Dating by Archaeomagnetic and Thermoluminescent Methods

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Phil. Trans. R. Soc. Lond. A 1970 **269**, 77-88
doi: 10.1098/rsta.1970.0087

Phil. Trans. Roy. Soc. Lond. A. **269**, 77–88 (1970) [77]
Printed in Great Britain

Dating by archaeomagnetic and thermoluminescent methods

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Magnetic measurements on orientated samples from the baked clay walls and floors of pottery kilns, etc., enable the ancient direction of the Earth's magnetic field to be determined. This direction is recorded at the last firing by the phenomenon of thermoremanent magnetism. The time variation of this direction is found from measurements on structures of archaeologically known date and this information can then be used in reverse for dating.

The above technique requires the existence of a reliable archaeological chronology. On the other hand, thermoluminescence measurements on fragments of pottery yield ages that are independent of existing chronologies. Thermoluminescent dating will therefore be valuable in checking the validity of the corrections to radiocarbon ages discussed in the preceding papers.

1. Introduction

It should be made clear at the outset that the phenomena involved in archaeomagnetism and thermoluminescence are quite different. However, it is not unreasonable to link them together in one paper since both involve the storage of chronological information in baked clay and in both cases this information is quite unconnected with the usual properties familiar to a ceramicist.

2. Archaeomagnetism

2.1. *Introduction*

In an earlier paper of these proceedings Bucha described how the ancient *intensity* of the geomagnetic field is recorded in baked clay. The present paper is concerned with the ancient *direction* of the field, and like the intensity it is determined from the *thermoremanent magnetization* (t.r.m.) that is induced in baked clay as it cools down. The two aspects are usually referred to as *archaeomagnetism* when archaeological material is concerned; this is to distinguish from *palaeomagnetism*, the much wider field of study embracing geological material and the whole of time.

Early archaeomagnetic studies were made by Folgheraiter at the end of the nineteenth century (Folgheraiter 1899). Although his results are unreliable because of lack of precision in his measuring apparatus, his discussion of principles is pertinent. He points out, for instance, that the stability of t.r.m. is proven by the differing magnetic directions of the bricks of an ancient wall, or by the similar angles of dip (with respect to the base) that he found in some Aretine vases which had been buried pell-mell for 2000 years. However, the pioneer who laid the foundations of archaeomagnetism as it is today is Professor E. Thellier, working in Paris from 1933 onwards. This account of archaeomagnetism should rightfully be given by him but as he is prevented from attending the meeting I am privileged to do it in his place.

As Professor Thellier has emphasized in a recent review (Thellier 1966) the term 'magnetic dating' should be used with reserve. In principle, knowing the past behaviour of the geomagnetic field direction, it is possible to use the direction recorded in baked clay (that has remained *in situ* since firing) to find the date of firing. In practice, since the variation of direction is an irregular and regional phenomenon, it is necessary to establish the past behaviour by measurements on archaeological structures of known age, for each region in which dating application is to be made. This implies that the method's dating role is in the refinement of an existing chronological framework rather than in the establishment of a new one. Since, as Professor Thellier suggests, a precision of around 20 years is attainable in good conditions, this role should not be belittled but, on the other hand, it is important to avoid giving archaeologists the impression that it is an independent dating technique comparable with radiocarbon.

The establishment of the past geomagnetic behaviour is a slow laborious process taking many years during which the archaeological 'benefit' is minimal. It is doubtful whether it would be undertaken were it not for the geophysical significance of the data obtained—data which are otherwise irretrievable.

