Geophys. J. Int. (1990) **102**, 753–756

RESEARCH NOTE

A method for correcting geographically separated remanence directions for the purpose of archaeomagnetic dating

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Accepted 1990 May 1. Received 1990 March 22; in original form 1989 August 22

SUMMARY
Spatial variations in the geomagnetic field must be taken into account if secular variation master curves and directional magnetic dates are to be optimized. Two methods for relocating remanence vectors have been proposed and in this paper their relative accuracies are compared using a numerical model based on the present-day field. A method which converts archaeomagnetic directions via a virtual geomagnetic pole is shown to be the more efficient transformation. For an 'archaeomagnetic region' the size of the British Isles, (900 km radius), the maximum error in relocating vectors to a central location is predicted to be of the order of 1.2°.

Key words: archaeomagnetism, geomagnetism, magnetic dating.

INTRODUCTION

Archaeomagnetic directional dating is based on comparing the remanent magnetization of an archaeological material with a reference curve of the geomagnetic secular variation. Sediments, soils and mortars, as well as fired materials have proved suitable, making this a versatile technique (Clark, Tarling & Noel 1988).

Research in archaeomagnetism has progressed to the stage where directional dating is now available as a routine service in the UK. Enabling factors have been the introduction of new methods for sample orientation, increase in the speed and sensitivity of laboratory instrumentation, associated reduction in required specimen volume, and extension and refinement of the geomagnetic master curve (Aitken 1970; Clark *et al.* 1988). The angular uncertainty associated with modern archaeomagnetic analyses of intact fired structures is typically in the range: $\alpha_{95} = 1°–5°$. The corresponding uncertainty in the magnetic date will depend on the rate of secular variation at any given time and the fidelity of the master curve. An attainable error as low as ±20 yr has been demonstrated for well-preserved fired structures sampled in the UK in the age range 0–2000 yr BP (Clark *et al.* 1988).

The British archaeomagnetic curve has been assembled using observatory data, lake sediment palaeomagnetic records and remanence directions from historically dated contexts. Geomagnetic reference curves for archaeological dating are being synthesized through similar work elsewhere (e.g. Thellier 1981; Kovacheva 1983; Sternberg 1983). These studies generally assume that within a restricted 'archaeomagnetic region' the geomagnetic secular variation is sufficiently coherent that it can be represented by a single 'master curve' assigned to a fixed reference site. An important consideration is then the choice of a suitable procedure for adjusting remanence vectors from outlying sites both to build the curve and provide optimum fits for archaeomagnetic dating (Shuey, Cole & Mikulich 1970). This paper compares an established correction method (Aitken & Hawley 1966) with a new model based on virtual geomagnetic poles and provides guidance as to the acceptable radius of an archaeomagnetic region.

CORRECTING ARCHAEOMAGNETIC DIRECTIONS FOR GEOGRAPHIC POSITION

About 80 per cent of the present geomagnetic field can be modelled closely by an inclined geocentric dipole while the remainder is due to non-dipole components. Because of core instabilities, both the intensity and direction of the axial and non-axial components vary with time to produce the geomagnetic secular variation which is the basis of archaeomagnetic dating. The problem is to find an optimum correction method which reduces the dependence of archaeomagnetic directions on position. The following two methods have been proposed.

The inclination correction

Early British archaeomagnetic studies (summarized in Aitken 1970) employed a simple remanence correction based on latitude difference to restore the measured vector to a reference site at London (e.g. Aitken & Hawley 1966). Here it is implied that the field configuration is always nearly axial and dipolar. If λ_s and λ_r are the latitudes of the sampling and reference sites respectively, then this scheme finds the new inclination I_r from the measured value, I_s, using the equation

$$I_r = I_s + \tan^{-1}(2\tan\lambda_r) - \tan^{-1}(2\tan\lambda_s). \quad (1)$$

However, the inclination correction takes no account of the measured declination, D_s, which is transferred, unmodified, to the reference site.

The conversion via pole method

In this method, the geomagnetic field is modelled by an inclined geocentric dipole and the remanence direction is converted to the reference site via a virtual magnetic pole. The dipole orientation is determined uniquely by D_s and I_s and this approach builds on established concepts in palaeomagnetism. The positions of the virtual pole, the sampling location and the reference site define a spherical triangle (Fig. 1) from which the corrected values D_r and I_r can be obtained,

$$I_r = \tan^{-1}(2/\tan c)$$

where c is the geomagnetic colatitude of the reference site,

$$c = \tan^{-1}\{[\sin\lambda_p \sin\lambda_r + \cos\lambda_p \cos\lambda_r \cos(\phi_p - \phi_r)]^{-2} - 1\}^{1/2}, \quad (2)$$

$$D_r = \sin^{-1}(\sin\beta\cos\lambda_p/\sin c),$$

where

$$\beta = \phi_r - \phi_p + \pi.$$

λ_r and ϕ_r are the latitude and longitude of the reference site. λ_p and ϕ_p apply to the virtual magnetic pole whose calculation has been described elsewhere (e.g. Irving 1964). D_r and I_r could also be obtained iteratively, using such a pole computing routine. Clark *et al.* (1988) employed the Conversion Via Pole (CVP) method for normalizing the revised British master curve to Meriden (52.43°N, 1.62°W).

