THE DETERMINATION OF ARCHAEOMAGNETIC FIELD VARIATIONS FROM ARCHAEOLOGICAL CERAMICS

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Archaeomagnetism, the study of the Earth's Magnetic Field during archaeological times, relies upon the fact that certain objects, either man-made or naturally occurring, "record" the strength and the direction of the magnetic field in which they are formed. The most common source material for this subject is fired clay which was used for pottery, kilns and bricks. Examples of other less common sources are sun-dried adobe bricks, coins, obsidian, lava flows, and sediments such as in-fills in ditches.

Magnetic properties of fired clays

The magnetic grains in a piece of clay can be likened to small compass needles which indicate the direction in which they are magnetised (Fig. 1). If the clay is heated above a certain temperature called the Curie point (typically 580–670°C) these magnetic grains are then randomized so that the sample has no net magnetization. When the sample cools in the presence of a magnetic field, the "compass needles" tend to align themselves with the field: the stronger the field the greater the degree of alignment. So we end up with a sample which has a magnetization (called the Natural Remanent Magnetization, or NRM) which is parallel to the ambient magnetic field and proportional to the strength of the field (Nagata 1943).

If such a fired artefact is found in situ, it may be possible to retrieve the original direction of the Earth's magnetic field when the sample was last fired. Changes in the direction of the Earth's magnetic field in time are known as secular variation. Records of secular variation by direct observation date back to about the 17th century (Fig. 2) (Aitken 1974), and by using well-dated archaeological samples the curves shown in fig. 2 have been extended back in time (e.g. Aitken 1970). These curves can be used to help archaeologists date some of their samples as long as the samples were found in situ.

However, most objects found on archaeological sites are not found in the exact position in which they were made, so we cannot deduce anything about the direction of the Earth's magnetic field from such samples. But we can derive values of the strength of the magnetic field when the sample was made. Direct records of measurements of the strength of the field only go back as far as the early 19th century, so we have to rely on archaeomagnetism to tell us about the way in which the strength of the Earth's magnetic field varied with time before this.

In principle the way to do this is quite straightforward (cf. e. g. Thellier and Thellier 1959). Having measured the value of the NRM acquired in the ancient magnetic field, B_{anc}, we re-fire the sample above its Curie point and let it cool in a known laboratory magnetic field, B_{lab}. The sample acquires a new magnetization called a TRM (thermoremanent magnetization) which is then measured. We deduce the value of B_{anc} from the equation

$$\frac{NRM}{TRM} = \frac{B_{anc}}{B_{lab}}$$

Although it may seem a very easy thing to do, there are many problems involved in actually carrying out this procedure. The most important of these is that when a sample is re-heated, the actual heating itself alters the chemical, and sometimes therefore the magnetic properties of the minerals, and this makes it difficult to decide