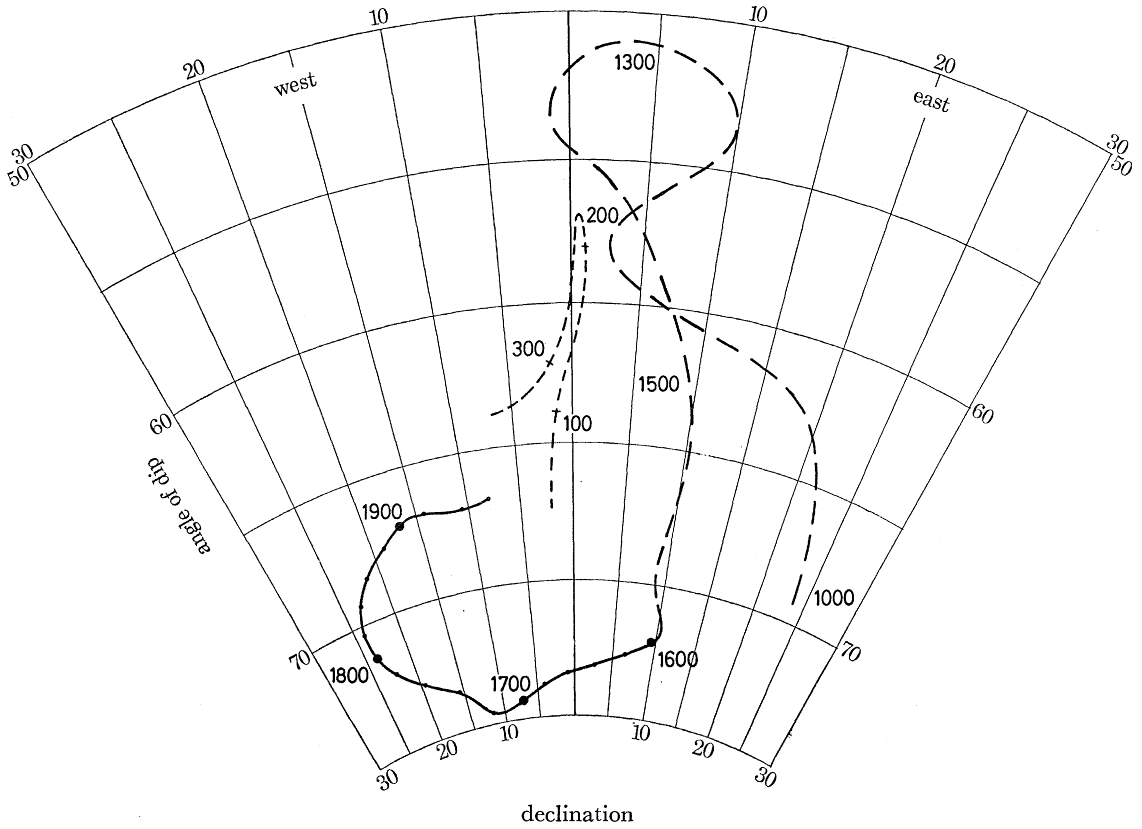

FIGURE 1. The secular variation of the declination, *D*, and the angle of dip, *I*, for London. The date is shown in years A.D. Before A.D. 1580, the data are archaeomagnetic.

2.2. *The secular variation of the geomagnetic direction*

Scientists in London have recorded observations of the declination (*D*) and the angle of dip (or inclination, *I*) since the beginning of the sixteenth century. These measurements have been collated by Bauer (1899) and are the basis of the appropriate part of the curve shown in figure 1. As plotted there the points are a good fit to an incomplete ellipse, and such fitting by Bauer led to the idea that the secular variation is a well-behaved cyclic phenomenon. This is of course directly at variance with the archaeomagnetic evidence for earlier centuries (also shown in figure 1) as well as being inconsistent with geophysical ideas about the cause of the secular variation (see Bullard 1958, for instance). The main geomagnetic dipole field is considered to arise from a fairly steady toroidal current pattern in the fluid core, and eddies in this pattern at the core-mantle boundary produce localized magnetic disturbances (of about 1000 km across) which have a life time of several hundred years. Observations over the past half-century (see Bullard, Freedman, Gellman & Nixon 1950, for instance) indicate that the disturbances drift westward at the rate of 0.2° of longitude per year and this drift, which is interpreted as relative motion of core and mantle, gives rise at a particular measurement station to the observed secular variation.

Although an indication of the past secular variation can be inferred from the present-day disturbances observed along the line of latitude through the measurement station looking westwards (see, for example, Yukutaki & Tachinaka 1968), for various reasons this is not a very accurate or reliable way of delving into the past. It is not certain that the drift-rate has always been the same, nor even always westward; also, the lifetime of the disturbance is relatively short. Consequently the only way to ascertain the secular variation in periods earlier than A.D. 1600 is by archaeomagnetic studies.

Bauer (1899) also records the secular variation for various other parts of the world and these confirm its expected regional nature. This gives occasion to reiterate the prerequisite of an existing chronological framework in each region in which archaeomagnetic studies are to be pursued. Of course this framework may in the future be obtainable from thermoluminescence dating of the same baked clay samples, though it should be borne in mind that the precision necessary is fairly demanding.

