constitute the Archaeological Dose of equation 1. ("second glow growth curve").

Fig. 3- A typical stratigraphic column at Alice Boer. Layer I is the present soil. Layers II to V are described in the text. All contacts between layers II to V are erosionnal surfaces. Note the inclination of contact lines between layers. From field observations it seems that the sedimentation itself was more or less parallel to these inclined contacts. The total thickness of the outcrop is of the order 4 to 5 meters.

Fig. 4- A typical saturated chert from Alice Boer: even the addition of strong β-radiation doses to the natural TL (up to nearly 5000 rads) do not modify the TL answer. All high temperature electron traps were already occupied. For comparison the TLA produced by a 3120 rads laboratory dose is shown.

Fig. 5- Variation of the equivalent β-dose with temperature for the 26 Alice Boer cherts of columns 1 and 5 of table 1. For temperatures above 250°C, the saturated and unsaturated cherts fall within two discrete areas of this diagram. Similar results for a population of cherts from various origins were obtained also by Melcher and Zimmerman (1977).



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TL dating of Alice Boer
Fig. 1a

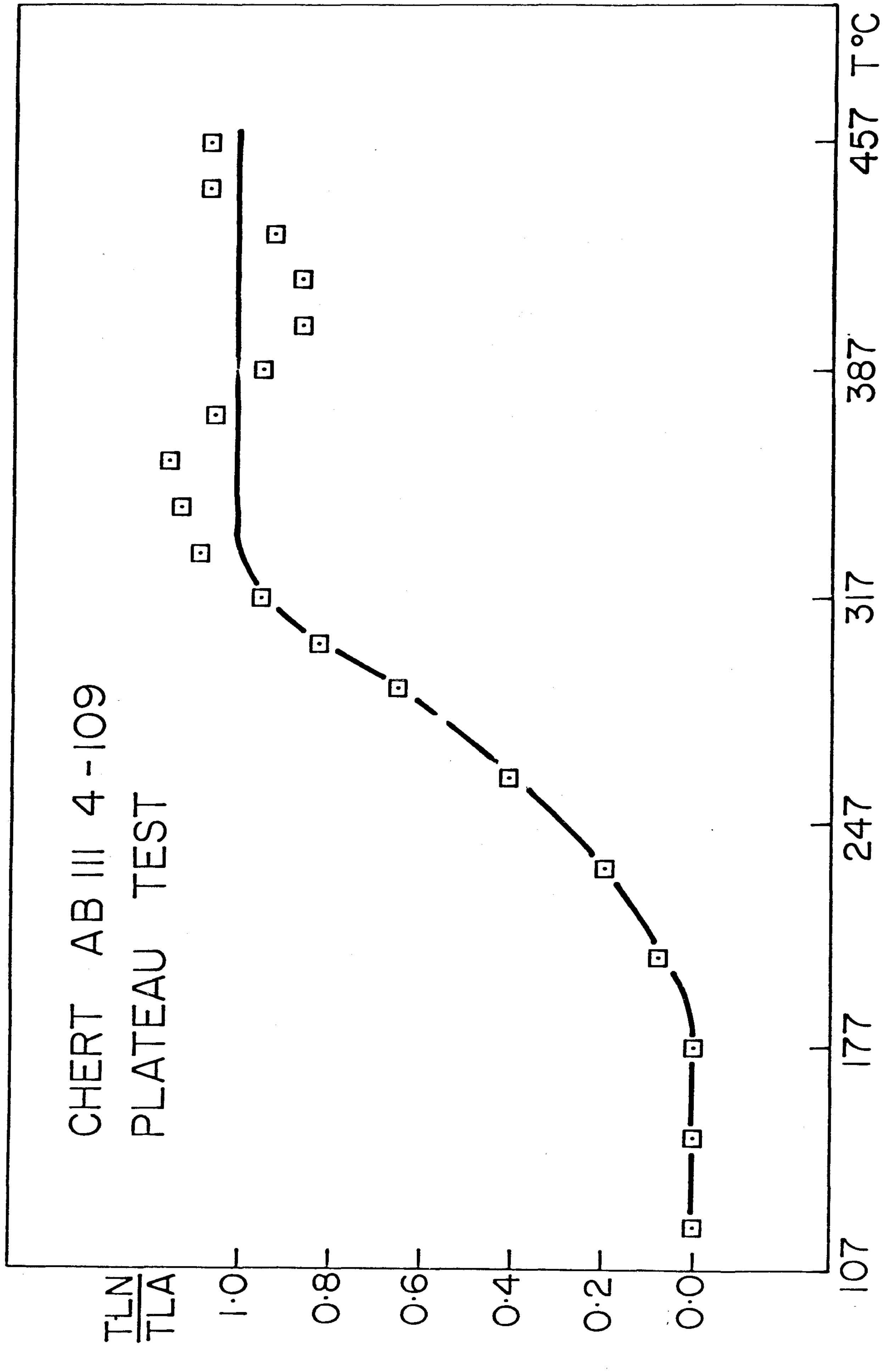

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Fig. 1b

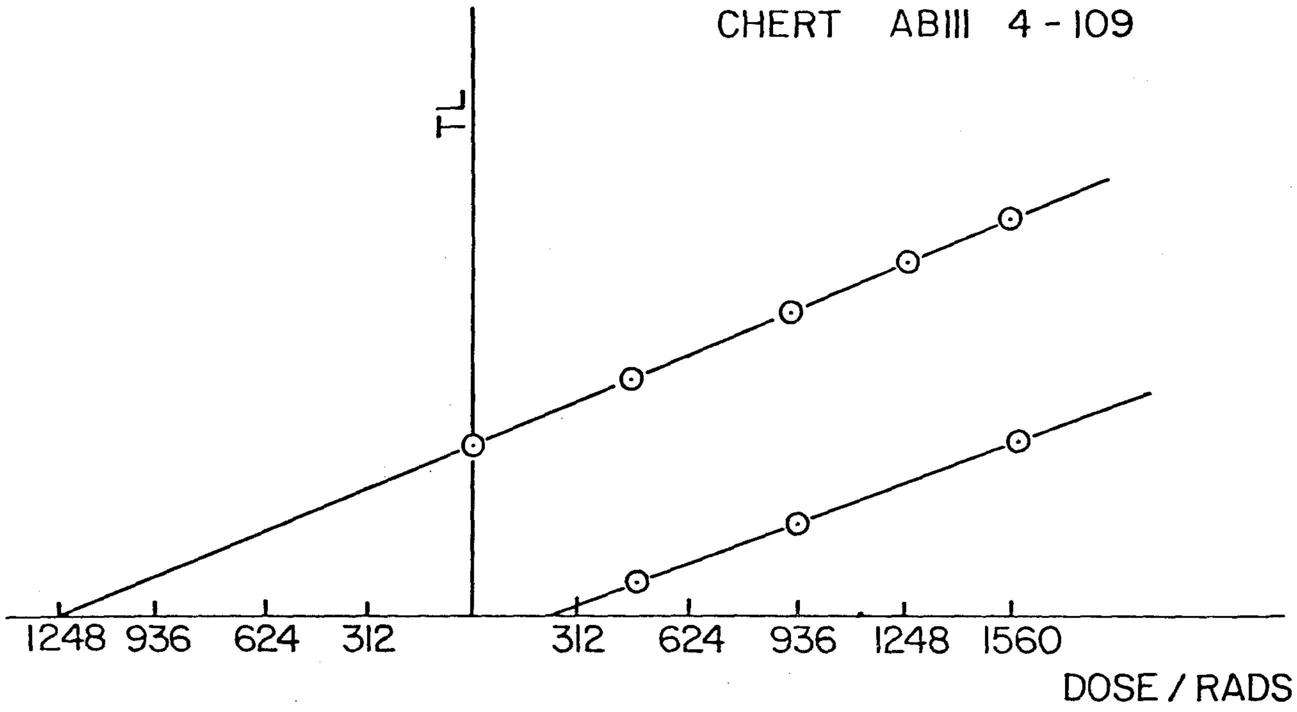

