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EUROPEAN PALEOMAGNETIC SECULAR VARIATION 13,00—0 B.P.

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ABSTRACT

Measurement of magnetization of gyttja in different cores within lake basins has produced repeatable direction vs. depth curves. The magnetic fluctuations reflect the past changes in direction of the geomagnetic field. ^{14}C analyses provide the time scale for a geomagnetic master curve from 13,000 to 10,000 y B.P. A master curve of geomagnetic changes in Europe for the last 1000 years is known from archeomagnetic studies and direct observations in historic times. Sediments which acquired their remanent magnetization in the direction of the geomagnetic field close to the time of deposition can thus be dated by correlation with the master curve. Sediments can acquire a remanent magnetization by either a detrital or chemical process.

1. INTRODUCTION

Secular variation of the geomagnetic field recorded in the natural remanent magnetization of limnic sediments has proved useful as a rapid magnetostratigraphic dating tool.

2. GEOMAGNETIC FIELD

Geomagnetic field fluctuations occupy a wide frequency spectrum (Tab. I) extending from less than 1 second (micropulsations) to longer than 10^7 years (change in average frequency of reversals). The high frequency processes of micropulsations, magnetic storms, annual variation and effects of the 11-year solar cycle are caused by meteorological and external processes. Middle frequency changes of secular variation which extend from 10 to at least 10^4 years reflect the time constants of dynamo processes due to thermal convection in the earth's fluid core. The very low frequency changes of reversal frequency are possibly related to physical changes of the core-mantle boundary such as growth of topographic features or development of hot and cold spots through deep convection of the earth's mantle. European secular variation of frequency between $5 \cdot 10^2$ and $5 \cdot 10^3$ years has been established principally from paleomagnetic measure-

Table I. Time constants of the geomagnetic field

Process	Time (y)
Change in average frequency of polarity inversions	$\geq 5\times 10^7$
Time between successive polarity inversions	10^7, 10^6, 10^5
Intensity and direction fluctuations of dipole and non dipole fields (secular variation)	10^4, 10^3, 10^2
11 year sunspot cycle	10^1
Annual variation	10^0
	10^{-1}
Diurnal variation	10^{-2}
Magnetic storms	10^{-3}
Micropulsations	$<10^{-4}$

ments of fine detritus gyttja from lake sites in Northern Britain. Secular variation during the last 400 years has been recorded directly at Magnetic Observatories and is known over the last 1000 years from archeomagnetic studies of pottery, tiles and kilns.

3. ORIGIN OF NATURAL REMANENT MAGNETIZATION

Sediments can acquire a magnetic remanence in the direction of the earth's ambiet field by two mechanisms. One type of mechanism is a chemical remanence which is acquired when magnetic grains grow larger than a critical grain size, the blocking volume. Even if the grain increases further in size or if the earth's magnetic field changes direction, the remanent magnetization remains fixed, parallel to the ambient field at the time of growth through the blocking volume. A second mechanism is a detrital remanence in which particles which already possess a magnetic remanence settle in still water and align in the ambient field direction. Fine grains may also rotate into the geomagnetic field direction in the water-filled interstices of unconsolidated sediment. In Windermere Lake sediments (Fig 1) the paleomagnetic intensity is higher in the organic-rich sediments than in the post-glacial and late-glacial detritus-ricn clays. This indicates a chemical rather than detrital type of remanence.

4. METHOD

The majority of paleomagnetic secular variation direction data have been measured in long, continuous piston cores such as Mackereth (1958) cores. The Jowsey (1966) sampler also collects orientated material suitable for paleomagnetic direction studies. Paleomagnetic declination and horizontal intensity changes can be scanned at about 3 m/hour while the sediment remains in a liner tube (Molyneux et