2.3. *Thermoremanent magnetism* (*t.r.m.*)

Most clays contain about 5 % of iron oxide and it is the ferrimagnetic and ferromagnetic properties of the minerals magnetic (Fe_3O_4) and haematite (α-Fe_2O_3) that are responsible for the t.r.m. The theoretical basis of t.r.m. has been reviewed and developed by Néel (1955), by Stacey (1963) and by Dunlop & West (1969); in respect of baked clay the main experimental investigations have been by Thellier and his colleagues.

In unbaked clay the magnetic domains in the minerals concerned are orientated randomly. When the clay is heated, thermal agitation allows preferential alinement in the direction of the geomagnetic field and on cooling, this alinement remains 'frozen' resulting in a weak magnetic moment (specific magnetization in the range 10^{-4} to 10^{-1} e.m.u. per gramme) of which the direction is identical with that of the geomagnetic field at the time of cooling. The magnetization becomes 'frozen' at what is termed the *blocking* temperature; this depends upon the size and nature of the magnetic grains but is of course always less than the Curie point—580 °C for magnetite and 675 °C for haematite. Because of the diversity of the grains in it, a given sample exhibits a continuum of blocking temperatures; except for grains with blocking temperatures below about 150 °C the t.r.m. is stable over at least thousands of years. Grains with a lower blocking temperature give rise to a *viscous* component which tends to follow changes in the geomagnetic direction; however, this viscous component is typically less than 5 % of the stable t.r.m. and in measurement its effect can be eliminated by prior heating (and cooling) to 150 °C in zero magnetic field—this destroys the alinement of the viscous grains but leaves the stable t.r.m. untouched.

2.4. *Sample extraction*

In order for baked clay to be useful in determining the ancient direction, its orientation during cooling-down must be accurately known. The best material is from structures such as kilns, ovens and hearths which have remained intact over the centuries of burial. Orientated samples are extracted from such structures by partially enclosing isolated stumps of baked clay in plaster of Paris moulds and marking the direction of geographic North on the horizontal surfaces of the moulds before the stumps are detached. Each isolated stump is obtained in the first place by cutting with a knife, hacking or sawing. In this way the ancient declination and the ancient angle of dip can both be determined.

The remanent directions found in a group of samples from the same structure show appreciable dispersion about the mean, the degree of dispersion varying from structure to structure, sometimes being correlated with type of structure. One cause of this dispersion is the distortion of the Earth's field by the magnetism of the structure itself, so that samples of strongly magnetic material often give poor results. Another cause of dispersion is the occurrence, since last cooling, of relative movement of different parts of the structure. In either case it is essential to take at least a dozen well-distributed samples.

2.5. *Measurement*

Two types of laboratory instrument can be used for measurement of the remanent directions of the samples. In the 'spinner' magnetometer the sample is rotated (e.g. at 300 rev/min) inside an electrical coil system and by determining the phase of the minute alternating voltage that is induced by the rotating magnetic moment of the sample the direction of magnetization can be deduced. In the 'astatic' magnetometer the sample is held near to one of a pair of small magnets which are mounted antiparallel at either end of a rigid vertical bar which is suspended on a quartz or phosphor-bronze fibre; because the torques on each magnet due to the Earth's field are equal and opposite the system only deflects if a sample is brought near to one of the magnets, and by measuring the deflexion for various orientations of the sample the direction of magnetization of the sample can be deduced. Both systems are sensitive to external magnetic and vibratory disturbance despite various compensating devices—in general the astatic type is the more delicate of the two. The spinner type also has the advantage that it can be more readily designed (see, for example, Aitken, Harold, Weaver & Young 1964) for measurements on large samples (e.g. up to 20 cm across) but it has the disadvantage that considerable centrifugal force is experienced by the sample during measurement and this raises problems in mounting.

2.6. *Results for Britain*

Following on from early work at Cambridge (Cook & Belshé 1958), the Oxford Research Laboratory for Archaeology has carried out measurements on some seventy archaeological structures, involving a total of well over a 1000 samples. This has successively been the work of M. R. Harold, G. H. Weaver and H. N. Hawley and the resulting curve obtained for the secular variation is shown in figure 1. It is appropriate to acknowledge here the collaboration of many archaeologists and in particular the valuable advice of G. Webster, B. R. Hartley and J. G. Hurst.