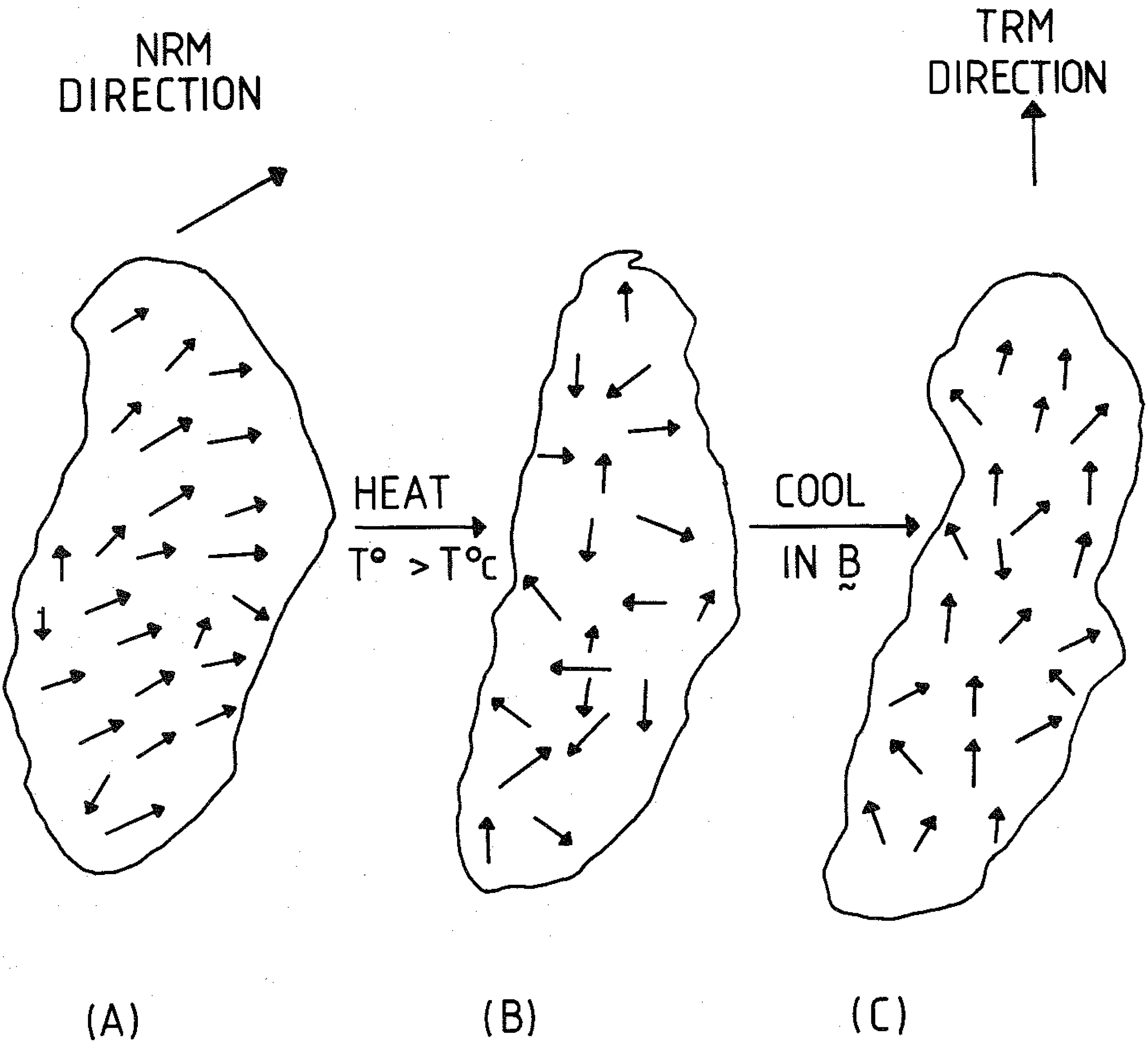

Fig.1

A schematic representation of how clay can be magnetized by heating. Initially, (a), the magnetic grains are magnetized in a particular direction as shown by the arrows. When the clay is heated to some temperature above its Curie point, T_c, the directions of magnetization become randomized, as in (b). In fact, the clay is no longer magnetic above its Curie point. As the clay cools in a magnetic field, $\underline{B}$, the grains tend to align themselves with this field and so the sample acquires a net magnetization as shown in (c).

