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Global holocene magnetostratigraphy

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Abstract

Paleolimnomagnetic records from five regions of the world have been combined with historical magnetic field observations in order to produce regional geomagnetic master curves.

Introduction

During the past 10 000 years the earth's magnetic field has been slowly changing. These secular changes in intensity and shape of the field have been produced by the ponderous yet turbulent fluid circulation of the liquid part of the earth's core. The variations in direction of the earth's magnetic field have been found to be recorded in the magnetization of some lake sediments. By measuring the remanence of these often weakly magnetized sediments using sensitive magnetometers, and by radiocarbon dating the organic fraction of the sediments, the past secular variations of the geomagnetic field have been determined at several localities around the world. Paleomagnetic records are now available from lakes in Australia, Japan, North America, Europe and the Near East. Work is also in progress on lake sediment cores from East Africa and South America and a detailed 2 000 year magnetic record is available from Japanese and Chinese archaeomagnetic studies.

In this paper the available well-dated paleolimnomagnetic records are gathered together, processed mathematically and converted to a common time scale to form regional master curves. (Figs. 1-4). The chronologies of the master curves are all based on the radiocarbon dating method combined with a tree ring calibration procedure (Clark 1975). Apart from historical measurements of the geomagnetic field, which have been used to construct the most recent part of the master curves, paleomagnetic measurements from lake sediments have been used exclusively to reconstruct the past geomagnetic changes.

Regional master curves

Regional geomagnetic master curves are presented for five different regions of the world. They have been derived from type lake sediment cores chosen, for each region, on the quality of their paleomagnetic records and their ^{14}C chronologies. The paleomagnetic data from these type cores have been processed using the mathematical methods described below. The final geomagnetic master curves resulting from these analyses are presented in Figs. 3 & 4. Whenever a single lake core did not cover as complete a time span as possible within a region, a second core was selected from a nearby lake to extend the type core record. The lakes and cores selected for the five regions are as follows: South Australia, Bullenmerri core BC extended by Keilambete core KF (Barton & McElhinny 1981); North America, St. Croix core 75 (Banerjee *et al.* 1979); Western Europe, Lomond core LLRP1 extended by Windermere core W3 (Thompson &

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Turner 1979); Eastern Europe, Pääjärvi core P4 (Huttunen & Stober 1980) extended by Lovojärvi core D (Tolonen *et al.* 1975); Near East, Kinneret core K8 (Thompson & Stiller, unpublished). The original direction vs depth data for these cores are plotted in Figs. 1 & 2. Smooth curves have been fitted to these data sets and converted to the tree ring calibrated time scale in order to form the re-