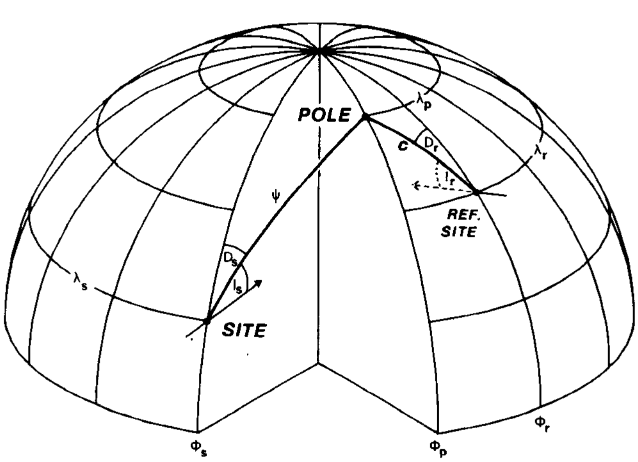

Figure 1. The Conversion Via Pole method. The archaeomagnetic field is assumed to arise from an inclined, geocentric dipole with an orientation specified by D_s and I_s. The position of the virtual pole and the coordinates of the sampling and reference sites define a spherical triangle from which the new values, D_r and I_r, can be calculated. λ = latitude, ϕ = longitude and $\psi = \cot^{-1}[(\tan I_s)/2]$

COMPARISON OF CORRECTIONS

The performance of the correction schemes in equations (1) and (2) have been compared using the IGRF (1985) as a convenient working model. Its use in this context can be justified on the grounds that the omitted higher harmonic field is in most places so small as to change the orientation of the field by less than a few tenths of a degree. An important assumption underlying any conclusions is that the harmonic content of the field has been broadly similar throughout archaeological time.

IGRF vectors are calculated around the perimeter of a circular region and then relocated to the centre using either the Inclination Correction or the CVP method (Fig. 2). The new directions are compared to the central IGRF field and a set of angular differences obtained. This procedure is repeated, moving the area at 10° intervals along the Meriden latitude and calculating the arithmetic mean of the full set of angular differences. This approach will lead to an over-estimate compared to a distribution of samples inside the region and will also help to reduce effects due to axial

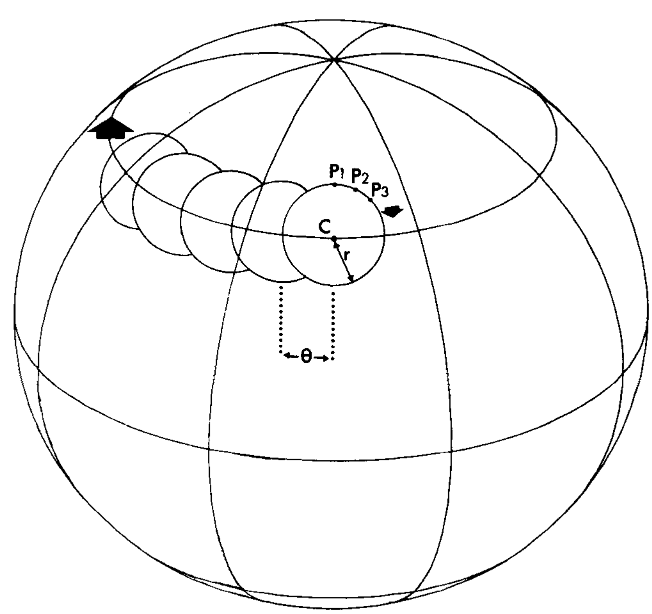

Figure 2. Geometry of the numerical model used to evaluate the two methods for relocating remanence directions. P1, P2, P3 etc. are 36 points on the boundary of a circular archaeomagnetic region, radius r, where the direction of the IGRF is calculated and transformed to the centre, C, using equation (1) or (2). A set of angular differences between the IGRF at C and the transformed values are thus obtained and the computation repeated, after longitude shifts of θ (10°), to yield a mean error.

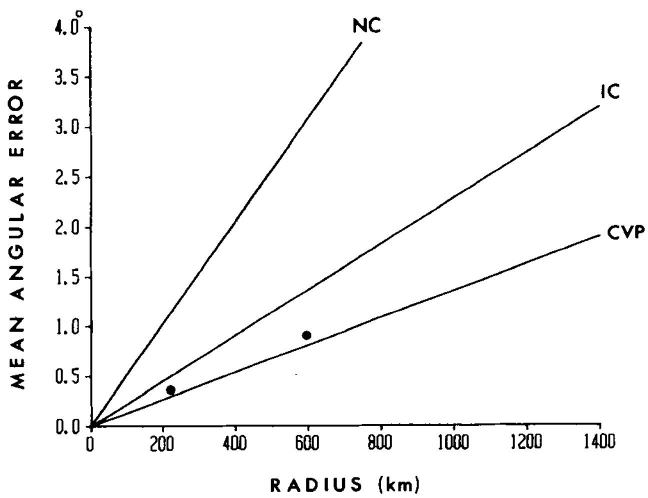

Figure 3. Mean angular errors at the centre ot an archaeomagnetic region as a function of radius. NC = no correction; IC = Inclination Correction (equation 1); CVP = Conversion Via Pole (equations 2). Calculations are based on IGRF (1985) and circular regions centred on latitude 52.43 °N. Circles give results of Tarling (1989 and personal communication) for two regions centred on Meriden.

asymmetry in the geomagnetic field. Finally, the entire calculation is repeated, increasing the radius of the region in 100 km steps (Fig. 3).