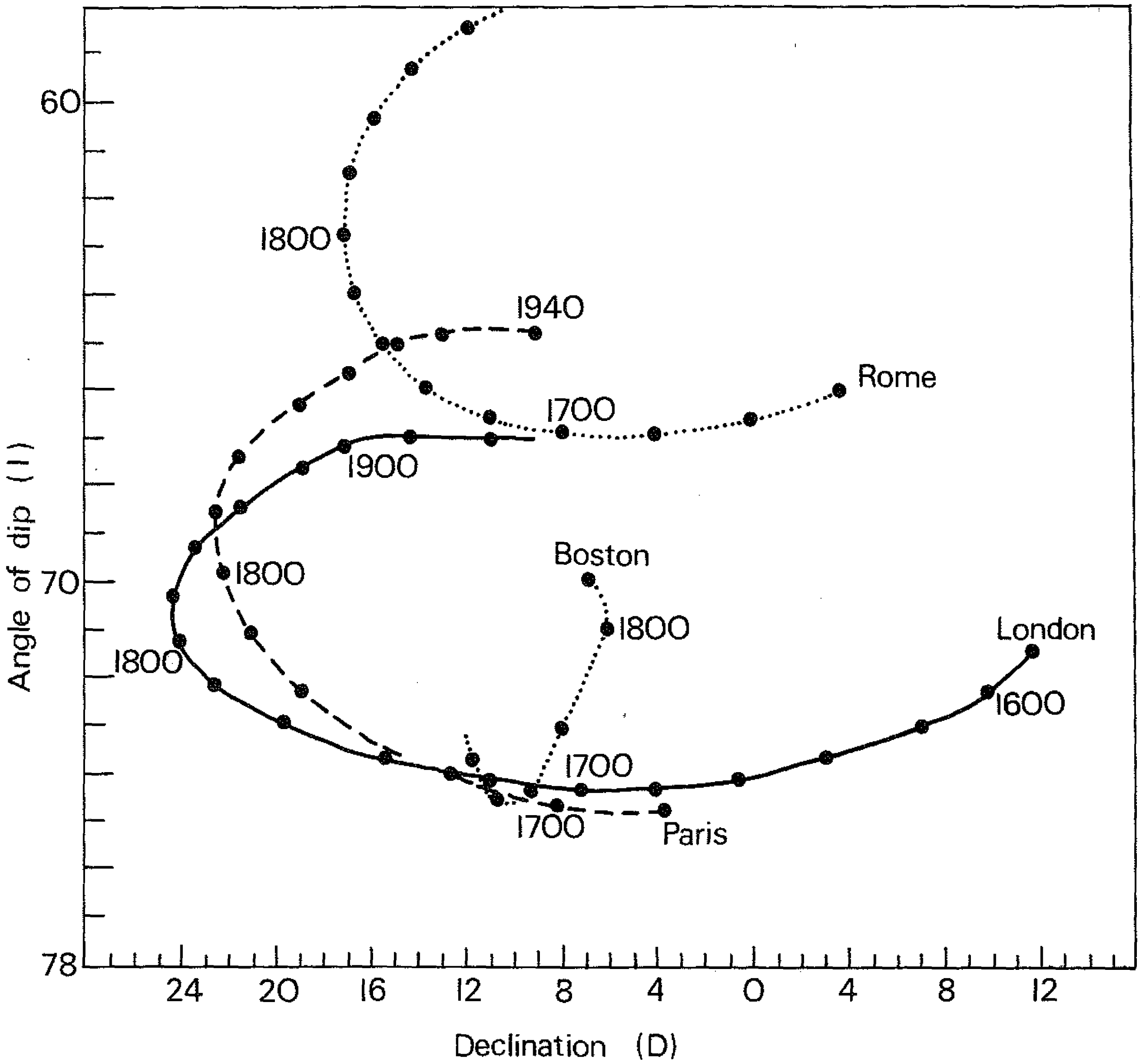

Fig. 2 Secular variation from historical records—London, Paris, Rome and Boston. The time scale is indicated by dots at 20 year intervals. (Aitken 1974.)