Figure 1 covers the periods A.D. 50 to 350 and A.D. 1000 to A.D. 1600 when the Bauer data begin. In addition, about two dozen prehistoric hearths have been sampled but in general they are not sufficiently well-dated to allow a curve to be drawn. Details of these and of the data on which figure 1 is based can be found in Aitken & Weaver (1962), Aitken, Hawley & Weaver (1963), and Aitken & Hawley (1966, 1967). The precision obtainable varies greatly from structure to structure; in general a well-baked solidly built flat floor (as in many kilns of the thirteenth, fourteenth and fifteenth centuries) gives good results, but for the circular walls of a Romano–British pottery kiln the result is often poor. In terms of standard error of the mean, 'good' corresponds to better than ±1° in I and ±2° in D, and 'poor' to worse than ±3° in I and ±6° in D.

In considering the implications of figure 1 for 'magnetic dating' it is first to be noted that during the Roman period I executes only a slow excursion and return, and D barely changes —rather as though even the geomagnetic field was subjugated by Imperial Rome! Whatever the reason, the change of direction is too slow to allow useful dating application in practice. On the other hand, for the six centuries following A.D. 1000 the movement is fairly dramatic and, were it not for the unfortunate fact that the direction for A.D. 1200 is about the same as that for A.D. 1400, these would be excellent centuries for application. Nevertheless, the method is of use in these periods, particularly if the archaeological evidence indicates one branch of the curve rather than the other. Of course from the fifteenth century onwards the method is at its prime and a 'good' structure can be placed in a span of a quarter of a century.

Turning now to the geophysical aspects of the results of figure 1, there is first of all the direct confirmation that the secular variation is irregular in its behaviour, as noted earlier. One implication of this is that, assuming the core/mantle drift always to have been in the same direction as at present (giving rise to the westward drift of magnetic disturbances), the eddies at the core boundary responsible for the secular variation have a lifetime of only a few hundred years (for further discussion see Aitken & Weaver 1964). It is also of interest to note that the average direction is much closer to that corresponding to an axial centred dipole than to the direction (I = 70°, D = 18° W) that corresponds to the dipole deduced from spherical harmonic analysis of the present-day field.

2.7. *Results elsewhere*

Archaeomagnetic results for D and I have also been obtained in various other parts of the world; notably in France (see Thellier 1966), Japan (Kawai *et al.* 1965), Arizona (Du Bois 1967), Iceland (Brynjólfsson 1957) and Russia (Burlatskaya *et al.* 1970). From a comparison of some of these results Kawai & Hirooka (1967) have inferred that a major part of the secular variation arises from movement of the main geomagnetic dipole. Although this may explain some of the broad features of the secular variation in different parts of the world it can hardly account for the detailed behaviour and allow magnetic dating in a region that is uncharted archaeomagnetically.

Archaeomagnetic measurements have also been made on the lava flows of Mount Etna, first by Chevallier (1928) and latterly by Tanguy (1970).

2.8. *Measurements on bricks and vases*

Because of the regular way in which bricks are stacked while being baked, it is possible to use them for finding the ancient value of I—as was early demonstrated by Thellier (1936, 1938). Extensive work using bricks has also been carried out in the U.S.S.R. (see, for example, Burlatskaya *et al.* 1970). It is also possible to deduce the ancient value of I by measurements on a vase—as was first demonstrated by Folgeraiter (1899)—as long as the vase is sufficiently heavily ornamented or glazed to necessitate that it was baked standing on its base on a horizontal surface. This is not usually the case for archaeological pottery; however, useful results have been obtained from Chinese Yuëh ware (Aitken 1958).

3. THERMOLUMINESCENT DATING

3.1. *Introduction*

Thermoluminescence is emission of light when a substance is heated and it is a phenomenon exhibited to varying degrees by many minerals. It is quite different to red-hot glow and represents the release of energy which has been stored as trapped electrons in the crystal lattice of the minerals. The stored energy is acquired by absorption from any nuclear radiation to which the mineral may have been exposed; consequently the amount of thermoluminescence observed is proportional to the overall dose of radiation which has been received.

The phenomenon has been studied for several hundred years—for example, by Sir Robert Boyle (1663)—but it is only in the past decade that, stemming from the work of Daniels, Boyd & Saunders (1953), the effect has been utilized in practical applications. The most important of these has been in measuring the accumulated exposure to radiation of patients undergoing radiotherapy and of research workers subject to nuclear hazard. For these purposes highly sensitive natural minerals such as calcium fluoride and artificially prepared phosphors such as lithium fluoride are used (see, for example, Cameron, Suntharalingan & Kenney 1968). The thermoluminescence (t.l.) observed is a measure of the cumulative dose of radiation to which the phosphor has been exposed since the last previous heating.