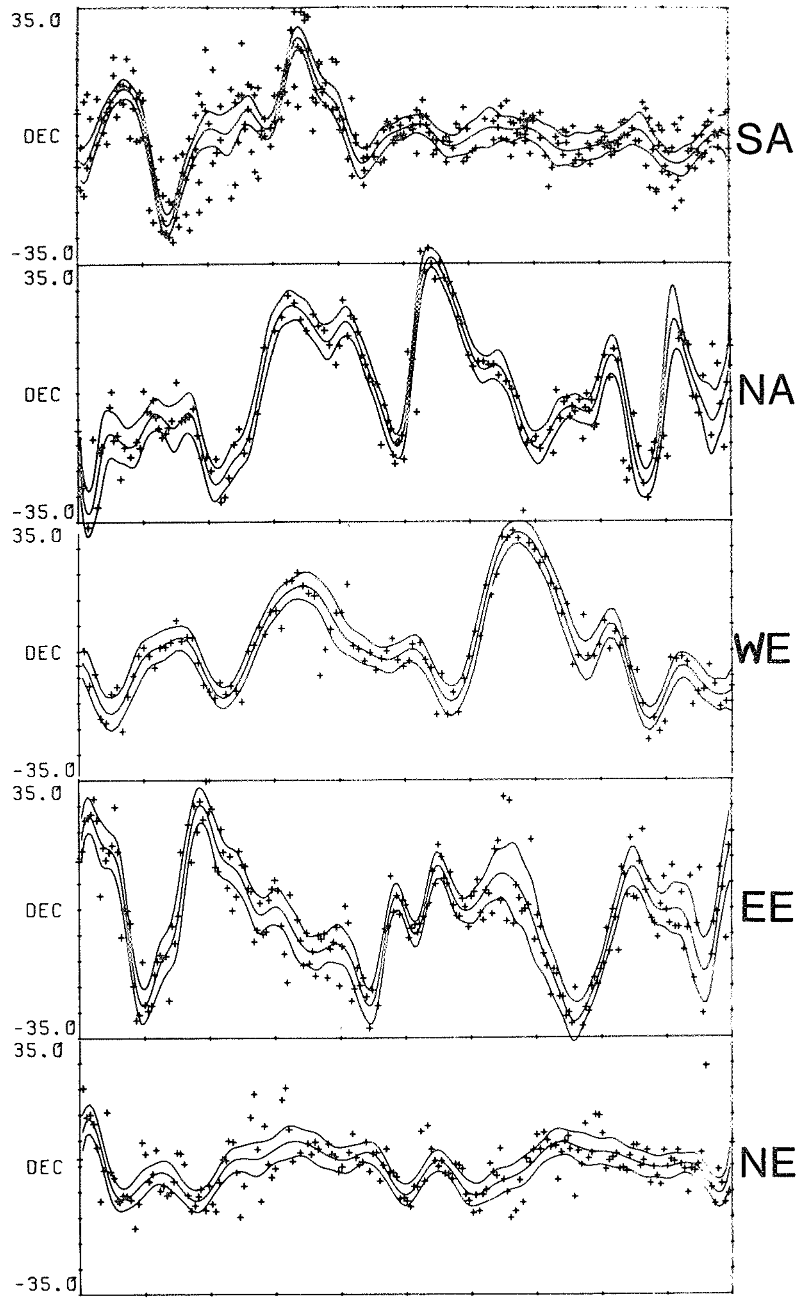

Fig. 1. Spline fit and 95% confidence bands for declination vs. depth data of type core records. Top of cores at left of diagram. Number of data points, number of spline pieces and depth range in metres as follows: SA: South Australia, 319, 30, 4.94 m; NA: North America, 156, 34, 18.40 m; WE: Western Europe, 120, 23, 2.80 m; EE: Eastern Europe, 211, 33, 4.96 m; NE: Near East, 180, 22, 4.45 m.

gional master curves presented in Figs. 3 & 4. Inspection of the curves reveals that magnetic direction changes have been quite different from one region to another. Although there are a few similarities in form of the various records of Figs. 3 & 4, which may suggest common geomagnetic origins, the overall picture is one of a complex Holocene field dominated by local dynamic processes.

The part of each regional master curve corresponding to the last 350 years is based on a spherical