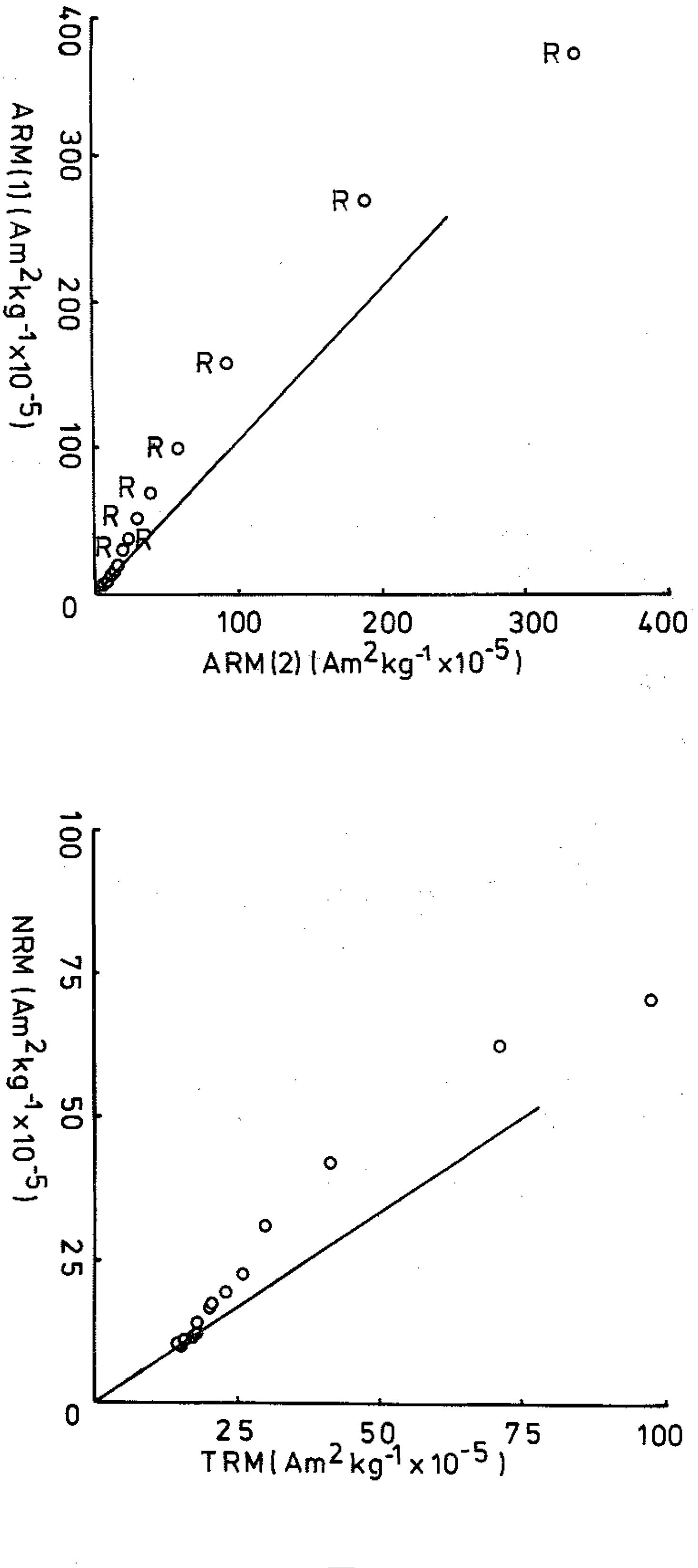

Fig. 3 Graphs of all the data for the NRM v TRM and ARM(1) v ARM(2) plots. The points labelled 'R' are rejected because they do not lie on the straight line of slope = 1.00 drawn on the plot of ARM(1) v ARM(2).

just how comparable the NRM and TRM are. In order to overcome this problem, ways have been found of subdividing the magnetization of the sample into a magnetic "spectrum". We can then look at different parts of this "spectrum" and hope to find regions which have not been altered by the refiring process. Fig. 3 shows a typical result for a piece of pottery using a method developed by John Shaw, at Liverpool (Shaw 1974). The first graph shows a plot of what can be thought of as an artificial remanent magnetization before (ARM1) and after (ARM2) the re-firing process. That part of the magnetic spectrum unaffected by the heating should lie on a straight line of slope = 1 and the altered part of the spectrum is indicated by points labelled R. The second graph is a plot of the spectra for the NRM and TRM, and that part of the spectrum which showed alteration in the first graph is rejected here. The best-fitting straight line is then drawn through the rest of the points, and the value of B_{anc} is determined from

$$\frac{B_{anc}}{B_{lab}} = \frac{NRM}{TRM} \text{ slope}$$

In this case, slope = 0.84, B_{lab} = 50 μT (microTesla) and B_{anc} = 42 μT. The techniques developed by archaeomagnetists over the last ten years have improved the accuracy of the determinations of ancient field strength, and with good samples we can now produce results with errors of less than ± 5%.