It is possible to date ancient pottery by t.l. because in most fabrics there are mineral constituents (e.g. quartz) that have this property of accumulating thermoluminescence and they receive a small but significant dosage of nuclear radiation which over thousands of years adds up to an appreciable total. This dosage comes from radioactive impurities (a few parts per million of uranium and thorium, a few per cent of potassium) in the clay of the pottery itself, and also, but to a lesser extent, from the radioactive impurities in the surrounding burial soil; cosmic rays make only a minor contribution to the dose.

Heating to above 500 °C removes the accumulated thermoluminescence and consequently the firing of clay into pottery sets the 'thermoluminescent clock' to zero. Thereafter the thermoluminescence grows with time. The growth is also dependent on the particular thermoluminescence constituents in a given pottery fragment as well as on the radiation dose-rate as explained above. By laboratory measurements the thermoluminescence carried by a pottery fragment can be evaluated in terms of the '*accumulated radiation dose*'. This is determined by exposing the pottery fragment to radiation from an artificial radioisotope and finding the amount of radiation required to induce a level of thermoluminescence equal to the 'natural' thermoluminescence carried by the fragment.

By measuring the amounts of uranium, thorium and potassium present in the pottery fragment and in the soil, the radiation dose received by the fragment each year can be calculated. In principle the age is then directly obtained as

$$\text{age} = \frac{\text{accumulated radiation dose}}{\text{dose per year}},$$

though in practice various factors make the determination much more complicated.

Early work on the t.l. dating of ancient pottery was carried out by Grogler, Houtermans & Stauffer (1960) and by Kennedy & Knopff (1960). Since then reports have been made by Aitken, Tite & Reid (1964), Ichikawa (1965), Mazess & Zimmerman (1966), Ralph & Han (1966), Tite (1966), Fleming (1966), Zimmerman (1967), Aitken, Zimmerman & Fleming (1968), Mejdahl (1969), and Zimmerman & Huxtable (1969). In the next section of this paper some salient points in the development of the technique at the Oxford Research Laboratory for Archaeology will be outlined. At present an absolute accuracy of around ±10% is achieved; eventually it is hoped to improve this to ±5% but for various reasons that is likely to be the limit of precision. This is somewhat poorer than is obtainable with radiocarbon dating, though when the full implications of the short-term fluctuations in ^{14}C concentration are worked out this may not really be the case in some periods. However, the t.l. method certainly has the advantage that the event dated is the actual firing of the pottery by ancient man, whereas in the case of radiocarbon dating of wood or charcoal the event dated is the felling of a tree and this may precede involvement with ancient man by one or two hundred years. Also, because of their durability, pottery fragments are relatively abundant on most archaeological sites.

3.2. *Development at Oxford*

Following helpful advice from Professor George Kennedy of the University of California, work at Oxford began in 1961 as the thesis topic of M. S. Tite; at various later stages of the project the development was carried on by Jeanette Reid, S. J. Fleming and D. W. Zimmerman. Early investigations established that the build-up of t.l. was due to the filling of existing electron (or hole) traps rather than to the creation of new traps and studies were made of the t.l. response of pottery to α, β and γ radiations. However, no satisfactory dating was achieved because of the predominance of 'spurious' t.l.—that is, t.l. induced not by radiation but by the process of grinding the pottery into powder for measurement or by the mere mechanical handling of the powder. The project was about to be abandoned as impracticable on this account when in 1963, following a suggestion by Dr E. Hamilton, it was found that by making the measurement in an atmosphere of nitrogen, the spurious t.l. was suppressed and only the true radiation-induced t.l. remained. This use of nitrogen completely altered the dating situation and when a new test was made with known-age pottery fragments a good proportionality was found between t.l. age and known age (Aitken *et al.* 1964).