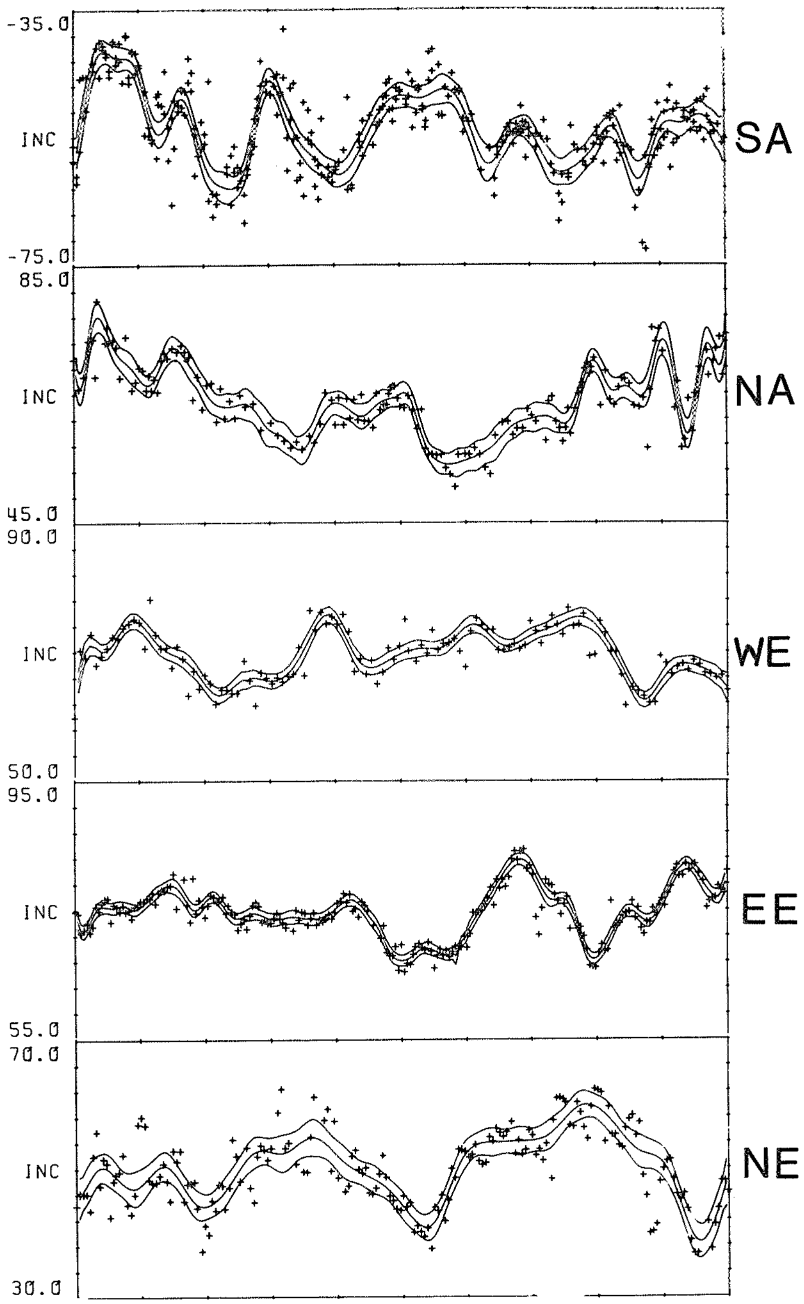

Fig. 2. Spline fit and 95% confidence bands for inclination vs. depth data of type core records. Core, data points, spline pieces and depth range as in Fig. 1.

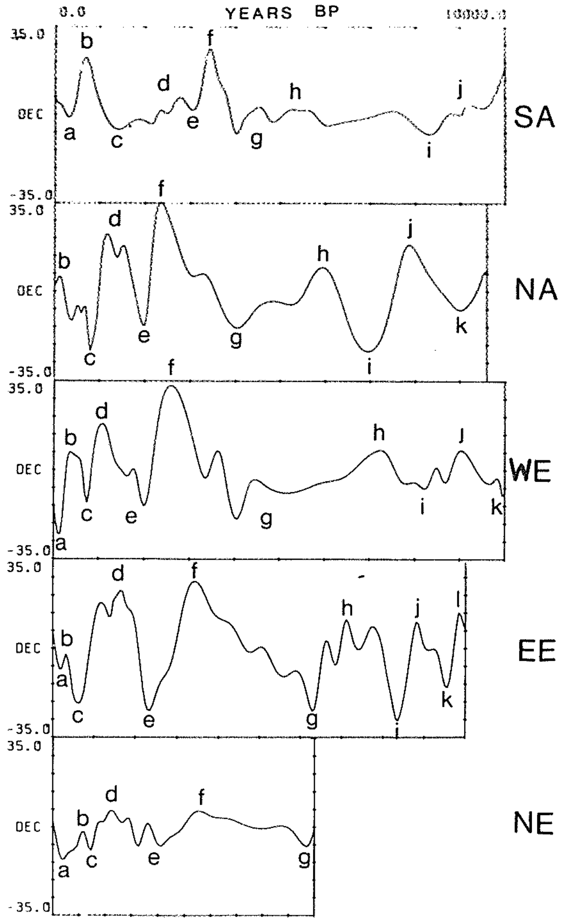

Fig. 3. Regional declination master curves. Tree ring calibrated time scale in years BP. (O BP = 1950 AD). Letters identify the turning points listed in Table 1.