Interpretation of Results

Before looking at the implications and usefulness of this work, I will briefly describe the Earth's magnetic field as it exists today. Essentially, the Earth's magnetic field looks like that due to a strong bar magnet, or dipole, at the centre of the Earth, the field being twice as strong at the poles (~ 60μT) as at the equator (30μT), and it shows a smooth variation with latitude. I use the word essentially because such a model can describe on average 95% of the field, and this 95% is called the Dipole Field. The other 5% is simply referred to as the non-dipole field, and exists as localised centres of varying strengths which grow and decay with time and which also appear to be drifting westwards at about 20° of longitude every 100 years. Even though this non-dipole field is on average only 5% of the total field, locally it can be as big as 18 μT, which can be a large proportion of the total field at that point.

Direct measurements of the strength of the magnetic field over the last 150 years have shown that the dipole field has been decreasing at about 5% per century (Fig. 4) (Smith 1967). Our aim as archaeomagnetists is to find out how both the dipole and non dipole fields have changed over the last 10,000 years. What we find by our studies in any one given area is how the total field (which is all we can measure) has changed at that place. Results obtained over the last 10 years or so (e.g. Fig. 5 and Fig. 6) indicate that the field has been changing much more rapidly in the past than we had previously expected from the information from direct observations. With such rapid variations in the magnetic field, the curves of magnetic field against time may prove a valuable dating adjunct for archaeologists. However, because we do not know how much of these changes is caused by the dipole field (world-wide effect) and how much is caused by non-dipole fields (local effect) we must for the present build up separate curves for particular regions (typically the size of, say, the British Isles).

Examples of Results

Two sets of data have been produced in our laboratory in Liverpool over the last six years. In Fig. 5, the results for Peru obtained by Nigel Gunn are presented,