However in absolute terms the ages were low by a factor of about 5 (Tite 1966) and so, although the relative ages of different pottery fragments could be found, there was no question of the method providing an independent chronology. Research was continued and, following work in this direction at the universities of Birmingham (Fremlin & Srirath 1964) and Kyoto (Ichikawa 1965), it was realized that a major part of the difficulty was because the thermoluminescence was carried mainly by quartz and other mineral inclusions embedded in the clay fabric of the pottery. Since the uranium and thorium were carried in the clay fabric rather than in the inclusions, the correct evaluation of the radiation dose received per year was in general much more difficult than had been assumed. However, for inclusions in the size range 0.1 to 0.15 mm and for fine grains of less than 0.005 mm the situation is fairly straightforward, but it is necessary to have one or other of these ranges separated out from the pottery in order to make the thermoluminescent measurements. Magnetic and density techniques were used to separate out crystalline grains of the former size range and it was demonstrated that this 'inclusion dating' could give correct absolute ages (Fleming 1966, 1970). The alternative approach of separating out the fine grains was achieved using sedimentation techniques, and again correct absolute ages were obtained (Zimmerman 1967, 1968). This 'fine-grain' technique is simpler in practice and is the one used routinely at present. Eventually both techniques will be applied to a given sample; this will give increased reliability since there are a number of possible sources of error which, if present, would affect the two techniques to different degrees.

One such possibility is in the assessment of the 'supralinearity' correction by which allowance is made for the non-linear acquisition of t.l. observed in some samples (Tite 1966; Fleming 1970). However, that is a laboratory problem and in the context of these proceedings it is more appropriate to mention some difficulties associated with the burial situation of the pottery fragment; it seems likely that these will limit the accuracy at the 5 % level already mentioned.

TABLE 1. TYPICAL DOSE-RATES IN POTTERY (rad/year)

internal	
effective† α dose-rate	0.225
β dose-rate from U and Th	0.052
β dose-rate from ^{40}K	0.131
external	
γ dose-rate from soil	0.077
cosmic ray dose-rate	0.015
total	0.500

† This assumes a '*k* value' of 0.15. This is the ratio of the t.l. produced by a given absorbed dose from α particles to the t.l. produced by the same absorbed dose from β particles.

3.3. *Environmental factors*

Table 1 gives typical values for the annual dosages in pottery. From this it will be seen that for fine-grain dating the contribution from the soil is about 15 % of the total. For inclusion dating the soil contribution is about 28 % of the total, since for the grain-size used in this technique the α particle contribution is negligible (the uranium and thorium are predominantly in the clay-matrix and the α particle range is much smaller than the grain diameter). If the radioactive content of the soil is greater than that of the pot then the soil contribution becomes more important still. About 95 % of this dose originates within a 30 cm radius (and 50 % from within a 7 cm radius); it is therefore important first, that the fragments should have been buried to a depth of at least 30 cm for the major portion of the burial time and secondly, that the material lying within 30 cm of the potsherds should be homogeneous. The ideal context is the middle of a pit or ditch. Heterogeneous contexts such as destruction layers, and tombs, are less satisfactory.

Even in homogeneous situations there are a number of difficulties associated with the evaluation of the γ dosage from measurements on an extracted soil sample. The most obvious effect is that of the presence of ground water (which is low in radioactivity) directly diluting the radioactive concentration of the burial medium by weight. Also, appreciable uncertainty exists as to the degree to which radon emanates from the soil when in the actual burial situation. Ninety-eight per cent of the total γ ray energy associated with the uranium chain lies beyond this gaseous decay product, and it is well known that a significant amount of radon diffuses into the air from the soil. This is less in wet weather than in dry so that attenuation of the radon emanation effect to some extent compensates the direct diluting effect of soil wetness. However, it must also be borne in mind that loss of radon by diffusion into the air is most serious in, say, the upper metre of soil.

Because of the foregoing, determination of the radioactive content of a soil sample gives only a first-order evaluation of the γ dosage. This is usually adequate for the fine-grain technique, but for the inclusion technique (in which the soil contribution is sometimes as high as

55 %) it is desirable to use an *in situ* method of measuring the γ dosage. This can be conveniently achieved (Aitken 1969) by placing a small capsule of natural fluorite (specially selected by M.B.L.E., Brussels, for high t.l. sensitivity) in as similar as possible a burial situation to that from which the pottery fragment has been removed. The phosphor sensitivity is sufficiently high for accurate measurements to be made within a few weeks but to average out the seasonal variations mentioned above the capsule is left in position for a year when possible. Doubt about the γ dosage from the soil is then centred about consideration as to what degree such short-term measurement correctly reflects the situation of long-term archaeological burial.