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Fig. 2

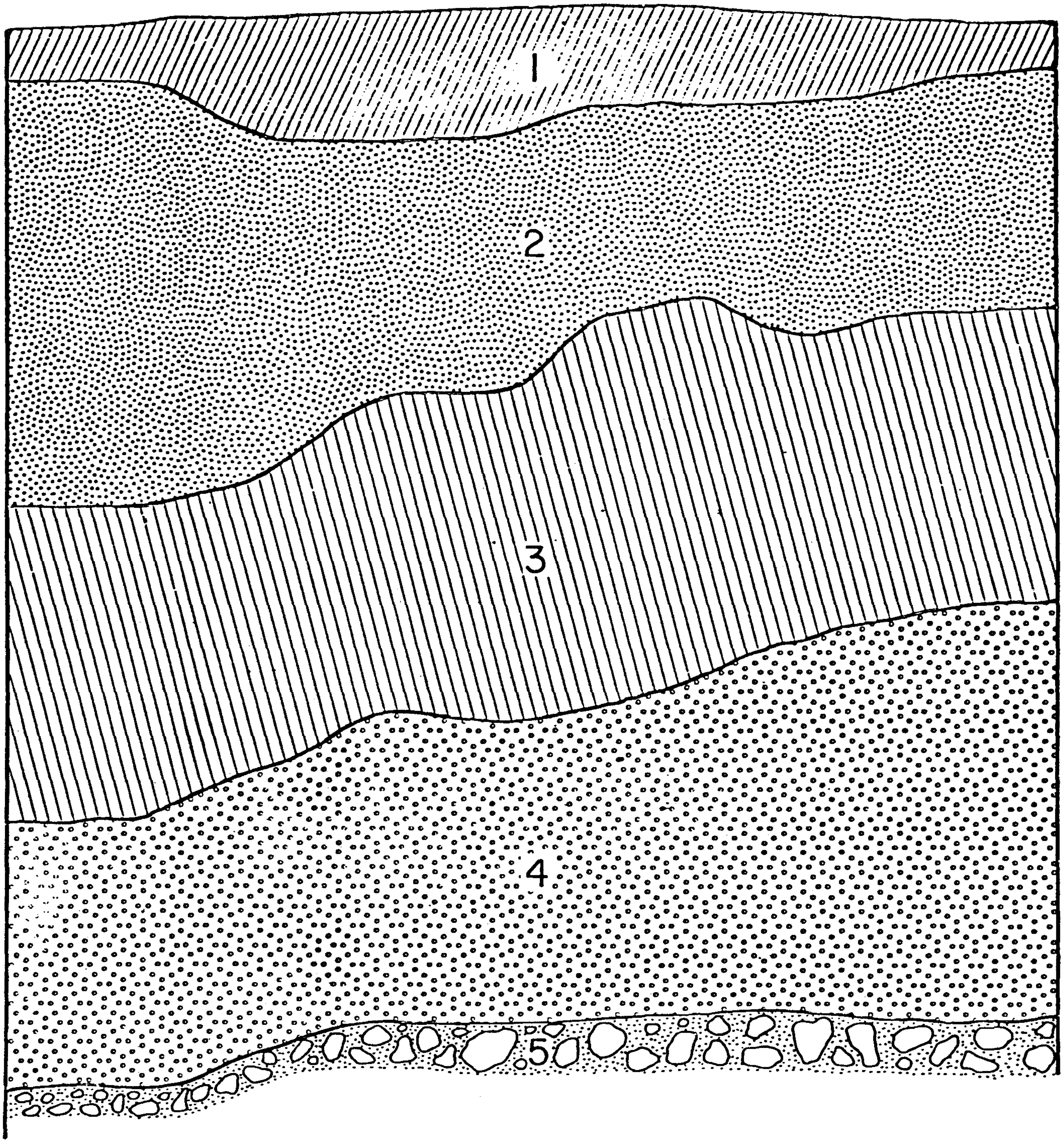

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Fig. 3

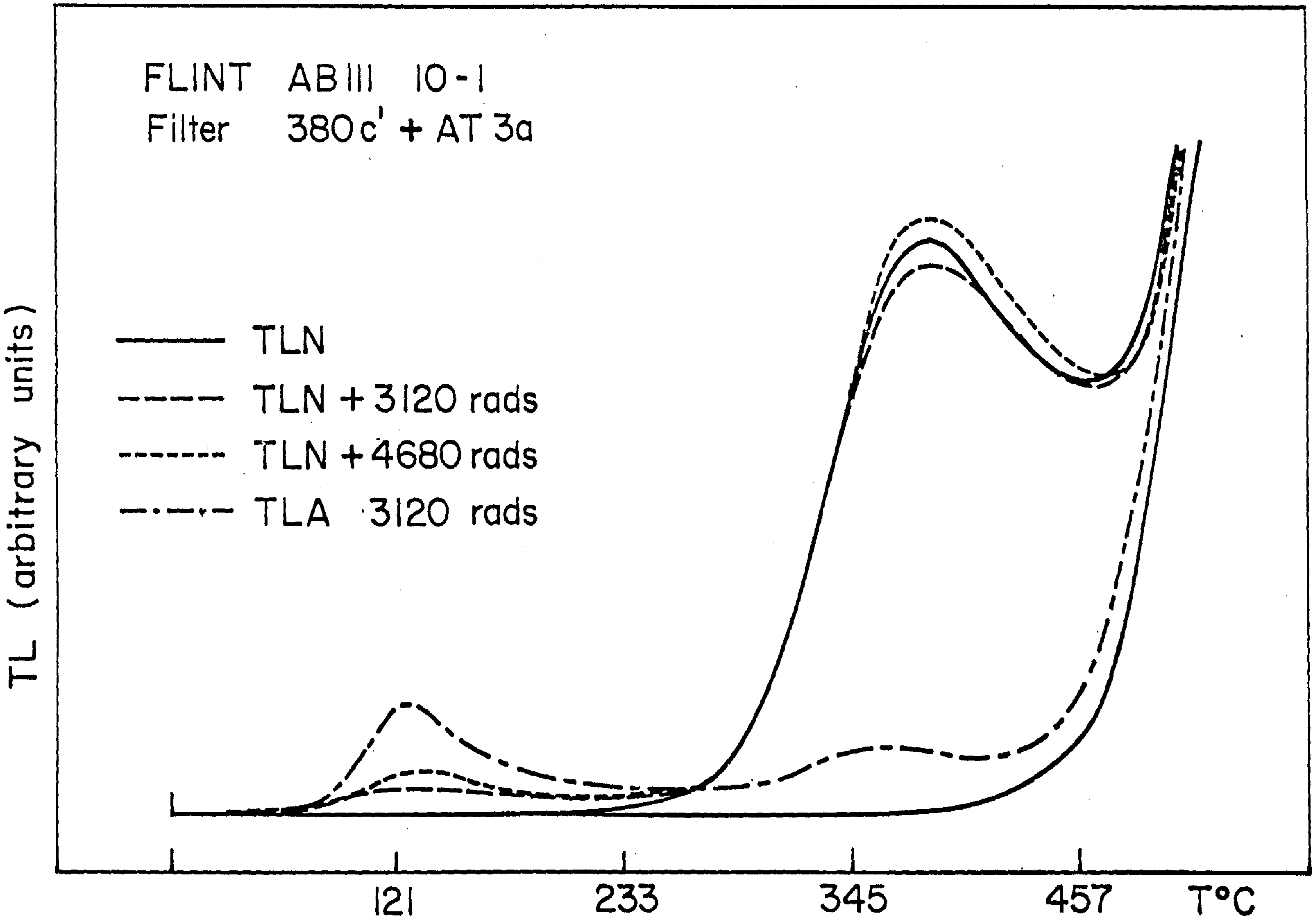

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Fig. 4

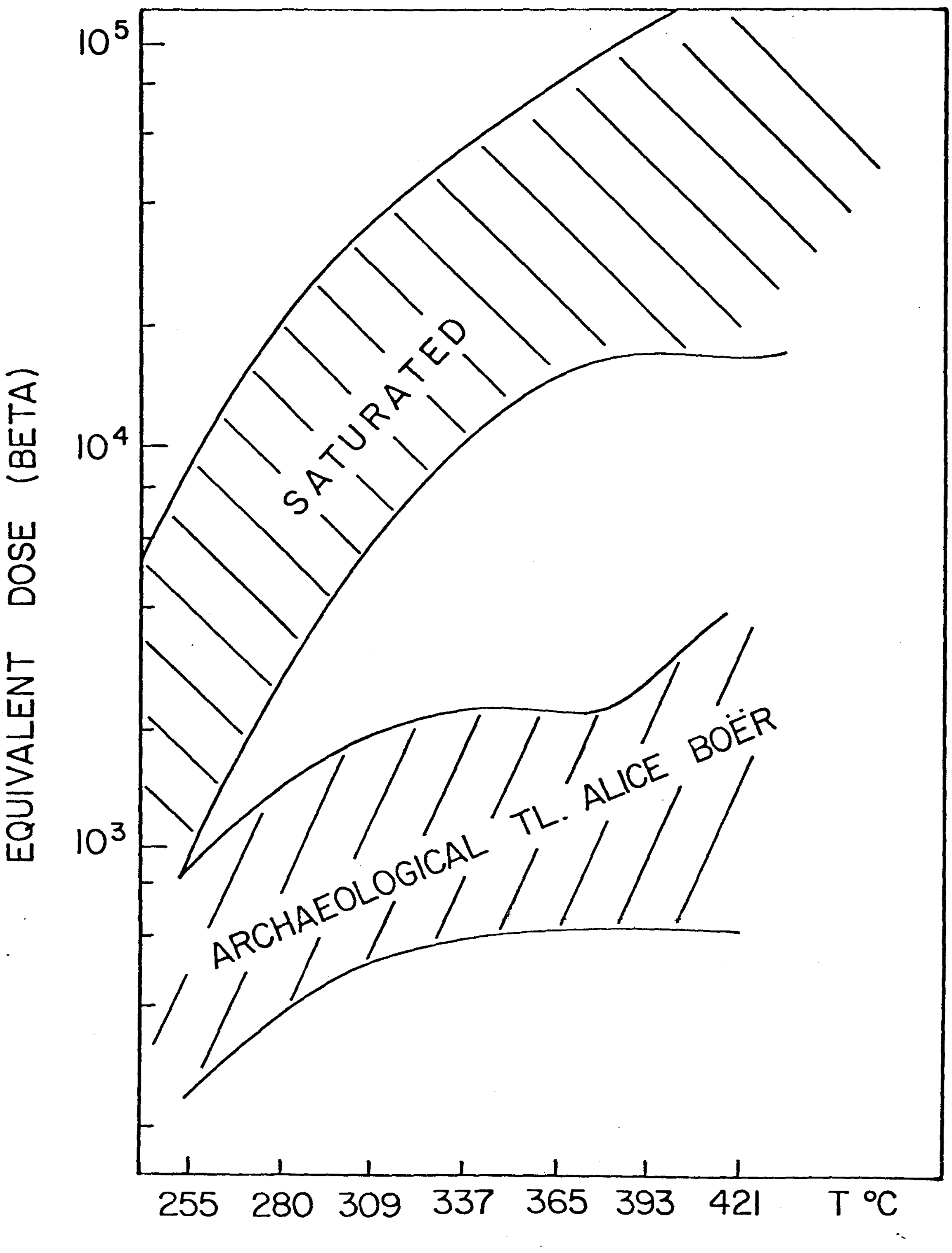

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Fig. 5