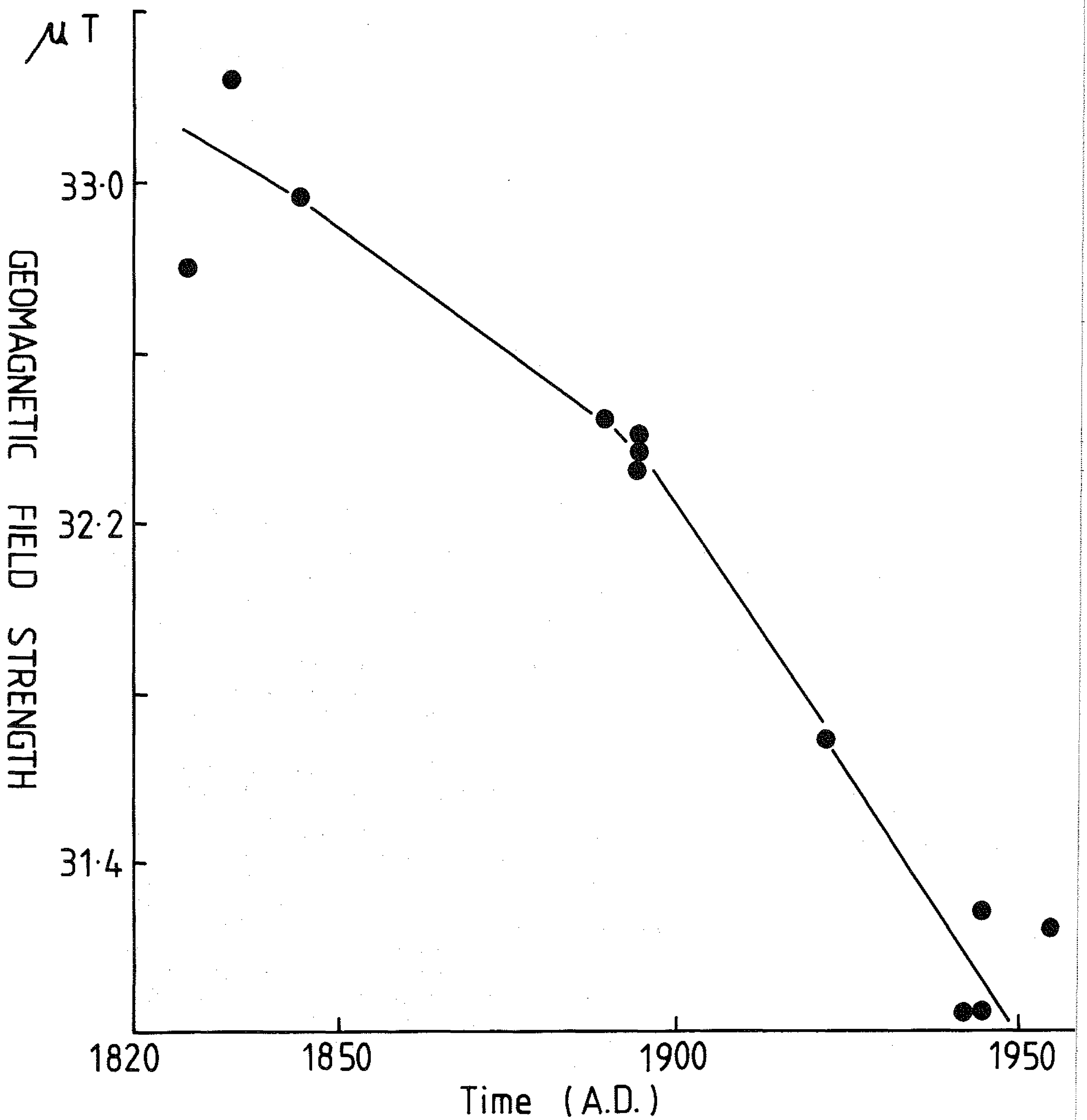

Fig. 4 Variation of the geomagnetic field strength with time since direct field observations were first made. The vertical axis shows the value of the magnetic field at the equator, assuming a dipole field model. (Smith, 1967.)