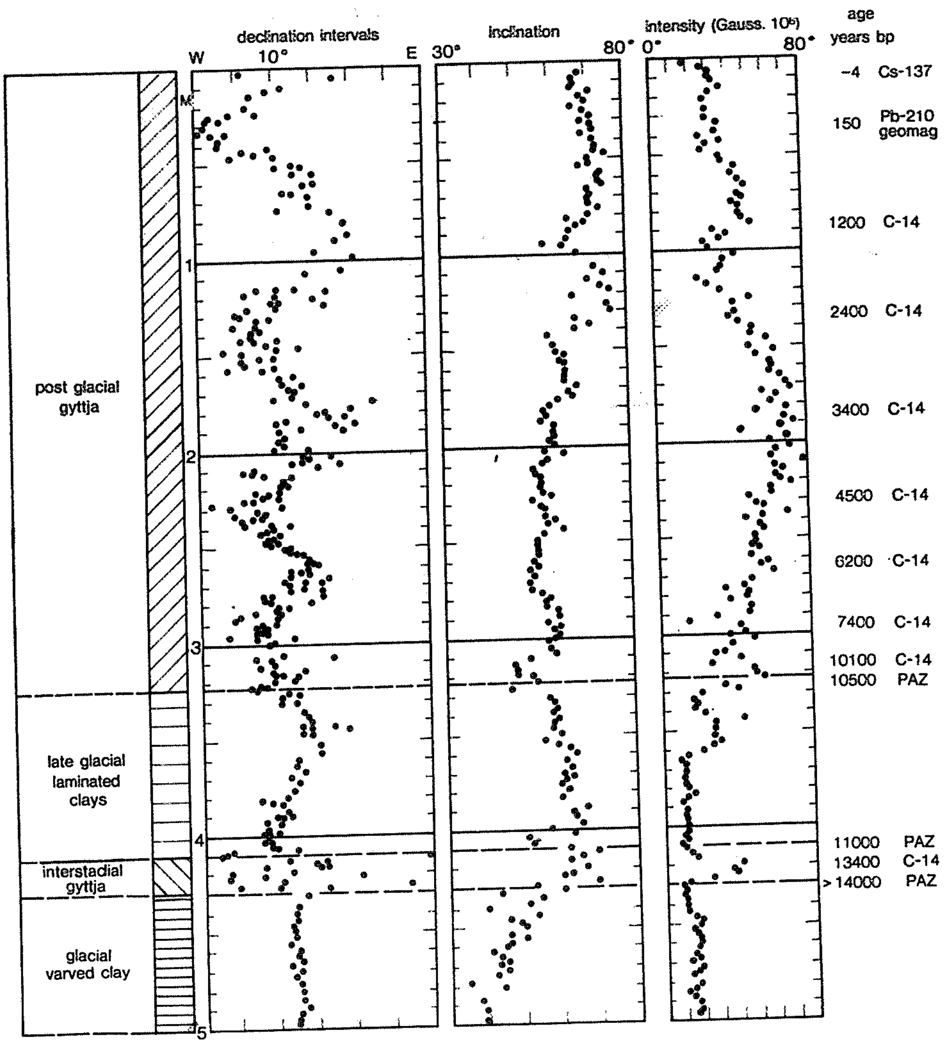

Fig. 1. Windermere Lake paleomagnetic data 1400 B.P. to present. Record built up from paleomagnetic data from four cores. Dating from ^{14}C (conventional ages), ^{210}Pb, ^{137}Cs, pollen assemblage zones (PAZ) and 1820 A.D. westerly maxima Magnetic Observatory records (Geomag.)

al. 1972). For detailed studies orientated subsamples in plastic holders of about 10 cc are taken at about 3 cm intervals from as plit core face. Magnetic declination, inclination and total intensity of a single sample can be measured in a few minutes. A detailed description of the units and magnetic parameters involved is given in the appendix of the associated paper on magnetic susceptibility in this volume (Oldfield et al. 1978).

Correlation of paleomagnetic records either with the master curve or between cores within a lake has previously been made subjectively. Statistical techniques are being investigated to provide objective between core correlation of paleomagnetic direction data. Long continuous cores are preferable for dating, as single horizon or short lengths of core cannot be reliably related to the master curve on account of its cyclic nature. However, present studies are producing repeatable structure finer than the 2700 year (calibrated ^{14}C ages) declination oscillations which could be useful for distinguishing the major cycles in sediments of high deposition rate. It should be noted that mechanical forces during coring can produce paleomagnetic patterns which superficially resemble geomagnetic changes. Such interpretation of problems can be minimized by showing that the paleomagnetic signature is repeatable in more than one core from the same site.