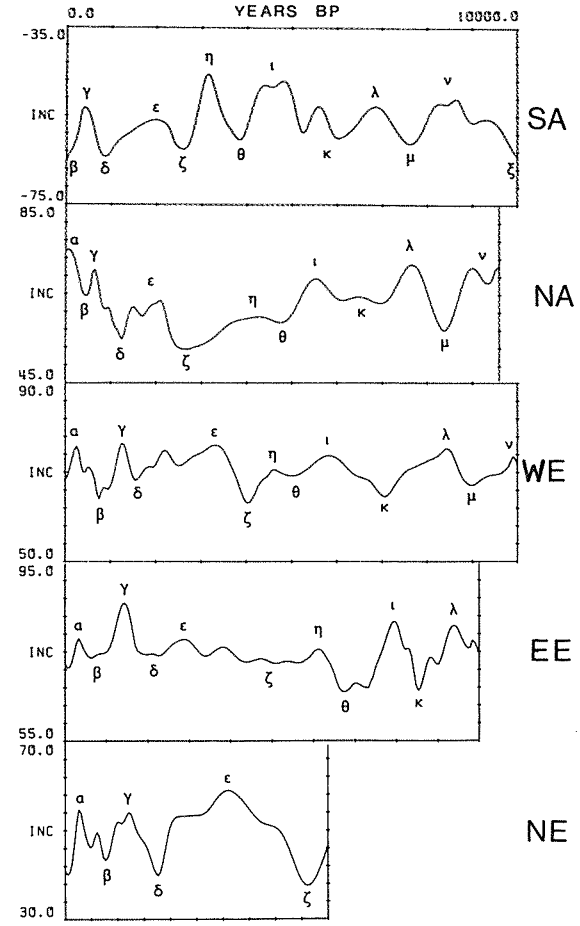

Fig. 4. Regional inclination master curves. Time scale as in Fig. 3. Letters identify the turning points listed in Table 1.

harmonic analysis model (Thompson & Barraclough 1981) of historical geomagnetic measurements (Fig. 5). Each curve in Fig. 5 shows a local change in virtual geomagnetic pole position from AD 1600 until AD 1975. The westerly declination maximum and the inclination maximum recorded in Europe around 1810 AD and 1710 AD, respectively, can be seen to have occurred in a region which extended as far south as Cape Town but not as far east as the Caspian Sea. Clockwise motion of the virtual geomagnetic pole is seen over the whole world except for an area centred on the Southern Indian ocean, where anticlockwise looping took place.

Data manipulation

Starting with the series of paleomagnetic direction measurements of Figs. 1 & 2 and their associated ^{14}C age/depth pair series, clearly defined mathematically reproducible procedures were followed in order to produce the regional master curves of Figs. 3 & 4. These mathematical procedures involved detrending the paleomagnetic data sets, curve fitting and then finally converting the depth scales to a common time-scale.

The specific operations performed on the paleomagnetic data to calculate the smooth curves from the data points of Figs. 1 & 2 were: (1) rotate data