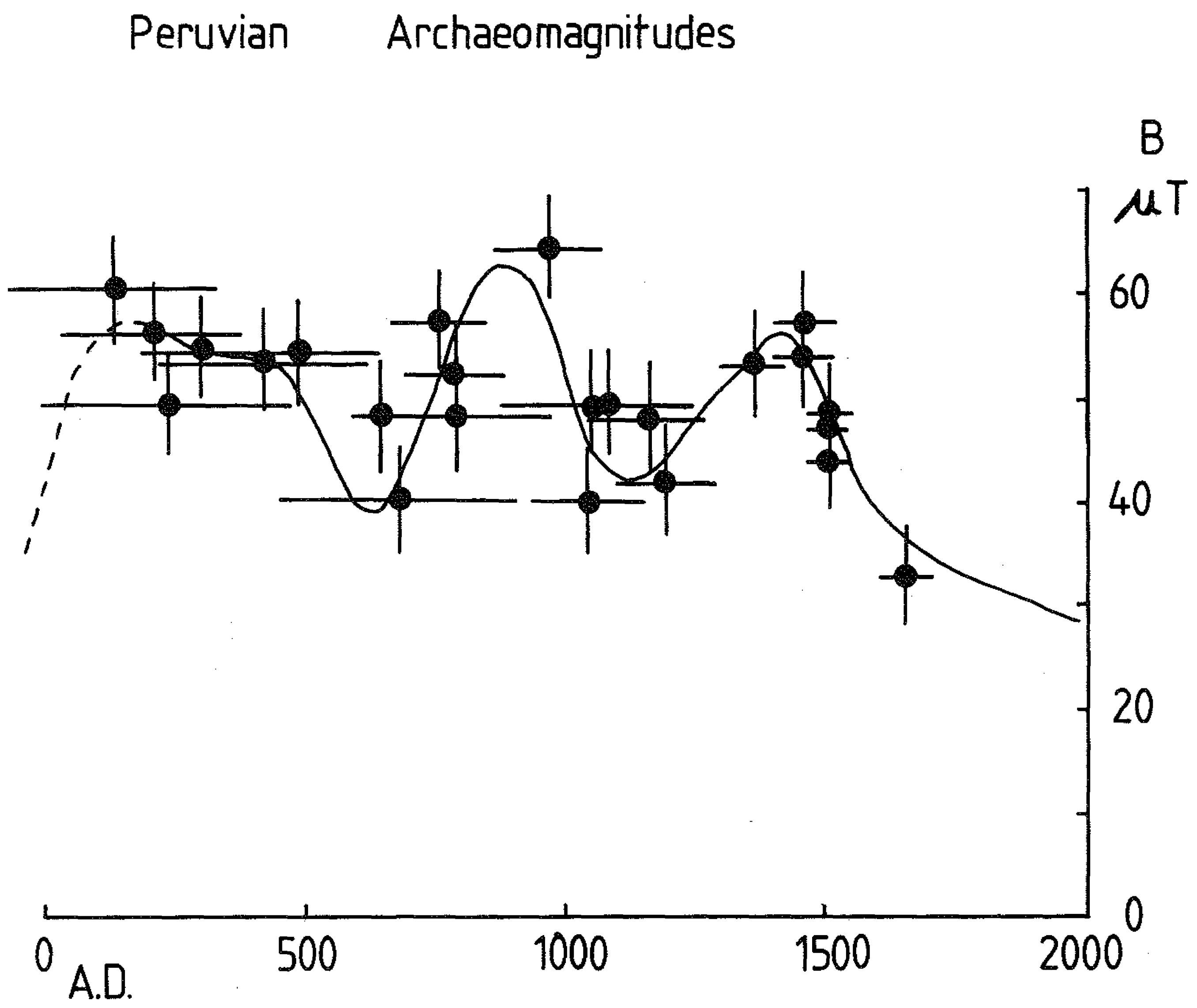

Fig. 5 Geomagnetic field magnitude against time for Peru using pottery samples. The graph shows the best data and postulated smooth variation curve.