5. MASTER CURVE

A master curve of geomagnetic field variations which has been used successfully as a chronological tool is described below. The curve is known in greatest detail during the last few hundred years.

1580 A.D. — present day

Direct measurement of the geomagnetic field began in 1580 A.D. at London. Records have since become increasingly detailed and now extend over the whole globe. For Europe a detailed master curve of secular variation is available for the last few hundred years (Fig. 2). During this time magnetic declination has varied through 47° with a westerly maximum in 1820 A.D. and magnetic inclination through 9° with a maximum in 1690 A.D.

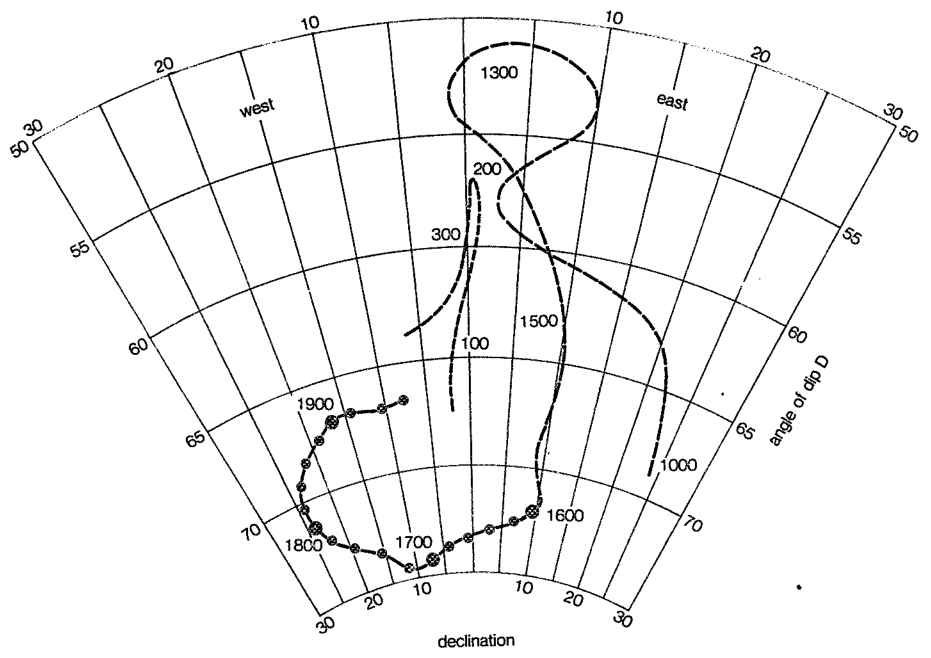

Fig. 2. The secular variation of declination and angle of dip (inclination) for London from historical data (continuous line) and archeomagnetic data (dashed line). Ages are given in years A.D.

1000 B.P. — 1580 A.D.

Archeomagnetic studies (Aitken 1970) provide the best record of secular change during this period (Fig. 2). Uncertainties in the absolute age of samples and less precision in the estimation of ancient field direction, due to the indirect method, naturally lead to a less well documented master curve than for the historic record. However the major features are well established.

11,000 B.P. — 1000 B.P.

Paleomagnetic measurements of four 6 m long cores from Windermere Lake provide the basis of the master curve for this period (Mackereth 1971, Creer et al. 1972). The time scale is given by ^{14}C age determinations. The declination variations have been confirmed in Lough Neagh (Thompson 1973); Ennerdale Lake and Blelham tarn (Thompson 1975). The smaller inclination variations are unlikely to be significant. Furthermore, studies in northeast (Tolonen et al. 1975) and southeast (Opdyke et al. 1972) Europe suggest that oscillations of inclination at Windermere have been lower in amplitude than occurred in Eastern Europe. This spatial pattern of nonzonal secular variation is suggestive of a standing but oscillating high order geomagnetic source field.

13,000 B.P. — 11,000 B.P.

The rate of deposition of sediment at Windermere Lake was very low for this period (Fig. 1). A more expanded record of geomagnetic field variations has been measured in Sweden (Thompson and Berglund 1976). This record demonstrats that the geomagnetic field was of normal polarity throughout the time interval 13,000 — 11,000 B.P.

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