The numerical modelling indicated that the CVP method produced the smallest dispersion of corrected vectors for all latitudes tested. Fig. 4 shows the result for latitude 45 °S, the worst case, while Fig. 5 shows the effect of varying the latitude. Taking a region of radius 900 km, centred on Meriden (encompassing all the British isles), the mean error is 1.2° which is similar to typical sample orientation and measurement errors in archaeomagnetism. On the other hand, using the Inclination Correction Method resulted in a mean error of 2.0°. These results are comparable to a preliminary investigation by Tarling (1989) who considered circular areas with radii 220 and 600 km, centred on Meriden (Fig. 3).

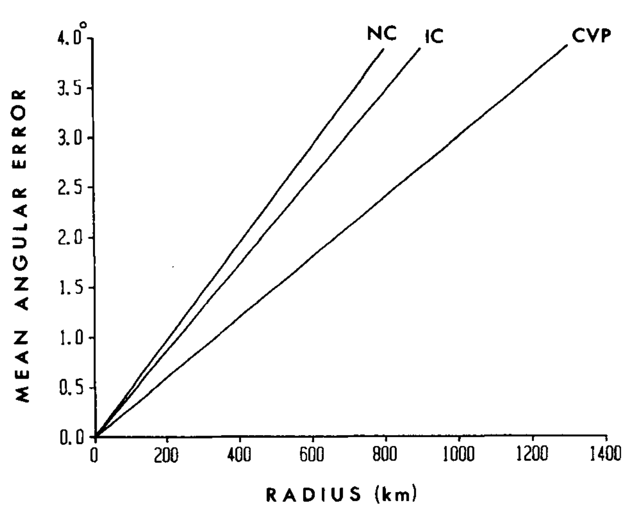

Figure 4. As for Fig. 3 except that these results are for latitude 45 °S where the mean errors were found to have their maxima.

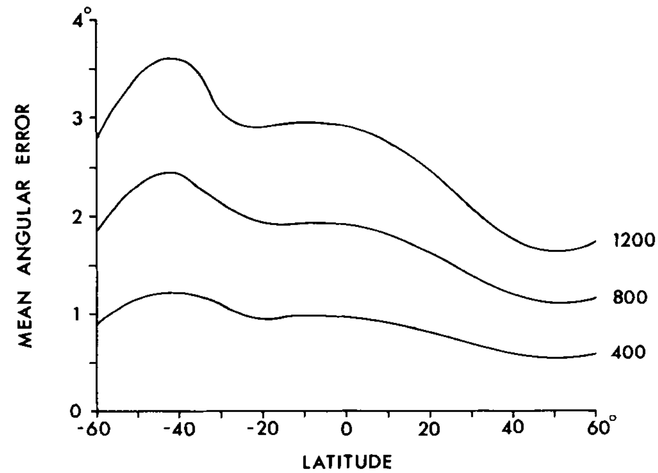

Figure 5. Mean angular errors at the centre of an archaeomagnetic region as a function of latitude (computed at 10° intervals). These results are all for the Conversion Via Pole method using archaeomagnetic areas of radius 400, 800 and 1200 km.

CONCLUSIONS

The results of this study suggest that the optimum method for converting remanence directions to a reference site is via a virtual geomagnetic pole. This procedure should minimize the dispersion of remanence vectors used to assemble a master curve and thus help to reduce errors in archaeomagnetic dates. Hitherto, reference sites have usually been chosen on geographic rather than geophysical criteria (e.g. London, Paris, Meriden). Clearly however, as a national data set is accumulated, this location may no longer correspond to the site of minimum angular dispersion in the relocated vectors, leading to errors in the secular variation master curve and in derived magnetic dates. One solution might be to have a floating centroid which is continually repositioned (according to some objective criteria) to provide an optimum synthesis of the archaeomagnetic curve. A more sophisticated correction model which incorporates higher harmonics of the geomagnetic field might further improve accuracy. Ultimately, it may be more convenient to represent all archaeomagnetic data in terms of pole positions, an approach which would then conform with established procedures in palaeomagnetism.

ACKNOWLEDGMENTS

We are grateful to D. H. Tarling for permission to use unpublished data and to a referee (Dr F. J. Lowes) for constructive comments. D. Barraclough, (British Geological Survey, Edinburgh) kindly supplied the IGRF routine. C. B. acknowledges support from the York Archaeological Trust and the Science and Engineering Research Council.

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