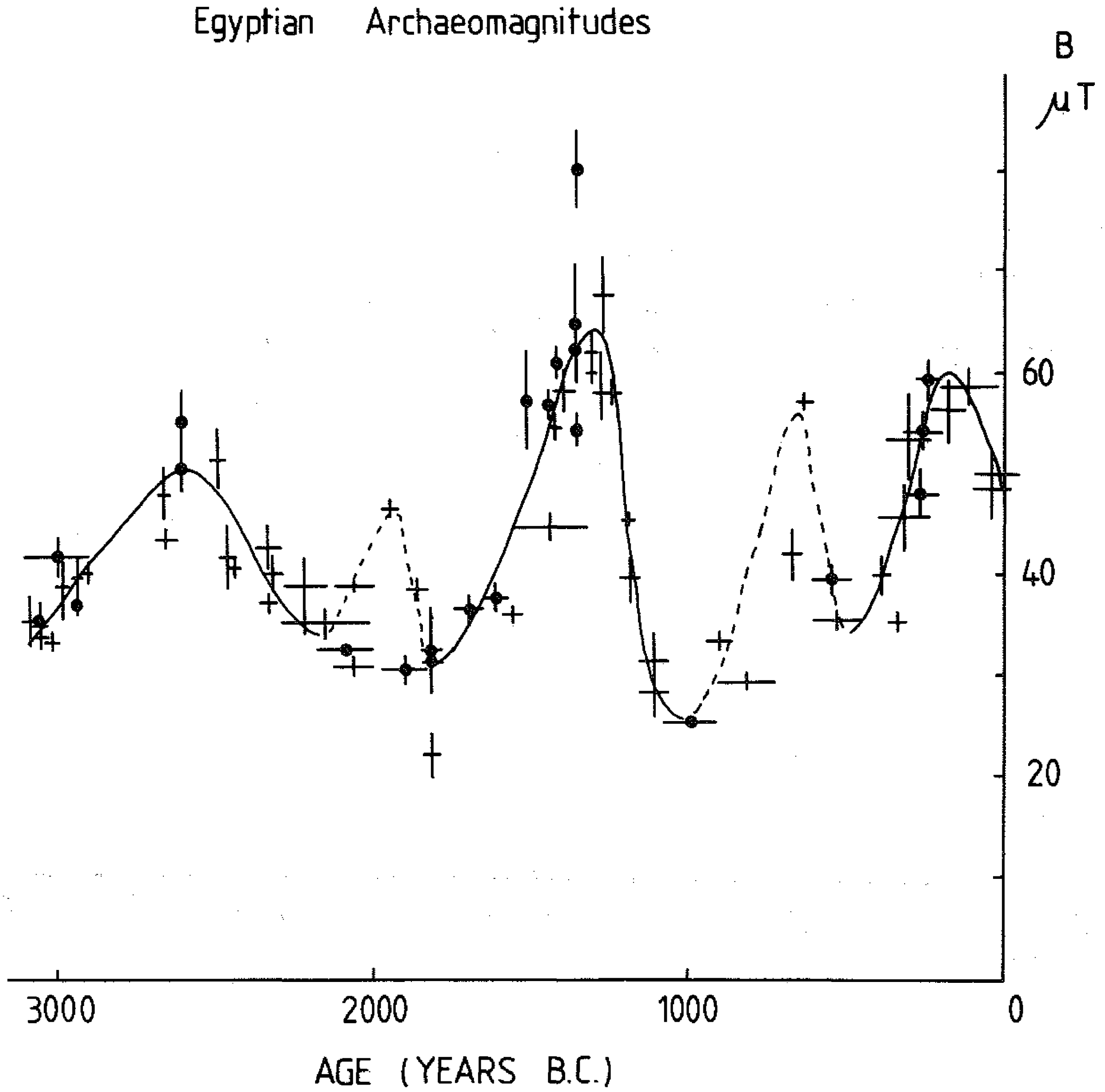

Fig. 6 Geomagnetic field magnitude against time for Egypt. Results obtained from adobe bricks are shown by simple crosses, those obtained by fired clays are shown by closed circles. A solid-line curve has been drawn where sufficient data exist, and a dashed-line curve where it is felt that more results are needed to define the curve satisfactorily.

covering mainly the period 0-1500 A.D. (Gunn & Murray 1980). The major difficulty with this project was obtaining accurate dates for the samples (fired clays), and most of the firm dates quoted were obtained by the TL method by Andrew Murray at Oxford. It can be seen that the large amplitude variations referred to previously are present in these results.

The other set of results was obtained by the author for Egypt from 0-3000 B.C. (Fig. 6), using both pottery and sun-dried adobe bricks (Games 1980). Again we see large variations in the field over fairly short time periods, and it is interesting to note the general agreement between results from pottery and mud-bricks. In this study the samples were all dated by archaeologists as they are confident of the Egyptian chronology.

Future Work

We have recently initiated a project in collaboration with the British Medieval Pottery Research group in which we hope to build up a curve for Britain from c. 900 A.D. up to the present. Very little work has been done over this time period in Britain, and by continuing the curve up to the present we will be able to check our results directly against observatory records in the last century or so. Looking at the curves in Fig. 5 and Fig. 6 it can be seen that for this pilot study we need to use accurately dated (± 25 years) material in order to establish the curve for Britain. Then we will be able to use the curve 'in reverse' to help to sort some archaeological dating problems.

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Thellier, E. and Thellier, O. 1959. Sur l'intensité du champ magnétique terrestre dans le passé historique et géologique. Ann. Geophys., 15, 285-376.

Cette étude porte sur les principes de la constatation de la force du champ magnétique de la Terre, enregistré sur des objets, par exemple la céramique L'enregistrement direct de la force du champ magnétique date du XIX^e siècle. Les resultats déjà obtenus pour le Pérou et l'Egypte sont décrits et le but de l'auteur est de bâtir une courbe semblable pour la Grande-Bretagne/l'Europe du nord à partir de 900 après J.-C. jusqu'au présant. Cette courbe sera alors pour les archéologues un accessoire précieux de la datation.

Dieser Artiken beschreibt die Prinzipien die bei der Bestimmung der Stärke des Erdmagnetfeldes, so wie sie in von Menschen gemachten Objekten, wie z.B. Keramik, festgehalten ist, von Bedeutung sind. Direkte Messungen der Stärke des Erdmagnetfeldes gibt es erst seit dem 19.Jahrhundert, so dass wir diese Prinzipien benötigen, um herauszufinden, wie das Magnetfeld sich vor dem 19.Jahrhundert verändert hat. Bisher gibt es bereits Ergebnisse für Proben aus Agypten und das Ziel des Autors ist es eine ähnliche Kurve für Grossbritannien und Nordeuropa aufzustellen. Sie soll den Zeitraum von 900 n.Chr. bis in die Gegenwart umfassen. Es wird erwartet, dass diese Kurve eine zusätzliche wertvolle Datierungsmöglichkeit für Archäologen darstellt.