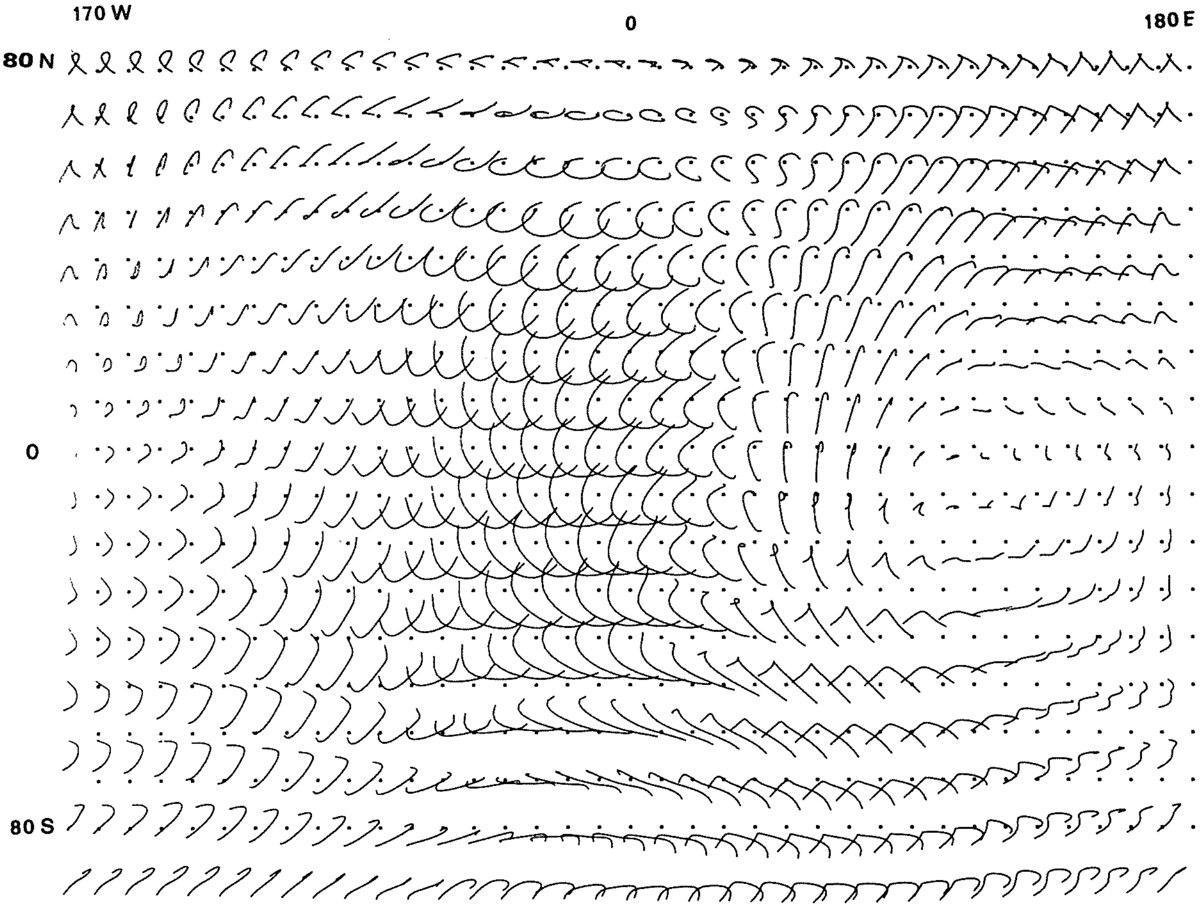

Fig. 5. Historical local virtual geomagnetic pole paths from AD 1600 to AD 1975 on a 10° latitude and longitude grid. The well known clockwise looping observed at London (Bauer 1895) can be seen in the left central part of the diagram. The region of low secular variation in the Pacific is seen at the centre of the spiral in the upper part of the diagram.

by firstly setting the mean declination to zero and secondly setting the mean inclination to zero; (2) linearly detrend the rotated declinations and inclinations using the robust weighted least squares curve fitting method described by Thompson & Clark (1981); (3) fit least squares cubic splines to the detrended data using the above curve fitting method, basing the degree of smoothing on cross validation (Thompson & Clark 1981).