The restriction upon accuracy due to uncertainty about burial circumstances is a serious limitation in t.l. dating at present. At some stage in the future it is hoped to remove this limitation by using the fine-grain technique and the inclusion technique in conjunction; by subtracting the equivalent radiation dose measured by the latter from that measured by the former, one is left with the effective dose due to α radiation, so that a knowledge of the environmental dose would no longer be required.

The wetness of the burial situation also affects the dose-rate due to radioisotopes in the fragment itself. The measurement of radioactive content is made upon a dry sample, so that correction must be made for the water content of the fragment typical of its burial state. The saturation water content of most of pottery is between 10 and 20 % by mass. This can be measured for each fragment and for the wet climates of NW Europe it is fairly safe to assume that the fragment has been permanently saturated. Where the climate is intermediate then the saturation water content at least indicates the upper limit of the correction to be applied. Here is one aspect at any rate in which the British climate is advantageous!

TABLE 2. SOME PRELIMINARY T.L. DATES: FINE-GRAIN TECHNIQUE

(Zimmerman & Huxtable 1970)

	conventional carbon-14	t.l.	
European Middle Neolithic: linear Bandkeramik pottery			
Bylany	*ca.* 4350 B.C.	5330 B.C.	± 700
Hienheim	4175	4610	± 600
Stein	*ca.* 4000	5350	± 700
Aegean: Lefkandi			
EB III	2170	2070	± 400
MH IIIA	1700 (pottery style)	1980	± 400

3.4. *Some preliminary results*

The first major application being made is to the linear Bandkeramik pottery of the Middle Neolithic of Central Europe. This was chosen because even without correction for reservoir fluctuation, radiocarbon dates for this period were some 1500 years earlier than the date-range 2500 to 3000 B.C. to which it had been ascribed on the basis of connexions with the Aegean and Egypt. When the radiocarbon dates are corrected by means of the Bristlecone Pine data the discrepancy is increased by a further 600 or 700 years; they are then consistent with the 'long' chronology proposed by Neustupny (1968) from a reinterpretation of the archaeological evidence.

The preliminary t.l. dates obtained by Zimmerman & Huxtable (1970) given in table 2 provide additional support for the 'long' chronology though they are not really sufficiently precise to confirm (or dispute) the reality of the radiocarbon corrections. Even so the t.l. evidence, being from a completely different technique, should help to dissuade from their continued adherence to the 'short' chronology those archaeologists who reject the radiocarbon dates (whether or not corrected).

The samples used for the results of table 2 were not ideal, for various different reasons. Further collection of material has now taken place with stricter regard for assessment of soil dosage (which in hindsight from the preliminary measurements is more important for some of the contexts concerned than on most sites). When measurement of this is complete it is hoped that the limits of accuracy will be significantly reduced below the 10 % level at present quoted.

3.5. *Authenticity testing*

The importance of the γ dose from the soil means that it is only possible to use t.l. dating on material specially collected from current excavations. However, t.l. provides museum curators with a very powerful independent judgement of what on their shelves is imitative and what is genuine (see, for example, Fleming, Moss & Joseph 1970) since for testing authenticity it is usually a question of distinguishing between an age of less than 100 years and one of upwards of several hundred. In such circumstances it is adequate to assume a typical value for the γ dosage. The sample for measurement is obtained by drilling a small hole in an unobtrusive position; at present successful application is being made to terra-cottas and pottery; because of its hardness porcelain presents special problems.

3.6. *Extension to other materials*

One essential of t.l. dating is that the level of stored t.l. in the specimen is zero at the time of the event being dated. For pottery this is achieved by the heating to above 500 °C that occurs during firing; burnt flint, burnt stone and volcanic lava also have their 't.l. clock' set to zero in this way. For shell and possibly bone the t.l. level may be zero on formation.

However, there are other important requirements that must be met. The t.l. properties of the substance concerned must be satisfactory: the level of spurious t.l. must be small, the growth of the t.l. must be reasonably linear and the temperature of the t.l. glow peak must be sufficiently high for electrons to remain stably trapped over the time period concerned. Encouraging preliminary measurements have been obtained in the dating of lava as old as 70000 years (Aitken & Fleming 1970), and in studies of the t.l. of shell (Johnson & Blanchard 1967). Another requirement is that the radioisotopes responsible for the radiation dosage must be long-lived or supported by a long-lived parent and this aspect requires further investigation for both lava and shell.

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