Magnetostratigraphic features

Estimated ages for the main secular variation features of the regional master curves of Figs. 3 & 4 are tabulated in Table 1. Only the major magnetic features which are likely to be of regional significance are included in the tabulation. The alphabetic system of labelling the broad features or turning points from the top of the core downwards follows that originally proposed by Thompson & Turner (1979). The features are labelled in order to aid their recognition and in order to simplify discussions. The labelling is not meant to imply that any of the features have been produced by the same underlying magnetic source. Some features are poorly developed and particularly difficult to label. For example, the South Australian declination turning points SAc to SAe and SAg to SAi are of very low amplitude. Inclination will probably be of more

Table 1. Magnetostratigraphic ages.

	SA	NA	WE	EE	NE	EA
Declination						
a	300	-	140	160	220	0
b	680	100	450	300	700	700
c	1300	750	600	600	850	1200
d	2000	1200	1000	1400	1300	1650
e	2800	2000	2000	2200	2300	2200
f	3500	2400	2600	3100	3200	3100
g	4500	4000	4900	5700	5600	4400
h	5500	5900	7100	6500	-	5100
i	8300	7000	8300	7600	-	7300
j	9000	7900	9100	8000	-	-
k	-	9000	10000	8700	-	-
l	-	-	-	9000	-	-
Inclination						
α	-	50	240	300	300	-
β	-	420	650	600	800	400
γ	400	750	1150	1300	1400	760
δ	900	1200	1650	1900	2000	1000
ϵ	1900	2300	3100	2600	3600	1300
ζ	2600	2900	3800	4600	5300	1550
η	3200	3700	4300	5500	-	1750
θ	3600	4400	5000	6400	-	2800
ι	4600	5300	6000	7200	-	4100
κ	6000	6600	7100	7800	-	4600
λ	6800	7700	8300	8600	-	5100
μ	7900	8400	8800	-	-	5600
ν	8600	9600	9700	-	-	6600
ξ	10000	-	-	-	-	-

SA	South Australia	(35°S 140°E)
NA	North America	(45°N 90°W)
WE	Western Europe	(55°N 05°W)
EE	Eastern Europe	(60°N 30°E)
NE	Near East	(30°N 35°E)
EA	Eastern Asia	(35°N 140°E)

a to l: declination turning points; α to ξ: inclination turning points. Ages tabulated ^{14}C years BP. The pre 2 000 BP EA magnetostratigraphic features are taken from Horie *et al.* (1981). The EA ages are rather poorly known, based here on a linear interpolation between the basal tephra layer and the archaeomagnetic features recorded in the upper sediments.

value in Australian Holocene magnetostratigraphic work. Some features e.g. WEe and WEg have double peaks which again can be difficult to label. For this type of double turning point the overall feature has been identified, rather than the more extreme peak, as broad overall features can generally be recognised more easily. The ages in Table 1 have been based on all available dating information. It is therefore recommended that the ages in Table 1, rather than the ages of the turning points, as indicated by the time scales of Figs. 3 & 4, are used in magnetostratigraphic dating studies. The curves of Fig. 5 form a global model which can be used for dating sediments deposited since AD 1600. The global model is summarized by a series of spherical harmonic coefficients which allow declination and inclination values to be calculated at 50 year intervals for any location in the world.

The procedure of labelling and dating the magnetic features is subjective so gauging the true accuracy of the ages in Table 1 is very difficult. However, bearing in mind the problems of labelling broad features and the uncertainties in ^{14}C-dating of lake sediments, the typical error in the estimated ages of the secular variation features of the regional master curve is probably around 5%.

By matching paleomagnetic features found in new sedimentary sequences with those of the regional master curves (Figs. 3–5) paleomagnetic measurements can be used as a chronological tool. The geographic areas over which the regional master curves of Figs. 3 & 4 will extend are yet to be determined. However, a number of observations suggest that the regions will be at least 1 000 km across. These observations include the reproducibility of paleolimnomagnetic records across Western Europe, the similarity of archaeomagnetic records between China and Japan (Wei *et al.* 1981) and the character of the present magnetic field. Furthermore, inspection of Fig. 5 indicates that the diameter of regions experiencing similar secular changes is again in the order of a few thousand kilometres.

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